CHANNEL ESTIMATION FOR WIRELESS COMMUNICATIONS USING SPACE-TIME BLOCK CODING TECHNIQUES

J. Yang[*]*, Y. Sun, J. M. Senior, and N. Pem*

Department of Electronic, Communication and Electrical Engineering
Faculty of Engineering and Information Sciences, University of Hertfordshire
Hatfield Herts AL10 9AB, United Kingdom
[*] Xidian University, Xi'an, China

ABSTRACT

This paper presents a method of estimating channel parameters in wireless communications using space-time block coding (STBC). After reviewing the concept of STBC, the system model of radio communication with STBC is described and the estimation method is derived. System performances have been simulated using MATLAB. The results of the simulations show that the proposed algorithm of channel estimation is practicable and effective as there is only little discrepancy between the performances using the estimated and known channel parameters.

Key Words

Transmit diversity, space-time block coding, channel estimation, wireless communications

1. INTRODUCTION

Space-time coding techniques have received much interest of research in recent years [1]~[7]. Space-time codes can be utilised to enhance the data rate and/or capacity in various applications and many of space-time coding ideas have already found their way to some of the current third generation wireless system standards.

Alamouti [1] proposed a simple but most effective transmit diversity technique which is called space-time coding because the source data are coded and transmitted through different antennas in different time slots. Initial and simple examples of implementation of space-time coding were given in [1], where two transmit antennas and two receive antennas were used. Tarokh, et al generalised the transmission scheme to an arbitrary number of transmit antennas, which can achieve the full diversity promised by the transmit and receive antennas [2], [3]. From their papers, we can find the key points of space-time coding. One of those is that more than one antennas could be used in both sides of the transmitter and receiver. It means that the radio links in space-time coding systems are multi-input multi-output (MIMO) radio channels.

It should be noted that the decoding of space-time block codes requires knowledge of channels at the receiver. In some of initial papers about space-time coding, the channel parameters are assumed known. Recently, channel parameter estimation was studied for OFDM systems with space-time codes in [4]. The work in our paper is on investigation and implementation of channel parameter estimation in space-time block coding (STBC) systems. An algorithm is proposed for channel estimation with STBC and computer programs are developed for implementing this algorithm.

The rest of this paper is organised as follows. In Section 2 the basic concept of space-time block codes is briefly described. In Section 3 the frame of radio links, which is to be studied in this paper, is presented. The algorithm of channel estimation is introduced and investigated in Section 4. Computer simulations of wireless communications with STBC are reported and results of the simulations are provided in Section 5. Finally, in Section 6, conclusions are given.

2. SPACE-TIME BLOCK CODES

It is assumed that there are N transmit antennas and M receive antennas in a wireless communication system in which STBC is used. The input source data bits are firstly modulated, and then carried into a space-time block encoder.

Mapping from the modulated symbols to a transmission matrix, which is completed by the STBC encoder, is a key step in STBC systems. The input symbols of the encoder are divided into groups of several symbols. The number of symbols in a group is according to the number of transmit antennas and mapping rule. A PxN transmission matrix means there are N transmit antennas and P time slots. Different symbol columns are transmitted through different antennas separately and different symbol rows in different time slots. For example, the encoded symbol of column i and row t should be transmitted through the i^{th} antenna in the t^{th} time slot.

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Let h_{ij} be the path fading parameter of complex from transmit antenna i to receive antenna j and $c_i(t)$ the symbol transmited by antenna i in slot t, then the received signal from antenna j at time slot t, $r_j(t)$, is given by

$$r_j(t)=\sum_{i=1}^{N} h_{ij}c_i(t)+\eta_j(t) \qquad (1)$$

where $j=1,\dots,M$, $t=1,\dots,P$, and noise samples $\eta_j(t)$ are the independent samples of a zero-mean complex Gaussian random variable.

