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Review Article

Systematic View of STC for the Communication Systems

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***Abstract** - This work systematically reviews the archetype of various space-time codes (STC) methods that lead to superior performance in terms of diversity gain and coding gain in the multiple-antenna wireless communication systems. This article gives readers a deliberate and all-encompassing perspective on various types of STC for wireless communication systems.*

***Keywords** - Space-Time Codes (STC), Space-Time Trellis Codes (STTC), Space-Time Block Codes (STBC), Orthogonal-STBC (O-STBC), Quasi O-STBC (QO-STBC), Beamforming, Linear Dispersion Codes (LDC), MIMO - Multiple Input Multiple Output.*

I. INTRODUCTION

The high data transmission rate is a sign of the communication system. One method to attain a high data rate over the wireless channel is to utilize the multiple numbers of transmitting and/or receiving antennas. The multiple transmit antennas in a scattering environment acquire reliability by way of "diversity techniques". STC provides transmit diversity for the multiple-antenna system [1].

STCs depend on the transmission of redundant copies of an information stream with different phase versions to the recipient over the multiple antenna fading channel with the expectation that some of them may reach the receiver with a low bit error rate at a high Signal to Noise Ratio(SNR). The objective of STC is to accomplish the maximum diversity, high coding gain, and of course, conceivable throughput with low complexity decoding methods. STC performs efficiently in the spatial-time domain in the wireless communication network to achieve the high diversity gain and coding gain at high SNRs and thereby enhances the performance of the communication system [7]. This has led to a lot of research on STC. As there has been remarkable and splendid performance on a variety of different STC for the known channel [8-10] and for the unidentified channel [11-15], thus it is understandable that transmit diversity acts as an elemental function in STC design. The massive MIMO system maximizes the Signal to Interference Noise Ratio(SINR) by using beamforming and overcomes the problem of deep fade by using Diversity. Outlining the contributions of this paper, the organization of the various sections is as follows:-

- Section 2 discusses the fundamental design criteria of STC
- Section 3 presents the description of the STTC
- Section 4 outlines the general construction of O-STBC and generalized Alamouti's coding scheme
- Section 5 reports the QO-STBC
- Section 6 describes the Differential Space-Time Modulation technique
- section 7 talks in detail about the analysis of LDC
- Section 8 presents the conclusions.

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II. DESIGN CRITERIA OF STC

The goal of defining the design criterion is to present the guidelines of acquiring the high data rates, maximum diversity, and coding gain to the various STCs to check the optimality of the code. There are three fundamental design criteria for constructing STC, which are given below [16,17,36]:

A. Rank Criteria

This rule is essential to achieve the maximum diversity gain of $N_t \times N_r$, where N_t and N_r is the number of transmitting and receiving antennas, respectively, in the multiple antenna system. The rank rule proposes that the error/difference matrix $D(\mathbf{C}^i, \mathbf{C}^j) = \mathbf{C}^j - \mathbf{C}^i$ must be the full rank matrix for $i \neq j$ to achieve maximum diversity gain, where D is the difference matrix, $\mathbf{C}^i$ is the transmitted codeword, and $\mathbf{C}^j$ is the erroneous codeword.

B. Trace and Determinant Criteria

This criterion is essential to acquire the high coding gain. This criterion says that the minimum determinant and minimum trace of matrix $D(\mathbf{C}^i, \mathbf{C}^j)^H.D(\mathbf{C}^i, \mathbf{C}^j)$ among all $i \neq j$ must be large to acquire maximum coding gains.

C. Maximum Mutual Information Criteria

This criterion is essential to achieve high throughput. It chooses the codeword **C**, which is characterized as a component of the symbol vector to increase the mutual data amid transmit and receive data.

