Comb type Pilot arrangement based Channel Estimation for Spatial Multiplexing MIMO-OFDM Systems

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Abstract---*Pilot symbols have been widely employed in many applications and standards. In conventional approaches, Pilot symbols are multiplexed among data stream, based on an exclusive pattern, on each transmitter antenna. Initial estimate of the channel is obtained using pilot assisted Least Square (LS) channel estimation using frequency domain approach. Recovered symbols are used to further enhance the channel estimate through time domain approach. The performance of the proposed estimator is demonstrated using computer simulations which are carried out under different channel conditions.*

Keywords-Channel estimation, Least Square, Spatial multiplexing, Sphere decoding, multi-input multi-output (MIMO), orthogonal frequency multiplexing division (OFDM).

1. INTRODUCTION

MIMO systems which use multiple antennas at transmit and receive ends are able to deliver high data rates, reliable and robust performance and high spectral efficiency. These gains however are possible if the channel state information (CSI) is available at the receiver end. OFDM can be combined with MIMO by using the OFDM operations namely IFFT/FFT and Cyclic Prefix (CP) at each transmit and receive antennas. MIMO techniques which have been demonstrated for single carrier (SC) modulation under frequency flat fading channel conditions can be applied to OFDM. The MIMO-OFDM systems so formed perform the operations on each carrier of OFDM symbol separately [1]. This makes MIMO –OFDM, the most practical approach of using MIMO in wireless scenario.

Spatial Diversity MIMO-OFDM system transmits coded data symbols on different subcarriers of OFDM symbol. The coded symbols can be overlaid on different subcarriers either in time domain or frequency domain. Accordingly, we have space frequency block coded (SFBC) MIMO-OFDM system or space time block coded (STBC) system [2]. Spatial multiplexing MIMO-OFDM systems transmit the data symbols on different subcarriers of OFDM symbols without using any encoding. The channel estimation schemes can be classified into three types. The Training Based Channel Estimation (TBCE), Semi-Blind Channel Estimation (SBCE) and Blind Channel Estimation (BCE). Training based schemes are accurate and robust in estimating a MIMO channel. But they require a large training overhead which reduces the system throughput [3]. Blind methods do not require the training overhead. But they require long data records over which the channel should remain static. Semi-blind methods are practical methods of channel estimation for MIMO systems. SBCE schemes use very few pilot symbols. Using these pilot symbols, initial estimate of the channel is obtained and it can be further enhanced using the information of channel contained in the data symbols.

In MIMO-OFDM System, there are number of ways in which the pilot symbols can be placed in different subcarriers of the OFDM symbols. The main two types are block type or comb type pilot placements. In block type method, the pilots are placed into all subcarriers of an 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. In comb type method, the pilots are placed in the subcarriers at fixed interval in one OFDM symbol. The channel estimate for these subcarriers is obtained using LS or Minimum Mean Square estimation (MMSE) technique. Estimate of channel state on remaining subcarriers is obtained using interpolation [4].

In Spatial Multiplexing MIMO system the main task is to design a powerful detection technique capable of separating the transmitted symbols. Several MIMO detection techniques were proposed in the literature for the same. These MIMO detection techniques are categorized as Maximum Likelihood Detector (MLD), linear detectors, successive interference cancellation and tree-search techniques. MLD has an optimum performance but the algorithm becomes exponentially complex with increase in number of transmit antennas and order of modulation because of which it cannot be used in practice.

In this work a new approach to channel estimation method is presented using both frequency and time domain approach for SM MIMO-OFDM system. The Initial assisted LS estimation and interpolation. This estimate is further enhanced by using detected data symbols. Sphere decoding is used to reduce computational complexity. The new approach clearly outperforms the simple training based approach.

