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Weighted Space-Time Bit Trellis Coded Modulation for Quasi-Static Rayleigh Fading Channel

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Abstract: The data rate of wireless communication system can be increased by MIMO system. The BICM and Space time trellis codes are transmission schemes but their decoding complexity grows exponentially as the number of antenna increases.We used the space-time bit trellis codes instead which are a concatenation of a bit convolutional code, modulator and spatial multiplexing without interleaving. In this paper we present the concept of weighted space-time bit trellis codes. These codes are a combination of space-time bit trellis codes and ideal beamforming. It has been shown that if perfect channel state information is available at the transmitter, the performance of a space-time bit trellis coded system can be further improved by weighting the transmitted signals. In this paper, we evaluate the performance of space-time bit trellis codes combined with ideal beamforming over slow fading channels. Simulation results show that the proposed scheme considerably outperforms the conventional space-time bit trellis codes without weighting.

We show simulation results for 4-QAM up to 4x4 transmit/receive antennas with a data rate of 2 bits per channel use.

Keywords: Weighted space time bit trellis codes, channel state information, beamforming, Rayleigh fading channel, MIMO.

I. INTRODUCTION

Multiple-input and multiple-output, or MIMO, uses multiple antennas at both the transmitter and receiver to improve communication performance. MIMO modulation schemes with receive-only channel knowledge are mainly of two types, diversity systems and spatial multiplexing systems. Diversity modulation, or space- time coding , uses code words designed to maximize the diversity advantage of the transmitted information. Such codes tend to maximize diversity gain at the expense of some loss in available capacity. Spatial multiplexing or Bell Labs Layered Space Time (BLAST) type systems , on the other hand, transmit independent data streams from each transmitting antenna, allowing spectral efficiency to be achieved at the expense of a loss in diversity advantage for a fixed number of receive antennas.

The space-time coding work began with the 1994 paper by Wittenben , which proposes a system using transmit diversity and coding techniques, followed by the groundbreaking paper by Tarokh, Seshadri and Calderbank in 1998 in which they stated the fundamental theory of space-time coding and introduce the first true space-time codes, namely space-time trellis codes (STTCs). STTCs can be decoded optimally with a non-iterative Viterbi algorithm. However, high data rates were difficult to realize. The modification was done in paper by Kienle and Gimmler in 2010 in which the Space-time bit trellis codes (STbitTC) and its new decoding algorithm offer both, high data rates and a non-iterative decoding algorithm.

In it has been shown that when perfect CSI is available at the transmitter, the performance of space-time coded system can be further improved by using the beamforming scheme which can enhance the performance of a STbitTC system by weighting the transmitted signals based on the available channel information

II. SYSTEM OVERVIEW

We consider a multiple-input multiple-output (MIMO) system with n_T transmit and $n_R$receive antennas. The transmitted data are encoded by a STbitTC encoder. At each time instant t, a block of m binary information symbols, denoted by

$$b_t = (b_t^1, b_t^2, b_t^3, \dots, b_t^m)$$

is fed into the convolutional encoder. The convolutional encoder maps the block of m binary input data into n_T modulation symbols from a signal set of $M = 2^m$ points, represented by an $n_T \times 1$ column matrix x_t,

$$x_t = (x_t^1, x_t^2, x_t^3, \dots, x_t^{n_T})^T$$

where T means the transpose of a matrix. The n_T parallel outputs are simultaneously transmitted by n_T different antennas, whereby symbol x_t^i, $1 \le i \le n_T$, is transmitted by antenna i and all transmitted symbols have the same duration of T sec. The vector of coded modulation symbols from different antennas, is called a space- time symbol.

For wireless communications, we assume a quasi-static Rayleigh fading channel model, for which the fading coefficients are constant within one frame but vary independently from one frame to another. The channel matrix H, at time t is given by,

$$H_t = \begin{bmatrix} h_{1,1}^t & \cdots & h_{1,n_T}^t \\ \vdots & \ddots & \vdots \\ h_{n_R,1}^t & \cdots & h_{n_R,n_T}^t \end{bmatrix}$$

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where the *j*,*i*-th element, denoted by $h_{j,i}^{t}$, is the fading attenuation coefficient for the path from transmit antenna *i* to receive antenna *j*.

