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Semi Blind Channel Estimation: An Efficient Channel Estimation scheme for MIMO-OFDM System

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Abstract: In this paper, an efficient channel estimation scheme for MIMO OFDM system has been presented. The semi-blind channel estimation is combination of blind estimation and least square training based channel estimation. Method uses linear prediction for estimating blind constraint and least square (LS) method to estimate ‘A’ matrix, which is further used to find semi-blind estimate. LS method and semi-blind method are compared based on BER and also mean square error. Results show that when same number of training data is used, semi-blind channel estimation provide lesser MSE and BER compared to LS method**.**

Key words: Communication channels, orthogonal frequency division multiplexing, time varying channel, channel estimation, linear prediction, semiblind.

INTRODUCTION

Multi Input Multi Output Orthogonal Frequency Division Multiplexing (MIMO OFDM) is a strongest competitor for next generation high speed wireless multimedia communication. It provides high data rate and high spectral efficiencies. It simplifies the implementation and is robust against frequency selective channels. Fourth generation wideband communication system uses OFDM along with space time processing. The MIMO OFDM system using multiple antennas at the receiver and the transmitter has a promising ability to combat multipath fading and improve system capacity, bandwidth and power efficiency. It is well known fact that the transmitted signal gets distorted due to the wireless channel. Hence an accurate estimation of wireless channel is essential for MIMO OFDM system performance.

We have three types of channel estimation methods namely training based, blind algorithm and the last one, the combination of both previous methods i.e. semiblind channel estimation. Training based algorithm includes least squares (LS), maximum likelihood (ML), minimum mean square error (MMSE) etc. Training based algorithm uses known data i.e. pilots for estimation. At receiver side, the channel is estimated based on how much the known data or the pilots are distorted (I. Barhumi *et al*., 2003) (Xiaoli Ma *et al*., 2005). Training based channel estimation provides high accuracy at the cost of bandwidth. More the number of pilots in an OFDM symbol better is the accuracy. On the other hand, blind channel estimation relies on second order statistics, correlation and other properties. A variety of second order statics (SOS) based blind estimators have been proposed (Karim Abed-Meraim *et al*., 1997) (C. Shin *et al*., 2007) (F. Gao *et al*., 2007) (A. Gorokhov *et al*., 1999). Among all those methods, the noise subspace based method is considered to be the most promising method due to its simple structure and good performance. Blind estimation gives better spectral efficiency in comparison to training based but has less accuracy. In order to have the advantages of both, the third channel estimation scheme, the semiblind channel estimation was proposed. Semiblind channel estimation is a combination of both training based and blind channel estimation. For same number of pilots, semiblind method provides better estimation compared to training based method. Hence with lower number of pilots we can obtain lower BER in semiblind method. Hence better spectral efficiency and accuracy.

This paper deals with semiblind channel estimation for MIMO OFDM system based on least squares method and blind channel estimation. Blind channel estimation involves the use of linear prediction principle along with the noise subspace method. The main idea is to represent the received signal as a finite order autoregressive (AR) series, provided the transmitted signals are uncorrelated in time. Using the AR representation, linear prediction filter can be derived and hence, can be used for second order deconvolution to estimate the channel (A. Medles *et al*., 2001) (Y. Zeng, *et al*., 2006).Some semiblind channel estimation algorithms (A. Gorokhov *et al*., 1999) have been derived using the combination of linear prediction filter along with higher order statistics on the weighted LS method. The main drawbacks connected to these algorithms are, they require more number of signal samples and they are not robust enough. Incorporating blind criterion obtained from linear prediction into training based LS cost function, (A. Medles *et al*., 2001) have proposed semiblind algorithm, which gives a closed form expression for channel estimation for MIMO channel. In these papers, it has been shown that semiblind channel method gives much better channel estimation performance compared to training based LS method. However, these papers didn’t provide semiblind channel estimation criteria for MIMO OFDM system and also the determination of weighting factor employed to trade off the LS

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and the blind method. Semiblind algorithm derived for MIMO system can't be directly implemented for MIMO OFDM system, since the signal model is different in both cases. In MIMO OFDM, the pilot signal is added to the signal in frequency domain and then converted to time domain unlike the normal MIMO system.