2. SYSTEM MODEL

Consider a SM MIMO-OFDM system with N_T transmit and N_R (>N_T) receive antenna. Let there be K subcarriers in one OFDM symbol. The channel is wireless and assumed to be Rayleigh channel. The channel remains unchanged during the OFDM block duration. The maximum multipath delay length is L. The length of CP is selected such that it is greater than L. It is also assumed that the channels between transmit and receive antenna pairs will 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$l = 0,1,2, \dots, L-1$.

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. The transmitted signal on sub-carrier k, associated with i^{th}transmit antenna is denoted by $X_i[n,k]$ where $i = 1,2, \dots . N_T; k = 0,1,2, \dots, K-1$ and $n = 0,1,2, \dots, N-1$. The received signal in time domain and frequency domain at j^{th} receive antenna is given by (1) and (2) respectively [6].

$$y_j(n) = \sum_{i=1}^{N_T} h_{ij}(n) \otimes x_i(n) + w_j(n) \qquad (1)$$

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

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

$X_i[n] = F x_i(n)$,$Y_j[n] = F y_i(n)$, $H_{ij}[n] = F h_{ij}$ and$W_j[n] = F w_j(n)$

Now let us represent the transmitted OFDM symbol from i^{th} antenna as,

$$X_i(n) = diag\{X_i[n,0], X_i[n,1] \dots X_i[n,K-1]\} \in C^{K \times K} \qquad (3)$$

The received OFDM symbol at j^{th} antenna as,

$$Y_j[n] = diag\{Y_j[n.0], Y_j[n,1], \dots, , Y_j[n,K-1]^T\} \in C^{K \times 1} \qquad (4)$$

The transmitted OFDM symbols from all transmit antennas as,

$$X(n) = [\, X_1[1] X_2[2] \dots \; X_{N_T}[n]] \in C^{K \times K N_T} \qquad (5)$$

The channel gain on each subcarrier from i^{th} transmit and j^{th} recieve antenna as,

$$H_{ij}[n] = \left[H_{ij}[n,0] H_{ij}[n,1] \dots H_{ij}[n,K-1]^T\right] \in C^{K \times 1} \qquad (6)$$

The entire channel gain matrix corresponding to all transmit j^{th} receive antenna as,

$$H_j(n) = H_{1j}^T[n] H_{2j}^T[n] \dots H_{N_T j}^T[n]]^T \in C^{K N_T \times 1} \qquad (7)$$

The additive white Gaussian noise on each subcarrier at j^{th} receive antenna as,

$$W_j(n) = \left[W_j[n,0] W_j[n,1] \dots W_j[n,K-1]\right] \in C^{K \times 1} \qquad (8)$$

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

$$Y_j(n) = X(n) H_j(n) + W_j(n) \qquad (9)$$

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

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

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

$$h_j(n) = h_{1j}^T[n] h_{2j}^T[n] \dots h_{N_T j}^T[n]]^T \in C^{L N_T \times 1} \qquad (11)$$

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

$$H_j(n) = F_M h_j(n) \qquad (12)$$

Where,

$$F_M = diag[F \times M, \quad F \times M, \quad \dots, \quad F \times M] \in C^{K N_T \times L N_T}$$

and $M = [I_{L \times L} O_{K-L \times L}]^T$

Substituting (12) in (9) we get,

$$Y_j(n) = X(n) F_M h_j(n) + W_j(n \qquad (13)$$

Now let, $A = X(n) F_M$ hence (13) can be written as,

$$Y_j(n) = A h_j(n) + W_j(n) \qquad (14)$$

Equation (9) and (14) are frequency domain and time domain representation of the received signal at j^{th} antenna respectively during transmission time n. These expressions will be used in this work for channel estimation at the receiver.

2.1 Types of pilot arrangement.

There are main two types of pilot placements in MIMO-OFDM systems. In a Block type pilot MIMO-OFDM system, the orthogonal pilots are designed to all subcarriers in an 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 an 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 Blok and Comb type pilot placements are shown in fig 1 and 2 respectively.

