Space Time Block Coded Design for Low Complexity based LDPC Coded OFDM

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Abstract—The space time block coded (STBC) based orthogonal frequency division multiplexing (OFDM) system exhibits high peak-to-average power ratio (PAPR) and high complexity if discrete Fourier transform (DFT)/ inverse discrete Fourier transform (IDFT) is applied at the transmitter/receiver .In this paper, a low density parity code (LDPC) based space time coded OFDM system is considered . Compared to the general LDPC based STC-OFDM system, the proposed system can significantly achieve better PAPR property and also exhibits lower transceiver complexity the by exploiting both spatial diversity and the selective fading diversity in wireless channels. An analysis on the capacity and performance of Alamouti like STBC OFDM systems over correlated fading channel, in the case of the channel being known at the receiver is considered in this paper and complexity analysis of LDPC based ST coded OFDM system is evaluated and studied.

Keywords— LDPC, OFDM, STBC.

1 INTRODUCTION

The key challenge encountered in future broadband wireless communication systems is to provide high speed data-rate wireless access at high quality of service (QoS) through severe multipath propagation channels[1]-[3]. In recent years, the spatial dimension in a broadband wireless communication system has been explored by employing multiple transmit and/or receive antennas. This offers the following several advantages over the traditional single antenna system:

- Spatial multiplexing gain which leads to higher capacity.
- Diversity gain which leads to more reliability.

The increasing demand for higher date rates requires transmission over a broadband channel which is frequency-selective [4]. As a result, inter-symbol interference (ISI) is

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The space time coding OFDM (STC-OFDM) system was proposed in [6]. The performance of OFDM systems using the Alamouti space time block code, which uses two transmit antennas and one receive antenna in its simplest form of (2 × 1 MISO channel) for the following reasons [7]:

1. The 2×1 Alamouti scheme offers full diversity gain of 2 without rate loss;
2. The Alamouti scheme is practically relevant. It has been included in various 3.5G/4G wireless communication standards such as 802.16-2005WiMAX and 3GPP LTE, where it is used in the downlink to allow for low complexity mobile terminals.
3. The Alamouti scheme does not require channel state information (CSI) at the transmitter.
4. The Alamouti scheme has a low complexity maximum-likelihood (ML) decoding algorithm and hence no dedicated feedback channel. Several research groups have been proposed low-density parity-check (LDPC) code design for high-order modulations on single-input single-output (SISO) channels to achieve spectral efficiency[8]-[12]. introduced, which severely degrades the system performance. On the other hand, the orthogonal frequency division multiplexing (OFDM) transforms a frequency-selective MISO channel into a set of parallel frequency-flat channel [5].

In this contribution, we design a low complexity transceiver structure for LDPC based STC –OFDM system. Compared with the general LDPC based STC-OFDM system, the proposed system can significantly achieve both spatial diversity and the selective fading diversity in wireless channels, better PAPR property and also exhibits lower transceiver complexity.

More recently, in [13], the complexity reduction and performance of convolutional coded STBC- OFDM system in fading channels is investigated. Since the STBC based on LDPC codes turns out to be good candidate for higher order modulations to achieve spectral efficiency. Here, we study the realization of LDPC based MISO diversity for OFDM systems over correlated Rayleigh channel, assuming that the CSI is known only to the receiver. As a promising coding technique to approach the channel capacity, Alamouti like

STC is employed as the channel code in this system. The goal of this paper is to provide a review of the basics of LDPC based STC-OFDM wireless system with a focus on transceiver design, implementation aspects. The remainder of this article is organized as follows. The next section contains a brief introduction into LDPC based STC-OFDM wireless systems. We have then discussed capacity, outage capacity and complexity analysis for the system. An analysis of LDPC based STC-OFDM wireless systems is followed by a summary of results on the computer simulation of LDPC based STC-OFDM wireless systems transceiver. Finally, a list of relevant open areas for further research is provided. 2.

