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EFFECTIVE CHANNEL ESTIMATION TECHNIQUE WITH ADAPTIVE MODULATION FOR MIMO-OFDM SYSTEM

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ABSTRACT

Multiple Input Multiple Output-Orthogonal Frequency Division Multiplexing (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. Irrespective of the techniques being employed in wireless communication System (such as OFDM, MIMO, or MIMO-OFDM techniques) to combat the effects of the channel on the transmitted signals, the availability of the channel state information (CSI) at the receiver end of the communication system remains a crucial factor for effective functioning of these techniques as well as for the successful recovery of the transmitted signal. The major challenge faced in MIMO-OFDM systems is how to obtain the channel state information accurately and promptly for coherent detection of information symbols In this paper, Least Squares (LS) channel estimation and Discrete Prolate Spheroidal Sequences based channel estimation methods are implemented for 2x2 MIMO OFDM systems with Alamouti technique and their performance is compared. In order to improve the performance of the systems further, Adaptive Modulation concept is introduced. The simulation outcome shows that the performance of MIMO OFDM is much better than the conventional methods.

Keywords: *MIMO, OFDM, Alamouti. Least Squares, DPS sequences, Adaptive Modulation*

1. INTRODUCTION

Wireless communications is, by any measure, the fastest growing segment of the communications industry. As such, it has captured the attention of the media and the imagination of the public. However, many technical challenges remain in designing robust wireless networks that deliver the performance necessary to support emerging applications. Wireless systems with mobile users will never be able to compete with wired systems in terms of data rates and reliability[19].

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 stream [13] 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.

The multiple antennas can be used to increase data rates through multiplexing or to improve performance through diversity. In MIMO systems the transmit and receive antennas can both be used for diversity gain. Multiplexing is obtained by exploiting the structure of the channel gain matrix to obtain independent signaling paths that can be used to send independent data. Indeed, the initial excitement about MIMO was remarkable spectral efficiencies for wireless systems with multiple transmit and receive antennas. These spectral efficiency gains often require accurate knowledge of the channel at the receiver, and sometimes at the transmitter as well. In addition to spectral efficiency gains, ISI and interference from other users can be reduced using smart antenna techniques. The cost of the performance enhancements obtained through MIMO techniques is the added cost of deploying multiple antennas, the space and power requirements of these extra antennas, and the added complexity required for multi-dimensional signal processing. These features make it so fashionable than other technology [19].

Transmitter side techniques like beam forming, adaptive modulation and coding etc. requires the information about the channel condition. The major challenge faced in MIMO-OFDM systems are how to obtain the channel state information accurately which is required in the detection of information symbols. The properties of the channel can be obtained through channel estimation. Channel estimation can be performed with and without pilot symbols. LS channel estimation which has been discussed in this paper is practical technique because it does not necessitate extra information about channel covariance and noise variation. Also, Discrete Prolate Spheroidal Sequences (DPSS) technique which is a type of Basic Expansion Model (BEM) based channel estimation technique has been discussed. The main advantage of BEM model is that, it can be used to estimate the time variation of the channel taps or the multi-path complex gains of a block for a fast fading channel which has many channel parameters [9] [10].

To further improve the performance of the system, Adaptive Modulation is applied to the system and the results are compared for each channel estimation technique. Adaptive transmission techniques improve the performance of wireless communication system by adjusting transmission parameter like type of modulation and its level and depending on the channel condition. For example, if the channel is good then more data will be transmitted using higher order modulation techniques. When the channel is affected by more amount of noise, less data will be transmitted to reduce the intensity of error and information failure.

The contents of this paper are in the following order: Introduction given in session 1, in session 2, the system models are described. In session 3, Rayleigh channel, LS channel estimation, DPSS-BEM based channel estimation and Adaptive Modulation concepts are discussed in session 4. Simulation Parameters and Results are discussed in session 5.

