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AN IMPROVED METHOD OF MIMO-OFDM CHANNEL ESTIMATION USING CHAOTIC PILOT SEQUENCE

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ABSTRACT

High data rate transmission, spectral efficiency and reliability are necessary for future wireless communication systems. MIMO-OFDM (multiple input multiple output- orthogonal frequency division multiplexing) technology, has gained great popularity for its capability of high rate transmission and its robustness against multi-path fading and other channel impairments with the available power and bandwidth. A major challenge to MIMO-OFDM systems is how to obtain the channel state information accurately and promptly for coherent detection of information symbols and channel synchronization. When perfect knowledge of the wireless channel conditions is available at the receiver, the capacity has been shown to grow linearly with the number of antennas. In this work, MIMO-OFDM channel estimation is done by using a novel pilot signal that is well suited for wide band applications. Least Square (LS) and Minimum Mean Square error (MMSE) channel estimation methods are employed. Blind channel estimation and training sequence based estimation for fading channels (Rayleigh and Rician) using these two methods have been carried out. To improve the performance a new chaotic sequence is used for channel estimation. Finally the Mean square Error (MSE) analysis is done for SISO-OFDM and MIMO-OFDM and comparison is made between LS and MMSE methods through MATLAB simulation with chaotic pilot sequence and conventional pilot sequence. The proposed chaotic pilot sequence estimation gives superior performance.

Keywords: SISO, MIMO, OFDM, channel estimation, AWGN Noise, LS, MMSE, MSE, chaotic sequence.

1. INTRODUCTION

MIMO technique can improve system capacity, enhance link reliability, and reduce interference. Due to this improvement, MIMO system provides spatial multiplexing (SM) gain and diversity gain. Spatial multiplexing gain is achieved by the parallel transmissions of independent data streams in the transmitting and receiving antenna pairs. Spatial diversity gain is yielded through the multiple replicas of the same signal in multiple antennas and thus improves link reliability [1].

Another important wireless broadband transmission technique is orthogonal frequency division multiplexing (OFDM), which removes the inter-symbol interference (ISI) in high-data rate transmission. OFDM also provides a degree of freedom for resource allocation in subcarriers [2]. By combining MIMO and OFDM, system performance can be enhanced from different aspects. MIMO-OFDM has become an important research area in the wireless communication [3]. It becomes so complicated in MIMO-OFDM system to accurately estimate the channel state information (CSI) because of many OFDM subcarriers.

The least square (LS) channel estimation method have been developed in [4], [5] for the MIMO-OFDM systems using pilot symbols. The minimum mean square error (MMSE) channel estimation method was proposed in [6]. The performance of MMSE estimation is much better than LS estimation but complex than LS. Pilot-embedded channel estimation was designed, where the pilot symbols and the data symbols are superimposed. Since no dedicated channel resource was assigned to pilot symbols, the pilot-embedded systems have higher spectral efficiencies [7]. The blind channel estimation can obtain the CSI by properly using the statistical properties of transmit signals, without the help of any pilot symbols or training sequences [8]. But compared to pilot channel estimation, the performance of blind estimation became reduced.

In this paper, we propose general LS channel estimation and MMSE channel estimation for MIMO-OFDM in fading channel, where new chaotic sequence are used as data sequence which are generated from Logistic map rules. Chaotic sequence is indestructible transmission towards noise and channel fading. It has less probability of interception and low correlation in time domain. The rest of this paper is organized as follows. In Section II, we briefly describe the SISO-OFDM system model. In Section III, we briefly introduce the MIMO-OFDM system model. In Section IV, we present the channel estimation methods. In Section V, proposed technique is detailed. In section VI, the performance of the proposed technique is compared with blind and pilot channel estimation. In Section VII, this paper is concluded.

2. SISO-OFDM

In other words, SISO-OFDM is regarded as OFDM system. Data on OFDM sub-carriers is modulated or in other words mapped with combined digital modulation arrangements. Here we use QAM modulation where the serial binary data is changed into composite numbers instead of constellation points. After the sequences of binary data undergo QAM mapping, the complex data is converted into a parallel stream.

