An Effective Channel Estimation Method for Transmit Diversity Systems

Ngoc Trung Tran, Xuan Nam Tran, and The Cuong Dinh
Department of Radio Electronic Engineering
Le Qui Don Technical University
100 Hoang Quoc Viet, Cau Giay, Hanoi, Vietnam
Email: namtx@lqdtu.edu.vn

***Abstract*— This paper presents a simple yet effective channel estimation method for transmit diversity systems. We propose to use the Alamouti's space-time encoding scheme to create pilot symbols and insert into the transmit data symbol streams from the transmit antennas. The orthogonality of the pilot symbols from the two transmit antennas allows to eliminate the interference among transmit antennas. The proposed pilot symbol assisted (PSA) method thus does not require pilot symbol expansion as in the previous methods. We also propose to use a simple temporal average operation to process channel decision statistics to replace temporal filters or interpolators. For a 16 pilot symbols in a 100 data symbol frame transmitted using the Alamouti's space-time block coding, the performance degradation of the estimated symbols is less than 0.2dB compared with the case of perfect channel estimation.**

I. Introduction

Wireless communications is moving toward the fourth generation (4G) where it is expected to provide data access up to hundreds megabits per second [1]. The main obstacle which limits the high-rate data access the wireless channels is fading due to the multipath propagation channels.

Diversity has been known as an effective technique for mitigating the fluctuation nature of the received signal. Of the diversity techniques space diversity is considered a practical approach as it does not require more frequencies and bandwidth expansion as with the frequency and time diversity. In 1998 Alamouti proposed a simple transmit diversity scheme for two transmit antennas, which encodes the transmit signal over both space and time domain, in order to achieve the same diversity order as that of the well-known maximum ratio combining (MRC) receive diversity [2]. The Alamouti's transmit diversity was later known as a special case of the space-time block code [3]. The simple nature of the orthogonal code design at the transmitter makes it easier to restore the transmitted symbols at the receiver by using only a linear combiner. As for the coherent detection the linear combiner requires the channel state information (CSI) of the single channels between all pairs of the transmit and receive antennas. Channel estimation thus becomes an important task for the signal estimation at the receiver. It should be emphasized that the channel estimation problem in the transmit diversity systems becomes more difficult compared with the case of single transmit antenna due to the interference among signals from different transmit antennas [4][5]. In order to avoid the interference during the pilot period, in [5] the authors proposed an alternating pilot assisted (PSA) channel estimator, in which pilot symbols are transmitted alternatively in time. This means that during a period interval only pilot symbols from the n-th transmit antennas are sent to the receiver, while other transmit antennas stop transmitting. The method requires N times large number of pilot symbols to estimate channels from N transmit antennas. To avoid the pilot symbol expansion reference [4] proposed a multirate PSA channel estimation method for the orthogonal frequency division multiplexing system with diversity. The method of [4] is, however, applicable only to OFDM systems as pilot symbols from different antennas are transmitted in different frequency bins.

In this paper we propose a simple, yet, effective PSA channel estimation method which does not require the pilot symbol expansion. The proposed method is also applicable to non-OFDM transmit diversity systems. The main idea of our proposal is to use the space-time block code (STBC) to encode the pilot symbols. The orthogonality of the transmit symbol streams from the transmit antennas during the pilot symbol period will eliminate the interference between the pilot symbols sent from the transmit antennas. We also propose to use a simple temporal average operation to process channel decision statistics to replace temporal filters or interpolators. We demonstrate that for a 16 pilot symbols in a 100 data symbol frame using the Alamouti's STBC, the performance degradation of the estimated symbols is less than 0.2dB compared with the case of perfect channel estimation.

The remainder of the paper is organized as follows. The signal model of the Alamouti's space-time coded systems is summarized in Sect.II. Section III presents our proposed channel estimation method. Simulation results is shown in Sect. IV, and, finally, the conclusion is made in Sect. V.