3. Spatial Multiplexing MIMO-OFDM

In Spatial Multiplexing MIMO-OFDM system, the input data symbols S_0, S_1 , . . .S_{2k-1} are divided in to $2k/N_T$ groups. Each of these groups is transmitted on different subcarriers on N_T different antennas. For example, for N_T = 2, symbols are transmitted on two antennas as below

$$X = \begin{bmatrix} s_0 & s_2 & s_4 & s_6 & \cdots & s_{2k-4} & s_{2k-2} \\ s_1 & s_3 & s_5 & s_7 & & s_{2k-3} & s_{2k-1} \end{bmatrix} \quad (15)$$

●----Pilot O ----- Data

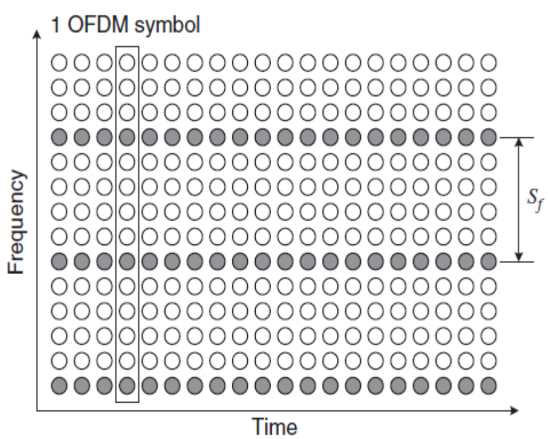

Fig.1 Comb type pilot arrangement.

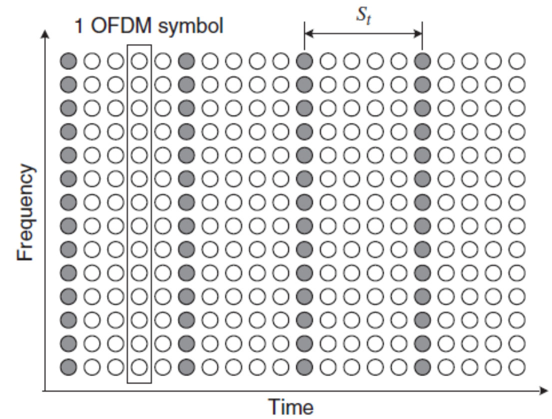

Fig.2 Block type pilot arrangement.

4. ESTIMATOR DESIGN

The channel estimator in Spatial Multiplexing MIMO-OFDM system can be obtained by frequency domain or time domain processing. Let us use the comb type pilot arrangement in which N_P orthogonal pilots are periodically placed. Let these set of pilots be denoted as X_P. Then the frequency domain channel equation is given by (16) which are obtained by applying least square estimation to (9).

$$\widehat{H_j}[n,k] = X_P^{\dagger}[n,k:k+N_T]Y_j[n,k] \quad (16)$$

Where, k=0, $\frac{k}{N_p}-1, \frac{2k}{N_p}-1, \ldots, k-1$.

Interpolation technique is used to obtain the estimate of channel on subcarriers. Using this channel estimate of each subcarrier, the symbols on the data subcarriers are deleted. Sphere decoding technique discussed in [5] is used for the detection. The detected symbols are used to further enhance the channel estimate using time domain processing. If the detected symbols are arranged again as (15), the time domain channel estimation is given by (17). The equation is obtained by applying LS estimation to (14).

$$\widehat{h}_j = A^{\dagger}Y_j \quad (17)$$

Where $A = XF_M$.

The frequency domain estimate is then obtained using DFT as,

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

The enhanced estimate obtained in (18) is used to detect the symbols on data subcarriers. The detected symbols 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 however is achieved at increased computational complexity.

5. RESULTS AND DISCUSSION

A SM MIMO-OFDM system is simulated. Two transmit and four antennas are used. Table I gives the specification of the system which are similar to IEEE 802.16a broadband wireless access.