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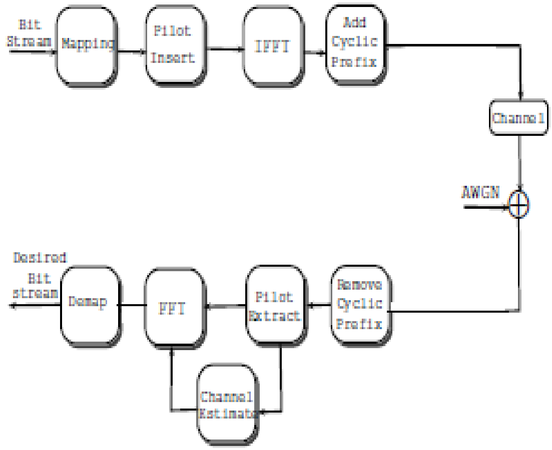

Figure-1. SISO-OFDM channel estimation.

The X data codes of complex parallel stream are coherently modulated using an Inverse Discrete Fourier Transform (IDFT) basis on N-1 subcarriers. Concept of IDFT is to alter the parallel data into time domain waveforms denoted as x_n.

$$x_n = \frac{1}{K}\sum_{k=0}^{N-1} A_k e^{-\frac{j2\pi kn}{N}}, n = 0,1,\dots,k-1$$

Where A_k is the complex amplitude for the k th sub-carrier.

The next step in the transmitter section is cyclic prefix (CP) addition where the last portion of the trials are copied and placed as a CP to form the OFDM symbol. Adding CP eliminates the ISI and ICI. Then the rows of symbols are transmitted over the fading channel. In channel, AWGN noise will be added up to the transmitted symbols. The received symbols after passed over the channel is,

$Y = HX + N$

Where H is the channel model and N is the AWGN noise.

At the receiver, the CP is removed from the symbol sequence and then FFT converted to represent in frequency domain. Furthermore, the resulting sequence are QAM demodulated and symbols are recovered as the original one.

3. MIMO-OFDM

Block diagram of MIMO-OFDM system is shown in Figure-2. MIMO-OFDM systems with two transmit antennas and two receive antennas are considered. The total number of subcarriers is taken as N. The input symbols in *Nt* transmission path is denoted as X,

$$X = \begin{bmatrix} X[0] & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & X[N-1] \end{bmatrix}$$

Where, X[k] denotes a pilot tone at the kth subcarrier, with E{X[k]} = 0 and Var{X[k]} = σ², k = 0, 1, 2,…, N-1. Here X should be a diagonal matrix, since we assume that all subcarriers are orthogonal.

Assume that the channel gain is H[k] for each subcarrier k, the received training signal Y[k] can be represented as

$$Y = \begin{bmatrix} Y[1] \\ \vdots \\ Y[N-1] \end{bmatrix} = \begin{bmatrix} X[0] & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & X[N-1] \end{bmatrix} \begin{bmatrix} H[1] \\ \vdots \\ H[N-1] \end{bmatrix} + \begin{bmatrix} W[1] \\ \vdots \\ W[N-1] \end{bmatrix}$$

where H is a channel vector given as H =[H[0],H[1], … , H[N-1]] and W is a noise vector given as W =[W[0], W[1], … , W[N-1]] with E{W[k]}= 0 and Var{W[k]}= σ², k= 0,1,2,… N-1.

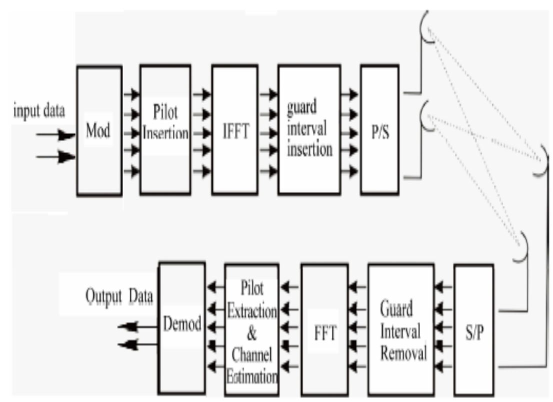

Figure-2. MIMO-OFDM channel estimation.

