A Combined Time and Frequency Domain Approach to Channel Estimation for SFBC MIMO-OFDM Wireless Communication System

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ABSTRACT
This paper presents a combined approach to channel estimation for multiple input multiple output (MIMO) orthogonal frequency division multiplexing (OFDM). It uses both time domain and frequency domain information in the received signal to estimate the channel. Initial estimate of the channel is obtained using pilot assisted least square (LS) channel estimation. The estimate is further enhanced by extracting information through the received data symbols. A frequency domain approach is used to estimate the channel using pilots whereas time domain approach is used to enhance the estimate of the channel. The performance of the proposed estimator is studied under various channel models. The simulation study shows that this approach outperforms the pilot assisted least square channel estimation method.

General Terms
Channel Estimation, MIMO-OFDM, Wireless Communication.

Keywords
Multiple input multiple output, orthogonal frequency division multiplexing, pilot assisted least square channel estimation, space frequency block coding.

1. INTRODUCTION
The demand of high data rates for wireless communication can be catered by use of multiple antennas both at transmitter and receiver end. The use of simple transmit diversity technique and Space time block codes for a MIMO system was proposed initially by Alamouti [1] and V Tarokh et. al [2], [3]. Orthogonal frequency division multiplexing converts frequency selective fading channel into set of frequency flat channels thereby combating the effect of fast fading. Multiple-input multiple-output (MIMO) wireless technology in combination with orthogonal frequency division multiplexing (OFDM) is an attractive air-interface solution for next-generation wireless local area networks (WLANs), wireless metropolitan area networks (WMANs), and fourth-generation mobile cellular wireless systems. OFDM directly extends to MIMO channels with IFFT/FFT and CP operations being performed at each transmit and receive antennas [4]-[6]. MIMO signaling for Single Carrier (SC) modulation in frequency-flat fading channels can be overlaid easily on OFDM by simply performing operations on a tone-by-tone basis [7]. Both spatial diversity and spatial multiplexing MIMO OFDM systems can be implemented. Space frequency coded MIMO-OFDM discussed in [8] consists of space time block coded symbols occupying adjacent tones in the same OFDM symbol. The bit stream to be transmitted is first modulated then encoded and interleaved. The resulting data symbols to be transmitted are mapped across space and frequency by a space-frequency encoder such as the one described in [9], [10]. The receiver demodulates the received signal and estimates the transmitted space-frequency codeword followed by de-interleaving and decoding. A space time frequency approach for MIMO-OFDM system is discussed in [11].

The system's ability to achieve MIMO capacity depends on channel state information. Accurately estimating MIMO channel is much more challenging than SISO channel [12] [13]. There are number of channel estimation schemes suggested in literature. These schemes can be categorized as training based channel estimation (TBCE), blind channel estimation (BCE) and semi-blind channel estimation (SBCE). Training based schemes are capable of accurately estimating a MIMO channel, provided a large training overhead is made available. Hence there is considerable reduction in system throughput [14]. Blind methods do not require the training overhead. However these methods not only impose high complexity and slow convergence, but also suffer from unavoidable estimation and decision ambiguities [15]-[17]. Semi-blind methods offer attractive practical means of implementing MIMO systems. Semi-blind channel estimation schemes, use a few training symbols to provide the initial MIMO channel estimation and make use of blind information to further improve the estimation [16] [18] [19].

The training based channel estimation in MIMO-OFDM system can be block type or comb type. In block type method the pilots are inserted into all tones of a OFDM symbol so that the channel estimate of each tone can be obtained in frequency domain. This type of technique is suitable when the channel is varying slowly. Comb type method inserts pilots in the tones at fixed interval in one OFDM symbol. The channel estimate for these tones is obtained using least squared (LS) or minimum mean squared error (MMSE) technique. The estimate of remaining tones is obtained by interpolation. The LS channel estimation with block-type pilot for MIMO-OFDM was first proposed in [20], and was simplified in [21]. In MIMO-OFDM system, the received OFDM symbols can be processed in time domain or frequency domain. Number of semi-blind channel estimation methods for MIMO-OFDM system are proposed in literature. See for example [22] and references therein. Performance of Space frequency block coded MIMO-OFDM system is given in [23].