Using Vertical Bell lab Layered Space Time (VBLAST) MIMO scheme, semiblind channel estimation for MIMO OFDM has been proposed in (F. Wan *et al*., 2007). The major drawback of VBLAST is that, the detection complexities at the receiver increases exponentially with number of transmit antennas. In this paper, we discuss semiblind channel estimation based on two transmit antenna Alamouti Space Time Block Coding (STBC) scheme. VBLAST systems can achieve high data rate with acceptable BER performance in a good channel state, whereas STBC systems can achieve better BER performance even for bad state channels but with lower data rates. The STBC scheme has got very low decoding complexity and it can be easily implemented to attain high spatial diversity.

In this paper, we discuss about semiblind channel estimation for MIMO OFDM employing least squares and blind algorithm. Second section deals with the MIMO OFDM system model and its related formulations. Three channel estimation techniques (i) training data based least squares method (ii) blind algorithm using linear prediction and noise subspace and (iii) the formulation of semiblind algorithm are discussed in the following sections. Last section deals with the simulation results for validation of the method. This paper will be adopting the following notations. $\dagger -$ pseudoinverse , $\otimes -$ kroneckor product, I_n is n×n identity matrix, T-transpose, H-conjugate transpose, $\circledast$ -circular convolution, $\| \|_F$ -Forbenius norm, vec()-stacking the columns in a matrix together into a vector and $E\{\}$-expectation.

MIMO OFDM System:

Consider a MIMO OFDM system having N_T transmitting and N_R receiving antennas. Usually we take N_R greater than N_T. The time varying channel can be modelled by L-tap finite impulse response (FIR) filters. We have a total of $N_R\times N_T$ FIR filter channels or L set of $N_R\times N_T$ coefficient matrix $\mathbf{H}(n)$ where n=0,1,…L-1. $(i_R,i_T)^{th}$ element $h_{i_R,i_T}(n)$ represents channel impulse response from i_T th transmitting antenna to i_R th receiving antenna. Let the transmitted signal vector be represented as $\mathbf{x}(n)=[x_1(n),\cdots,x_{N_T}(n)]^T$ and received signal vector be $\mathbf{y}(n) \triangleq [y_1(n),\cdots,y_{N_R}(n)]^T$.

Consider one OFDM symbol with K subcarriers. If we add cyclic prefix which is not less than channel length 'L' , then after removing cyclic prefix at the receiver, we can write the received signal at the i_R th receiving antenna as,

$$y_{iR}(n) = \sum_{i_T=1}^{N_T} h_{iR,iT}(n) \circledast x_{iT}(n) + v_{iR}(n) \tag{1}$$

where n=0, 1,…, K-1 and v_{iR} is the noise. Unlike MIMO system, MIMO OFDM system involves circular convolution.

Least Square Channel Estimation:

In OFDM system, the training data i.e pilots are added to the signal in frequency domain and then converted to time domain via IFFT block. The frequency domain equation can be written as:

$$\mathbf{Y = XH + N} \tag{2}$$

where $\mathbf{Y}$ is the received signal, $\mathbf{X}$ the transmitted signal, $\mathbf{H}$ is the Fourier transform of channel impulse response and $\mathbf{N}$ is the noise.

We use comb type pilot arrangement for LS criterion as it gives better accuracy compared to block type. Though the channel is fast varying, we assume that channel is constant for two OFDM symbol time period. This assumption is crucial for two transmit Alamouti STBC coding.

We now consider signal received at one receiver antenna. Let the number of data in one OFDM symbol transmitted from one transmit antenna be denoted as 'k' and number of pilots be 'p'. The pilot locations can be denoted by writing $k_1, k_2, ..., k_p$. The frequency domain representation of received signal at pilot locations can be given by,

$$\mathbf{Y}_{ip} = \mathbf{X}_p\mathbf{H}_{ip} + \mathbf{N}_{ip} \tag{3}$$

Where $\mathbf{Y}_{ip} = \left[Y_i(k_1)\ Y_i(k_2)\ \ldots\ldots\ Y_i(k_p) \right]^T$ for $i = 1,2,\ldots N_R$. The transmitted matrix is given by $\mathbf{X}_p = \left[\mathbf{X}_{1p}\ \mathbf{X}_{2p}, \cdots, \mathbf{X}_{N_T p} \right]$ and $\mathbf{X}_{jp} = \text{diag}\left[X_j(k_1)\ X_j(k_2) \cdots X_j(k_p) \right]$ for j=1, 2,…, N_T**.** The noise vector is given by $N_{ip} = \left[\mathbf{N}_i(k_1) \mathbf{N}_i(k_2)\ \ldots\ldots \mathbf{N}_i(k_p) \right]^T$.