Commonly, the MIMO-OFDM transmitter has *Nt* parallel transmission paths which are similar to the SISO-OFDM system, each branch performing signal mapping (QAM), pilot insertion, *N*-point IFFT and cyclic extension before transmission. At receiver, the CP is removed and *N*-point FFT is performed per receiver branch. Next the pilot sequence is extracted from the N point FFT symbol stream and is being used for channel estimation. Further the received sequences will be subjected to demodulation for the recovery of transmitted symbol sequence.

4. CHANNEL ESTIMATION

Communication system utilizes channel estimation and signal detection operations in equalization at the receiver. Channel estimation is simply defined as the process of characterizing the effect of the physical channel on the input sequence. A channel model on the other hand can be thought as a mathematical representation of the transfer characteristics of this physical medium. Channel estimated algorithms allow the receiver to approximate the impulse response of the channel and explain the behavior of the channel. This knowledge of the channel behavior is well-utilized in modern radio communications. A Channel impulse response (CIR) characteristic is required to ensure successful equalization (removal of ISI) and extraction of

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information so as to minimize the error between the actual transmitted symbols and the symbols extracted from the received signal.

Two types of channel estimation techniques used are:

Blind channel Estimation
Pilot based Channel Estimation

A. Blind channel estimation

The blind channel estimation is carried out by evaluating the statistical information of the channel and certain properties of the transmitted signals. Blind channel estimation has its advantage in that it has no overhead loss; it is only applicable to slowly time-varying channels due to its need for a long data record.
In this work,

B. Pilot based channel estimation

In pilot based channel estimation algorithm, training symbols or pilot tones that are known a priori to the receiver are multiplexed along with the data stream for channel estimation. In this we have used block type pilot insertion.

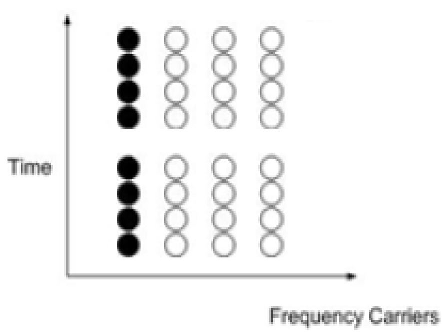

Figure-3. Block type pilot insertion.

A block type pilot arrangement is depicted in Figure-3. In this type, OFDM symbols with pilots at all subcarriers (referred to as pilot symbols herein) are transmitted periodically for channel estimation. Using these pilots, a time-domain interpolation is performed to estimate the channel along the time axis.

C. LS channel estimation

The least-square (LS) channel estimation method finds the channel estimate $\hat{H}$ as following,

$$\begin{aligned} J(\hat{\mathbf{H}}) &= \|\mathbf{Y}-\mathbf{X}\hat{\mathbf{H}}\|^2 \\ &= (\mathbf{Y}-\mathbf{X}\hat{\mathbf{H}})^H(\mathbf{Y}-\mathbf{X}\hat{\mathbf{H}}) \\ &= \mathbf{Y}^H\mathbf{Y}-\mathbf{Y}^H\mathbf{X}\hat{\mathbf{H}}-\hat{\mathbf{H}}^H\mathbf{X}^H\mathbf{Y}+\hat{\mathbf{H}}^H\mathbf{X}^H\mathbf{X}\hat{\mathbf{H}} \end{aligned}$$

By setting the derivative of the function with respect to $\hat{H}$ to zero,

$$\frac{\partial J(\hat{\mathbf{H}})}{\partial \hat{\mathbf{H}}} = -2(\mathbf{X}^H\mathbf{Y})^* + 2(\mathbf{X}^H\mathbf{X}\hat{\mathbf{H}})^* = 0$$