III. STTC

Trellis-coded modulation integrates antenna diversity, modulation, and error control coding to accomplish maximum coding gain without expanding the bandwidth. Basically, STTC design rules are based on the determinant and rank criterion of STC. It transmits the data through various transmitting antennas over the MIMO channels and gives the superior presentation for a specified bandwidth contrasted with uncoded modulation techniques. STTC for N_t transmitting antennas is modeled by allocating N_t CSs to each state in a trellis. The fundamental thought behind this coding scheme is the utilization of structuralized redundancy to diminish the impacts of noise. [1,18-22,36].

A. STTC Encoding

STTC is a trellis-based code, and it is described with a trellis diagram. The STTC encoder with M-PSK has M number of states (or nodes), and the branch bridging the two nodes shows the state transitions. The STTC encoder maps a block of bbits into $N_t$modulated symbols from a signal set with M = 2^bsignal points because the M-ary signaling scheme is considered. At each instance t, the block of m bits is encoded. Let S_t be the transmitted signal vector, which is given as $S_t = [S_t^1, S_t^2, \ldots, S_t^{N_t}]^T$

Where,S_t^j, for j = 1,2,…., $N_t$are the signals to be transmitted through N_t transmit antennas. The fundamental steps of STTCtechnique are given below:

- The initial step is set partitioning, as shown in figure 1. This step requires the partitioning of the arrangement of Constellation symbols (CSs) onto a hierarchy of subsets, known as constellation points, with the goal that the minimum Euclidean distance (d_{min})increments at every partitioning level. A larger value of d_{min} reduces the effect of noise signal; however, it results in decreasing the coding rate because the size of available CSs is also decreased. Compensating the rate reduction by increasing the constellation size and utilizing a subset of the increased constellation at each time slot.
- The 2nd step in the structure is to allocate various subsets to various trellis-paths. Determination of subset for each time slot can be performed by a Finite State Machine (FSM) described by a trellis. At each stage, a group of l input

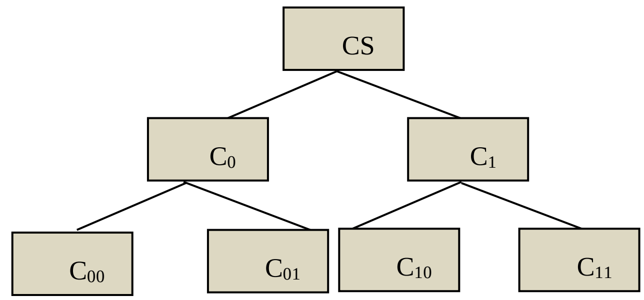

Fig.1 Set partitioning concept for 8-PSK

bits known as "coded bits" are responsible for state transitions. These bits select one of the 2^lbranches arising from the state. The leftover $b - l$ bits known as "uncoded bits" are used to select one of the 2^{b-l} parallel paths.

Now, considering the case of two transmitting antennas, i.e., 2 symbols are transmitting from 2 antennas for each path in the trellis. The code utilizes a QPSK constellation that comprises indices 0, 1, 2, 3 to speak to 1, j,−1,−j, individually, as shown in figure 3.2. Initially, the encoding begins at state 0. Utilizing the basic two steps of the TCM technique, the two transmit symbols $c_{t,1}, c_{t,2}$ are selected from the constellations, which are then transmitted by 2 antennas, accordingly at the same time. The rate of the system is 2 bits/s/Hz as the transmitter transmits the 2 symbols at the same time. The encoder departs to states t+1, which is at the R.H.S of the chosen branch. Towards the end-terminal, additional branches are grasped to ensure that the encoder halts at state 0 because the encoder is required starting at zero states at the first input of the frame and ending with zero states. Utilizing a comparable strategy, we can configure STTCs for other constellations [36].