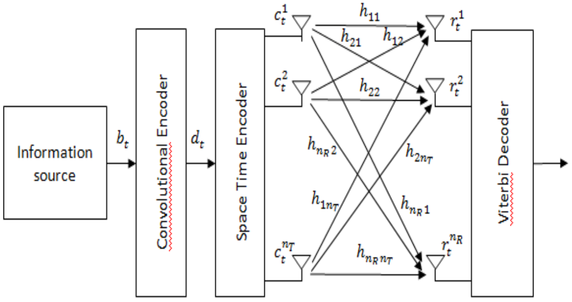

Fig. 1. General structure of STbitTC system

At the receiver, the signal at each of the n_R receive antennas is a noisy superposition of the n_T transmitted signals degraded by channel fading. At time *t*, the received signal at antenna $j, j = 1,2, \dots, n_R$, denoted by r_j^t, is given by,

$$r_t^j = \sum_{i=1}^{n_T} h_{j,i}^t \, x_t^i + n_t^j$$

Where n_t^j, is the noise component of receive antenna *j* at time *t*, which is an independent sample of complex Gaussian random variable with zero-mean and variance of $N_0/2$ per dimension.

Let us represent the received signals from n_R receive antennas at time t by an $n_R \times 1$ column matrix.

$$r_t = (r_t^1, r_t^2, r_t^3, \dots, r_t^{n_R})^T$$

The noise at the receiver can be described by an $n_R \times 1$ column matrix, denoted by n_t,

$$n_t = (n_t^1, n_t^2, n_t^3, \dots, n_t^{n_R})^T$$

where each component refers to a sample of the noise at a receive antenna. Thus, the received signal vector can be represented as,

$$r_t = H_t x_t + n_t$$

We assume that the decoder at the receiver uses Viterbi algorithm to perform maximum likelihood decoding, to estimate the transmitted information sequence and that the receiver has ideal channel state information (CSI) on the MIMO channel. On the other hand, the transmitter has no information about the channel. At the receiver, the decision metric is computed based on the squared Euclidean distance between the hypothesized received sequence and the actual received sequence as,

$$\sum_t \sum_{j=1}^{n_R} \left| r_t^j - \sum_{i=1}^{n_T} h_{j,i}^t x_t^i \right|^2$$

Then we assume perfect CSI is available at the receiver and the transmitter both. The received signal at time *t*, at the *j*th receive antenna is a noisy superposition of independently Rayleigh faded versions of the n_T transmitted signals and is denoted by r_t^j, $1 \le j \le n_R$. The discrete complex baseband output of the *j*th receive antenna at time t is given by,

$$r_t^j = \sum_{i=1}^{n_T} h_{j,i}^t \, c_t^i + \eta_t^j$$

where, $h_{j,i}^t$ is the path gain between the *i*th transmit and *j*th receive antennas and η_t^j is the noise associated with the *j*th receive antenna at time *t*. The path gains, $h_{j,i}^t$, are modeled as samples of independent complex Gaussian random variables with zero mean and variance of ½ per dimension. The noise quantities are samples of independent complex Gaussian random variables with zero mean and variance of $N_0/2$ per dimension.

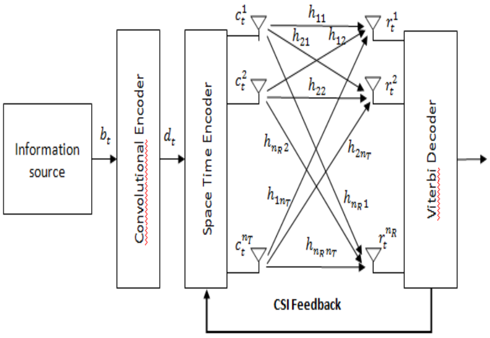

Fig. 2. General structure of WSTbitTC system

The information bits encoded by the convolutional encoder are weighted by the weighting matrix based on the CSI feedback from the receiver.