II. Signal Model

Consider an wireless system employing the Alamouti's space-time block code [2] with two transmit antennas and one receive antenna as illustrate in Fig. 1. The transmit symbol sequence $\{s\} = \{s_k, s_{k+1}\}$ containing odd symbols s_k and even symbols s_{k+1} is first space-time encoded (STE)

978-1-4244-2681-2/08/$25.00 ©2008 IEEE

according to the following encoding rule

$$\mathbf{s}_k = \begin{bmatrix} s_k & s_{k+1} \\ -s_{k+1}^* & s_k^* \end{bmatrix} \quad (1)$$

The coding rule in (1) is explained as follows. At the odd time slots, the first transmit antenna transmits s_k while the second antenna transmits s_{k+1}; and at the even time slots the first antenna transmits $-s_{k+1}^*$, while the second s_k^*. Here * denotes the complex conjugation.

The channel gain between each pair of the receive and transmit antennas $h_n, n = 1, 2$, is assumed quasi-static and independent and identically distributed (iid). The later assumption implies a rich scattering environment. It is common to model h_n using a complex Gaussian variable with zero mean and unit variance, i.e., $h_n \in \mathcal{N}_c(0, 1)$, for a Rayleigh fading channel. The additive white Gaussian noise (AWGN) samples z_k at the receive antenna and time slot k are assumed iid and modeled using a Gaussian random variable with zero mean and variance σ_z^2, i.e., $z_k \in \mathcal{N}_c(0, \sigma_z^2)$.

The receive signals at the two time slots at the receive antenna are expressed as

$$y_k = h_1 s_k + h_2 s_{k+1} + z_k \quad (2)$$

$$y_{k+1} = -h_1 s_{k+1}^* + h_2 s_k^* + z_{k+1}. \quad (3)$$

In order to estimate s_k and s_{k+1}, Alamouti proposed to use a simple linear combining method as the follows [2]

$$\tilde{s}_k = h_1^* y_k + h_2 y_{k+1}^* \quad (4)$$

$$\tilde{s}_{k+1} = h_2^* y_k - h_1 y_{k+1}^*. \quad (5)$$

It then straightforwardly follows that

$$\tilde{s}_k = (|h_1|^2 + |h_2|^2) s_k + h_1^* z_k + h_2 z_{k+1}^* \quad (6)$$

$$\tilde{s}_{k+1} = (|h_1|^2 + |h_2|^2) s_{k+1} - h_1 z_{k+1}^* + h_2^* z_k. \quad (7)$$

It can be observed from (6) and (7) that the system provides the second order of diversity. These decision statics are then fed to a maximum likelihood detector (MLD) to quantize them into signal constellation points as

$$\bar{s}_k = \arg \min_{s_k \in \chi_c} \left\{ (|h_1|^2 + |h_2|^2 - 1)|s_k|^2 + |s_k - \tilde{s}_k|^2 \right\}, \quad (8)$$

where χ_c denotes the signal constellation. It is worth noting that in order to be able to linearly combine the receive signals to obtain the decision statistics $\tilde{s}_k$ and $\tilde{s}_{k+1}$ as in (6) and (7), and perform the maximum likelihood detection as in (8) the receiver needs to estimate individual channels h_n. In the next section, we will discuss about methods to estimate channel parameters and propose an effective pilot-symbol assisted (PSA) method for estimating channel parameters of transmit diversity systems.

III. Channel Estimation for Transmit Diversity Systems

A. Previous Channel Estimation Methods

The common methods for channel estimation can be classified into two categories, namely, decision-directed channel estimation and pilot-symbol-assisted (PSA) channel estimation. With the decision-directed channel estimation, decoded symbols are used to estimate the channel parameters during the data transmission period, while with the PSA channel estimation, pilot symbols, which are known at both the receiver and the transmitter, are inserted into the transmit symbol frame. At the receiver, the pilot symbols are extracted to provide a temporal estimate of the channel parameters during the pilot period. These temporal estimates are then either filtered or interpolated to provide estimates of the channel parameters. Under quasi-static fading channel, it is commonly assumed that the channel is not changed during one transmit frame duration. Therefore, the estimated channel parameters during the pilot period can be used to estimate the transmitted data symbols during the data transmission period.

