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Enhanced Semi-Blind Sparse Channel Estimation Technique for MIMO-OFDM System

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Abstract : OFDM (Orthogonal Frequency Division Multiplexing) can be viewed either as a modulation or multiplexing technique. It is a special case of multicarrier transmission, where a single data stream is transmitted over a number of lower rate subcarriers. Increased robustness against frequency selective fading or narrowband interference is the primary benefit of using OFDM. MIMO (Multiple-input Multiple-output) is one of the smart antenna technology which uses multiple antennas at the transmitter and receiver side to increase the performance of the system. When paired with the OFDM technology, a MIMO communication system can deliver dependable high data rate transmission over broadband wireless channels. A wireless channel can be modeled as a sparse channel, in which the delay spread could be very large. Channel estimation is of crucial importance to MIMO-OFDM because the system performance depends on the quality of channel estimate. Channel estimation techniques can be categorized into three classes: training-based, blind and semi-blind methods. The common problem of the sparse channel estimation methods is that a large number of pilots are needed in order to render an accurate MST (Most Significant Taps) detection and effective channel estimation. An efficient semi- blind sparse channel estimation which combines the blind constraint with training based least square criterion for improving the system performance is to be estimated. For that it requires only a small number of OFDM symbols and pilot subcarriers.

IndexTerms - **Most Significant Taps (MST), multiple input multiple output orthogonal frequency division multiplexing (MIMO-OFDM), semi-blind estimation, sparse channel estimation.**

I. INTRODUCTION

Physical limitations of the wireless medium create a technical challenge for reliable wireless communication. Techniques that improve spectral efficiency and overcome various channel impairments such as signal fading and interference have made an enormous contribution to the growth of wireless communications. Moreover, the need for high-speed wireless Internet has led to the demand for technologies delivering higher capacities and link reliability than achieved by current systems. Multiple-input multiple-output (MIMO) based communication systems are capable of accomplishing these objectives.

Multiple input multiple output (MIMO) systems take advantage of spatial diversity obtained through the spatially separated antennas in a dense multipath scattering environment. Spatial diversity can boost gain diversity, which in turn raises the wireless link's dependability. MIMO systems' capacity increases linearly as the number of transmit antennas is increased

The multiple antenna configuration exploits the multipath effect to accomplish the additional spatial diversity. However, the multipath effect also causes the negative effect of frequency selectivity of the channel. OFDM is a promising multi-carrier modulation scheme that shows high spectral efficiency and robustness to frequency selective channels. Therefore, combining OFDM and MIMO is a viable strategy to increase system performance and bandwidth efficiency. In fact, MIMO-OFDM is being considered for the upcoming IEEE 802.11n standard, a developing standard for high data rate WLANs.

In [1] channel estimation for a MIMO system is performed. The channel of this system is frequency selective fading channel. In this a low complexity optimal training signal is used for block transmissions over frequency-selective channel. Maximizing a lower constraint on the ergodic capacity, which is demonstrated to be equivalent to minimizing the mean square error of the linear channel estimator, is the ideal design practice for training schemes. In [2] a novel maximum a posterior probability-based channel estimation method is used. In this pilot symbols are used. The channel estimation is done over a fast Rayleigh fading channel. A zero forcing receiver is used to detect the spatially multiplexed data. The main disadvantage of training-based method is that it requires a consumption of spectral resources.

The channel can be estimated using blind method also. In [3] a blind channel estimation technique based on subspace approach is used. In [4] a blind channel estimation method for MIMO-OFDM system is explained. In this the channel parameters are estimated in the time domain for all subcarriers instead of frequency domain. In [5] maximum likelihood detection method is used for orthogonal space time block coded OFDM in unknown block fading channel. In [6] channel estimation is done with the help of cyclic prefix. By using cyclic prefix MSTs are estimated blindly. This detection scheme needs a large number of OFDM symbols as well as large cyclic prefix length in order to obtain precise MST (Most Significant Tap) position. In [7] a time-domain based channel estimation for OFDM system is described. In this pilot and data are multiplexed together. The problem of the sparse channel estimation methods is that large number of pilots is needed in order to render an accurate MST detection and effective channel estimation. A sparse channel is a wireless channel in which delay spread is very large and number of significant paths is very small.

