Implementation of Linear Dispersion Codes for MIMO-OFDM Systems

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Abstract—This paper presents the implementation of space-time-frequency linear dispersion (LD) codes for multiple-input multiple-output (MIMO) antenna systems employing orthogonal-frequency-division-multiplexing (OFDM). The important properties of the LD codes are it can be used for any number of transmit and receive antennas and it is very simple to encode. Linear Dispersion Codes perform better than Alamouti codes. In this paper LD codes are implemented for 2X2 MIMO-OFDM system and the simulatation results show that the LD codes perform better than Alamouti codes.

Key Words: Linear Dispersion (LD) codes, multiple-input multiple-output orthogonal-frequency-division-multiplexing (MIMO-OFDM).

1. Introduction

It is widely acknowledged that reliable fixed and mobile wireless transmission of video, data, and speech at high rates will be an important part of future telecommunications systems. One way to get high rates on a scattering-rich wireless channel is to use multiple transmit and/or receive antennas [1]. MIMO communication systems have a great potential to play an important role in the design of the next-generation wireless communication systems due to the advantages that such systems can offer. By employing multiple transmit and receive antennas, the adverse effects of the wireless propagation environment can be significantly reduced[2]. Unlike the Gaussian channel, the wireless channel suffers from attenuation due to destructive addition of multipaths in the propagation media and due to interference from other users. Severe attenuation makes it impossible for the receiver to determine the transmitted signal unless some less-attenuated replica of the transmitted signal is provided to the receiver. This resource is called diversity and it is the single most important contributor to reliable wireless communications [3]. Motivated by the huge capacity gains promised by MIMO systems over rich scattering channels [4], the seminal work of [3] derived code design criteria (namely, the rank and determinant criteria) based on a high signal-to-noise-ratio (SNR) pair wise error probability analysis and proposed novel space-time codes for the Rayleigh fading channel. On the other hand, the need to construct codes with feasible decoding complexities has led to the development of LD codes which are space-time codes characterized by a generator matrix [1] and permit lower complexity decoders (or demodulators).

Emergence of OFDM as the preferred air interface or access technique has spurred the design of LD codes tailored for OFDM. (OFDM) is a popular technique for signalling over frequency selective fading channels. The popularity of OFDM as an effective multicarrier technique for wireless transmission is due to its ability to transform a frequency-selective fading channel into a set of parallel flat fading subchannels using a low cost, digital fast Fourier transform-based transmitter–receiver structure[8]. The chief advantage that OFDM holds over single carrier modulation is that it enables the use of high data rates with a relatively low complexity receiver, requiring only a fast Fourier transform (FFT) processor followed by single tap equalizers across the subcarriers. Optimal LD coding would require to jointly spread data symbols across all the transmit antennas and all the OFDM tones in order to simultaneously extract both the maximum possible spatial and frequency diversity available in the MIMO-OFDM channel and the best possible coding gain [5].

In this paper we implement space-time-frequency LD codes for MIMO-OFDM communication systems. The LD code is simple and very easy to encode. It performs better than the Alamouti codes. LD Codes for MIMO-OFDM systems are the space time codes which try to maximize the mutual information between the transmitter and receiver.

The presentation of this work can be divided into four sections. In Section II, the design procedure of LD Codes is given. Section III contains the system model and the implementation issues. Finally the conclusions and results are discussed in Section IV.

II. Linear Dispersion Code Design

A Linear Dispersion (LD) Space-Time Block Code (STBC) C [1] over a signal set S , is a finite set of nxl matrices ($n \le l$), where any codeword matrix belonging to the code C is of the form ,

$$S(x_1, x_2, \ldots x_Q) = \sum_{i=1}^{Q} (x_i A_i + x^*_i \, B_i) \qquad (1)$$

where, A_i and B_i are fixed nxl complex matrices defining the LD code, $x_1, x_2, \ldots x_Q$ are complex scalars staking values from the signal set S and $x_i{}^*$ denotes the complex conjugate of x_i. A subclass of LD codes is the *purely* complex LDSTBCs, where any matrix $S(x_1, x_2, \ldots x_Q)$ is a complex linear combination of $\{A_1, A_2, \ldots\ldots A_Q\}$ only. We call the set $\{A_1, A_2, \ldots A_Q\}$ as dispersion matrices or weight matrices. The real scalars can be determined by

$$x_q = x_i + x^*_i, i = 1, \ldots\ldots\ldots Q \qquad (2)$$

The codes break the data stream into sub streamss that are dispersed in linear combinations over space and time. We refer to them simply as linear dispersion codes (LD codes). A LD space-time block code is said to be information-lossless if it does not disturb the maximum mutual information between the transmit and receive signals.