Theoretically, the advantage of the decision-directed channel estimation over the PSA channel estimation is that it does not require bandwidth expansion as pilot symbols are not necessary. In practice, however, as past decisions are used to estimate the channel parameters in the decision-directed channel estimation method, it is very sensitive to error propagation, especially, when there is a deep fade such as in a mobile fading channel. As a result, known symbols are also periodically transmitted during data transmission period in order to avoid excessive error propagation [4]. Eventually, the decision-directed channel estimation also requires bandwidth expansion and the PSA channel estimation method is more often used in practice.

In a transmit diversity system such as the Alamouti's space-time block code considered in this paper there are multiple transmission streams transmitted simultaneously from transmit antennas making channel estimation become more difficult. Since it is difficult to resolve the interferences during the data transmission mode, the PSA channel estimation method was shown to be the better choice for the transmit diversity systems [4]. In order to avoid the interferences during the pilot period, in [5] the authors proposed an alternating PSA channel estimator in which pilot symbols are transmitted alternatively in time. This means that during a period interval only pilot symbols from the n-th transmit antenna are sent to the receiver, while other transmit antennas stop transmitting. This method requires N times large number of pilot symbols to estimate channels from N transmit antennas. To avoid the pilot symbol expansion [4] proposed a multirate PSA channel estimation method which does not require expansion in pilot symbols for orthogonal frequency divsion multiplexing system with diversity. The method of [4] is, however, applicable to OFDM systems as pilot symbols from different antennas are transmitted in different frequency bins.

B. Proposed Simple Channel Estimation Method

In this paper we propose a simple, yet, effective channel estimation method which does not require the bandwidth expansion and is also applicable to non-OFDM transmit diversity systems. The main idea of our proposal is to use the space-time block coding to encode the pilot symbols. The orthogonality

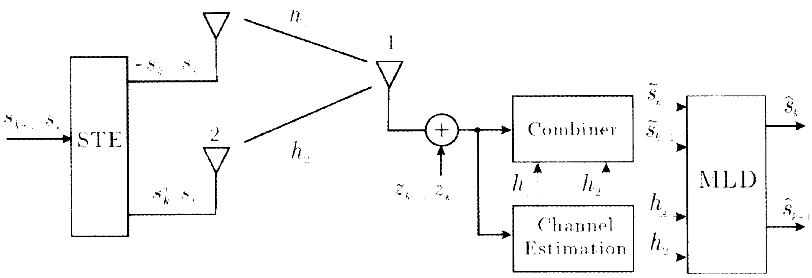

Fig. 1. Configuration of a wireless system employing Alamouti's STBC

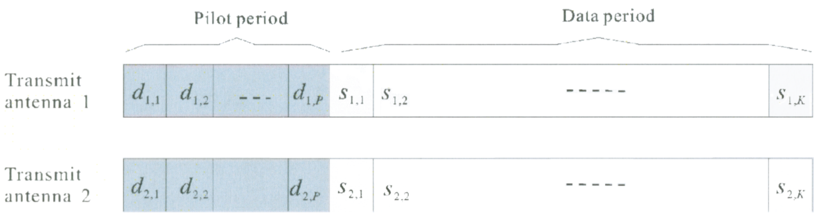

Fig. 2. Configuration of a wireless system employing Alamouti's STBC

of the transmit symbol streams from the transmit antennas will eliminate the interferences among the pilot symbols sent from the transmit antennas. The data frame which consists of the pilot symbol period and the data transmission period is illustrated Fig. 2. For simple explanation, we will limit ourselves to the case of two transmit antennas using the Alamouti's STBC. It should be noted that the proposed method here can be easily extended to the case of multiple transmit antenna systems.