II. PRELIMINARIES

2.1 System Model

A MIMO-OFDM system with P transmit antennas and M receive antennas is presented[8-10]. To achieve a high throughput, spatial multiplexing is applied, and independent data streams are transmitted through different antennas. Before transmission, each data stream is modulated by an N-point IDFT, and CP is inserted at the beginning of each OFDM symbol. Let the i^{th} block signal from the p^{th} transmit antenna before OFDM modulation be

$$\beta_{i,p}(m)= [\beta_{i,p}[m,0]\ \beta_{i,p}[m,1] - - - \beta_{i,p}[m,N-1]]^T \quad (1)$$

This is the frequency-domain signal vector. Here, the frequency-domain signal is assumed to be white with zero mean and unit variance. Performing N-point IDFT, the so-called time-domain signal vector is generated as

$$b_{i,p}(m)=[b_{i,p}[m,0]\ b_{i,p}[m,1] \text{ - - - } b_{i,p}[m,N-1]]^T=F_N*\beta_{i,p} \quad (2)$$

where F_N is an N x N IDFT matrix. After the CP insertion, the transmitted i^{th}OFDM symbol from the p^{th}transmit antenna is

$$s_{i,p} = [s_{i,p}[m,0]\ s_{i,p}[m,1] \text{ - - - } s_{i,p}[m,N-1]]^T \quad (3)$$

$$N' = N + L_{CP} \quad (4)$$

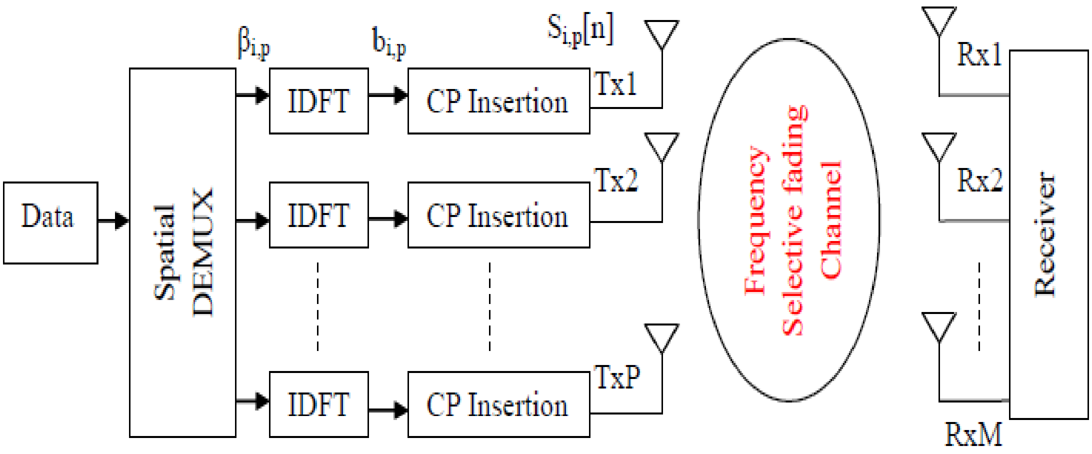

Fig. 1 MIMO OFDM system model

Each OFDM symbol is then simultaneously transmitted over quasi-static frequency-selective fading MIMO channels. Generally, the frequency-selective fading channel is modelled as an L-tap FIR filter, so that the M × 1 sampled received signal vector in the i^{th} received OFDM symbol is written as

$$Y_i[n] = \sum_{p=1}^{P} \sum_{l=0}^{L} h_p(l) * S_{i,p}[n] + W_i[n] \qquad n = 0,1,..N'-1 \quad (5)$$

where $h_p(l)$ is an M × 1 channel response vector; represents the M × 1 additive noise vector; and $s_{i,p}$[n] = $s_{(i=1)}$[N'+n] when n < 0, and $s_{i,p}$[n] = $s_{(i+1)}$[n-N'] when N'≤ n. Without loss of generality, the channel length is assumed to be far less than the number of subcarriers in one OFDMsymbol, i.e., $L << N$. The noise is assumed to be independent of the transmitted signals $s_{i,p}$[n] and is independently identically distributed complex Gaussian with zero mean and variance σ^2. Similarly, to [C], the CP is not discarded, and N' sampled received signal vectors are collected at the receiver as