$\hat{H}$ is least square (LS) channel estimation which is given as,

$$\hat{\mathbf{H}}_{LS} = (\mathbf{X}^H\mathbf{X})^{-1}\mathbf{X}^H\mathbf{Y} = \mathbf{X}^{-1}\mathbf{Y}$$

The mean-square error (MSE) of this LS channel estimate is given as,

$$\begin{aligned} MSE_{LS} &= E\{(\mathbf{H}-\hat{\mathbf{H}}_{LS})^H(\mathbf{H}-\mathbf{H}_{LS})\} \\ &= E\{(\mathbf{H}-\mathbf{X}^{-1}\mathbf{Y})^H(\mathbf{H}-\mathbf{X}^{-1}\mathbf{Y})\} \\ &= E\{(\mathbf{X}^{-1}\mathbf{Z})^H(\mathbf{X}^{-1}\mathbf{Z})\} \\ &= E\{\mathbf{Z}^H(\mathbf{X}\mathbf{X}^H)^{-1}\mathbf{Z}\} \\ &= \frac{\sigma_z^2}{\sigma_x^2} \end{aligned}$$

The MSE in the above equation is inversely proportional to the SNR σ^2_x / σ^2_z which implies that it may be subjected to noise enhancement, especially when the channel is in a deep null. LS method has been widely used for channel estimation due to its simplicity.

D. MMSE channel estimation

The MMSE (Minimum Mean Square Error) channel estimation is derived from the solution of LS estimation solution.

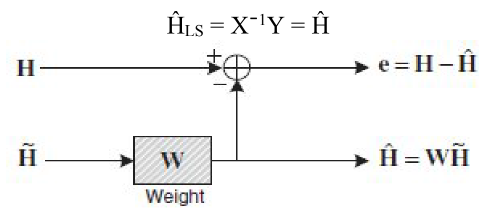

Figure-4. MMSE method of MSE estimator.

Using the weight matrix W, define $\hat{H}$ =W.H, which corresponds to the MMSE estimate. Figure-4 depicts the estimation of MSE from the MMSE method. The channel estimate $\hat{H}$ is given by

$$J(\hat{\mathbf{H}}) = E\{||\mathbf{e}||^2\} = E\{||\mathbf{H}-\hat{\mathbf{H}}||^2\}$$

Then, the MMSE channel estimation method finds a better (linear) estimate in terms of W in such a way that the MSE in the above equation is minimized. The estimation error vector e = H- $\hat{H}$ is orthogonal to $\hat{H}$ due to orthogonality principle. So the equation becomes,

$$\begin{aligned} E\{\mathbf{e}\tilde{\mathbf{H}}^H\} &= E\{(\mathbf{H}-\hat{\mathbf{H}})\tilde{\mathbf{H}}^H\} \\ &= E\{(\mathbf{H}-\mathbf{W}\tilde{\mathbf{H}})\tilde{\mathbf{H}}^H\} \\ &= E\{\mathbf{H}\tilde{\mathbf{H}}^H\}-\mathbf{W}E\{\tilde{\mathbf{H}}\tilde{\mathbf{H}}^H\} \\ &= \mathbf{R}_{\mathbf{H}\tilde{\mathbf{H}}}-\mathbf{W}\mathbf{R}_{\tilde{\mathbf{H}}\tilde{\mathbf{H}}} = \mathbf{0} \end{aligned}$$

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Weight matrix 'W' is given as,

$$\mathbf{W} = \mathbf{R}_{\mathbf{H}\tilde{\mathbf{H}}}\mathbf{R}_{\tilde{\mathbf{H}}\tilde{\mathbf{H}}}^{-1}$$