$\mathbf{H}_{ip}$ is the pilot location values of Fourier transform of impulse response at the i-th receiver. Channel impulse response vector can be written as,

$$\mathbf{h}_i = \left[\mathbf{h}_{i1}{}^T \mathbf{h}_{i2}{}^T \ldots\ldots \mathbf{h}_{iN_T}{}^T \right]^T$$

where $\mathbf{h}_{ij} = \left[h_{ij}(0)\ h_{ij}(1)\ \ldots\ldots\ h_{ij}(L-1) \right]^T$.$\mathbf{H}_p$can be written as

$$\mathbf{H}_{ip} = \mathbf{CFM}\ \mathbf{h}_i$$

M is a mapping matrix of dimension $N_T K \times N_T L$ to pad zeros to the channel vector. **F** is a FFT block matrix of size $N_T K \times N_T K$ with K×K FFT matrix as diagonal blocks. **C** is a mapping matrix of dimension $N_T p \times N_T K$, to extract out the pilot position Fourier transform values.
Equation (3) can be rewritten as

$$\mathbf{Y}_{ip} = \mathbf{X}_p \mathbf{CFM}\ \mathbf{h}_i + \mathbf{N}_{ip} \qquad (4)$$

We now define $\mathbf{A}_p = \mathbf{X}_p \mathbf{CFM}$, and we have

$$\mathbf{Y}_{ip} = \mathbf{A}_p \mathbf{h}_i + \mathbf{N}_{ip}$$

$$\mathbf{h}_{ls} = \mathbf{A}_p{}^{\dagger} \mathbf{Y}_{ip}$$

when rank of $\mathbf{A}_p$ is $N_T L$, pseudo inverse of $\mathbf{A}_p$ is given by:

$$\mathbf{A}_p{}^{\dagger} = \left(\mathbf{A}_p{}^H \mathbf{A}_p \right)^{-1} \mathbf{A}_p{}^H$$

and we have

$$\mathbf{h}_{ls} = \left(\mathbf{A}_p{}^H \mathbf{A}_p \right)^{-1} \mathbf{A}_p{}^H \mathbf{Y}_{ip} \qquad (5)$$

We can generalise LS criteria as:

$$\mathbf{Y_p} = \tilde{\mathbf{A}}\mathbf{h} + \mathbf{N}$$

$\mathbf{Y}_p = \left[\mathbf{Y}_{1p}{}^H, \mathbf{Y}_{2p}{}^H, \cdots, \mathbf{Y}_{N_R p}{}^H \right]^H$, $\mathbf{h} = \left[\mathbf{h}_1{}^H\ \mathbf{h}_2{}^H \cdots \mathbf{h}_{N_R}{}^H \right]^H$ and noise **N** is given by $\left[\mathbf{N}_{1p}{}^H\ \mathbf{N}_{2p}{}^H \cdots \mathbf{N}_{N_R p}{}^H \right]^H$.

We have the LS criterion as:

$$\left\| \mathbf{Y}_p - \tilde{\mathbf{A}}\hat{\mathbf{h}} \right\|^2$$

where $\hat{\mathbf{h}}$ is the estimated LS channel.

Blind Channel Estimation:

Let the transmitted signal vector be $\mathbf{x}(n) = [x_1(n), \cdots, x_{N_T}(n)]^T$ consisting of uncorrelated signals and let the received signal vector be represented by $\mathbf{y}(n) \square [y_1(n), \cdots, y_{N_R}(n)]^T$. We have, for i_R.th receiver antenna

$$y_{iR}(n) = \sum_{i_T=1}^{N_T} h_{iR,iT}(n) \otimes x_{iT}(n) + v_{iR}(n)$$

$v_{iR}(n)$ is spatio temporally uncorrelated noise with variance δ_v^2. $h_{iR,iT}(n)$ represents channel impulse response from i_T th transmitting antenna to i_R th receiving antenna. The idea is to represent the received MIMO signal as a finite order autoregressive (AR) series provided the transmitted signals are uncorrelated with respect to time. It implies we can represent **y**(n) as a linear combination of its own finite past and $\mathbf{H}(0)\mathbf{x}(n)$ where **H**(0) is $N_R \times N_T$ matrix representing the first tap channel coefficients. Now we briefly describe MIMO linear prediction and hence semiblind channel estimation.
Let 'P' denote the order of linear predictor. Let

$$\mathbf{y}_P(n-1) = \left[\mathbf{y}^T(n-1), \mathbf{y}^T(n-2)\ldots, \mathbf{y}^T(n-P)\right]^T$$

