Performance analysis of MISO-OFDM & MIMO-OFDM Systems

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Abstract— **MIMO-OFDM system is a new wireless broadband technology which has gained great popularity for its capability of high rate transmission and its robustness against multi-path fading and other channel impairments. Precise and competent channel estimation for MIMO-OFDM systems is necessary to improve error performance of the system. In this paper, Least Squares (LS) channel estimation is implemented for 2x1 and 2x2 type of OFDM systems with Alamouti technique. The results are compared and it shows that the performance of the system has been improved.**

Keyword- MIMO, OFDM, Alamouti. Least Squares channel Estimation

I. Introduction

OFDM (Orthogonal Frequency Division Multiplexing) is a very popular multi-carrier modulation technique for transmission of signals over wireless channels. OFDM divides the high-rate data stream into parallel lower rate data and hence prolongs the symbol duration, thus eliminating Inter Symbol Interference (ISI). It also allows the bandwidth of subcarriers to overlap without Inter Carrier Interference (ICI) as long as the modulated carriers are orthogonal.

Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) has capability of high rate transmission and its robustness against multi-path fading and other channel impairments.

The major challenge faced in MIMO-OFDM systems is how to obtain the channel state information accurately for detection of information symbols at the receiver side. The channel state information (CSI) can be obtained through channel estimation. LS channel estimation which has been discussed in this paper is practical technique because it does not need extra information about channel covariance and noise variation.

The contents of this paper are in the following order: In section 2, the system model is described. In section 3, Rayleigh channel and LS channel estimation are discussed. Section 4 consists of Simulation Parameters, Results and discussion.

II. SYSTEM MODEL

Our system model for MISO-OFDM and MIMO-OFDM are given in fig.2 and fig.3 respectively. Least Squares Channel estimation is applied to both the systems and the results are compared in terms of bit error rate (BER).

A. Orthogonal Frequency Division Multiplexing

OFDM is a multi-carrier modulation technique where data symbols modulate a sub-carrier which is taken from orthogonally separated sub-carriers with equal separation within each sub-carrier. This utilizes the bandwidth efficiently as the subcarriers are overlapping and orthogonal to each other. To maintain the orthogonality, there should be a minimum separation between the sub-carriers to avoid ICI (Inter Carrier Interference). In practice, discrete Fourier transform (DFT) and inverse DFT (IDFT) processes are useful for implementing these orthogonal signals. Note that DFT and IDFT can be implemented efficiently by using fast Fourier transform (FFT) and inverse fast Fourier transform (IFFT), respectively. Fig. 1 shows the spectrum of the OFDM signal transmitted.

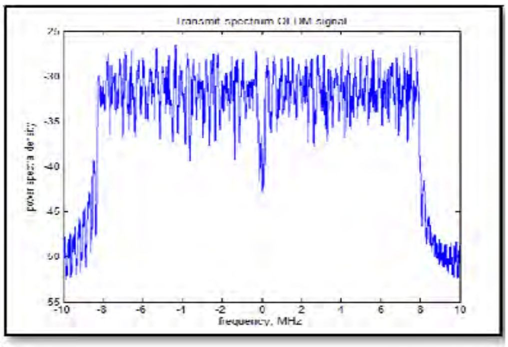

Fig. 1Transmit Spectrum of OFDM signal

B. Multiple Input Multiple Output Systems

In this paper, MIMO is implemented using Alamouti algorithm with 2 antennas at the transmitter and 2 antennas at the receiver side and it is shown in fig. 3. A complex orthogonal space-time block code [8] for two transmit antennas was developed by Alamouti [1]. In the Alamouti encoder, two consecutive symbols x_1 and x_2 are encoded with the following space-time code word matrix:

$$X = \begin{pmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{pmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