LDPC based STBC-OFDM SYSTEM

We have considered an LDPC based STC-OFDM system with NT 2 transmit antennas and NR 1 receives antennas, signaling through correlated Rayleigh channel

a. LDPC Encoding & Modulation:

In LDPC based STC-OFDM system, the modulating bits are encoded by LDPC encoder and encoded output mapped on 16 ary QAM modulation. LDPC code is defined by a parity check matrix that is sparse. A parity check code of length N is a linear binary block code whose code words all satisfy a set of M linear parity check constraints. It is defined by its M N parity check matrix H, whose M rows specify each of the M constraints. The parity check code is the set of binary vectors satisfying all constraints i.e., the set of C satisfying [14]-[17]

CHT=0

An example of a parity check matrix H is demonstrated in Figure.2.

$$H = \begin{bmatrix} 1 & 0 & 1 & 1 & 0 & 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 1 & 0 & 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 1 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & 1 \end{bmatrix}$$

Figure.1. Parity check matrix

b. Alamouti STBC Encoding:

We assume *2* transmit antennas and one receive antenna, where the information symbols x_1 and x_2 are transmitted using Alamouti like space time block codes [18]. All the complex encoded information symbols are first grouped together by a modulator and then passed through an STBC encoder. Then they are transmitted over *Ts* =1, 2, symbol periods.

The STBC encoder takes the block of two modulated symbols x_1 and x_2 in each encoding operation and hands it to the transmit antennas according to the code matrix

$$X_{12} = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \quad (1)$$

The first row represents the first transmission period and the second row the second transmission period. During the first transmission, the symbols x_1 and x_2 are transmitted simultaneously from antenna one and antenna two respectively. In the second transmission period, the symbol $-x_2^*$ is transmitted from antenna one and the symbol x_1^* from transmit antenna two. It is seen that the encoding is performed in both time and space domain.

b. OFDM Modulation

After received data are encoded by using STBC encoding, N point IFFT is performed. From Figure.2, the LDPC based STC coded signal of proposed system is organized into an array of two dimensions, and their N point IFFT is implemented. Unlike the general COFDM system with N subcarriers, COFDM system with N subcarriers is defined over an array of two dimensions.

The outputs of IFFTs are converted into parallel by using interleaved. Finally, the result is appended with cyclic prefix (CP).The length of CP is the same to that the conventional OFDM systems [19], [20].

d. Channel Model:

The received signals at the time t and t + T can then be expressed as

$$r_1 = x_1 h_1 + x_2 h_2 + n_1 \quad (2)$$

$$r_2 = -x_2^* h_1 + x_1^* h_2 + n_2 \quad (3)$$

Where r_1 and r_2 are the received signals at time t and t + T, n_1 and n_2 are complex random variables representing receiver noise.

This receive signal (r_i) at time *i* can be written in matrix form as:

$$r_i = \sum_{j=1}^{n} h_{ji} x_{ij} + n_i \qquad i = 1,2 \quad (4)$$

Where n_i is a complex channel frequency response and Variance, x_{ij} equals with one of the following complex information symbols [$\pm x_1$, $\pm x_2$, $\pm x_1^*$ $\pm x_2^*$]

e. Alamouti STBC Decoding at Receiver:

The ML space-time block decoder is the optimal decoder. It chooses the code word, which is the most likely to be transmitted given the received signals. Without loss of generality, assuming that the transmitted sequence is (x_1 x_2) = (1 1). Let $\Pr(\hat{x}_1 \quad \hat{x}_2)$ be the probability that the ML space-time decoder picks $(\hat{x}_1 \quad \hat{x}_2)$ given the transmitted sequence (1 1). If the channel coefficients h_1 and h_2 can be perfectly estimated at the receiver, the decoder can use them as CSI. Assuming that all the signals in the modulation constellation are equiprobable, a ML detector decides for that pair of signals $(\hat{x}_1 \quad \hat{x}_2)$ from the signal modulation constellation that minimizes the decision metric

$$d^2(r_1, h_1x_1 + h_2x_2) + d^2(r_2, -h_1x_2^* + h_2x_1^*) = |r_1 - h_1x_1 - h_2x_2|^2 + |r_2 + h_1x_2^* - h_2x_1^*|^2$$