The autocorrelation matrix is given by,

$$\mathbf{R}_{n-1} = E\left\{\mathbf{y}_P(n-1)\mathbf{y}_P{}^H(n-1)\right\}$$

and cross correlation matrix as:

$$\mathbf{R}_n = E\left\{\mathbf{y}(n)\mathbf{y}_P{}^H(n-1)\right\}$$

MIMO linear predictor $\mathbf{W}_P$ is given by,

$$\mathbf{W}_P = \mathbf{R}_n \mathbf{R}_{n-1}{}^{-1} = \left[\mathbf{W}_P(1)\ , \mathbf{W}_P(2), \ldots\ldots \mathbf{W}_P(P)\right] \quad (6)$$

Where $\mathbf{W}_p(n)$ for n=1,2,…P is $N_R \times N_R$ matrix representing the coefficient at the n-th tap of prediction filter $\mathbf{W}_P$. The covariance matrix of the prediction error of **y**(n) from **y**(n-1) can be given as:

$$\boldsymbol{\delta}_y^2 = \mathbf{R}(0) - \mathbf{W}_P \mathbf{R}_n^H \quad (7)$$

R(0) is the autocorrelation matrix of **y**(n) data given by,

$$\mathbf{R}(0) = E\left[\mathbf{y}(n)\mathbf{y}^H(n)\right]$$

Now we can represent prediction filter as:

$$[\mathbf{I} - \mathbf{W}_P]\mathbf{H} = [\mathbf{H}(0)\ \mathbf{0}\ \ldots \mathbf{0}] \quad (8)$$

where

$$\mathbf{H} = \begin{bmatrix} \mathbf{H}(0) & \mathbf{H}(1) & \cdots & \mathbf{H}(\text{L-1}) & \cdots & \mathbf{0} \\ \mathbf{0} & \mathbf{H}(0) & \cdots & & & \mathbf{0} \\ \vdots & \vdots & \ddots & & \ddots & \vdots \\ \mathbf{0} & \cdots & & \mathbf{H}(0) & \cdots & \mathbf{H}(\text{L-1}) \end{bmatrix}$$

is a block toeplitz matrix of dimension $(P+1)N_R \times (L+P)N_T$. As in (Xiaoli Ma *et al*., 2005), the covariance matrix from the above expression can be rewritten as:

$$\boldsymbol{\delta}_y^2 = \mathbf{H}(0)\mathbf{H}(0)^H \quad (9)$$

Denote the null column space of $\mathbf{H}(0)$ as $\mathbf{U}_{null}$. $\mathbf{U}_{null}$ can be easily estimated from $\boldsymbol{\delta}_y^2$ as in (7). Applying singular value decomposition of $\boldsymbol{\delta}_y^2$ we get $\mathbf{U}_{null}$. The eigen vector corresponding to the smallest Eigen value will give $\mathbf{U}_{null}$(noise subspace) and we have

$$\mathbf{U}_{null}{}^{H}\mathbf{H}(0)=\mathbf{0} \tag{10}$$

Let $\mathbf{H}_F = \left[\mathbf{H}(0)^H, \ldots\ldots, \mathbf{H}(L-1)^H\right]^H$ and $\mathbf{W}_Q$ be $(L+P)N_R \times LN_R$ block toeplitz matrix with first block column as $\left[\mathbf{I}, \ -\mathbf{W}_P{}^H(1), \ldots., \ -\mathbf{W}_P{}^H(P), \mathbf{0}.., \mathbf{0}\right]^H$.