The weighted signal transmitted at time *t*, denoted by c_t, can be written as

$$c_t = (c_t^1, c_t^2, c_t^3, \dots, c_t^{n_T})^T$$
$$= (w_t^1 x_t^1, w_t^2 x_t^2, w_t^3 x_t^3, \dots, w_t^{n_T} x_t^{n_T})^T$$

where, T means the transpose of a matrix, x_t^i, $1 \le i \le n_T$, is signal coded by convolutional encoder at the stream *i* at time *t*, w_t^i is the weighting coefficient of signal c_t^i, $c_t^i = w_t^i x_t^i$ denotes the weighted signal transmitted through antenna *i* at time *t*. Based on our assumption of perfect CSI available at the transmitter the beamforming coefficients are given by

$$w_t^i = \sum_{j=1}^{n_R} \left(\frac{\left(h_{j,i}^t\right)^*}{\sqrt{\sum_{k=1}^{n_T} \left|h_{j,k}^t\right|^2}} \right)$$

where (.)* represents the complex conjugate operator.

The Viterbi algorithm selects the path with the minimum path metric as the decoded sequence .

III. SIMULATION RESULTS

We consider WSTbitTC systems designed for an underlying 16-QAM constellation with up to 4 transmit and 4 receive antennas. We use STbitTCs as component codes. We assume a quasi-static Rayleigh fading channel model which is constant over a frame and varies independently between frames. We consider a frame size of 129 symbols. Detection/Decoding of the received symbols is done via Near ML Viterbi decoder.

For performance comparison, we consider STbitTC system which has similar specifications as described above for the WSTbitTC system. We show that WSTbitTCs considerably outperforms the conventional STbitTCs without weighting and without sacrificing the capability of simultaneously providing bandwidth efficiency, diversity

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improvement and coding gain with reduced decoding complexity.

We consider the effect of receive diversity on the error performance of the code. Performance is evaluated using 2 transmit antennas and 2 and 4 receive antennas. The effect of transmit diversity on the error performance of the code is evaluated using 2 receive antennas and 3 and 4 transmit antennas.
The Frame Error Rate (FER), Symbol Error Rate (SER) and the Bit Error Rate (BER) performance of a WSTbitTC system is represented by FER1, SER1, BER1 and the performance of STbitTC system is represented by FER, SERand BER is shown in Fig. 3 (a-d). Two identical 4-state STbitTCs based on trace criterion are used as component codes.
We use component codes designed for 2 transmit antennas, trellis diagram of which is shown in Fig. 4. The result shows that increasing the number of receive antennas or transmit antennas yield a significant performance gain.

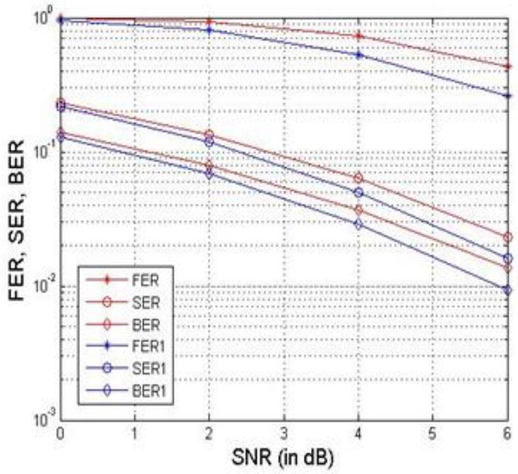

Fig. 3(a). FER, SER, BER performance of WSTbitTC vs.STbitTC for two transmit and two receive antennas using Rayleigh fading channel.