The design of LD codes depends crucially on the choices of the parameters Q ,and the dispersion matrices $\{A_i, B_i\}$. To choose the $\{A_i, B_i\}$ we propose to optimize a nonlinear information-theoretic criterion: namely, the mutual information between the transmitted signals $\{x_i, x^*_i\}$ and the received signal. This criterion is very important for achieving high spectral efficiency with multiple antennas.

III. System Model

Consider a MIMO-OFDM system with M_T transmit antennas and M_R receive antennas. Assume that the channel is flat fading and remains constant for τ symbol intervals, and the fading coefficient from the i th transmit antenna to the j th receive antenna is denoted by $h_{i,j}$. The MIMO channel is assumed to be constant over each OFDM block period, but it may vary from one OFDM block to another. At the k th OFDM block, the channel impulse response from transmit antenna i to receive antenna j at time □ can be modeled as

$$h_{i,j}(\tau) = \sum_{l=0}^{L-1} \alpha_{i,j}(l) \delta(\tau - \tau_l) \qquad (3)$$

where τ_l is the delay and $\alpha_{i.j}(l)$ is the complex amplitude of the l th path between transmit antenna i and receive antenna j .The $\alpha_{i.j}(l)$'s are modeled as zero-mean complex Gaussian random variables with variances,

$E\left|\alpha_{i.j}(l)\right|^2 = \delta_l^{\,2}$ where E stands for the expectation. We assume that the MIMO channel is spatially uncorrelated, so the channel coefficients $\alpha_{i.j}(l)$'s are independent for different indices (i, j).

The signal transmitted from the ith transmit antenna at time index t is denoted by $x_{t,i}$, while the signal received at the jth receive antenna at time t is denoted by $y_{t,j}$. From (3), the frequency response of the channel is given by

$$H_{i,j}(f) = \sum_{l=0}^{L-1} \alpha_{i,j}(l) e^{-j2\pi f\tau l} \qquad (4)$$

where $j = \sqrt{(-1)}$.

OFDM converts a frequency-selective fading channel to a set of parallel flat fading channels. At the receiver, after removing the cyclic prefix, and applying FFT, the received signal at the receive antenna j is given by

$$y_{t,j} = \sum_{i=1}^{M_T} h_{i,j} x_{t,i} + w_{t,j}, t = 1,..\tau, j = 1,...M_R \qquad (5)$$

Where $w_{t,j}$ is independent zero-mean complex Gaussian noise with unit variance. The transmitted energy on all M_T antennas at any given time is normalized to unity. Equation (3) can be written in matrix form as

$$Y = XH + W \qquad (6)$$

Where Y is the $\tau x M_R$ matrix of the received signal, X is the $\tau x M_T$ matrix of the transmitted signal, W is the $\tau x M_R$ matrix of the additive white Gaussian noise, and H is the $M_T x M_R$ MIMO channel matrix.

Where $Y = [y_1 y_2 ....y_T]^t$

$X = [x_1 x_2 ....x_T]^t$

and

$W = [w_1 w_2 .....w_T]^t$

where the superscript t denotes "transpose".