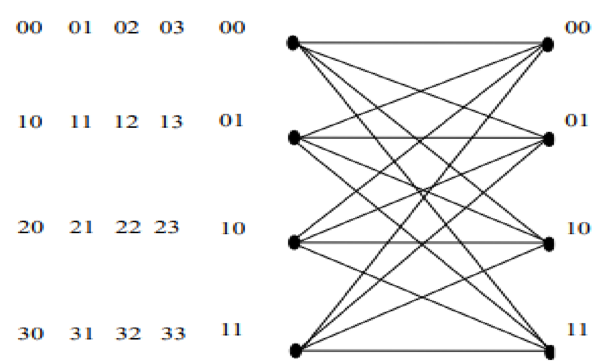

Fig.2 Diagram of 4-PSK, 4-state, N = 2 STTC encoder

A. STTC Decoding

At the decoder side, assume that $r_1, r_2, \ldots, r_{t+q}$are the received symbols.The Viterbi algorithm can be utilized for the ML decoding of STTCs. The distance between the chosen CSs ($c_1, c_2, \ldots, c_{t+q}$)and the received signal is

$\sum_{t=1}^{T+Q}|r_t - c_t|^2$Which is known as the "path metric".The most probable path is the one that has the least path metric or least distance from the received signals. The Maximum-Likelihood (ML) decoding detects the valid paths that begin from state 0 and ends at state 0 after time T+Q. The decoder detects the arrangement of CSs that resolves the below optimization problematic condition:

$$\underset{c1,c2,\ldots\ldots cT+Q}{\mathrm{Min}} \sum_{t=1}^{T+Q}|r_t - c_t|^2 \qquad (1)$$

The count of conceivable valid paths develops increasingly with the frame length t. The number of branches departs from each state at each and every time slot is 2^l. Therefore, there are $2^{l(t+q)}$ paths per state. The subtleties of the Viterbi calculation follow.

Initially, the trellis is at state 0. At time t + 1, the total number of branches combining to each state is 2^l. The Viterbi procedure detects the paths with the least partial metric among 2^l paths; that ideal partial path is well-known as Survivor Path (SP). Point to be noted that there is just a single SP per state. Rehashing a similar technique for each state, we finish with survivor path at time t + 1. The procedure has proceeded till the end of most time slots. Because the trellis should finish at state 0, the arrangement of the optimization issue in (1) relates to the SP that closes at state 0. The input data stream that produces this SP is the result of the ML decoding. This algorithm creates all path metrics and detects the SP at time t + q + 1 preceding it can produce any decoded bit. One can utilize different strategies to diminish the delay of decoding.

IV. O-STBC

STTC performs accurately at the price of immense complexness. Generalizing the coding scheme for the multiple numbers of transmission antennas by employing the concept of orthogonal design property, thus commanding the idea of-STBC [23,24,36].

A. Alamouti Codes (ALC)

Alamouti presented an elementary transmit diversity technique for 2 transmit antennas that achieve the full diversity without CSI at the transmitter. This coding scheme performs the transmission of one symbol, *b* bits, per time slot, i.e., a full diversity coding scheme. The ALChas two significant properties.

- Easy decoding: transmit symbols are decoded independently utilizing simple linear processing.
- Full diversity: this coding scheme accomplishes the rank criterion of STC and gives the highest probable diversity to achieve high reliability of the data signal.

Consider a 1 × 2 MISO system i.e., $N_t = 2$ and $N_r = 1$. For transmitting b bits/cycle, utilize a modulation technique that maps each and every *b* bits to one CS out of 2^b symbols. First of all, the transmitter selects 2 CSs utilizing a block of 2*b* bits. When symbols s_1 and s_2 are chosen for 2*b* bits, the transmitting unit transmits s_1 and s_2 from antenna 1 and 2, respectively, at 1st instance of time. Afterward, at 2nd-time instance, it transmits $-s_2^*$and s_1^*From antennas 1 and 2, respectively. Thus, the transmitted codeword is:

$$C = \begin{pmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{pmatrix} \qquad (2)$$

Assuming two transmit symbols (s_1', s_2') and the correspondent codeword is given by:

$$C' = \begin{pmatrix} s_1' & s_2' \\ -s_2'^* & s_1'^* \end{pmatrix} \qquad (3)$$

The difference matrix for the above codeword(C,C′) is presented by:

$$D(C,C') = \begin{pmatrix} s_1' - s_1 & s_2' - s_2 \\ s_2^* - s_2'^* & s_1'^* - s_1^* \end{pmatrix} \qquad (4)$$

The determinant of the D(C,C′)= $|s_1' - s_1|^2 + |s_2' - s_2|^2$ is 0 providing that $s_1' = s_1$ and $s_2' = s_2$. Hence, D(C,C′) is constantly a full rank matrix when C′≠C and this O-STBC ensure the determinant criterion of STC. This code delivers a diversity of $N_t \times N_r$and. As a result, it is a full diversity code.