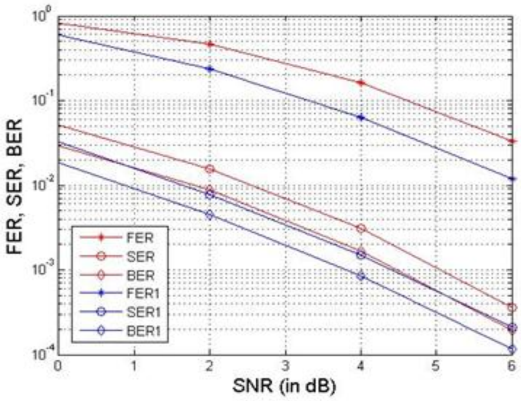

Fig. 3(b). FER, SER, BER performance of WSTbitTC vs.STbitTC for two transmit and four receive antennas using Rayleigh fading channel.

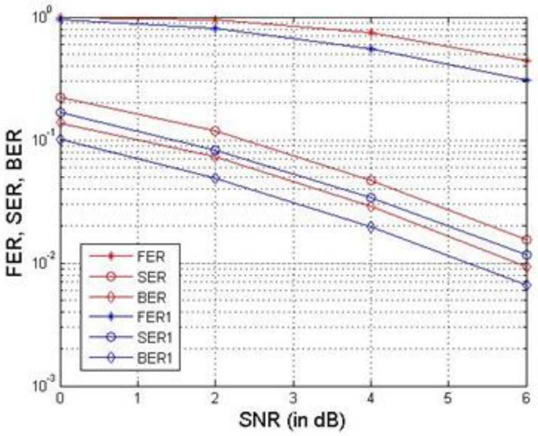

Fig. 3(c). FER, SER, BER performance of WSTbitTC vs.STbitTC for three transmit and two receive antennas using Rayleigh fading channel.

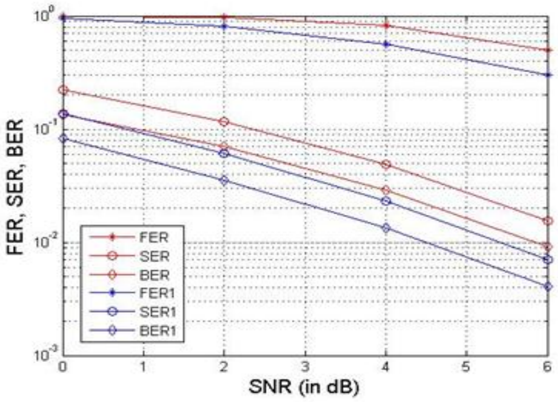

Fig. 3(d). FER, SER, BER performance of WSTbitTC vs.STbitTC for four transmit and two receive antennas using Rayleigh fading channel.

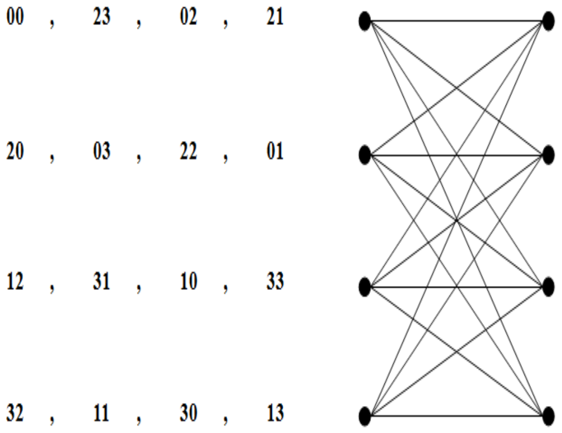

Fig. 4.Trellis structure for a 4-state STbitTC designed using Trace Criterion for two transmit antennas.

IV. CONCLUSION

The work of F. Kienle and **C. Gimmler** in which STbitTCs were designed. The system performance can be improved dramatically if perfect or partial CSI is made available at the transmitter. A novel design criterion for STbitTC with CSI at transmitter is proposed, that

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incorporates the statistical information concerning the channel estimates. New improved Weighed STbitTC codes are obtained using a novel combination of beamforming and STbitTC.

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