The proposed method is explained as follows. Similar to the Alamouti's SBTC, during the first time slot of the pilot symbol period the first antenna transmits $d_{n,t} = d_t$ while the second antenna transmits $d_{n+1,t} = d_{t+1}$. In the next time slot, the first antenna transmits $d_{n,t+1} = -d_{t+1}^*$ while the second antenna transmits $d_{2,2} = d_t^*$. Here, we have used $t = 1, 2, ..., P$ to differentiate the pilot symbol index with the data symbol index, where P denotes the pilot symbol period length and is an even integer number. The transmit symbols received at the two receive antennas and two time slots are then given by

$$r_t = h_{1,t}d_t + h_{2,t}d_{t+1} + z_t \quad (9)$$

$$r_{t+1} = -h_{1,t}d_{t+1}^* + h_{2,t}d_t^* + z_{t+1}. \quad (10)$$

The problem now becomes estimating h_1 and h_2 given d_t and d_{t+1}. As the pilot symbols d_t and d_{t+1} are known at the receiver we can apply a linear combining operation similar to that proposed by Alamouti in [2] to obtain the decision statics of the channels as follows obtain

$$\tilde{h}_{1,t} = d_t^* r_t - d_{t+1} r_{t+1} \quad (11)$$

$$\tilde{h}_{2,t} = d_{t+1}^* r_t + d_t r_{t+1} \quad (12)$$

In fact, this linear combining provides the following channel decision statistics

$$\tilde{h}_{1,t} = \left(|d_t|^2 + |d_{t+1}|^2\right) h_{1,t} + z_t d_t^* - z_{t+1} d_{t+1} \quad (13)$$

$$\tilde{h}_{2,t} = \left(|d_t|^2 + |d_{t+1}|^2\right) h_{2,t} + z_t d_{t+1}^* + z_{t+1} d_t \quad (14)$$

In the previous channel estimation methods, the channel decision statistics are often interpolated or filtered to obtain the estimated channel parameters [4]. Here, using the ergodic and quasi-static properties of the fading channel, we propose to do a simple temporal average to estimate the channel parameters. This means that the estimated channels can be simply obtained by

$$\tilde{h}_1 = \frac{1}{P}\sum_{t=1}^{P} \tilde{h}_{1,t} \quad (15)$$

$$\tilde{h}_2 = \frac{1}{P}\sum_{t=1}^{P} \tilde{h}_{2,t} \quad (16)$$

The simplicity of the temporal average allows to eliminate the needs of designing the filter and temporal interpolator as in the previous approaches.

C. The multiple receive antenna case

Although the proposed method is presented for the case of a simple two transmit and single receive antenna system, it can be easily extended to the case of a multiple transmit antenna and multiple receive antenna, which is also known as MIMO, system using the linear combining method similar to that proposed for STBC presented in [3].