This paper presents a channel estimation method using both frequency and time domain approach for a MIMO-OFDM system. The initial estimate of the channel is obtained using comb-type pilot assisted LS estimation and interpolation. This estimate is further enhanced by using detected data symbols. The new approach clearly outperforms the simple training based approach. Rest of the paper is organized as follows. Section 2 describes the system model. The design of the proposed estimator is given in section 3. The simulation results and discussion on the results is given in section 4. Finally section 5 gives the conclusion.

Throughout our discussions we adopt the following notational conventions. Boldface capitals and lower-case letters stand for matrices and vectors, respectively. $\boldsymbol{I}$ denote the identity matrix. $(.)^T$ $(.)^H$ and $(.)^\dagger$ are transpose, conjugate transpose and Moore-Penrose pseudo inverse operators respectively.

2. SYSTEM MODEL

Consider a MIMO-OFDM system with N_T transmit and $N_R(> N_T)$ receive antennas. Let there be K subcarriers in one OFDM symbol. It is assumed that time-variant wireless channel obey Rayleigh distribution and is quasi-static in one OFDM block duration. The maximum multipath delay length is *L*. The length of Cyclic Prefix (CP) is chosen to be longer than *L*. Channels between each transmit and receive antenna pairs are assumed to be mutually uncorrelated. The channel impulse response between *j*-th receive and *i*-th transmit antenna corresponding to *l*-th path delay is denoted as $h_{ij}(l)$; where $l=0, 1, 2 \ldots L-1$.

At a transmission time n, binary data is grouped according to type of modulation (MQAM or MPSK) and mapped onto different sub-carriers depending on the coding to be used. Then the signal on *k*th sub-carrier at ith transmit antenna is denoted by $X_i[n,k]$ where $i = 1, 2, \ldots, N_T$, $k = 0,1,2, \ldots, K-1$, $n = 0,1,2, \ldots, N-1$. The received signal in time domain and frequency domain at *j*-th receive antenna is given by (1) and (2) respectively [21], [24].

$$\mathbf{y_j}(n) = \sum_{i=1}^{N_T} \mathbf{h}_{ij}(n) \otimes \mathbf{x}_i(n) + \mathbf{w}_j(n) \qquad (1)$$

$$Y_j[n,k] = \sum_{i=1}^{N_T} H_{ij}[n,k]\, X_i[n,k] + W_j[n,k] \qquad (2)$$

Where $j = 1, 2, \ldots, N_R$, $H_{ij}[n,k]$ is the frequency response between antennas *i* and *j*, $W_j[n,k]$ is the additive Gaussian noise with zero mean and variance σ_n^2 . If $\boldsymbol{F}$ denotes DFT matrix then we have following relationships.

$$\mathbf{X}_i[n] = F\mathbf{x}_i(n),\ Y_j[n] = \boldsymbol{F}\mathbf{y}_j(n),\quad \mathbf{H}_{ij}[n] = \boldsymbol{F}\mathbf{h}_{ij}(n)$$

and $\mathbf{W}_j[n] = \boldsymbol{F}\mathbf{w}_j(n)$

Now Let us represent the transmitted OFDM symbol from *i*th antenna as,

$$\mathbf{X}_i[n] = \mathrm{diag}\{X_i[n,0], X_i[n,1] \ldots X_i[n,K-1]\} \in \mathbb{C}^{K\times K} \qquad (3)$$

The received OFDM symbol at *j*-th antenna as,

$$\mathbf{Y}_j(n) = [Y_j[n,0], Y_j[n,1] \ldots Y_j[n,K-1]^T \in \mathbb{C}^{K\times 1} \qquad (4)$$

The transmitted OFDM symbols from all transmit antennas as,

$$\mathbf{X}(n) = [X_1[n]\ X_2[n]; \ldots, X_{NT}[n]] \in \mathbb{C}^{K\times KN_T} \qquad (5)$$

The channel gain on each subcarrier from *i*th transmit and *j*th receive antenna as,

$$\mathbf{H}_{ij}[n] = [H_{ij}[n,0], H_{ij}[n,1], \ldots H_{ij}[n,K-1]]^T \in \mathbb{C}^{K\times 1} \qquad (6)$$