2. SYSTEM MODEL

2.1 Orthogonal frequency division multiplexing

On the subject of the transmission techniques for mitigating the physical limitation of wireless channels caused by multipath fading, dispersion, and interference, a very popular multi-carrier modulation technique which has emerged recently [20]-[21] in the communication field is Orthogonal Frequency Division Multiplexing (OFDM) technique. 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. In practice, discrete Fourier transforms (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. Figure 1 shows the transmit spectrum of the OFDM signal.

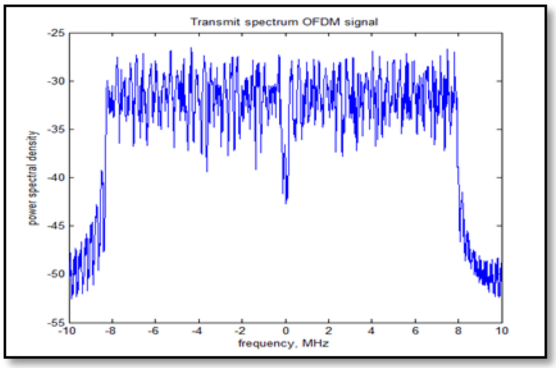

Figure 1: OFDM signal transmit Spectrum

2.2 Multiple Input Multiple Output systems

The multiple antennas can be used to increase data rates through multiplexing or to improve performance through diversity. In this paper, 2x2 MIMO is implemented using Alamouti algorithm. A complex orthogonal space-time block code 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:

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

Alamouti encoded signal is transmitted from the two transmit antennas over two symbol periods. During the first symbol period, first transmitter sends 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.

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

$$y_1 = h_1x_1 + h_2x_2 + z_1$$

$$y_2 = -h_1x_2^* + h_2x_1^* + z_2 \qquad (2)$$

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

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

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

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

$$= (|h_1|^2 + |h_2|^2)\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} h_1^*z_1 & h_2z_1^* \\ h_2^*z_1 & -h_1^*z_1^* \end{pmatrix} \qquad (4)$$

We obtain the input-output relation as

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

Where,

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

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

Figure 2 [4] shows the system model for 2x2 MIMO-OFDM system which has been implemented in this paper.

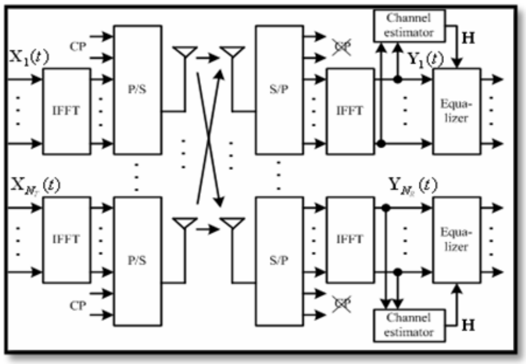

Figure 2: MIMO-OFDM system Model

3. CHANNEL ESTIMATION

When a signal propagates through a wireless channel, it experiences random fluctuations in time if the transmitter, receiver, or surrounding objects are moving, due to changing reflections and attenuation. Thus, the characteristics of the channel appear to change randomly with time, which makes it difficult to design reliable systems with guaranteed performance [19]. The fundamental phenomenon which makes reliable wireless communication difficult is time varying multipath fading. It may be achieved by higher transmit power or additional bandwidth. It makes the system inefficient. In MIMO OFDM, high data rate communication can be achieved without increment in Bandwidth or transmitting power required [14].To estimate the channel response of each subcarriers, different channel estimation techniques like training based, DFT based and Decision directed are used in MIMO OFDM system [15]. In this paper training symbol based estimation is discussed.

3.1 Rayleigh Channel

If there is no direct path between transmitter and receiver then the multipath components of the fading channel [12] can be approximated using Rayleigh distribution in flat fading channels. The received signal can be simplified to:

$$r(t) = s(t)*h(t) + n(t) \qquad (6)$$

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:

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

where σ^2 is the time-average power of the received signal [5],[6]. Figure 3 shows the received field intensity for the Rayleigh channel.