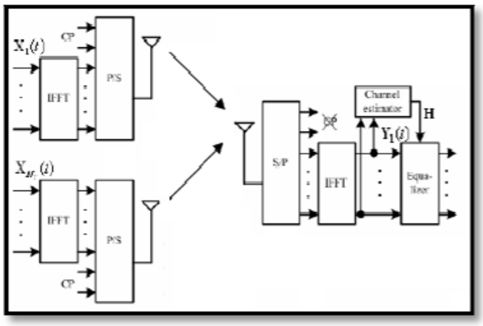

Fig. 2 MISO OFDM system with Alamouti

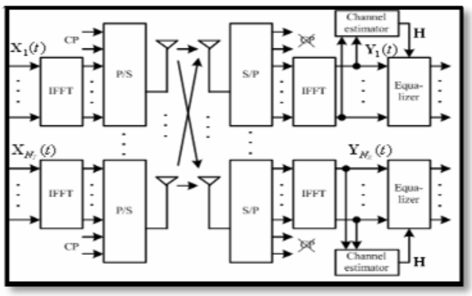

Fig. 3 MIMO OFDM system with Alamouti

Alamouti encoded signal is transmitted from the two transmit antennas over two symbol periods. During the first symbol period, first transmitter transmits x_1 and the second transmitter transmits x_2 simultaneously. During the second symbol period, these symbols are transmitted again, where $-x_2^*$ is transmitted from the first transmit antenna and x_1^* transmitted from the second transmit antenna. Fig.4 shows the Alamouti encoder used in our system [1].

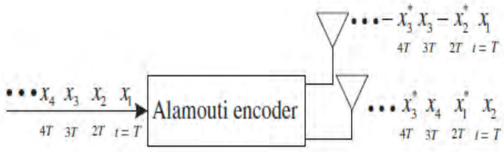

Fig.4 Alamouti Encoder

Let y_1 and y_2 denote the received signals at time t and t+T_s, respectively, then

$y_1 = h_1x_1 + h_2x_2 + z_1$

$y_2 = -h_1x_2^* + h_2x_1^* + z_2$ …….(2)

where z_1 and z_2 are the additive noise at time t and t+T_s, respectively.

$\begin{pmatrix} y_1 \\ y_2^* \end{pmatrix} = \begin{pmatrix} h_1 & h_2 \\ h_2 & -h_1^* \end{pmatrix} * \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} z_1 \\ z_2^* \end{pmatrix}$ …….(3)

Multiplying both sides of equation (3) by Hermitian transpose of channel transpose we get

$$\begin{pmatrix} h_1 & h_2 \\ h_2 & -h_1^* \end{pmatrix}\begin{pmatrix} y_1 \\ y_2^* \end{pmatrix} = \begin{pmatrix} h_1 & h_2 \\ h_2 & -h_1^* \end{pmatrix}\begin{pmatrix} h_1 & h_2 \\ h_2 & -h_1^* \end{pmatrix}\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} h_1 & h_2 \\ h_2 & -h_1^* \end{pmatrix}\begin{pmatrix} z_1 \\ z_2^* \end{pmatrix}$$

$$= (|h_1|^2 + |h_2|^2)\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} h_1^* z_1 & h_2 z_1^* \\ h_2^* z_1 & -h_1^* z_1^* \end{pmatrix} \quad \text{……….(4)}$$

We obtain the input-output relations

$\begin{pmatrix} \check{y}_1 \\ \check{y}_2 \end{pmatrix} = (|h_1|^2 + |h_2|^2)\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} \check{z}_1 \\ \check{z}_2 \end{pmatrix}$…………(5)

where

$\begin{pmatrix} \check{y}_1 \\ \check{y}_2 \end{pmatrix} = \begin{pmatrix} h_1 & h_2 \\ h_2 & -h_1^* \end{pmatrix}\begin{pmatrix} y_1 \\ y_2^* \end{pmatrix}$

$\begin{pmatrix} \check{z}_1 \\ \check{z}_2 \end{pmatrix} = \begin{pmatrix} h_1 & h_2 \\ h_2 & -h_1^* \end{pmatrix}\begin{pmatrix} z_1 \\ z_2^* \end{pmatrix}$

III. Channel Estimation

In this session we discussed the fading channel used and the algorithm used to measure channel parameters [11].

A. *Rayleigh fading channel*

If there is no direct path between transmitter and receiver then the multipath components of the fading channel can be approximated using Rayleigh distribution in flat fading channels. The received signal can be simplified to:

r(t) = s(t)*h(t) + n(t) ………. (6)

where h(t) is the random channel matrix having Rayleigh distribution and n(t) is the additive white Gaussian noise. The Rayleigh distribution is basically the magnitude of the sum of two equal independent orthogonal Gaussian random variables whose probability density function (pdf) given by:

$p(r) = \frac{r}{\sigma 2} e^{\frac{r^2}{2\sigma 2}} \quad r \geq 0$ ………… (7)

where σ^2 is the time-average power of the received signal [5]-[6]. Fig. 5 shows the Power delay profile of the Rayleigh channel variable.