$$y_i^k = [y_i[-k]^T y_i[-k]^T \ldots y_i[N'-1-k]^T]^T \qquad k=0, \pm1,\pm2\ldots \quad (6)$$

where y_i[n] corresponds to the signal vector at the (i-1) threceived OFDM symbol and is equal to $y_{i-1}[n+N']$ when n<0, whereas it corresponds to the signal at the $(i+1)^{th}$ received OFDM symbol and is equal to $y_{i+1}[n-N']$ when N'≤ n. In fact, the received signal vector y_i^kcorresponds to the i^{th} received OFDM symbol shifted by k samples and can be expressed as

$$y_i^k = H*x_i^k + w_i^k \qquad k = 0,\pm1, \pm2.. \quad (7)$$

If the length of the cyclic prefix is not less than the channel length L, the time domain signal model for the frequency-selective fading channel is given by

$$y_{iR}(m,n)= \sum_{i_T=1}^{N_T} h_{i_R,i_T}(n) \otimes x_{i_T}(m,n) + v_{i_R}(m,n) \qquad m\text{€}\{0,\ldots,g-1\} \quad (8)$$

Where g is the number of OFDM symbols within which the channel remains unchanged, and v_{i_R}(m,n) € C is a spatio-temporally uncorrelated noise with zero mean and variance σ_{v^2}.

2.2 Channel Estimation

The binary signal is modulated and sent over a multipath fading channel after the digital source is typically shielded against fading by channel coding and interleaving. The sum signal is obtained after adding additive noise. Due to the multipath channel, there is some intersymbol interference (ISI) in the received signal [11-12]. Therefore, to achieve successful equalization (removal of ISI), a signal detector (such MLSE or MAP) needs to be aware of channel impulse response (CIR) characteristics. It should be noted that equalization with decision-feedback, blind equalizers, for example, is also achievable without independent channel estimates. To recover the original message after discovery, the signal is deinterleaved and the channel is decoded.

The ultimate goal at the receiver is to recover the signal that was originally transmitted. A variety of signal detection techniques have been developed for MIMO systems depending on whether it is a diversity or spatial multiplexing system. Regardless of the type of MIMO system, most of the detection schemes require knowledge of the channel information in order to recover the signal. Hence, developing an efficient method of approximating the transmission channel between the transmitter and receiver is an essential component of the receiver design. Various channel estimation methods of MIMO are training based channel estimation, blind channel estimation.

2.3 Training Based Channel Estimation

In certain classes of channel estimation algorithms, training symbols or pilot tones that are known to the receiver, are multiplexed along with the data stream for channel estimation.

The idea behind these methods is to exploit knowledge of transmitted pilot symbols at the receiver to estimate the channel. The frequency and spacing of transmitted pilot tones across both time and frequency is determined by the channel. However, the addition of pilots is at the cost of the data and depending on the nature of the channel, the pilot tones might have to be transmitted more frequently, thereby reducing the overall data rate. For a block fading channel, where the channel is constant over a few OFDM symbols, the pilots are transmitted on all subcarriers in periodic intervals. This type of pilot arrangement is called the block type arrangement.

There are two types of estimation in training-based channel estimation. The estimation can be performed using either least squares (LS) or minimum mean squared error (MMSE) constraints and the estimate is used to correct the distortion in the subsequent OFDM symbols.

2.3.1 Least Square Estimation

The least squares (LS) estimator is more commonly used due to its ease of implementation and acceptable performance. The criteria for a good estimator are that it is unbiased and has minimum variance. The LS estimator uses variance as a measure of performance by choosing an estimate that minimizes the error between the estimate and the true value. The general linear model is given by

$$Y = H.\ \theta + W \tag{9}$$

Where H is a known $N\times P$ matrix, θ is $P\times1$ vector, and W is $N\times 1$ vector. The objective is to determine an estimate θ vector. The LS approach tries to solve the estimation problem by minimizing the cost function.

2.3.2Minimum Mean Square Error

In statistics and signal processing, a MMSE estimator describes the approach which minimizes the mean square error (MSE), which is a common measure of estimator quality.