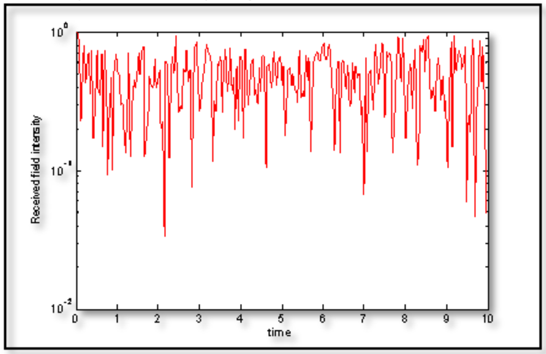

Figure 3: Received Field Intensity

Figure 4 illustrates the generated Rayleigh channel coefficients using Jakes model described in [11].

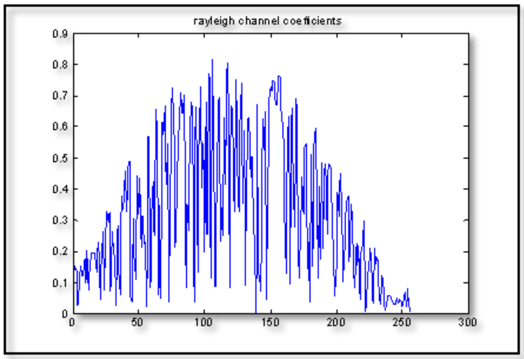

Figure 4: Rayleigh Channel Coefficients

3.2 Least squares channel estimation

The LS channel estimation technique, which is a type of training based channel estimation is discussed [4], [15].The frequency domain equation for the received signal is given by:

$$Y = X H + N \qquad (8)$$

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 channel coefficient can be measured as [15], $H_{LS}=X^{-1}Y$.

The above equation can be re-written as

$$Y(k,t) = \sum_{i=1}^{N_T}(k,t)H_i(k) + N(k,t) \qquad (9)$$

where $X_i(k,t)$ denotes the transmit signal on kth subcarrier in the t^th^ OFDM symbols at the i^th^ transmit antenna.

3.3 Discrete Prolate Spherpoidal Sequences channel estimation

The Discrete Prolate Spheroidal Sequences have a double orthogonal property over a finite set {0,…,M-1} and the infinite set {-∞,…..,∞} = Z simultaneously [7]. This property overcomes the drawbacks of windowing during channel estimation in case of Fourier basis expansion. The performance of the two channel estimation techniques-LS and DPSS is compared for 2x2 MIMO-OFDM system.

Channel taps are measured using Discrete Prolate Spheroidal Sequence BEM coefficients [7],[18]. The received sequence y[m] is given by the multiplication of the symbol sequence and the sampled time-variant channel $h[m] \triangleq h(mT_S)$ plus additional circular symmetric complex white Gaussian noise z[m] with zero mean and variance σ_Z^2.

$$y[m] = h[m]d[m] + z[m], \qquad m = \{0,\ldots,M-1\} \quad (13)$$

The pilot symbols are independent identically distributed and are chosen with equal probability from the QPSK symbol set $p[m] = \{\pm 1 \pm j\}/\sqrt{2}$ for m Є P and rest values are zero. The pilot placement P is defined through the index set

$$P = \left\{\left\lfloor i\frac{M}{j} + \frac{M}{2j}\right\rfloor \mid i \in \{0,\ldots,J-1\right\} (14)$$

Figure 5 shows an example of the pilot set P [7].