Let S be defined as the set of all possible symbol groups, $s=\{s_1,s_2,\dots,s_N\}$, the receiver computes the optimum maximum likelihood decision metric

$$d_m=\sum_{t=1}^{P}\sum_{j=1}^{M}\left|r_j(t)-\sum_{i=1}^{N}h_{ij}c_i(t)\right|^2 \qquad (2)$$

over the set S and decides in the favor of the symbol group that minimizes the metric d_m. The ML decoding rule in Equation (2) can be further simplified according to the orthogonality of STBC encoding [3],[6].

It is clearly indicated in Equation (2), that the knowledge of channel parameters, h_{ij}, is required for ML decoding. These parameters are cosidered to be known in references [3], [5] and [6]. In this paper a method of estimating the channel parameters is proposed.

3. SYSTEM DESCRIPTION

The architecture of a radio transmission system using STBC with channel parameter estimation, which is studied in this paper, is given in Fig. 1.

The user data of source are transmitted in the frame structure. At the beginning of a frame, a training or pilot sequence, of which the bits are known, is transmitted for channel parameter estimation at the receiver. The bursts of source data are grouped into several blocks for space-time block coding. The bit number in a group depends on the number of transmit antennas and the coding method of STBC.

Let vector $\mathbf{a}=[a_1,\dots,a_K]^T$ denote the transmited data group. After modulation, the transmitted symbol vector, $\mathbf{s}=[s_1,\dots,s_L]^T$, is formed and carried into the STBC encoder. In the encoder, $\mathbf{s}$ is mapped to transmission matrix $\mathbf{c}$ of PxN,

$$\mathbf{c}=\begin{bmatrix} c_1(1)\dots c_N(1) \\ \dots \\ c_1(P)\dots c_N(P) \end{bmatrix} \qquad (3)$$

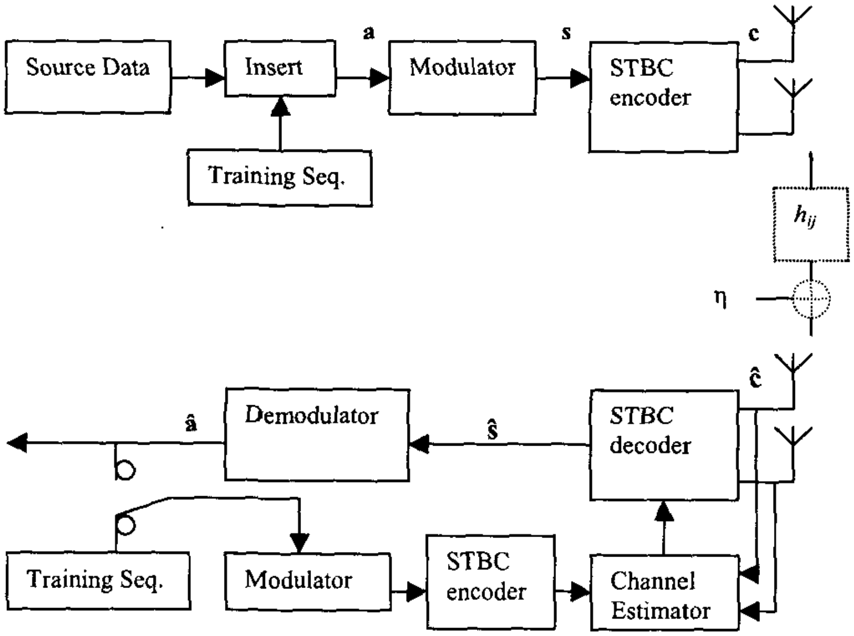

Fig. 1. STBC System with Channel Estimator.

The Symbols of column i of matrix $\mathbf{c}$ are transmitted through antenna i and those of row t are transmitted in time slot t.