The term MMSE specifically refers to estimation in a Bayesian setting, since in the alternative frequency setting there does not exist a single estimator having minimal MSE. A somewhat similar concept can be obtained within the frequency point of view if one requires unbiasedness, since an estimator may exist that minimizes the variance (and hence the MSE) among unbiased estimators. Such an estimator is then called the minimum-variance unbiased estimator (MVUE).

Let X be an unknown random variable, and let Y be a known random variable (the measurement). An estimator is any function of the measurement Y, and its MSE is given by

$$MSE=E\{(\hat{X}-X)^2\} \tag{10}$$

where the expectation is taken over both $\hat{X}$ and X.

The MMSE estimator is then defined as the estimator achieving minimal MSE.

In many cases, it is not possible to determine a closed form for the MMSE estimator. In these cases, one possibility is to seek the technique minimizing the MSE within a particular class, such as the class of linear estimators. The linear MMSE estimator is the estimator achieving minimum MSE among all estimators of the form AY+b. If the measurement Y is a random vector, A is a matrix and b is a vector.

2.3.3 Blind Channel Estimation

For spectrally efficient transmission, blind channel estimation methods that do not use pilot symbols. For OFDM systems, the existing blind method exploits the cyclo-stationarity that the cyclic prefix induces in the transmitted signal. The channel is recovered using either cyclic statistics of the received signal or subspace decomposition of correlation matrix of the pre- DFT received blocks.

The blind algorithm has lower complexity, where a correlation structure among the symbols in different subcarriers is imposed at the transmitter. The receiver exploits the correlation among the received signals in different subcarriers to estimate the channel. The blind methods rely on time averaging over different OFDM symbols, thus requiring that the channel be slow varying over a large block of symbols, which makes them unsuitable for fast varying channels.

The key is to employ the second-order statistics-based MIMO linear prediction method to obtain a blind constraint on the channel vector namely,

$$H=[h_1{}^T, \ldots . h_{N_R}{}^T]^\wedge T \quad (11)$$

By using the properties of the MIMO linear predictor, a blind constraint for the channel vector h can be derived as

$$B= (I \otimes P_\Sigma) E_P \quad (12)$$

where E_P is a known permutation matrix, and P_Σ is a matrix determined by a block toeplitz matrix consisting of P_p(n),(n=1,…P).

In both these methods there is a disadvantage that more number of pilot symbols are used in training based method and in blind method, the estimation is not perfect. Hence these methods do not suit for channel estimation.

III. Proposed Semi-blind Sparse Channel Estimation

To perform frequency domain equalization, a channel estimate is required at the receiver. Sending out pilot tones intermittently for a training-based approach consume precious bandwidth and decrease capacity, while purely blind schemes have trouble resolving an accurate channel estimate. Semi-blind approach takes advantage of the known structure in the transmitted sequence, and combines it with limited pilot tones in order to accurately estimate channels with minimal training overhead.

From the received signal Y=HX+N the H value is estimated using training based method. Y is the received signal, H is the channel matrix, X is thee transmitted signal and N is the noise matrix. The channel matrix is given by

$$H = \begin{bmatrix} h_{11} & h_{12} & h_{13} & \cdot & h_{1P} \\ h_{21} & h_{22} & h_{23} & : & h_{2P} \\ \vdots & \vdots & \vdots & & \vdots \\ h_{M1} & h_{M2} & h_{M3} & \cdot & h_{MP} \end{bmatrix} \quad (13)$$

A correlation matrix is then developed as a function of channel matrix. In the absence of noise, the correlation matrix R(l) of the received signal can be expressed in terms of channel matrices H(l) as

$$R(l) = \begin{Bmatrix} \sum_{i=l}^{L-1} H(i) H^H(i-l) & l = 0,1, \ldots L-1 \\ 0 & l > L-1 \end{Bmatrix} \quad (14)$$

By combining the blind constraint equation with a training-based LS criterion, a semi-blind channel estimation problem can be formulated as

$$\hat{z} = [\bar{A}_Z^H \bar{A}_Z + \propto B_Z^H B_Z]^\dagger \, \bar{A}_Z^H Y_{pilot} \quad (15)$$

where Y_{pilot} is the corresponding received signal vector, B_z is an estimate of the blind constraint and α>0 is a weighting factor.