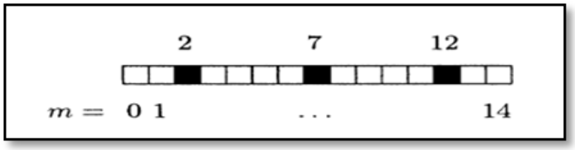

Figure 5: Example Pilot pattern P={2,7,12} defined for m=15 and j=3

The Slepian Basis Expansion has been discussed in [7]. Figure 6 shows the Slepian sequences u_i for a block elength M=256 and maximum normalized Doppler bandwith $v_{Dmax}=3.9 .10^{-3}$. The pilot pattern helps in obtaining the channel knowledge for m Є P. The vector is defined as,

$$f[m] = \begin{bmatrix} u_0[m] \\ \vdots \\ u_{D-1}[m] \end{bmatrix} \in R^D \qquad (15)$$

with the instantaneous values of the basis functions and correlation matrix

$$G = \sum_{m \in P} y[m]p^*[m]f^*[m] \qquad (16)$$

The basis expansion parameters are estimated according to

$$\hat{\gamma} = G^{-1}\sum_{m \in P} y[m]p^*[m]f^*[m] \qquad (17)$$

where

$$\hat{\gamma} = [\hat{\gamma}_{0,}\ldots,\hat{\gamma}_{(D-1)}]^T \qquad (18)$$

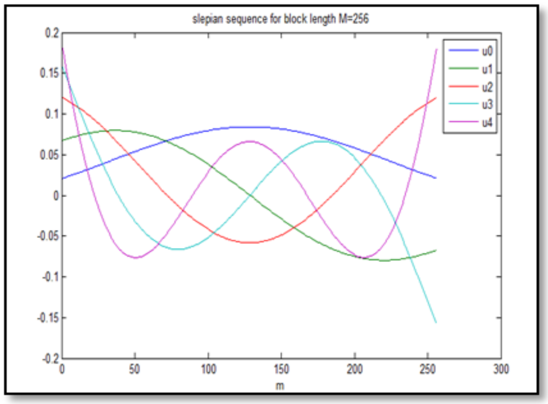

Figure 6: Slepian sequences $u_i^{(s)}[m]$ for block length m=256 and maximum normalized Doppler bandwidth $v_{Dmax}=3.9 . 10^{-3}$

4. ADAPTIVE MODULATION

The technique which is widely utilized in wireless communication systems is called adaptive modulation and coding (AMC). Which are the efficient resource allocation technique, and utilized to optimize the system resources through switching the system among various modulation coding schemes. Thus, by depending on the channel quality which is estimated through the receiver, AMC allows the transmitter switches it's adaptive schemes. The channel state information (CSI) through adapting transmit parameters, like modulation constellation, transmit power, coding parameters [16] are fed back to the transmitter from the receiver side. So that, for the next transmission, this information will be utilized by AMC to choose the most appropriate modulation and coding algorithm that have better match with the instantaneous channel conditions. Modulation scheme efficiency represents the amount of bits that will be carried through each transferred symbol [17].

In addition to the channel estimation techniques, Adaptive modulation has been implemented for both LS and DPSS channel estimation techniques for 2x2 MIMO-OFDM systems. Here, the modulation technique varies according to the channel condition. After transmitting the OFDM symbol over the channel, channel estimation techniques (LS and DPSS) are implemented on the receiver side. Depending on the estimated channel parameters, threshold values are chosen. These threshold values are used to select the modulation scheme for next transmission, which is fed back to the transmitter. Initially the signal is transmitted using BPSK modulation. Based on the channel values, any one modulation out of the following four modulation schemes (BPSK, 4-QAM, 8-QAM, 16-QAM) are used.

5. RESULTS AND DISCUSSION

The system model shown in Figure 2 is implemented based on the simulation environment mentioned in the Table 1. Least Squares and Discrete Prolate channel estimation techniques are implemented to 2x2 MIMO-OFDM system and their results are compared based on BER vs SNR analysis. Adaptive modulation is then applied separately to LS and DPSS channel estimated results. Adaptive modulation results are then compared with Constant Modulation for respective channel estimation techniques.