Let $M(n)$ denote the set of check nodes connected to symbol node n, i.e., the position of 1s in the nth column of the parity check matrix H and let $N(m)$ denote the set of symbol nodes that participate in the mth parity check equation i.e., the positions of 1s in the mth row of H. furthermore, $N(m)\setminus n$, excluding the nth symbol node and similarly $M(n)\setminus m$ represents the set $M(n)$, excluding the mth check node. In addition , $q_{n\to m}(x), \quad x \in \{0,1\}$ denotes the message that symbol node n sends to check node m indication the probability of symbol n being 0 or 1,based on all the checks involving n except m . Where $d(x_1, x_2) = |x_1 - x_2|$. On the other hand, using a linear receiver, the signal combiner at the receiver combines the received signals r_1 and r_2 as follows

$$\hat{x}_1 = h_1^* r_1 + h_2 r_2^* = (|h_1|^2 + |h_2|^2)x_1 + h_1^* n_1 + h_2 n_2^* \quad (6)$$

$$\hat{x}_2 = h_2^* r_1 - h_1 r_2^* = (|h_1|^2 + |h_2|^2)x_2 - h_1 n_2^* + h_2^* n_1 \quad (7)$$

Hence $\hat{x}_1$ *and* $\hat{x}_2$ are two decisions statistics constructed by combining the received signals with coefficients derived from the channel state information (CSI). These noisy signals are sent to ML detectors and thus the above ML decoding rule can be separated into two independent decoding rules for x_1 and x_2, namely

For detecting x_1,

$$\hat{x}_1 = \arg\min_{\hat{x}_1 \in X} d^2(\hat{x}_1, x_1) \quad (8)$$

For detecting x_2,

$$\hat{x}_2 = \arg\min_{\hat{x}_2 \in X} d^2(\hat{x}_2, x_2) \quad (9)$$

f. Demodulation & LDPC Decoding:

The Sum product algorithm used to decode LDPC codes was discovered independently several times. It is an algorithm expressed in probabilistic terms [21]. Expressed in probabilistic terms [21].

Let $M(n)$ denote the set of check nodes connected to symbol node n, i.e., the position of 1s in the nth column of the parity check matrix H and let $N(m)$ denote the set of symbol nodes that participate in the mth parity check equation i.e., the positions of 1s in the mth row of H. furthermore, $N(m)\setminus n$, excluding the nth symbol node and similarly $M(n)\setminus m$ represents the set $M(n)$, excluding the mth check node. In addition , $q_{n\to m}(x), \quad x \in \{0,1\}$ denotes the message that symbol node n sends to check node m indication the probability of symbol n being 0 or 1,based on all the checks involving n except m .(5)

Similarly, $r_{m\to n}(x), \quad x \in \{0,1\}$ denotes the message that the mth check node sends to the nth symbol node indicating the probability of symbol n being 0 or 1, based on all the symbols checked by m except n. Finally $y = \{y_1, y_2, y_3, ...y_N\}$ denotes the received word corresponding to the transmitted code word $c = \{c_1, c_2, c_3, ...c_N\}$

The LLR of a binary valued random variable C is defined as

$$L(C) = \log \frac{P(C=0)}{P(C=1)}$$

Where, P(C=0) denotes the probability that the random variable C takes the value 0

P(C=1) denotes the probability that the random variable C takes the value 1.The decoding algorithm is containing two probabilities calculation. The first probability is the probability $q_{m\to n}$. It is the probability associated with mth code bit conditioned on the corresponding parity check equations which are being satisfied except the nth parity check. The second probabilities set indicate that the conditions of a check node are satisfied when the value of a single bit given. It is represented by $r_{n\to m}$. $r_{n\to m}$ is the probability which is conditioned on all possible values of the coded bit C, when nth parity check is satisfied. In SPA algorithm, decoding is repeated for a number of iterations [22]. The algorithm is as follows.

Step 1

Initialization: set the maximum number of iterations, and initialize the probabilities based on the modulation technique in use and probabilistic characteristics of noise on the channel.

$$q_{m\to n}(0)=1-p_m=pr(v_m=+1|y_{eq})$$

For AWGN channel,

$$q_{m\to n}(0)=\frac{1}{1+\exp\left(\frac{-2y_{eq}}{\sigma^2}\right)}$$

$$q_{m\to n}(1)=p_m=pr(v_m=-1|y_{eq})$$

For AWGN channel,

$$q_{m\to n}(1)=\frac{1}{1+\exp\left(\frac{2y_{eq}}{\sigma^2}\right)}$$

$$r_{n\to m}(0)=\frac{1}{2}+\frac{1}{2}\prod_{m'\in M(n)\backslash m}(1-2q_{m'\to n}(1))$$

$$r_{n\to m}(1)=1-r_{nm}(0)$$

Step2

(ii) **Message update**: The messages from variable to check nodes are computed based upon observed value of the variable node and some of the messages passed from the neighboring check nodes to that variable nodes.