Let MxN matrix $\mathbf{h}$ be channel parameters of MIMO channels and MxP matrix $\mathbf{r}$ be the signals received, then Equation (1) can be rewritten in matrix form as

$$\mathbf{r}=\mathbf{h}\mathbf{c}^T+\boldsymbol{\eta} \tag{4}$$

where

$$\mathbf{h}=\begin{bmatrix} h_{11} \dots h_{1N} \\ \dots \\ h_{1M} \dots h_{NM} \end{bmatrix} \tag{5}$$

$$\mathbf{r}=\begin{bmatrix} r_1(1) \dots r_1(\mathrm{P}) \\ \dots \\ r_\mathrm{M}(1) \dots r_\mathrm{M}(\mathrm{P}) \end{bmatrix} \tag{6}$$

and $\boldsymbol{\eta}$ is an MxP noise matrix, the elements of which are independent samples of a zero-mean complex Gaussian random variable.

The element h_{ij} of $\mathbf{h}$ is the parameter of the channel from transmit antenna i to receive antenna j. In $\mathbf{r}$, $r_j(t)$ is the signal received at receive antenna j in time slot t. As in [1] and [3], the channel is assumed to be a flat fading channel. In the receiver, the received symbol vector, $\hat{\mathbf{s}}$, is recovered from $\mathbf{r}$ by the STBC decoder according to Equation (2) or using some simplified methods [3]. Then, after demodulation, the received user data, $\hat{\mathbf{a}}$, can be obtained.

The channel parameters which are needed by decoding are obtained by the estimator. In the training period, the training sequence, being the same as the transmitted training sequence, is applied to the modulator and STBC encoder in the receiver, then into the estimator. In the burst period, the recovered user data can be used (See Fig. 1). The algorithm of channel parameter estimation is presented in the next section.

4. ALGORITHM OF ESIMATION

Let $\hbar_{ij}$ be the estimated parameter of the channel from transmit antenna i to receive antenna j. It can be obtained by minimising the mean square error (MSE) cost function:

$$D(\hbar_{ij})=\sum_{t=1}^{P}\left|r_j(t)-\sum_{i=1}^{N}\hbar_{ij}c_i(t)\right|^2 \tag{7}$$

$j=1,\dots,M.$

This is a problem of solving the extreme value of a multi-variable function. Hence, $\hbar_{ij}$ can be obtained by

$$\frac{\partial D(\hbar_{ij})}{\partial \hbar_{ij}}=0,\quad i=1,\dots,N, j=1,\dots,M. \tag{8}$$

Direct calculation yields that Equation (8) is equivalent to

$$\sum_{t=1}^{P}\left[r_j(t)-\sum_{i=1}^{N}\hbar_{ij}c_i(t)\right]c_i*(t)=0,$$

$j=1,\dots,M,$ (9)

where $c_i*(t)$ is the complex conjugate of $c_i(t)$. Equation (11) can be rewritten in matrix form as

$$\mathbf{R}_c\boldsymbol{\hbar}_j=\check{\mathbf{r}}_j \quad j=1,\dots,M \tag{10}$$

where $\mathbf{R}_c$ is the sum of NxN correlation matrices of the signals transmitted in time slot t, that is,

$$\mathbf{R}_c=\sum_{t=1}^{P}\mathbf{R}_t \tag{11}$$

where

$$\mathbf{R}_t=\begin{bmatrix} c_1(t)c_1*(t) & \dots & c_N(t)c_1*(t) \\ \dots & \dots & \dots \\ c_1(t)c_N*(t) & \dots & c_N(t)c_N*(t) \end{bmatrix} \tag{12}$$

$\check{\mathbf{r}}_j$ is the sum of the vectors, $\check{\mathbf{r}}_j(t)=[r_j(t)c_1*(t) \dots r_j(t)c_N*(t)]^T$,

$$\check{\mathbf{r}}_j=\sum_{t=1}^{P}\check{\mathbf{r}}_j(t) \tag{13}$$

and $\boldsymbol{\hbar}_j$ is a vector whose elements are the parameters of the channels from N transmit antennas to receive antenna j, that is $\mathbf{h}_j=[h_{1j},h_{2j},\dots,h_{Nj}]^T$. If the coefficient matrix $\mathbf{R}_c$ is non-singular, $\boldsymbol{\hbar}_j$ can be calculated as

$$\boldsymbol{\hbar}_j=\mathbf{R}_c^{-1}\cdot\check{\mathbf{r}}_j \tag{14}$$

where $\mathbf{R}_c^{-1}$ is the inverse matrix of $\mathbf{R}_c$.