The entire channel gain matrix corresponding to all transmit and *j*th receive antenna as,,

$$\mathbf{H}_j(n) = [\mathbf{H}_{1j}^T[n], \mathbf{H}_{2j}^T[n], \ldots,\ \mathbf{H}_{N_Tj}^T[n]]^T \in \mathbb{C}^{KN_T\times 1} \qquad (7)$$

The additive white Gaussian noise on each subcarrier at *j*-th receive antenna as,

$$\mathbf{W_j(n)} = \{W_j[n,0], W_j[n,1] \ldots W_j[n,K-1]\} \in \mathbb{C}^{K\times 1} \qquad (8)$$

Using (4), (5), (7) and (8) we can express the received signal at *j*-th receive antenna in frequency domain as

$$\mathbf{Y_j}(n) = \mathbf{X}(n)\, \mathbf{H_j}(n) + \mathbf{W_j}(n) \qquad (9)$$

Now the time domain representation of the channel between *i*th transmit and *j*th receive antenna is given by

$$\mathbf{h_{ij}}[n] = [h_{ij}[n,0], h_{ij}[n,1], \ldots h_{ij}[n,L-1]]^T \in \mathbb{C}^{L\times 1} \qquad (10)$$

The time domain representation of the channel at *j*-th receive antenna from all transmit antennas is given by,

$$\mathbf{h_j}(n) = [\mathbf{h_{1j}^T}[n], \mathbf{h_{2j}^T}[n], \ldots, \mathbf{h_{N_Tj}^T}[n]]^T \in \mathbb{C}^{LN_T\times 1} \qquad (11)$$

The relationship between $H_j(n)$ and $h_j(n)$ is given by,

$$\mathbf{H_j}(n) = \boldsymbol{F_M}\mathbf{h}_j(n) \qquad (12)$$

Where, $\boldsymbol{F_M} = \mathrm{diag}[\ \boldsymbol{F}\times\mathbf{M}, \boldsymbol{F}\times\mathbf{M}, \ldots, \boldsymbol{F}\times\mathbf{M}] \in \mathbb{C}^{KN_T\times LN_T}$ and $M = [I_{L\times L}\ 0_{K-L\times L}]^T$

Substituting (12) in (9) we get,

$$\mathbf{Y_j}(n) = \mathbf{X}(n)\, \boldsymbol{F_M}\mathbf{h}_j(n) + \mathbf{W}_j(n) \qquad (13)$$

Now let, $\mathbf{A} = \mathbf{X}(n)\, \boldsymbol{F_M}$ hence (13) can be written as,

$$\mathbf{Y}_j(n) = \mathbf{A}\mathbf{h}_j(n) + \mathbf{W}_j(n) \qquad (14)$$

Equation (9) and (14) are frequency and time domain representations of the received signal at *j*-th antenna respectively during transmission time *n*. These expressions will be used in this paper for channel estimation at the receiver.