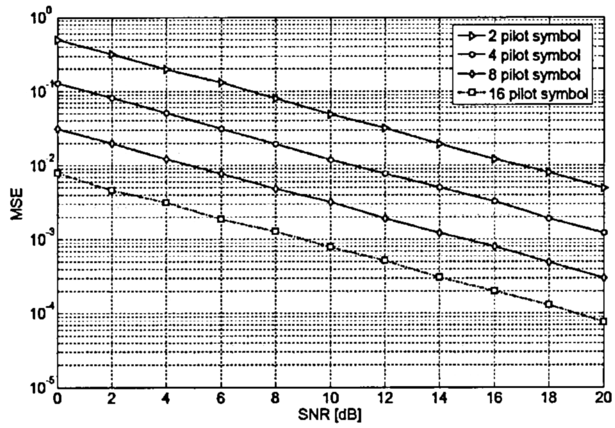

Fig. 3. MSE performance versus different pilot symbol lengths

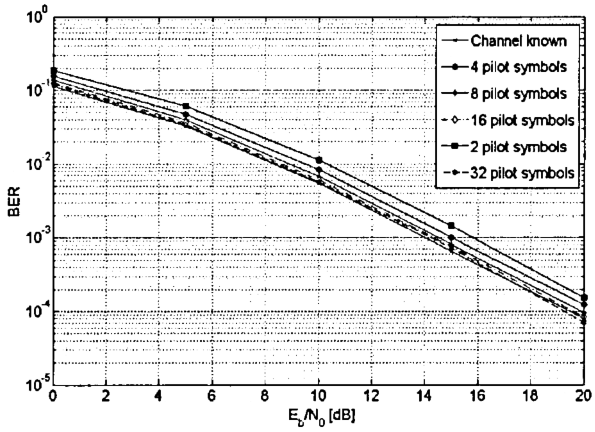

Fig. 4. BER performance obtained using different pilot symbol lengths

IV. Simulation Results

In order to evaluate the performance of the proposed channel estimation method, we have carried out a computer simulation for a simple Alamouti's STBC system with two transmit and one receive antenna as illustrated in Fig. 1. For simplicity, binary phase shift keying (BPSK) was used for modulation. The pilot and data symbols were arranged in a frame as shown in Fig. 2, where the data symbol length was $K = 100$ and the pilot symbol length P was varied from 2 to 32 to find the optimum length of P.

Figure 3 shows the mean square error (MSE) versus the signal to noise ration (SNR) for different values of the pilot symbol lengths. It is clearly seen in the figure that increasing the pilot symbol length reduces the MSE of the channel parameters.

In Fig. 4, the estimated channels were used to simulate the bit error rate (BER) of the system. BER for the case of perfect channel estimation, i.e., channels are known at the receiver, is also shown for comparison. It is realized from the figure that longer pilot symbol lengths help to improve the BER performance. With 2 pilot symbols, the channel estimation errors increase BER and it requires about 2dB in E_b/N_0 to achieve the same BER perfoamnce compared with the case of the perfect channel estimation. Doubling the pilot symbol lengths to 4 allows to reduce the gap in E_b/N_0 to 1dB. With 16 pilot symbols, the obtained BER is almost the same as that obtained in the case of perfect channel estimation. It can also be seen from the figure that using 32 pilot symbols does not provide much difference in the BER performance compared with the case of 16 pilot symbols. This observation leads to conclusion that $P = 16$ is a good selection of the pilot symbol length.

V. Conclusion

In this paper, we have presented an effective channel estimation method for transmit diversity systems. We have shown that using the proposed method does not require pilot symbol expansion. We have also demonstrated that for only 16 pilot symbols in a 100 data symbol frame, the proposed scheme can provide almost the same BER performance as with that of the perfect channel estimation case. The proposed is not only used for the Alamouti's STBC system but also applicable to other transmit diversity systems.

References

[1] S. Hara and R. Parasad, *Multicarrier Techniques for 4G Mobile Communications*, Artech House, 2003.

[2] S. M. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communications", *IEEE J. Select. Areas in Commun.*, vol. 16, no. 8, pp. 1451–1458, October 1998.

[3] J. Yuan and B. Vucetic, *Space-Time Coding*, John Wiley & Sons Ltd,, 2003.

[4] K. F. Lee and D. B. Williams, "Pilot-Symbol-Assisted Channel Estimation for Space-Time Coded OFDM Systems," *EURASIP Journal on Applied Signal Processing*, vol.2002, Issue 5, pp. 507-516, May 2002.

[5] Y. Li, N. Seshadri, and S. Ariyavisitakul, "Channel estimation for OFDM systems with transmitter diversity in mobile wireless channels," *IEEE J. on Select. Areas in Commun.*, vol. 17, no. 3, pp. 461471, 1999.