$$Y^t = HX^t + W^t \qquad (7)$$

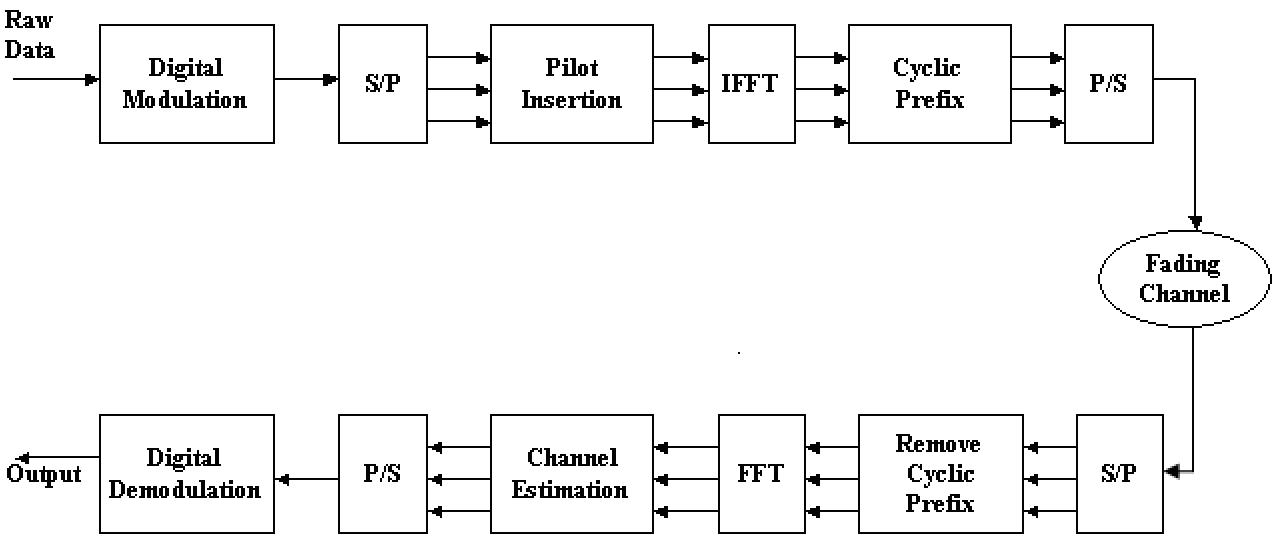

Fig.1 Block diagram of a simple OFDM transceiver

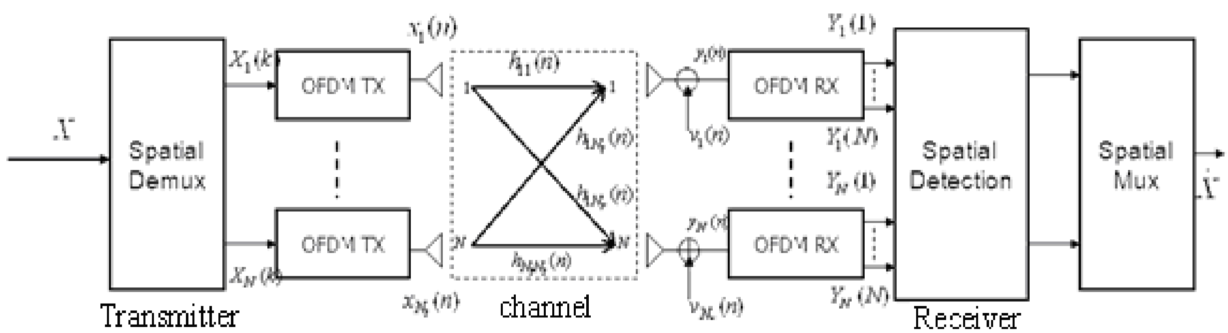

Fig.2 $N_t x N_r$ **MIMO-OFDM System**

It is generally more convenient to write this equation in its transposed form. We have omitted the transpose notation from H and simply redefined this matrix to have dimension MxN .

MIMO offers the following gain:
1) Diversity gain (M_T) (combat fading, stabilize link quality, increase coverage)
2) Spatial multiplexing gain (transmit multiple independent data streams, increase link capacity)
3) Array gain (captures more received energy, improve average SNR, increase coverage)
4) Co-channel interference reduction gain (attenuate interference from adjacent cells, increase cellular capacity).

A. OFDM Generation:

Fig.1 shows the block diagram of a general OFDM transmitter and receiver. To generate OFDM successfully the relationship between all the carriers must be carefully controlled to maintain the orthogonality of the carriers. For this reason, OFDM is generated by firstly choosing the spectrum required, based on the input data, and modulation scheme used. Each carrier to be produced is assigned some data to transmit. The required amplitude and phase of the carrier is then calculated based on the modulation scheme (typically differential BPSK, QPSK, or QAM). The required spectrum is then converted back to its time domain signal using an Inverse Fourier Transform. In most applications, an Inverse Fast Fourier Transform (IFFT) is used. The IFFT performs the transformation very efficiently, and provides a simple way of ensuring the carrier signals produced are orthogonal.

TABLE I
SYSTEM PARAMETERS

Noise	AWGN
Carrier Frequency	2 GHz
FFT points (N)	512
Subcarrier Spacing	15 KHz
Modulation	QAM
Tx antenna spacing	$\lambda/2$
Rx antenna spacing	$\lambda/4$
Scenario	urban micro

The Fast Fourier Transform (FFT) transforms a cyclic time domain signal into its equivalent frequency spectrum. This is done by finding the equivalent waveform, generated by a sum of orthogonal sinusoidal components. The amplitude and phase of the sinusoidal components represent the frequency spectrum of the time domain signal. The IFFT performs the reverse process, transforming a spectrum (amplitude and phase of each component) into a time domain signal. An IFFT converts a number of complex data points, of length which is a power of 2, into the time domain signal of the same number of points. Each data point in frequency spectrum used for an FFT or IFFT is called a bin.