Equation (8) can be rewritten as:

$$\mathbf{W}_Q\mathbf{H}_F = \left[\mathbf{H}(0)^H, \mathbf{0}, \ldots\ldots, \mathbf{0}\right]^H \tag{11}$$

Using the concept of null column space and from (10), (11) can be written as

$$(\mathbf{I}_{L+P} \otimes \mathbf{U}_{null}^H)\mathbf{W}_Q\mathbf{H}_F = \mathbf{0} \tag{12}$$

and $(\mathbf{I}_{L+P} \otimes \mathbf{U}_{null}^H)\mathbf{W}_Q$ can be replaced by $\mathbf{W}_\Sigma$, hence

$$\mathbf{W}_\Sigma\mathbf{H}_F = \mathbf{0} \tag{13}$$

Now, in order to vectorise $\mathbf{H}_F$, we have (13)

$$(\mathbf{I} \otimes \mathbf{W}_\Sigma)\mathrm{vec}(\mathbf{H}_F) = \mathbf{0} \tag{14}$$

$\mathrm{vec}(\mathbf{H}_F) = \mathbf{E}_P\mathbf{h}$, where $\mathbf{E}_P$ is a permutation matrix of dimension $(N_T \times N_R \times L) \times (N_T \times N_R \times L)$ given by

$$\mathbf{h} = \left[\mathbf{h}_1{}^T\mathbf{h}_2{}^T \ldots\ldots \mathbf{h}_{NR}{}^T\right]^T$$

and $\mathbf{h}_i = \left[h_{i,1}(0)\ldots. h_{i,1}(L-1)\ h_{i,2}(0)\ldots.\ h_{i,2}(L-1)\ \ldots..h_{i,NR}(0)\ldots.\ h_{i,NR}(L-1)\right]^T$.

Equation (14) now can be replaced as:

$$(\mathbf{I} \otimes \mathbf{W}_\Sigma)\mathbf{E}_P h = \mathbf{0} \tag{15}$$

$$\mathbf{Bh} = \mathbf{0} \tag{16}$$

where parameter $\mathbf{B}$, which is equal to $(\mathbf{I} \otimes \mathbf{W}_\Sigma)\mathbf{E}_P$, is the blind constraint on the channel vector '**h**'.

Semiblind Channel Estimation:

The minimum error function for semiblind channel estimation, combining both least square estimation and blind estimation can be given as:

$$\frac{\partial \Delta}{\partial \hat{\mathbf{h}}^H} = -\tilde{\mathbf{A}}^H(\mathbf{Y}_{pilot} - \tilde{\mathbf{A}}\hat{\mathbf{h}}) + \alpha\hat{\mathbf{B}}^H\hat{\mathbf{B}}\hat{\mathbf{h}} = \mathbf{0} \tag{17}$$

In order to minimise the error, differentiating the equation with respect to the estimated channel, we get

$$\frac{\partial \Delta}{\partial \hat{\mathbf{h}}^H} = -\tilde{\mathbf{A}}^H(\mathbf{Y}_{pilot} - \tilde{\mathbf{A}}\hat{\mathbf{h}}) + \alpha\hat{\mathbf{B}}^H\hat{\mathbf{B}}\hat{\mathbf{h}} = \mathbf{0}$$

This can be written as

$$(\tilde{\mathbf{A}}^{H}\tilde{\mathbf{A}} + \alpha\hat{\mathbf{B}}^{H}\hat{\mathbf{B}})\hat{\mathbf{h}} = \tilde{\mathbf{A}}^{H}\mathbf{Y}_{pilot}$$

The semiblind channel is given by

$$\hat{\mathbf{h}} = (\tilde{\mathbf{A}}^{H}\tilde{\mathbf{A}} + \alpha\hat{\mathbf{B}}^{H}\hat{\mathbf{B}})^{\dagger}\tilde{\mathbf{A}}^{H}\mathbf{Y}_{pilot} \quad (18)$$

where α is a constant whose value lies between 0 and 1. From (18) it is quite clear that the performance of semiblind algorithm largely depends on α value.

Simulation Results:

For simulation, we consider a MIMO OFDM system with two transmitter and four receiver antennas. The number of subcarriers in OFDM symbol is 512 and the modulation used is the quaternary phase-shift keying (QPSK).The length of cyclic prefix is set to ten. The channel model selected is Rayleigh channel model. Channel is characterised by a three tap MIMO-FIR filter, in which each tap corresponds to a 2×4 random matrix. All the elements in the matrix are independent identically distributed (i.i.d.) complex Gaussian variables with zero mean and unit variance. The order of linear predictor is taken as four. The coding scheme used is STBC Alamouti coding. The estimation performance is measured in terms of the MSE of the estimate of the channel given by

$$\text{MSE}=\frac{1}{\text{N}_{\text{MC}}}\sum_{n=1}^{N_{MC}}\left\|\hat{\mathbf{h}}_n-\mathbf{h}_n\right\|^2$$

N_{MC} denotes number of Monte Carlo runs in the simulation. $\hat{\mathbf{h}}_n$ denote estimated channel and $\mathbf{h}_n$ denote original channel value.

