



A Review of Space time trellis codes with ideal beamforming for quasi-static Rayleigh fading channel

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Abstract: In this Paper we review and analyze space time trellis codes with & without ideal beam forming at transmitter. Space time trellis code with ideal beam forming at transmitter termed as weighted space time trellis codes. We also reviewed and analyze that weighted space-time trellis codes (WSTTC) achieves more reliable wireless communication system than space time trellis codes. WSTTC improved FER than normal STTC.

Keywords: Space time codes (STC), Space time block codes (STBC), Space time trellis code (STTC), Weighted Space time trellis codes (WSTTC), Multi-input Multi-output (MIMO), Frame error rate (FER).

I. Introduction

Multiple-input and multiple-output (MIMO), uses multiple antennas at both the transmitter and receiver to improve communication performance. MIMO technology has involved consideration in wireless communications, as it offers major increase in data throughput and link range without further bandwidth or increased transmit power. It attains this goal by distributing the same total transmit power over the antennas to achieve an array gain that improves the spectral efficiency (more bits per second per hertz of bandwidth) or to achieve a diversity gain that improves the link reliability (reduced fading). MIMO schemes that assume the channel knowledge is only available at the receiver enhances a lot of research interest in this field [1]. MIMO modulation schemes with channel knowledge at receiver only are generally of two types, spatial multiplexing systems and diversity systems. Spatial multiplexing or Bell Labs Layered Space Time (BLAST) type systems [2], on the other hand, transmit independent data streams from each transmitting antenna, permitting spectral efficiency to be attained at the cost of a loss in diversity advantage for a fixed number of receive antennas. Diversity modulation, or space-time coding [3], uses codewords designed to maximize the diversity advantage of the transmitted information. Such codes incline to maximize diversity gain at the expense of some loss in available capacity. The space-time coding work initiated with paper by Winters [4], which proposes a system using transmit diversity and coding techniques, followed by the innovative paper by Tarokh, Seshadri and Calderbank in 1998 [5] in which they stated the essential theory of space-time coding and lead the first true space-time codes, namely space-time trellis codes (STTCs). This paper was followed by Alamouti's paper [6], which managed to the improvement of space-time block codes (STBCs). The original BLAST structure was developed by Foschini [7] which uses a multi-element antenna array at both the transmitter and receiver, where every antenna transmits an independent sub stream of data.

Advanced signal processing at the receiver is used to estimate and decode the received signal blocks. A BLAST system requires more receive than transmit antennas and a rich scattering environment, which often occurs indoors. Vertical-BLAST (V-BLAST) and Diagonal-BLAST (D-BLAST) [8] are the two major classes of BLAST transmission formats. In the beginning MIMO was projected for indoor WLANs and fixed wireless access networks. However, it has since found wider applications and some practical MIMO systems have been built and experimentally tested in industry. MIMO plays a vital role in modern wireless communication standards such as IEEE 802.11n (Wi-Fi), 4G, 3GPP LTE, WiMAX and HSPA+. MIMO technology can also be used in non-wireless communications systems. Home networking standard ITU-T G.9963 is one of example is the, which defines a power line communications system that uses MIMO techniques to transmit multiple signals over multiple AC wires (phase, neutral and ground).

II. Space Time Coding

Space-time coding (STC) [3] exploits the diversity provided by the MIMO channel in both space (antenna) and time domains, thus significantly increasing the system capacity as well as improving the reliability of the wireless link. To exploit the scattering environment and minimize transmission errors at the receiver, the spatial-temporal correlation is used. STC can attain coding gain and transmit diversity as equated with spatially uncoded systems without sacrificing bandwidth. STBCs and STTCs can be measured as two main classes of space-time codes. In this thesis we concentrate on STTCs proposed by Tarokh [5]. STTC is a class of signalling techniques that conglomerate the design of the channel code with transmit and optionally receive antenna diversity. Furthermore to the diversity advantage, a certain amount of coding gain can be attained by a well-designed STTC. Code design criteria for STTC depends upon upper limits on the pair-wise error probability. The design criteria are the determinant criterion, corresponding to maximization of coding gain and the rank criterion, corresponding to maximization of diversity advantage. STTCs use a trellis encoder to host redundancy into the transmitted symbol stream, and to accomplish coding gain. The coding gain is reliant on the length of the memory in the encoder and on the construction criteria of the code. A number of several structures have been projected for STTCs.