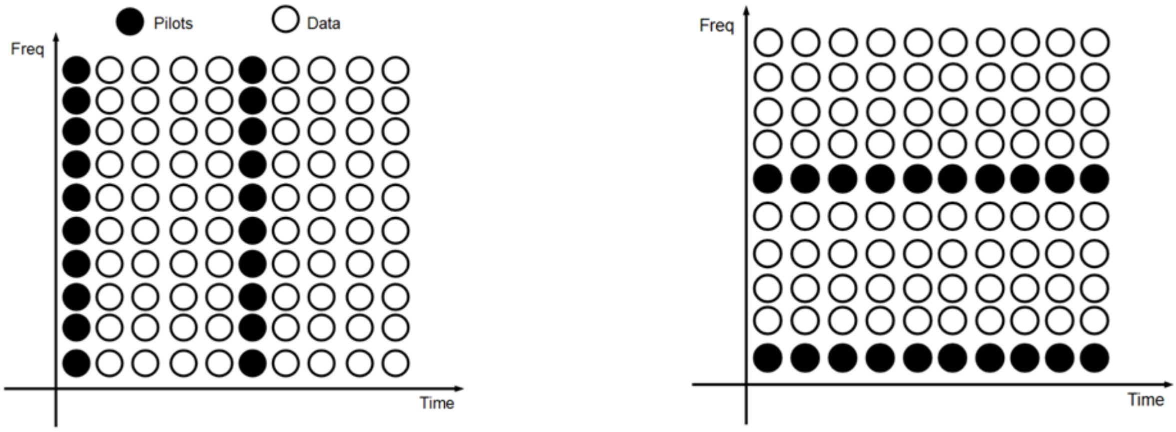
2.1 Pilot placement

There are main types of pilot placements in MIMO-OFDM systems. In a block-type pilot MIMO-OFDM system, the orthogonal pilots are assigned to all subcarriers in a OFDM symbol. These pilots are transmitted periodically. From these pilots, the channel is estimated and used for detection of data carried by subsequent OFDM symbols. Block type pilot placement is useful where the channel is time invariant over number of OFDM symbols i.e. channel is slow fading. In the Comb-type pilot MIMO-OFDM system, pilots are inserted into a set of subcarriers in a OFDM symbol and channel is estimated for rest of the subcarriers using interpolation. This type of pilot placement is useful where the channel is fast fading. The block-type and comb-type pilot placement is shown in fig 1.

2.2 SFBC MIMO-OFDM

In SFBC MIMO-OFDM system, the input data symbols $S_0, S_1 \dots S_{K-1}$ are converted into K parallel symbols. These symbols are divided into K/N_T groups. Each of these groups is coded using space time block coding and transmitted on different subcarriers on N_T different antennas. For example, for $N_T = 2$ G2 coded symbols are transmitted on two antennas as below

$$\boldsymbol{X} = \begin{bmatrix} S_0 & -S_1^* & S_2 & -S_3^* & \dots & S_{K-2} & -S_{K-1}^* \\ S_1 & S_0^* & S_3 & S_2^* & \dots & S_{K-1} & S_{K-2}^* \end{bmatrix} \quad (15)$$



(a) Block Type **(b) Comb Type**

Fig. 1: Pilot and data arrangement on each transmit antenna

3. ESTIMATOR DESIGN

The channel estimation in SFBC MIMO-OFDM system can be obtained by frequency domain or time domain processing. Let us use the block-type pilot arrangement in which out of K subcarriers, Np orthogonal pilots are periodically placed. Let these set of pilots be denoted as $\boldsymbol{X_p}$. Then the frequency domain channel estimation is given by (16) which is obtained applying least square (LS) estimation to (9).

$$\widehat{\boldsymbol{H}}_j[n,k] = \boldsymbol{X_p^\dagger}[n, k{:}\, k + N_T]\, \boldsymbol{Y}_j[n,k] \quad (16)$$

where $k = 0, \frac{K}{Np}, \frac{2K}{Np}, \dots . \frac{(Np-1)K}{Np}$.

Channel gains of remaining subcarriers are obtained using interpolation. Using the channel estimate of each subcarrier, the data sent on the corresponding subcarriers is detected using space frequency block decoding technique [25]. The detected symbols are used to further enhance the channel estimate. Time domain channel estimation is used for this purpose. If the detected symbols are arranged again as (15), the time domain channel estimation is given by (17) which is obtained by applying LS estimation to (14).

$$\widehat{\boldsymbol{h_j}} = \boldsymbol{A}^\dagger \boldsymbol{Y}_j \quad (17)$$

Where, $\boldsymbol{A} = \boldsymbol{XF_M}$.

The frequency domain estimate is then obtained as

$$\widehat{\boldsymbol{H}}_j = \boldsymbol{F}\widehat{\boldsymbol{h}}_{\boldsymbol{j}} \quad (18)$$

Using this enhanced estimate of the channel, the data is detected which will be more accurate than the pilot assisted LS estimator. Hence the BER performance of the proposed scheme is better than the pilot assisted LS estimator. This advantage is achieved at increased computational complexity.

4. SIMULATION RESULTS AND DISCUSSION

A SFBC MIMO-OFDM system with 2 transmit and 4 receive antennas was simulated. Alamouti’s [1] code is used for performance evaluation. Table I gives the specifications of the system which are similar to IEEE 802.16a Broadband Wireless Access [26].