Consider 2 symbols s_1 and s_2; in the 1st transmit instant, the symbol s_1 and s_2 are transmitting from the transmit antenna 1and 2, respectively. Therefore, the transmit symbol vector in the first time instant is given as $\begin{bmatrix} s_1 \\ s_2 \end{bmatrix}$. Further, the received symbol r(1) at the receiver is :

$$r(1) = [H_1 \quad H_2]\begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + n(1) \qquad (5)$$

In the 2ndtransmit instant, the symbol $-s_2^*$ and s_1^* Is transmitted from the the1stand 2ndtransmitting antenna, respectively. Therefore, the transmit symbol vector in the first time instant is given as $\begin{bmatrix} -s_2^* \\ s_1^* \end{bmatrix}$. Further, the received symbol r(2) at the receiver is :

$$r(2) = [H_1 \quad H_2]\begin{bmatrix} -s_2^* \\ s_1^* \end{bmatrix} + n(2) \qquad (6)$$

Equation (16) can be simplified as-

$$r^*(2) = [H_2^* \quad -H_1^*]\begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + n^*(2) \qquad (7)$$

Now, the received symbols from equations (5) and (7) can be stacked to write the combined system model for the first and second time instants in the ALC as:

$$\begin{bmatrix} r(1) \\ r^*(2) \end{bmatrix} = \begin{bmatrix} H_1 & H_2 \\ H_2^* & -H_1^* \end{bmatrix}\begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} n(1) \\ n^*(2) \end{bmatrix} \qquad (8)$$

Consider the columns c_1 and c_2 of the channel matrix given as:

$$c_1 = \begin{bmatrix} H_1 \\ H_2^* \end{bmatrix}, \quad c_2 = \begin{bmatrix} H_2 \\ -H_1^* \end{bmatrix}$$

A real orthogonal design fulfills the below two criteria to provide full diversity and simple ML decoding.

Orthogonality Properties :

- $\mathbf{c_1^h c_2 = 0}$

Proof:
$$c_1^h c_2 = [H_1^* \quad H_2]\begin{bmatrix} H_2 \\ -H_1^* \end{bmatrix} = H_1^* H_2 - H_2 H_1^* = 0$$

It can, therefore, be seen that the columns c_1 and c_2 are orthogonal to each other. This satisfies the orthogonality property of columns c_1 and c_2 of the effective channel matrix, which is a key property of the ALC. Hence, the ALC is termed as O-STBC. Space-time refers to the actuality that the ALC involves two symbols x_1 and x_2, which transmit over two antennas over two instants of time. Therefore, on average, it transmits one symbol per time instant. Hence, the net rate of the code is 1 symbol per time instant, i.e., the rate r=1, i.e., full-rate code.

- $\mathbf{G^hG = (|x_1|^2 + |x_2|^2 + \ldots |x_N|^2) I_N}$

STBC can also be defined by using generator matrix (G), whose elements are linear combinations of indeterminant variables $x_1 \ldots x_{Nt}$ and their conjugates $x_1^* \ldots x_{Nt}^*$. Considering that the framework of the ALC is expressed by the generator matrix:-

$$G = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \quad (9)$$

A significant inquiry is that it is conceivable to plan comparable codes for a more prominent number of N_t? We learn this inquiry as given below. An understanding of maximal ratio combining techniques is important in understanding the construction of STBC.