The semi-blind method developed requires only less number of OFDM symbols and pilot subcarriers. This algorithm contains only a small number of significant or non-zero taps for the sparse channels. Here we consider the point to point MIMO systems, in which transmit and receive antenna pairs are co-located. Hence the propagation delay is same for all transmit and receive antenna pairs.

IV. Simulation Results

The channel estimation is the process of finding out the conditions of a channel. The performance of a MIMO-OFDM system depends on the quality of channel estimate. If a channel is estimated perfectly the bit error rate will be low. In this a MIMO-OFDM system with two transmit and four receive antennas is considered. The number of subcarriers is set to 1024, the length of CP is 30, and the length of the linear predictor in the semi-blind algorithm is $P = L$. In the simulation, the quaternary phase-shift keying (QPSK) modulation and binary phase shift keying (BPSK) modulation is used, and both Rayleigh and sparse channel is used.

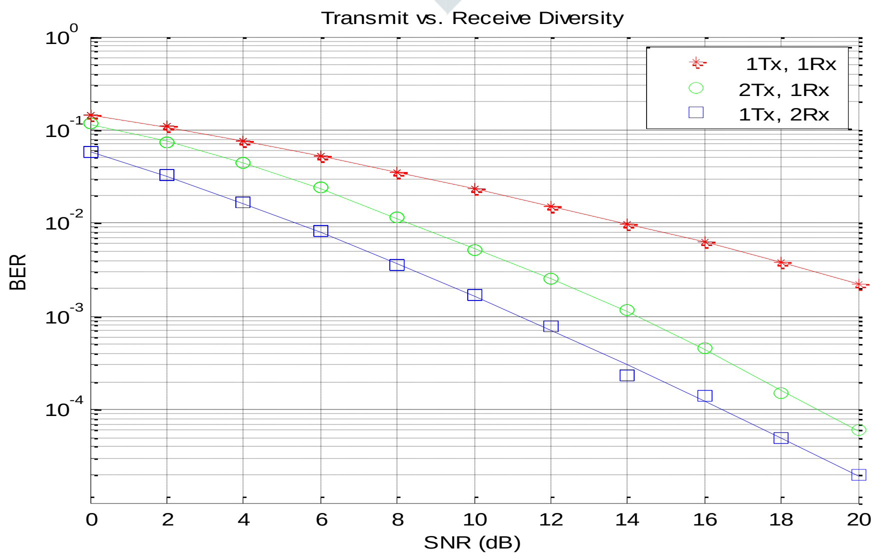

Fig. 2 Antenna diversity

4.1 Experiment 1: SNR versus BER

In this experiment the antenna diversity is investigated. Antenna diversity refers to a method for improving the reliability of a message signal by transmitting over several different propagation paths. The simulation results shows that the bit error rate of a transmission in which single antenna is used at transmitter and receiver side is more compared to multiple antennas at transmitter and receiver side. It is clear from the graph that transmit diversity (more than one antennas at transmitter side) has a 3 dB disadvantage when compared to receive diversity (more than one antenna at receiver side). It is assumed that channel is known perfectly at the receiver.

4.2 Experiment 2: SNR versus BER for Least square channel estimation

LS method is a training based method. In this method pilots are used for channel estimation. A graph for SNR vs BER is shown below. From the simulation result it is clear that bit error rate of this method is large. Here only few pilots are used. This resulted in increased bit error rate. Bit error rate is high that is 10^{-2} even when SNR is 20. Rayleigh fading channel is used for the simulation.

$$Y = H.\theta + W \tag{15}$$

where H is a known N × P matrix,

θ is P×1 vector, and

W is N× 1 vector.