$R_{\hat{H}\hat{H}}$ is a autocorrelation matrix of $\hat{H}$, which is given as,

$$\begin{aligned}\mathbf{R}_{\tilde{\mathbf{H}}\tilde{\mathbf{H}}} &= E\{\tilde{\mathbf{H}}\tilde{\mathbf{H}}^H\}\\ &= E\{\mathbf{X}^{-1}\mathbf{Y}(\mathbf{X}^{-1}\mathbf{Y})^H\}\\ &= E\{(\mathbf{H}+\mathbf{X}^{-1}\mathbf{Z})(\mathbf{H}+\mathbf{X}^{-1}\mathbf{Z})^H\}\\ &= E\{\mathbf{H}\mathbf{H}^H+\mathbf{X}^{-1}\mathbf{Z}\mathbf{H}^H+\mathbf{H}\mathbf{Z}^H(\mathbf{X}^{-1})^H+\mathbf{X}^{-1}\mathbf{Z}\mathbf{Z}^H(\mathbf{X}^{-1})^H)\}\\ &= E\{\mathbf{H}\mathbf{H}^H\}+E\{\mathbf{X}^{-1}\mathbf{Z}\mathbf{Z}^H(\mathbf{X}^{-1})^H\}\\ &= E\{\mathbf{H}\mathbf{H}^H\}+\frac{\sigma_z^2}{\sigma_x^2}\mathbf{I}\end{aligned}$$

$R_{H\hat{H}}$ is the cross-correlation matrix between the true channel vector and temporary channel estimate vector in the frequency domain. Using the last Equation, the MMSE channel estimate is as follows:

$$\begin{aligned}\hat{\mathbf{H}} &= \mathbf{W}\tilde{\mathbf{H}} = \mathbf{R}_{\mathbf{H}\tilde{\mathbf{H}}}\mathbf{R}_{\tilde{\mathbf{H}}\tilde{\mathbf{H}}}^{-1}\tilde{\mathbf{H}}\\ &= \mathbf{R}_{\mathbf{H}\tilde{\mathbf{H}}}\left(\mathbf{R}_{\mathbf{H}\mathbf{H}}+\frac{\sigma_z^2}{\sigma_x^2}\mathbf{I}\right)^{-1}\tilde{\mathbf{H}}\end{aligned}$$

5. PROPOSED WORK

SISO-OFDM channel estimation using blind and pilot based methods for Rayleigh fading channel have been performed. Next the MIMO-OFDM channel estimation using blind and pilot based (with binary pulse pilot sequence and chaotic pilot sequence) methods have been performed. Also the MIMO-OFDM channel estimation is done by transmitting simply QPSK modulated chaotic data sequence through Rayleigh and Rician fading channels. Figure-7 and Figure-8 depicts the results of MIMO-OFDM channel estimation for both blind and pilot methods for Rayleigh channel. Further, analysis of MIMO-OFDM channel estimation on Rician channel does not yield better performance. We proposed channel estimation using pure chaotic signal transmission. This is chaotic blind channel estimation. Chaotic communications are recently used in wireless transmission. These are highly non-correlated and secured signals and can be easily generated. In this work, the sources of chaotic signals used are logistic map.

Logistic Map: $x(i) = x(i+1) + 4.x(i)^3 - 3.x(i)$, $2 \leq i \geq 24$

With initial condition: $x(1) = 0.2$

Experiments have also been carried out with chaotic signals as pilot carrier transmitted alongwith information.

6. SIMULATION RESULT

The Table-1 summarizes the parameters of MIMO-OFDM system, used in simulation. A 2×2 MIMO-OFDM system, which contains 2 transmitter antennas and 2 receiver antennas, is simulated in MATLAB software. Guard interval is chosen to eliminate ISI. Two fading channel used are Rayleigh and Rician fading channel type. Block type channel estimation need not require any pilot inputs. But for pilot based channel estimation, pilots are inserted among data based on block type to estimate channel. As previously described in section IV, pilots are extracted and channel is estimated, using LS and MMSE estimation method. For block type, size of input symbol is 32 with the cyclic prefix length of 4. For pilot based estimation input is of size 24, pilot size is 8 and cyclic prefix size of 4. Data are QAM modulated first and further OFDM modulated before transmission. At receiver, all of procedures such as adding CP are reversely done and pilots are extracted after FFT operation for LS estimation and MMSE estimation. The performance is analyzed using mean square error.

$$MSE = \frac{1}{N}\sum_{k=1}^{N}\frac{|H(k) - H_e(k)|^2}{|H(k)|}$$

Table-1. Parameters used in simulation.