III. Space time trellis code

In 1998, V. Tarokh, H. Jafarkhani, and A. R. proposed the model of STTCs using multiple transmit antennas. STTCs can concurrently provide substantial coding gain, spectral efficiency and diversity improvement. But with the increase in number of antennas and the size of the modulation there is exponential increase in decoding complexity set is a major drawback. So, basically we can't use them for larger constellations. Space-Time Trellis Codes can simultaneously provide coding gain, spectral efficiency, and diversity improvement on flat fading channels. In this chapter, we study, space-time trellis codes (STTC), which were initially proposed by Tarokh, Seshadri and Calderbank [5] and those later improved by Vucetic [9]. Multiple-input multiple-output (MIMO) system with n_R receive antennas and n_T transmit antennas as shown in Fig.1.

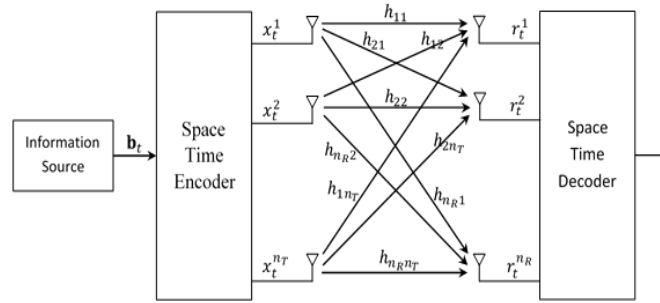


Figure 1: Block diagram of a MIMO system.

The signal at each n_R receive antennas is a noisy superposition of the n_T transmitted signals infected by channel fading. The received signal at antenna j where $j = 1, 2, \dots, n_R$ at time t represented by r_t^j is given by,

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

Thus, the received signal vector can be represented as,

$$\mathbf{r}_t = \mathbf{H}_t \mathbf{x}_t + \mathbf{n}_t \quad (2)$$

We suppose that the decoder at the receiver uses Viterbi algorithm to achieve maximum likelihood decoding and that the receiver has ideal CSI on the MIMO channel. In contrast, the transmitter has no information about the channel. At the receiver, the decision metric is calculated on the basis of squared Euclidean distance between the theorized received sequence and the actual received sequence as,

$$d = \sum_t \sum_{j=1}^{n_R} |r_t^j - \sum_{i=1}^{n_T} h_{j,i}^t x_t^i|^2 \quad (3)$$

The Viterbi algorithm chooses the path with the minimum path metric as the decoded sequence [10]. The spectral efficiency of the system is,

$$\eta = \frac{r_b}{B} = m \text{ bits/sec/Hz} \quad (4)$$

Where B is the channel bandwidth and r_b is the data rate.

The encoder routes binary data to modulation symbols, where the routing function is described by a trellis diagram. The encoder output at time t for transmit antenna i , represented by x_t^i , can be computed as,

$$x_t^i = \sum_{k=1}^m \sum_{j=0}^{v_k} g_{j,i}^k b_{t-j}^k \mod M \quad (5)$$

The space-time trellis coded M-PSK can achieve a bandwidth efficiency of m bits/s/Hz. The total memory order of the encoder, denoted by v , is given by:-

$$v = \sum_{k=1}^m v_k \mod M \quad (6)$$

Where, v_k , $k = 1, 2, \dots, m$ is the memory order for the k_{th} encoder branch. The value of v_k for M-PSK constellations is determined by:-

$$v_k = \left\lfloor \frac{v+k-1}{\log_2 M} \right\rfloor \quad (7)$$

IV. Weighting Space time trellis algorithm

In 2001, Vucetic and Yonghui [9], we present the design of the combined STTCs and beamforming [9], over slow fading channel thereby stated as weighted space-time trellis codes (WSTTCs). It have shown that when perfect CSI is made available at the transmitter, by using the beamforming scheme, the performance of space-time coded system can further be improved by weighting the transmitted signals based on the available channel information. Let us study a WSTTC system as shown in Fig.2, with n_R receive antennas and n_T transmit antennas