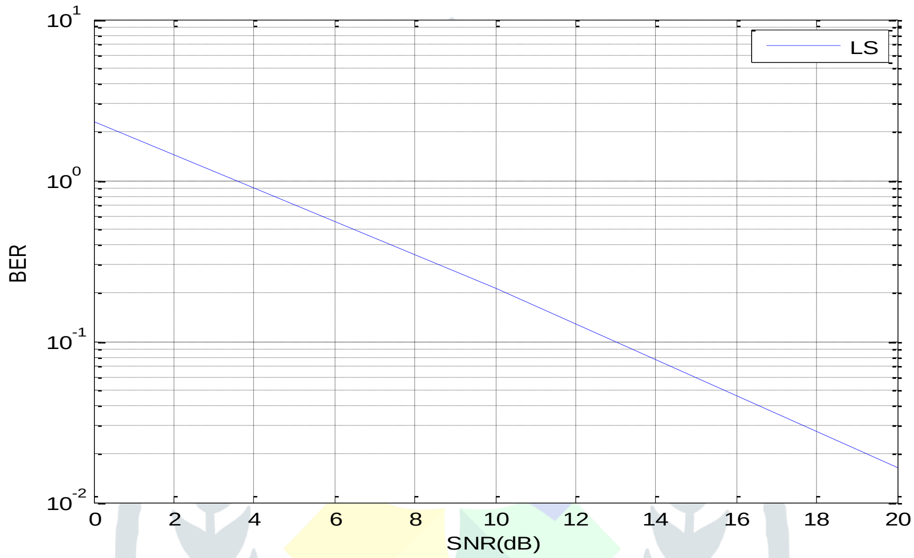

Fig 3. Least square channel estimation

4.3 Experiment 3: Minimum Mean Square channel estimation

It is one of the training-based method. In this known pilot signals are transmitted. This method is used only if the channel and noise distributions are known. Fig.4 shows the performance of minimum mean square channel estimation. Bit error rate of the channel estimated using this method is shown in the graph. It is clear from the graph that the bit error rate is going below 10^{-2} only when SNR dB value is 20. This method is better than least square method but can be used only when the channel and noise value is known.

$$H_{MMSE} = (R^{-1} + (P^T * I)^H S^{-1} (P^T * I)^H S^{-1} vec(y)) \tag{16}$$

R- channel correlation matrix

S - noise matrix

P – pilot signals

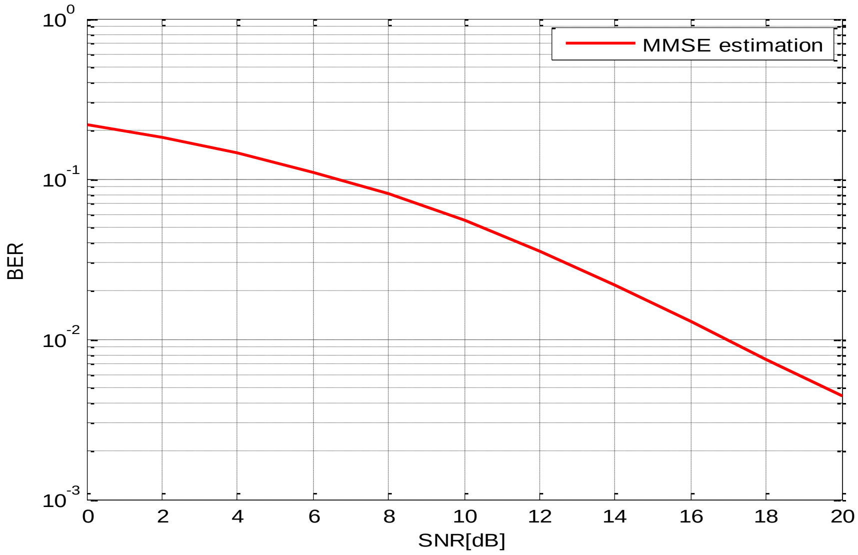

Fig 4. Minimum Mean Square channel estimation

4.4 Experiment 4: Blind Channel estimation

In this method channel is estimated using the details obtained from the received signal. The performance of blind channel estimation is shown with respect to MSE value. It is clear from the graph that the error occurred after estimation in this method is more. Since no training signals are used the special diversity of this method is more. Since estimation is done without any training signal more data symbols can be transmitted. In the graph the SNR dB value Vs MSE value is plotted. It is clear from graph that the error value decreases as the SNR value increases. SNR value increases as the signal strength increases. The error value also decreases.