Parameters	Specifications
Number of Transmitters	2
Number of Receivers	2
FFT Size	32
Number of Active Carriers(N)	32
Pilot Ratio	1/8
Guard Interval	4
Guard Type	Cyclic Extension prefix
Signal Constellation	4-QAM
Channel Model	Rayleigh Fading, Rician Fading

We can examine increase in diversity gain by means of Mean Square Error (MSE) Vs SNR. Figures 5 and 6 are the performance evaluation of SISO-OFDM. Figures 7, 8, 9 shows the results of MIMO-OFDM channel estimation for block and pilot type. Figures 10, 11 and 12 shows the result of MIMO-OFDM Channel estimation using new chaotic sequences for estimating channel in blind and pilot based.

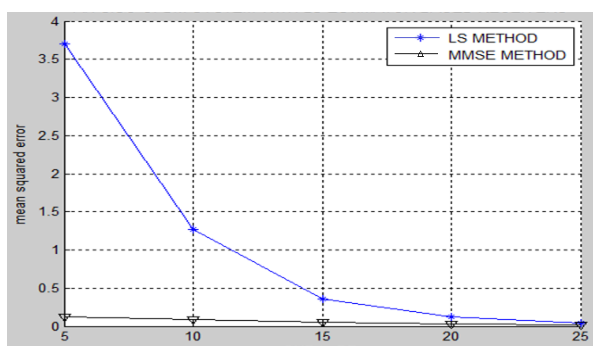

Figure-5. SISO-OFDM blind estimation (Rayleigh Channel).

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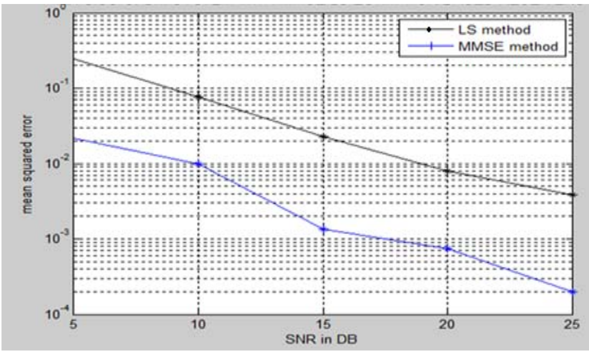

Figure-6. SISO-OFDM pilot estimation (Rayleigh channel).

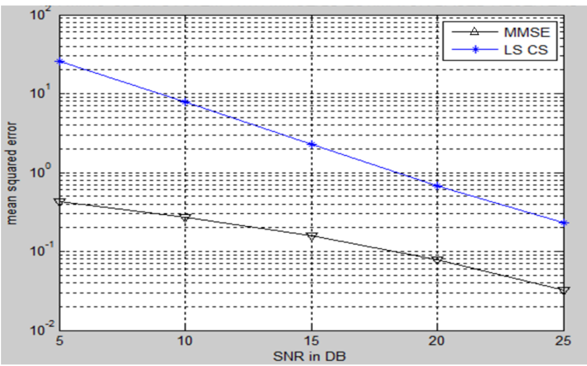

Figure-7. MIMO-OFDM blind estimation (Rayleigh channel).

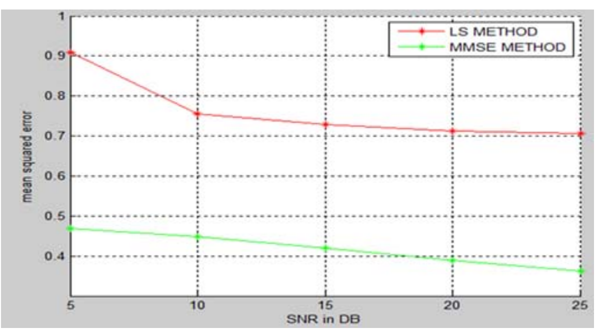

Figure-8. MIMO-OFDM pilot estimation (Rayleigh channel).