Check code update

$$q_{m\to n}(0)=k_{m\to n}(1-p_m)\prod_{n'\in N(m)\backslash n} r_{n'\to m}(0)$$

$$q_{m\to n}(1)=k_{m\to n}\prod_{n'\in N(m)\backslash n} r_{n'\to m}(1)$$

Where the constants k_{mn} are chosen to ensure that $q_{m\to n}(0)$ + $q_{m\to n}(1)$=1. Compute for all m.

Step 3

Symbol node update

$$\lambda_m(0)=k_m(1-p_m)\prod_{n\in c_m} r_{n\to m}(0)$$

$$\lambda_m(1)=k_m\prod_{n\in c_m} r_{n\to m}(1)$$

Where, k_m are chosen to ensure that $\lambda_m(0)+\lambda_m(1)=1$

Step 4

Decision: If received code word satisfies the decision condition, the decoding is completed successfully, otherwise move on to the next iteration of message update.

$$\hat{d}i=\begin{cases}1 & if\quad \lambda_m(1)>0.5\\ 0 & else\end{cases}$$

Once the decoding is done (the maximum number of iterations is performed), the message bits need to be extracted.

g. Channel Capacity:

In this section, we consider the channel capacity of the system. Assuming that the CSI is not available at the transmitter, the source data is transmitted at a constant rate. Since no CSI is available at the transmitter, data transmission takes place over all fading states including deep fades where the data is lost and hence the effective capacity is significantly reduced. Outage capacity is used for slowly varying channels where the instantaneous SNR ° is assumed to be constant for a large number of symbols. Unlike the ergodic capacity scenario, schemes designed to achieve outage capacity allow for channel errors. Hence, in deep fades these schemes allow the data to be lost and a higher data rate can be thereby maintained than schemes achieving Shannon capacity, where the data needs to be correctly received over all fading states [23]. a design parameter P_{out} is selected that indicates the probability that the system can be in outage, i.e. the probability that the system cannot successfully decode the transmitted symbols.

The Minimum received SNR, ($\gamma_{\min}$) Corresponding to this outage probability, given by

$$P_{out}=p(\gamma<\gamma_{\min}) \quad (10)$$

For received SNRs below $\gamma_{\min}$, the received symbols cannot be successfully decoded with Probability 1, and the system declares an outage. Since the instantaneous CSI is not known at the transmitter, this scheme transmits using a constant data rate which is successfully decoded with probability 1 − Pout. The outage capacity is given by

$$C_{out}=B\log_2(1+\gamma_{\min}) \quad (11)$$

5. Simulation Results

We consider the LDPC based STC-OFDM system with N point DFT (N=96 is taken for an example) using 16-QAM modulation (M ary=16, where, k=4 bits/symbol), simulated by randomly generated data. In this paper, we consider the irregular LDPC codes and the corresponding coding rate R is ½. Figure.2. shows the BER performance of SISO and 2×1 STBC for LDPC based OFDM systems with 16 –QAM modulation. From Figure.2, it can be observed that the performance with two transmit antennas is much better than that of the system with one transmit antenna.

At BER level of 10^{-1}, the LDPC based 2×1 STBC system achieves SNR about 16 dB which is about 4 dB lower than system without space time coding.

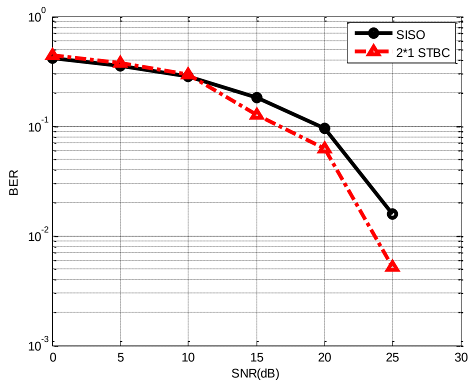

Figure.2. BER performance of SISO and 2×1 STBC for OFDM system on a

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