Table 1. Simulation parameters for MIMO-OFDM System

System Parameters	Parameter Value
Modulation	QPSK, 64 QAM
Channel Bandwidth	20 MHz
FFT/IFFT size	256
Cyclic Prefix Length	64 (25%)
Pilots placement	Comb-type

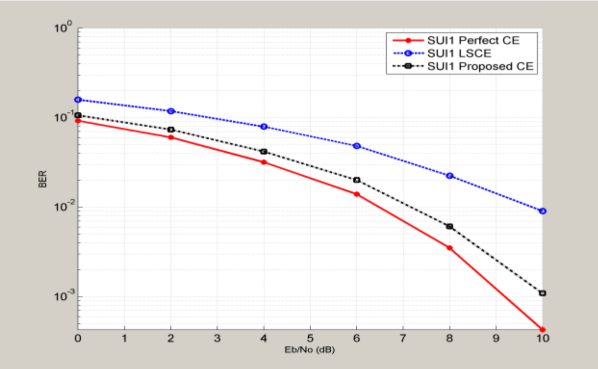
The channel models used in the simulation are modified Stanford University Interim (SUI) channel models described in [27]. The channel is assumed to be quasi static i.e. it remains constant for one OFDM symbol duration. In the simulation, the modulation scheme is same for all data and pilot subcarriers with average energy E_s and the noise is complex additive white Gaussian with zero mean and variance $N_o/2$.

From the results in fig. 2 we observe that the proposed scheme has an advantage of almost 2dB over the pilot assisted LS channel estimation. The performances of proposed frequency and time domain combined scheme result into steady decay rate for low delay spread channel models SUI-1, SUI-2 and SUI-3. The rest of the models i.e. SUI-4, SUI-5 and SUI-6 exhibit low decay rate at high SNR as they have large delay spread. Table 2 gives some tabulated values of BER with

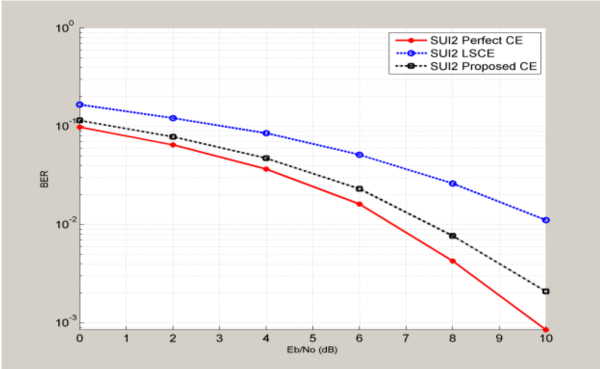
Eb/No=6dB for LS and proposed estimator.

In fig. 3 we present the BER performance with SUI-1 and SUI-5 channel models for a similar setup as described above except that the modulation scheme used is QPSK

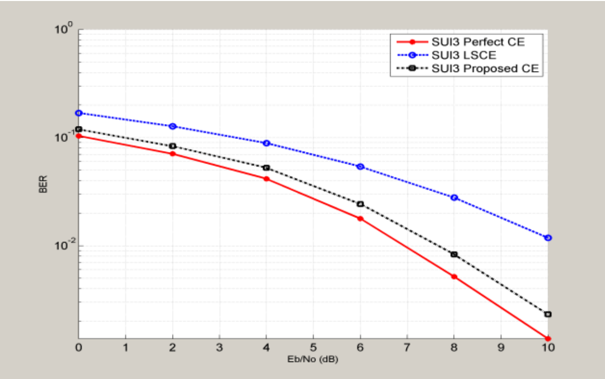
From the results of fig. 3 we find that the BER performance of the proposed scheme is better than the LS estimator. At high SNR the proposed scheme exhibit slightly faster decay rate than the LS estimator for all channel models. Thus, for lower modulation order the proposed scheme exhibits still better performance.