Table 1 Simulation parameters

Parameters	Types/values
Number of subcarriers	1024
Carrier Frequency	2GHz
Cyclic prefix	25% of OFDM symbol size
Sampling interval	50 ns
Modulation used	BPSK,4-QAM, 8-QAM, 16-QAM
Transmitting antennas	2
Receiving antennas	2
Radio channel model	Rayleigh Fading Channel
Vehicle speed	200km/hr
Maximum excess delay	10 µs
FFT size	64

Figure 7 shows the BER Vs SNR comparison between LS channel estimated output and DPSS channel estimated output.

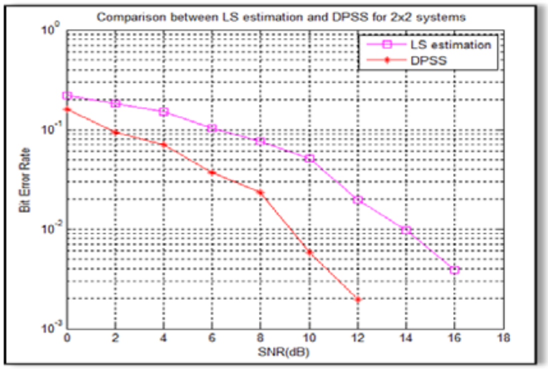

Figure 7: BER vs SNR comparison between LS channel estimated output and DPSS channel output for 2Tx-2Rx

Figure 8 shows the BER vs SNR comparison between Adaptive and Constant Modulation for LS channel estimated output.

Figure 9 shows the BER Vs SNR comparison between Adaptive and Constant Modulation for DPSS channel estimated output.

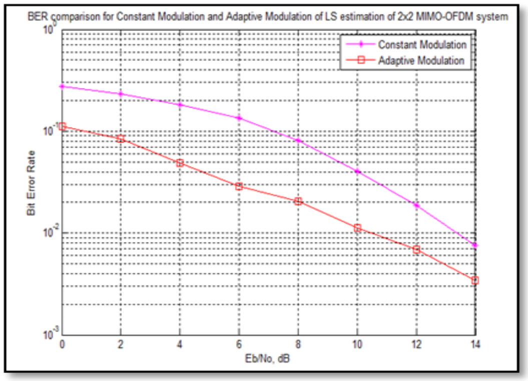

Figure 8: BER vs SNR comparison between Adaptive and Constant Modulation for LS channel estimated output.

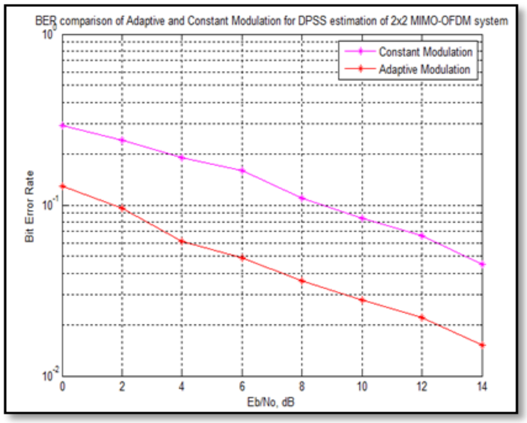

Figure 9: BER vs SNR comparison between Adaptive and Constant Modulation for DPSS channel estimated output.

From figure 8 and 9 it is very clear that system performance has been improved when the modulation is selection based on channel condition compared with constant modulation technique.

5. CONCLUSIONS

In this paper, Least Squares channel estimation technique and Discrete Prolate Speroidal Sequences based channel estimation technique was implemented 2x2 MIMO-OFDM systems. It can be observed from results in Figure 7 that DPSS channel estimation gives better result than LS channel estimation. Thus it can be concluded that DPSS channel estimation is a better channel estimation technique than LS channel estimation technique. From results shown in figure 8 and Figure 9 it can be concluded that Adaptive modulation further enhances the results of channel estimation.

Error performance of the system can be further improved by using adaptive coding concept and channel estimation with feedback mechanism.

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