The orthogonal carriers required for the OFDM signal can be easily generated by setting the amplitude and phase of each bin, then performing the IFFT. Since each bin of an IFFT corresponds to the amplitude and phase of a set of orthogonal sinusoids, the reverse process guarantees that the carriers generated are orthogonal.

One of the most important properties of OFDM transmissions is the robustness against multipath delay spread. This is achieved by having a long symbol period, which minimizes the inter-symbol interference.

b. Implementation of LD Codes for MIMO-OFDM Systems

Fig.2 shows the general block diagram for implementation of LD codes for MIMO-OFDM systems. MIMO-OFDM system is an effective solution to improve communication quality, performance, capacity, and transmission rate. MIMO-OFDM is a promising technology that embraces advantages of both MIMO system and OFDM. Space time codes such as LD codes are applied to MIMO-OFDM system to increase the capacity.

Assume that the data sequence has been broken into Q sub streams (for the moment we do not specify) and the complex symbols are chosen from an arbitrary, say r-QAM, constellation. Then the constellation signals are fed as input to the OFDM transmitter block where the serial data is converted to parallel data , then the pilot insertion is done after that the IFFT of that pilot inserted signal is cyclic prefixed which is again converted to serial data. The channel used here is Rayleigh fading channel.

After passing through the channel the serial data is again converted to parallel data, then the cyclic prefix is also removed. The FFT of that data is cyclic prefixed and then the channel estimation is done. Again the parallel data is converted to serial data and finally the output is demodulated.

The demodulated outputs are combined to get the final LD coded output.

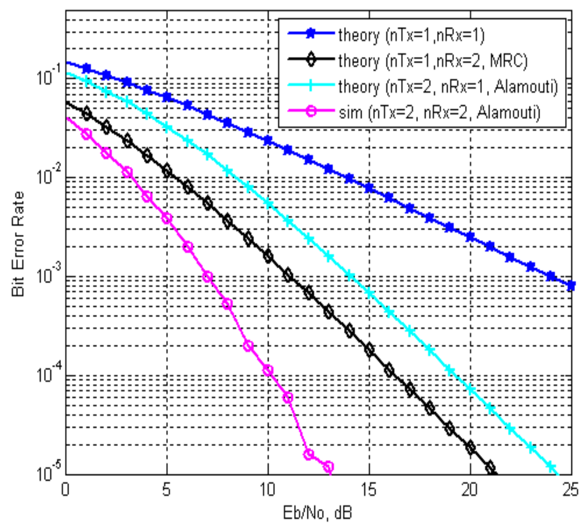

Fig.3 BER for QAM modulation with 2Tx,2Rx Alamouti STBC (Rayleigh Channel)

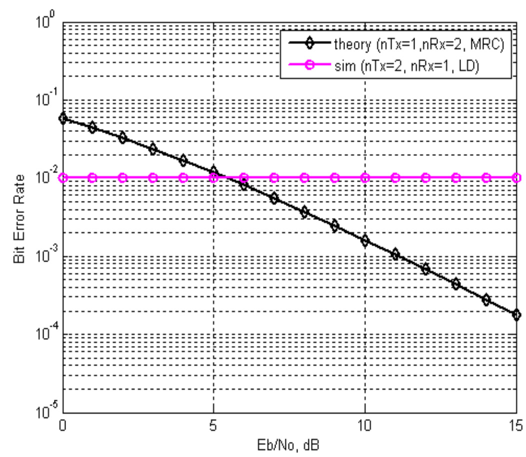

Fig.4 BER for QAM modulation with LD STBC (Rayleigh Channel)

Fig.3 shows the BER performance for QAM modulation with two transmitter and two receiver Alamouti space time block codes.

IV.Conclusion

In this paper, we proposed the implementation of space-time-frequency linear dispersion (LD) codes for multiple-input-multiple-output (MIMO) antenna systems employing orthogonal-frequency-division-multiplexing (OFDM). The LD code is quite simple and easy to encode. It has been shown that the BER performance of LD code is better than the Alamouti codes.

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