The key of this algorithm is that the matrix $\mathbf{R}_c$ is non-singular. We find that if the training sequence is treated by the modulator and STBC encoder with the same rules as for user data, then $\mathbf{R}_c$ is always non-singular because of the orthogonality of STBC codes.

5. SIMULATION AND RESULTS

The system model of simulation is shown in Fig. 1. A pseudo random sequence generator is used for producing source user data. The method of modulation chosen is QPSK. Two and four antennas are used in the transmitter, and one and two antennas in the receiver. Correspondingly, $\mathcal{G}_2$ and $\mathcal{G}_4$ of STBC codes are used[3]. The channel parameter matrices and noise matrices are generated separately by two model functions using corresponding algorithms. Modulation and demodulation, encoding and decoding, and channel estimation are also performed by relevant model functions, of which the algorithms are described in Sections 3 and 4.

The system performances of STBC with channel parameter estimation were simulated. The results are shown in bit error probability (BER) for different transmit and receive antenna combinations. The bit streams that are run in our simulations are long enough for confidence in the results. The performance curves from the simulations with known channel parameters are identical to those in [1].

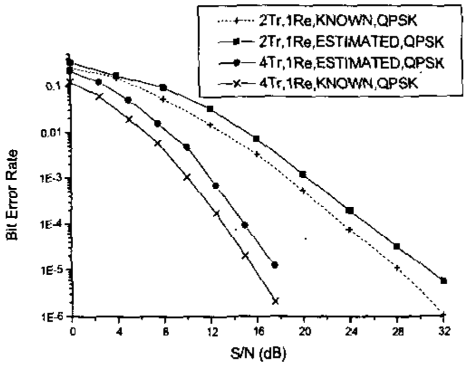

Fig. 2. Performance with 1 receiver.

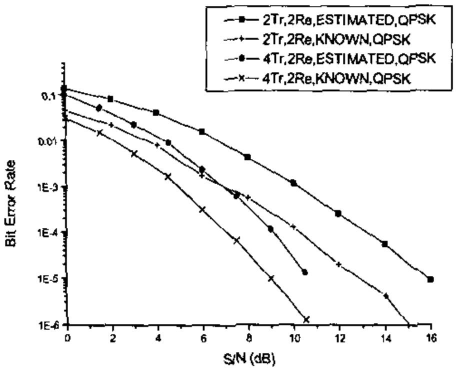

Fig. 3. Performance with 2 receivers.

In Figs. 2 we provide BER for transmission using two and four transmit antennas and one receive antenna. The results for channel parameters known and estimated are separately exhibited in each figure. It can be seen that at the bit error rates from 10^{-2} to 10^{-5} the average loss of performance for channel parameter estimation is only 2.5 ~ 3.0 dB, lower than that of known channel parameters.

Similar results can be seen from Fig.3 for the case of two receivers.

6. CONCLUSIONS

In this paper, we have studied the estimation of channel parameters for radio links with space-time block codes and developed an algorithm of MIMO channel estimation. Literature has shown that significant gains can be achieved theoretically by using space-time coding in high data rate wireless radio systems. Estimation of channel parameters which are necessary for ML detection of STBC is important for practicability of the space-time coding techniques. The simulated results have shown a good agreement of system performances by using estimated channel parameters and known channel parameters. Therefore, the proposed channel estimation method for STBC wireless communications is practicable and effective.

7. CONCLUSIONS

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