Table I. Parameters for MIMO-OFDM system simulation

System parameters	Parameter value
FFT/IFFT size	512
Channel Bandwidth	40 MHz
Subcarrier Spacing	78.125 KHz
OFDM Symbol Time	12.8 μs
Carrier Prefix	64
Modulation	QAM,16-QAM, 32-QAM
Channel Delay Profile	SUI1, SUI5
Pilots Placements	Comb type
Channel Estimation	Enhanced CE

The channel models used in the simulation are modified Stanford University Interim (SUI) channel models described in [9]. It is assumed that the channel remains constant for duration of one OFDM symbol. 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 $N_0/2$. The 2 pilot subcarriers are placed after every 6 data subcarriers.

Fig.3 shows that Bit Error Rate (BER) performance of the system with SUI-1 channel model and QAM modulation. From the results in the Fig.3 we observe that the proposed scheme has an advantage of almost 4-5dB over the Perfect channel estimation.

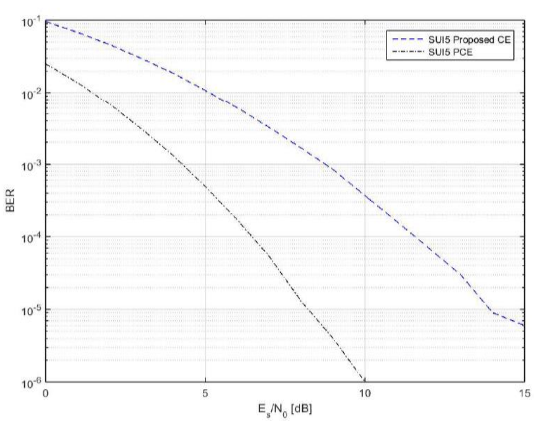

Fig.3 BER Vs. E_b/N_0 plot for 2X4 SM MIMO-OFDM system under SUI-5 channel model and QAM Modulation

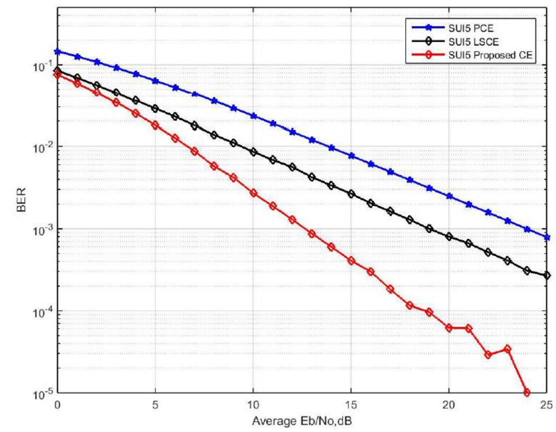

Fig.4 BER vs. E_b/N_0 plot for 2X4 SM MIMO-OFDM system under SUI-5 channel model and 16 QAM Modulation

From the results shown in fig.4, we observe that the BER performance of the proposed is better than the LS estimator. At high SNR the proposed scheme exhibit slightly faster decay rate than the LS estimator for both channel models. Thus for lower modulation order the proposed scheme exhibits still better performance.

Fig.4 show the BER Plot for SUI-5 channel model from these results proposed scheme has advantage of 4 -5 dB over the LS CE technique. Thus it can be observed that the proposed scheme can performs better under different channel conditions and for lower and higher order modulation schemes.

6. CONCLUSION

Enhanced channel estimation with combined time and frequency domain approach for SM MIMO-OFDM system is proposed. Initially, LSCE technique is used to obtain estimate of the channel. This process is done in frequency domain. The data symbols are decoded using sphere decoder and used as pilots to further enhance the estimate. This process is done in time domain. The BER performance proposed scheme is tested under different SUI channel models. This performance is compared with the technique of channel estimation is found to outperform the LSCE technique. Future work will include performance testing and improvement of the estimator under high mobility channel conditions.

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