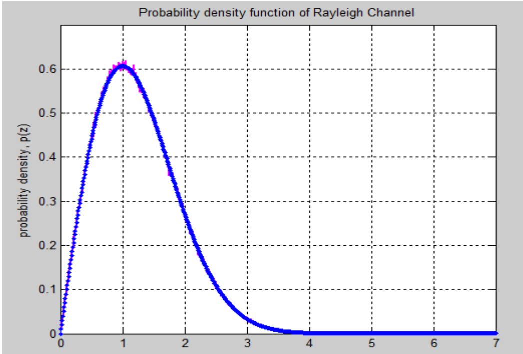

Fig. 5 Probability Density function of Rayleigh random variable

Fig. 6 shows the received field intensity for the Rayleigh channel [7]. Fig. 7 illustrates the generated Rayleigh channel coefficients.

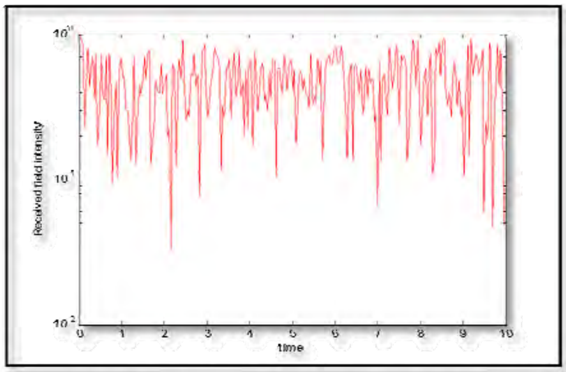

Fig.6 Received Field Intensity for Rayleigh channel

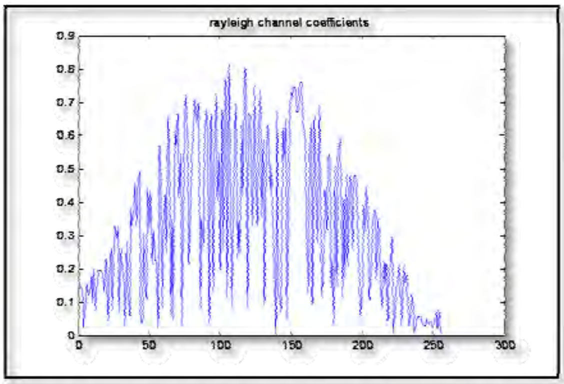

Fig. 7 Rayleigh Channel coefficient

B. *Least Squares Channel Estimation*

The LS channel estimation technique discussed in this section is based on [4].The frequency domain equation for the received signal is given by:

Y = X H + N……………….. ….. (8)

where Y is the received signal, H is the channel, X is the transmitted signal and N is the Additive White Guassian Noise (AWGN).

The above equation can be re-written as

$Y(k,t) = \sum_{i=1}^{N_T} X_i(k,t)Hi(k) + N(k,t)$……… (9)

where Xi(k,t) denotes the transmit signal on k^{th} subcarrier in the t^{th} OFDM symbols at the i^{th} transmit antenna.

If number of the pilots is denoted by 'p', then in terms of pilot locations, we can write equation 1 as
$Y_p = X_pH_p + N_p$ ……… …………..(10)

H_p is the fourier transform of channel impulse response at pilot points.
Define,

$Y_p= [Y(k_1)\ Y(k_2)$………….. $Y(k_p)]^T$
X_{pi}= diag [Xi(k1,) Xi(k2)………….. Xi(kp)]
$X_p= [\ X_{p1}X_{p2}$ …………. $X_{pNT}]$
where i=1,2, N_T
N_T= number of transmitters.

Frequency response of channel
$H_{pi}= [H_i(k1)\ H_i(k2)$ ………….. $H_i(kp)]^T$
$H_p= [\ H_{p1}^T\quad Hp_2^T$ …………. $H_{pNT}^T]^T$
Impulse response of channel
hi = [hi(0) hi(1) ……….. hi(L-1)]^T
h = [$h1^T$ $h2^T$ …………. $h_{NT}^T]^T$
therefore we can write,
Hp = C F M h
where C is the mapping matrix to separate out only the pilot positions (N_T P * N_T K), F is FFT matrix (N_T K * N_T K), M is the mapping matrix (N_T K * N_T L)
Thus, the equation 8 can be re-written as,
$Y_p= X_pC\ F\ M\ h+ N_p$ ....(11)
Let,
$A_p = X_pC\ F\ M$
Therefore from equation 11,
$Y_p= A_p\ h+ N_p$
Least squares estimation is given by,
$h_{LS}= A_p†Y_p$
where,
$A_p†=(A_p^HA_p)^{-1}A_p^H$
Therefore, the LS estimated output is,
$h_{LS} = (A_p^HA_p)^{-1}A_p^HY_p$ ....(12)