At time t , Output of j^{th} receive antenna r_t^j is specified by,

$$r_t^j = \sum_{i=1}^{n_T} h_{j,i}^t x_t^i + \eta_t^j \quad (8)$$

Where, $h_{j,i}^t$ is the path gain between 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 shown as samples of independent complex Gaussian random variables with zero mean and variance of $\frac{1}{2}$ per dimension. WSTTC encoder operates on the STTC encoder, by having weighting scheme over feedback link from STTC decoder to STTC encoder as shown in Fig.3.

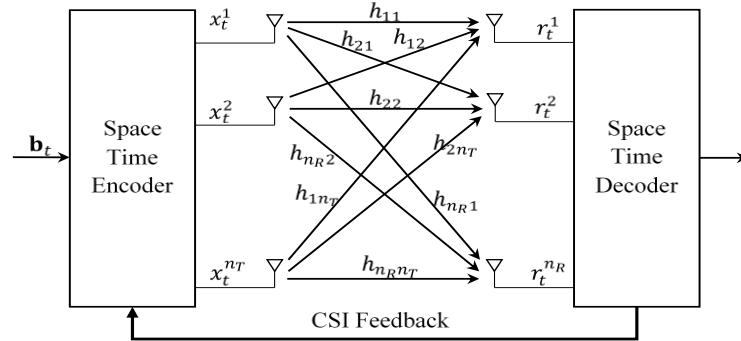


Figure 2: General structure of a WSTTC system

The information signal bits encoded by the STTC encoder are weighted by the weighting matrix based on the CSI feedback from the receiver. At time t , $\mathbf{c}_t$ is the weighted signal transmitted and can be represented as

$$\mathbf{c}_t = (c_t^1, c_t^2, \dots, c_t^{n_T})^T = (w_t^1 x_t^1, w_t^2 x_t^2, \dots, w_t^{n_T} x_t^{n_T})^T \quad (9)$$

Where, T is the transpose of a matrix, x_t^i , $1 \leq i \leq n_T$, is signal coded by the STTC encoder at the stream i at time t , w_t^i represents 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 . As per our supposition of perfect CSI is available at the transmitter the beamforming coefficients [10] are given by

$$w_t^i = \sum_{j=1}^{n_R} \left(\frac{(h_{j,i}^t)^*}{\sqrt{\sum_{k=1}^{n_T} |h_{j,k}^t|^2}} \right) \quad (10)$$

Where $(.)^*$ denotes the complex conjugate operator.

V. Detection/Decoding

Decoder is used to decode the received data which is encoded by WSTTC, available at receiver antenna, as shown in Fig.3. The decoder initializes decoding by the output of the first component code. The estimated values of $\mathbf{x}_t(1)$ i.e. $\hat{\mathbf{x}}_t(1)$ is then passed to the next decoding stage and is then used to decode the values of $\mathbf{x}_t(L-1)$ and so forth. The final stage of the decoder uses the estimates attained from levels 1 to $L-1$, namely $\hat{\mathbf{x}}_t(1), \hat{\mathbf{x}}_t(2), \dots, \hat{\mathbf{x}}_t(L-1)$ to get $\hat{\mathbf{x}}_t(L)$. At time t , the signal received at the j^{th} receive antenna is given by,

$$r_t^j = \sum_{i=1}^{n_T} h_{j,i}^t w_t^i x_t^i + \eta_t^j \quad (11)$$

VI. Simulation Results

We evaluate the effect of receive diversity on the error performance of the code. Performance is calculated by using 2 transmit antennas and different number of receive antennas for Rayleigh fading channel. The performance of a WSTTC system for Rayleigh fading channel is given by plotting Frame Error Rate (FER)

against SNR (dB) as shown in below Fig.4. The simulation results are taken for STTC and WSTTC with 4-QAM & 4-QPSK constellation and with the spectral efficiency of 2 bits/sec/Hz. We considered both cases i.e. with and without ideal beam forming at transmitter. The result demonstrates that increasing the number of receive antennas returns a major performance gain. FER performance for 4-QPSK constellation, STTC system for Rayleigh fading channel are shown in below Fig.4 Performance is calculated with 2 transmits antennas i.e. $n_t = 2$ and different number of receive antennas for $n_r = 1, 2, 4$. The results demonstrates that with increasing the number of receive antennas results into significant performance gain.