B. ML Decoding and MRC

a) Ml Decoding: This method decodes each, and everyone transmits symbols individually using a simple linear processing algorithm. Considering that the path gain from 1st and 2nd transmitting antenna to a receive antenna is α_1 and α_2, respectively. Then according to the MIMO model, the decoding section receives the signal r_1 and r_2 at the 1st and 2nd-time instance, respectively, such that:

$$\begin{cases} r_1 = \alpha_1 s_1 + \alpha_2 s_2 + n_1 \\ r_2 = -\alpha_1 s_2^* + \alpha_2 s_1^* + n_2 \end{cases} \quad (10)$$

For a coherent detection approach, where the receiving unit has the information about the α_1 and α_2, the ML detection leads to optimize the problem:

$$|r_1 - \alpha_1 s_1 - \alpha_2 s_2|^2 + |r_2 + \alpha_1 s_2^* - \alpha_2 s_1^*|^2 \quad (11)$$

This detection method needs a full search algorithm upon all probable pairs (s_1,s_2), and generally, its complexness increases for a large number of transmitting antennas. When elaborating equation (11), it gets deteriorates into 2 sections, one of which is just a component of s_1, and the other one is just an element of s_2. It is required to limit the cost capacities over the estimation of s_1 and s_2. Truth be told, the receiver ought to limit:

$$|s_1 - r_1\alpha_1^* - r_2^*\alpha_2|^2$$

to decode s_1 and minimize

$$|s_2 - r_1\alpha_2^* - r_2^*\alpha_1|^2$$

To decode s_2. Hence, the decoding comprises of first evaluating

$$\begin{cases} \tilde{s_1} = r_1\alpha_1^* + r_2^*\alpha_2 \\ \tilde{s_2} = r_1\alpha_2^* - r_2^*\alpha_1 \end{cases} \quad (12)$$

where, $\tilde{s_1}$ and $\tilde{s_2}$ Are the estimated transmit symbol at the receiver. Then, to decode s_1 and s_2, the receiving unit detects the nearest symbol to $\tilde{s_1}$ and $\tilde{s_2}$ Respectively in the constellation. Alamouti's scheme facilitates ML detection dependent on linear processing. ML decoding is an optimal decoding algorithm for the M=1 receive antenna. For M>1, the general ML decoding equations can be accomplished utilizing MRC.

b) Maximal Ratio Combining (MRC): The diversity combining method increases the reliability of the data signal by decreasing the channel fluctuations caused by fading. This decoding algorithm ensures that the multiple antennas receive distinct versions of the same signal with low fading probability. Within diversity combining, there are 3 common methods: selection combining, MRC, and Equal Gain Combining (EGC). The aim of all three methods is to detect a set of weights w that reduce the effect of fading, as displayed in the figure. 4.1. The three methods are distinct in a way how this weight vector is selected and considering that the receiver has the knowledge about Channel State Information (CSI). MRC is the optimal combiner in which:

- the received signals from every channel are summating together,
- the channel gain increases with the Root mean square (RMS) value of the signal and decreases with the mean-square noise level in that channel.
- Distinctive proportionality constants are utilized for each and every channel.

The orthogonality property of the ALC simplifies the receive processing method. Consider, now beamforming using the vector w_1 defined in terms of column c_1 as:

$$w_1 = \frac{1}{\|c_1\|} c_1 = \frac{1}{\|H\|} \begin{bmatrix} H_1 \\ H_2^* \end{bmatrix} \quad (13)$$

where, $\|H\|$ denotes the norm of vector H and is defined as: $\|H\| = \sqrt{|H_1|^2 + |H_2|^2}$

w_1 is derived from c_1, and therefore, it is orthogonal to c_2. Multiplying the received signal by w_1, we are able to remove the interference caused by s_2 and decode s_1 as:

$$w_1^H r_1 = \begin{bmatrix} \frac{H_1^*}{\|H\|} & \frac{H_2}{\|H\|} \end{bmatrix} \begin{bmatrix} H_1 & H_2 \\ H_2^* & -H_1^* \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + w_1^H n$$