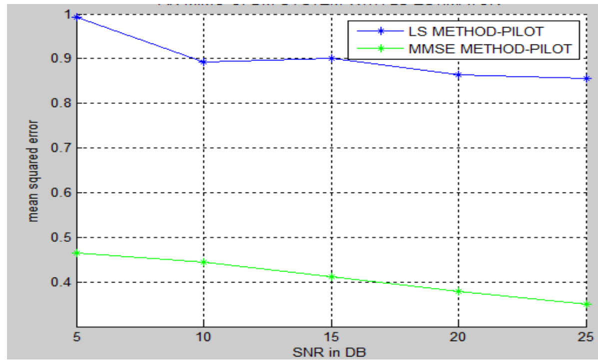

Figure-9. MIMO-OFDM pilot estimation (Rician channel).

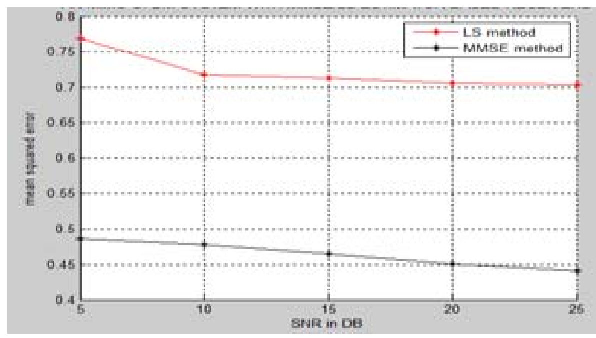

Figure-10. MIMO-OFDM blind estimation (Rayleigh channel) using Chaotic Data.

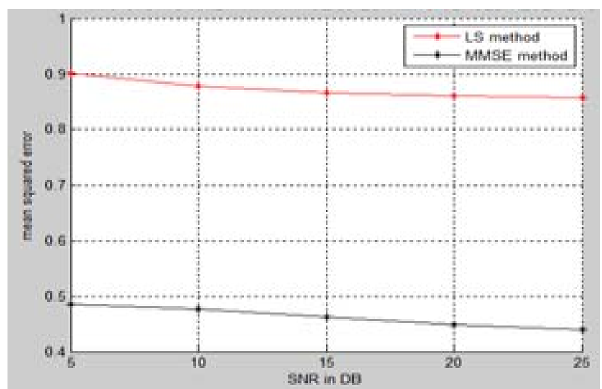

Figure-11. MIMO-OFDM blind estimation (Rician channel) using Chaotic Data

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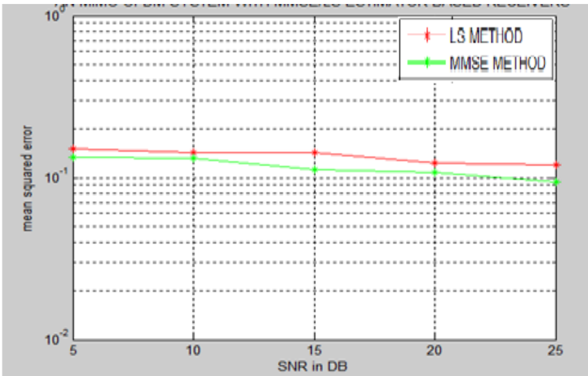

Figure-12. MIMO-OFDM blind estimation (Rayleigh channel) using Chaotic Data.

7. CONCLUSIONS

Wireless Channel estimation methods are proposed. Blind channel estimation and pilot channel estimation have been performed on Rayleigh and Rician channels for SISO-OFDM and MIMO-OFDM communication systems. In each method, channel is characterized using least square and minimum mean square error algorithms. MSE analysis has been done with conventional pilot channel estimation and chaotic pilot estimations. The blind channel estimation with chaotic signals using MMSE algorithm is found to be superior in performance in MIMO-OFDM communication systems. With this perfectly estimated channel matrix, further the bit error performance, capacity and power optimiation can certainly be proved to be superior in MIMO-OFDM communication system.

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