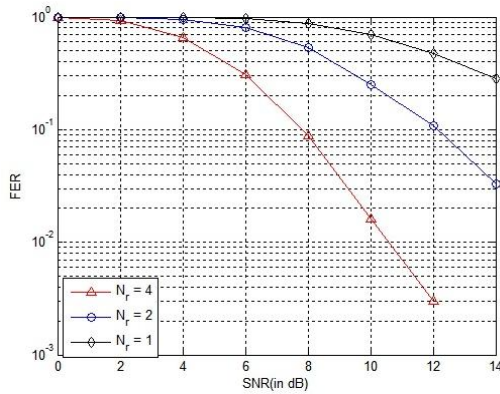


Figure 3: Receiver Diversity QPSK for STTC

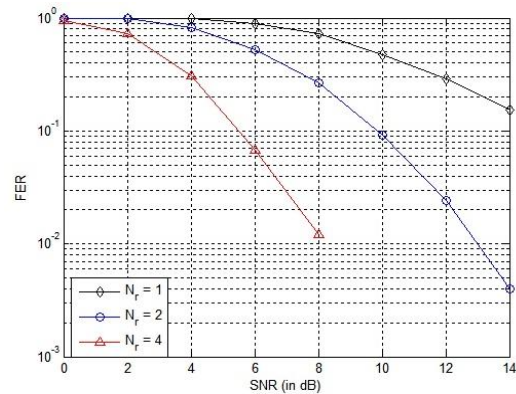


Figure 4: Receiver Diversity QPSK for WSTTC

FER performance for 4-QPSK constellation, WSTTC system for Rayleigh fading channel are shown in below Fig.5. Performance is calculated with 2 transmits antennas i.e. $n_t = 2$ and different number of receive antennas for $n_r = 1, 2, 4$. The results demonstrates that WSTTC outperforms STTC in terms of error performance with increasing the number of receive antennas.

FER performance for 4-QAM constellation, WSTTC system for Rayleigh fading channel are shown in below Fig.6 and 7. Performance is calculated with 2 transmits antennas i.e. $n_t = 2$ and different number of receive antennas for $n_r = 1, 2, 4$. The results demonstrates that WSTTC outperforms STTC in terms of error performance with increasing the number of receive antennas.

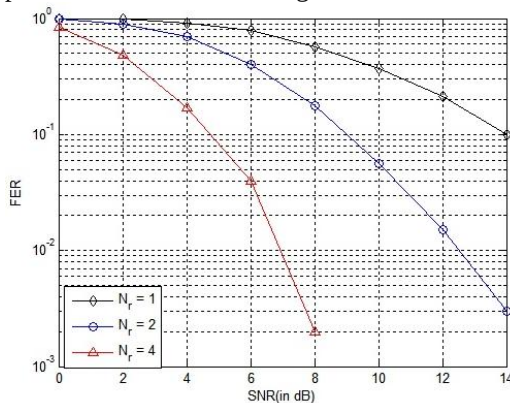


Figure 5: Receiver Diversity PSK for WSTTC

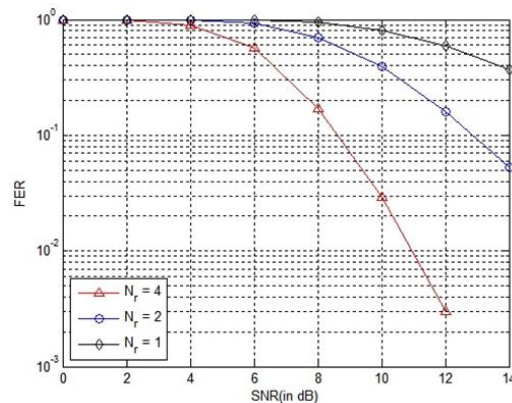


Figure 6: Receiver Diversity PSK for STTC

VI. References

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