IV. Simulations and results

Least Squares channel estimation is applied to 2x2 MIMO-OFDM and 2x1 MISO-OFDM systems for the following simulation environment and is tabulated in Table 1. Phase shift keying modulation techniques is used [9]. Rayleigh fading channel is used [7],[10]. Fig. 8 shows the BER Vs SNR comparison for the channel with and without estimation for 2Tx-1Rx MIMO-OFDM system.

TABLE 1
Simulation Parameters

Parameters	Types/values
Number of subcarriers	1024
Carrier Frequency	2 GHz
Cyclic prefix	25 % of OFDM symbol size
Sampling interval	50 ns
Modulation	BPSK
Transmitting antennas	2
Receiving antennas	1 (MISO) , 2 (MIMO)
Radio channel model	Rayleigh
vehicle_speed	200 km/hrs
maximum excess delay	10 μ s

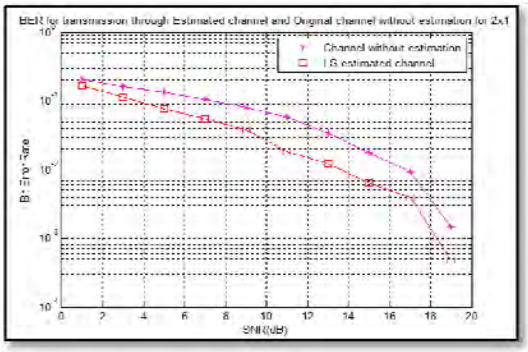

Fig.8 BER Vs SNR comparison between LS channel estimated output and output with no channel estimation for 2Tx-1Rx

Fig. 9 depicts the BER Vs SNR comparison between LS channel estimated output and output with no channel estimation for 2Tx-2Rx MIMO-OFDM system. Fig. 8 compares the two LS estimated outputs for 2x1 and 2x2 MIMO-OFDM systems.

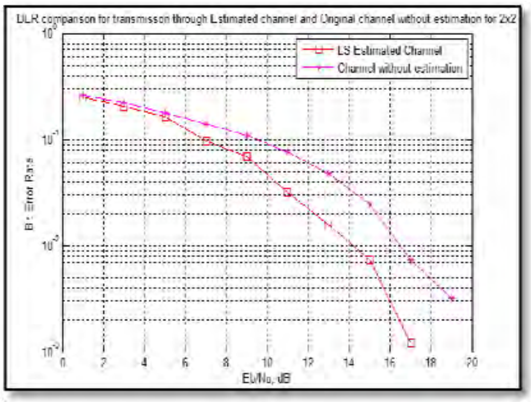

Fig. 9 BER Vs SNR comparison between LS channel estimated output and output with no channel estimation for 2Tx-2Rx

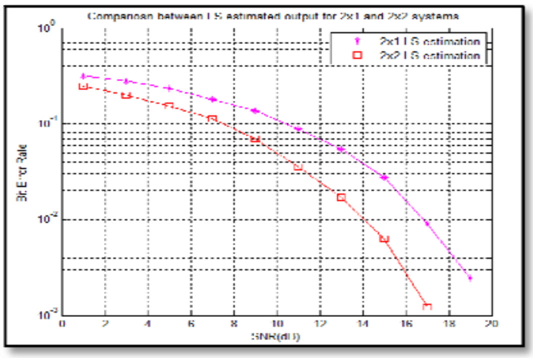

Fig. 10 Comparison of LS estimated outputs for MISO-OFDM & MIMO-OFDM systems

V. CONCLUSION

In this paper, Least Squares channel estimation technique was implemented for 2x1 and 2x2 MIMO-OFDM systems. It can be observed from results that LS channel estimated output gives the better error performance results than with the original channel without estimation. Also from Fig.10, it can be observed that the performance of LS channel estimation is better for 2x2 MIMO-OFDM system than 2x1 MISO-OFDM system. Performance of the system can be further improved by using efficient channel estimation techniques like using basis expansion model based algorithm and suitable error control technique.

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