$$w_1^H r_1 = \|H\| s_1 + \tilde{n}_1 \quad (14)$$

Similarly, to decode s_2, the beamformer w_2 is given as:

$$w_2 = \frac{1}{\|c_2\|} c_2 = \frac{1}{\|H\|} \begin{bmatrix} H_2 \\ -H_1^* \end{bmatrix} \quad (15)$$

w_2 is derived from c_2, and therefore, it is orthogonal to c_1. Multiplying the received signal by w_2, we are able to remove the interference caused by s_1 and decode s_2 as:

$$w_2^H r_2 = \|H\| s_2 + \tilde{n}_2 \quad (16)$$

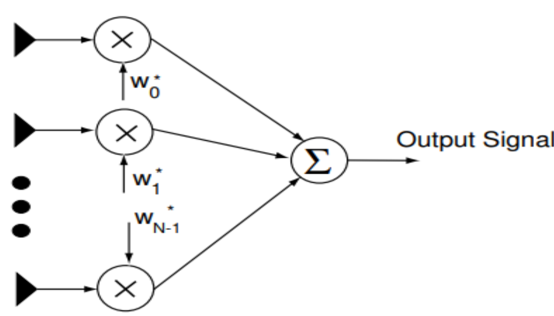

Fig.3 The receiver in a diversity combining system

For the discussion of the SNR at the receiver, consider that:-

- there are N_r receiving antennas and a single transmitting antenna with Rayleigh flat fading channel
- the channel acquired by all receiving antennas is irregularly changing in time. For the i[th] receive antenna, every transmits signal gets multiplied by h_i, which is Gaussian distributed with mean μ_{h_i} =0 and variance $\sigma^2_{h_i}$ = 1/2.
- on every receiving antenna, the noise n has the Gaussian pdf with $p(n) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(n-\mu)^2}{2\sigma^2}}$ with μ=0 and $\sigma^2 = \frac{N_0}{2}$.
- In the presence of channel h_i, the instantaneous bit energy to noise ratio (E_b / N_0) at i[th] receive antenna is $|h_i|^2(E_b/N_0)$. For notational convenience, let us define-$\gamma_i = \frac{|h_i|^2 E_b}{N_0}$

On the i[th] receive antenna, the received signal is Y_i, expressed as:

$Y_i = h_i x + n_i$

And the output signal is R, which is expressed as:

$R = w^H Y = w^H hx + w^h n$

As the transmit signal x has an average power of unity, the instantaneous output SNR is

$$\gamma = \frac{|w^H h|^2}{E\{|w^H n|^2\}} ,$$

where, $E\{|w^H n|^2\} = \sigma^2 \|w\|^2$ and scale w so that $\|w\|$ = 1. The SNR is thus presented by

$\gamma = |w^h h|^2 / \sigma^2$.

According to the cauchy-schwarz inequality, SNR reaches the maximum when w is directly proportional to h. The equalized symbol is:

$$\check{x} = \frac{h^H y}{h^H h}$$

Note that, $h^H h = \sum_{i=1}^{Nr} |h_i|^2$ i.e., the addition of the channel powers over all the receiving antennas. For N_r receive antenna case, the effective γ is :

$$\gamma = \sum_{i=1}^{Nr} \frac{|h_i|^2 E_b}{N_0}$$

$$\gamma = N_r . \gamma_i$$

The above expression shows that the output SNR is the addition of the SNR at each receive antenna.

V. QO-STBC

Implementation of the transmission matrix for N > 2 using full-rate O-STBC is challenging. QO-STBC provides high data transmission rates while surrendering the full diversity.QO-STBC performs the decoding algorithm with pairs of transmit symbols rather than a single symbol [26-31].