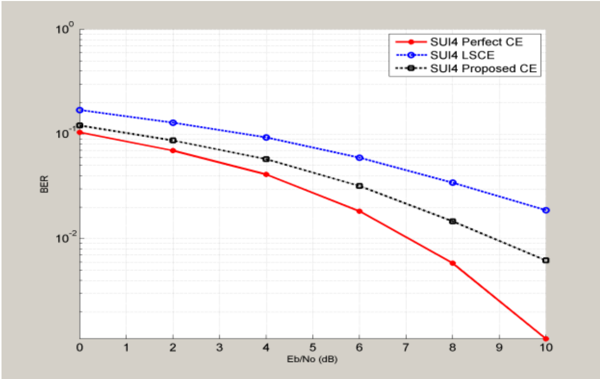
(a) SUI-1 Channel Model



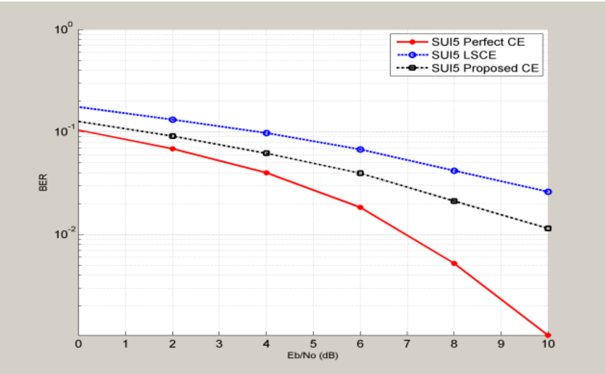
(b) SUI-2 Channel Model



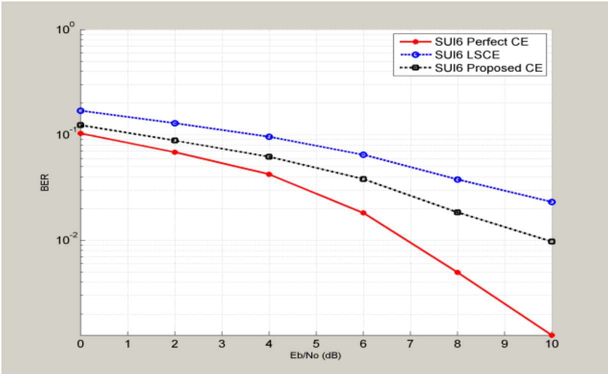
(c) SUI-3 Channel Model



(d) SUI-4 Channel Model



(e) SUI-5 Channel Model



(f) SUI-6 Channel Model

Fig 2: BER Performance of 2X4 SFBC MIMO-OFDM System with different channel models, 64-QAM Modulation.

Table 2. BER values for LS and proposed Estimator for Eb/No=6dB, 64-QAM Modulation

Channel / Estimator	SUI-1	SUI-2	SUI-3	SUI-4	SUI-5	SUI-6
LS CE	0.04771	0.05146	0.05396	0.05949	0.06774	0.06497
Proposed CE	0.02044	0.02315	0.02431	0.03194	0.03963	0.03823

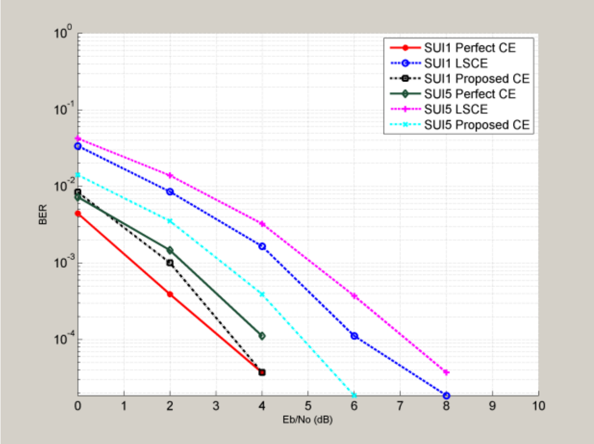


Fig 3: BER Performance of 2X4 SFBC MIMO-OFDM System with SUI-1 and SUI-5 channel model, QPSK Modulation.

5. CONCLUSIONS

A combined time and frequency domain approach for channel estimation for SFBC MIMO-OFDM system is proposed. The BER performance of proposed scheme is tested under different SUI channel models and compared with the pilot assisted LS estimator. The proposed scheme exhibits better performance for the channel with low delay spread. The proposed scheme exhibits low decay rate especially when we use higher order modulation scheme and channel with large delay spread. Future work will include performance testing and improvement of the estimator under high mobility channel conditions. Work on reduction in computational complexity of the estimator can also be undertaken.

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