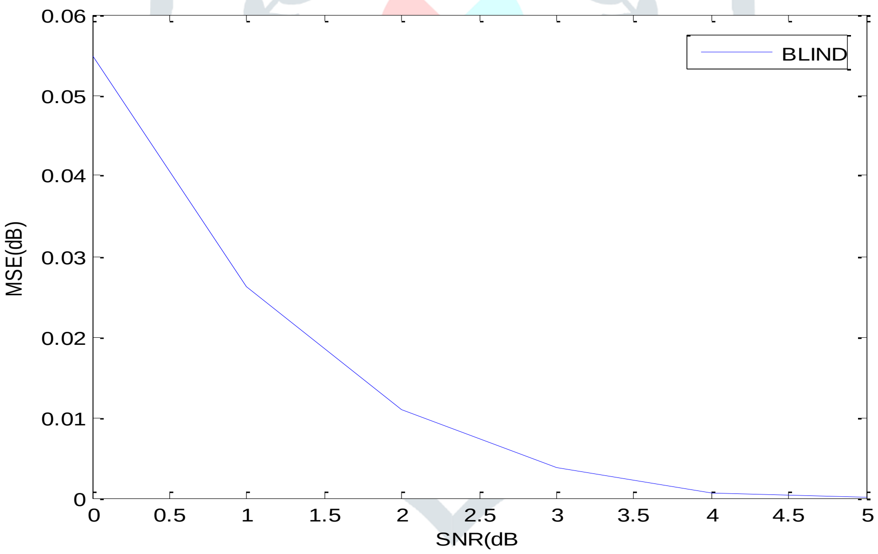

Fig 5. Blind Channel estimation

4.5 Experiment 5: Semi-Blind Channel Estimation

In this method the channel state information received from the pilot symbol is used to create the channel matrix. A blind constraint is formed from the received signal and both the values are combined together to form the semi-blind channel matrix. A graph is plotted for SNR dB VS BER. The performance of this estimation method is more compared to other existing methods. The bit error rate is less than 10^{-4} when the SNR dB value is 12.so it shows that when a channel is estimated using this method the error can be minimized to the maximum extent.

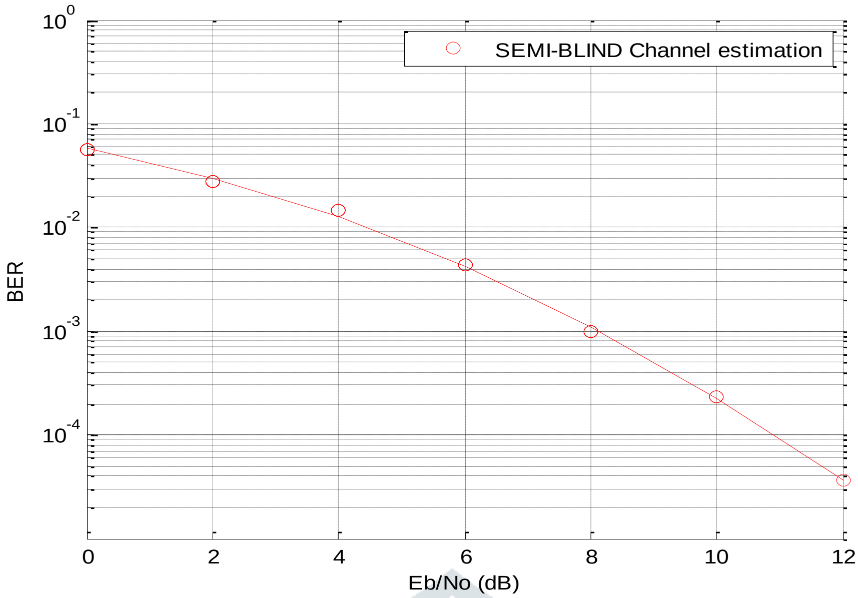

Fig 6. Semi-blind channel estimation

V. Conclusions

In this paper, a semi-blind sparse channel estimation technique has been proposed for general MIMO-OFDM system. Based on the received signal that passes through a sparse channel, an algorithm for obtaining a blind constraint on the sparse channel vector with respect to the MSTs has been developed. By formulating semi blind problem that combines the blind constraint with a training-based sparse LS criterion, a semi blind solution to the estimation of the effective channel has been obtained. For that it requires only a small number of OFDM symbols and pilot subcarriers. The performance of MIMO-OFDM system was improved by reducing BER using semi blind estimation technique. Computer simulations have confirmed that the proposed sparse semi-blind approach significantly outperforms the LS method and the blind techniques.

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