MSE versus SNR :- We examine the mean square error for channel estimation as a function of SNR. Simulation has 500 Monte Carlo runs for the transmission of one OFDM symbol. Fig. 1 shows MSE Vs. SNR for two methods, least squares and semiblind. It is clear from the graph that semiblind achieve a better gain in comparison to least squares regardless of the level of SNR.

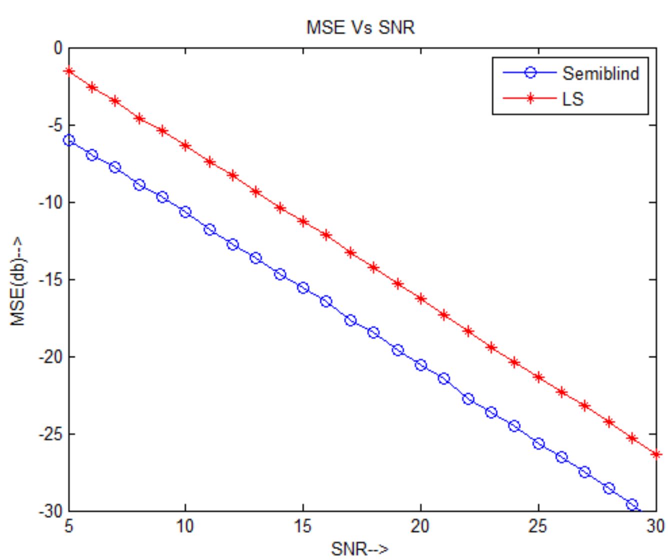

Fig. 1: MSE versus SNR.

BER Versus SNR: In this experiment, we study about bit error rate performance of MIMO OFDM system with respect to SNR. The space time coding used is Alamouti coding. Simulation consists of 500 Monte Carlo runs over one OFDM symbol. Number pilots used for 512 subcarriers is 8 pilots with a pilot spacing of N=64. Fig.2 shows the BER performance for various SNR. It can be clearly understood that semiblind algorithm performs better than LS algorithm by 2-5Db.

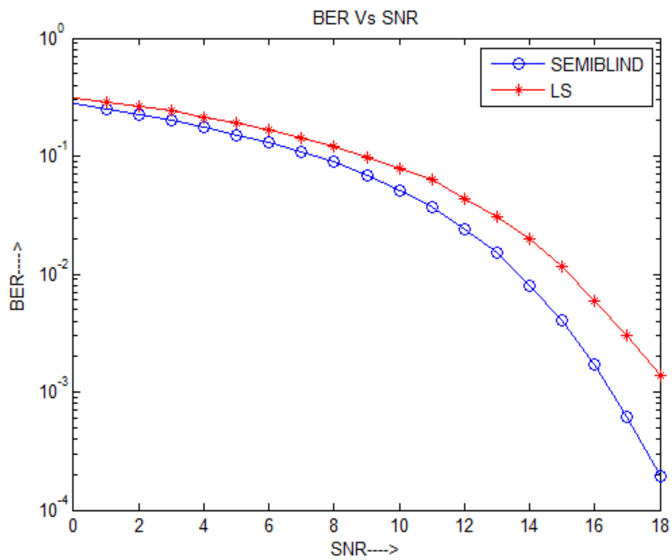

Fig. 2: BER versus SNR.

Conclusion:

A semi-blind MIMO-OFDM channel estimation based on blind channel estimation and least squares algorithm has been studied. Blind method uses a combination linear prediction and noise subspace method. A proper formulation of received signals, linear prediction and least squares has been done. The two transmit Alamouti STBC scheme used in simulation has got low decoding complexity and provides better BER performance even for bad state channels in comparison with VBLAST. The semiblind algorithm for MIMO OFDM was simulated and results were compared with least squares (LS) method. The MSE versus SNR and BER versus SNR graph clearly depict the superiority of semiblind algorithm over LS method.

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