This section discusses the structure that works on partitioning the transmission matrix columns into groups, where the columns in every group are not orthogonal to one another. However, distinct groups are orthogonal to one another. This type of scheme is known as quasi-orthogonal design. In this coding scheme, the generator matrix gets changed to accentuate the undefined transmit variables x_1, x_2, x_3 and x_4 in the structure. The generator matrix for the QO-STBC is given below:

$$G = \begin{bmatrix} G(x_1, x_2) & G(x_3, x_4) \\ -G^*(x_3, x_4) & G^*(x_1, x_2) \end{bmatrix} \quad (17)$$

where, $G(x_1,x_2) = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix}$

$$G = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ -x_3^* & -x_4^* & x_1^* & x_2^* \\ x_4 & -x_3 & -x_2 & x_1 \end{bmatrix} \quad (18)$$

where, $G^*(x_1,x_2) = G(x_1^*, x_2^*) = \begin{bmatrix} x_1^* & x_2^* \\ -x_2 & x_1 \end{bmatrix}$

Denoting the i[th] column of G by V_i . $<V_1,V_2> = <V_1,V_3> = <V_2,V_4> = <V_3,V_4> = 0$, that is why, this coding scheme is termed as "quasi-orthogonal".

The encoding procedure is similar to O-STBCs. The constellations required 2^bpoints for transmitting bits per time slot. Utilizing 4*b* bits, CSs $s_1,...,s_4$ are chosen. Adjusting x_k= $s_k$for$k$ = 1, 2, 3, 4….N_t in *G*, accounting a codeword matrix C = $G(s_1, s_2, s_3, s_4)$. G matrix contains the indeterminates $x_1,...,x_{Nt}$whilethe matrix C consists of the linear combinations of the constellation symbols, which are transmitted from the $N_t$antennas. At t time-instant, the 4 components in the *t*[th] row of Gare send from the 4 transmitting antennas as shown in equation (18), which clearly shows that the code rate = 1 for QO-STBC.

A. Rotated QO-STBC

Rotated QO-STBC is effective because it gives a high coding rate with improved diversity and easy pairwise decoding efficiency by rotating the symbols prior to the transmission. Denoting$\tilde{x}_3$ and $\tilde{x}_4$ as the rotated versions of x_3 and x_4, individually. It is probable to increase the diversity gain by substituting (x_3, x_4) with ($\tilde{x}_3$,$\tilde{x}_4$) where,$\tilde{x}_3$= $e^{j\varphi}x_3$ and $\tilde{x}_4$= $e^{j\varphi}x_4$.

Assuming that the transmitter employs a signal constellation technique with 2^belements.At1[st]time slot, input bits select the CSs (s_1,...,s_N). Placing x_i = s_i for i = 1,..., N in G gives a matrix C whose entries are linear combinations of the c_i and their conjugates. The necessary requirement to attain improved diversity is that the Coding Gain Distance (CGD) between a pair of codewordsC= $G(s_1, s_2, \tilde{s}_3, \tilde{s}_4)$ andC′ = $G(s_1', s_2', \tilde{s}_3', \tilde{s}_4')$ is given by

$$CGD(C, C') = \det[D(C, C')^H \cdot D(C, C')] \quad (19)$$

B. Optimal Rotation

Representing the minimum CGD of a revolved QO-STBC by $CGD_{min}(\varphi)$, which is a function of φ. The optimal rotation of QO-STBC aims to increase $CGD_{min}(\varphi)$ among all practicable rotations. The term $CGD_{min}(\varphi)$ can be utilized as a distance between the original constellation and its rotated constellation. It can be evaluated from the subsequent minimization :

$$CGD_{min}(\varphi) = \min|(s_1 - s_1')^2 - (\tilde{s}_3 - \tilde{s}_3')^2|^4 \quad (20)$$

where, $d_{\min} = \min|s_1 - s_1'|$ =minimum Euclidean interval amid all constellation points. Selecting $\tilde{s}_3 = \tilde{s}_3'$ in (20), the equation becomes $a d_{\min}(\varphi) \le d_{min}^8$, where, d_{min}^8 is an upper bound on $CGD_{\min}(\varphi)$?

VI. DIFFERENTIAL SPACE-TIME MODULATION

Up to this point, we are discussing the codes on the case that the receiver has knowledge about CSI. This coding scheme utilizes the concept of differential decoding for multiple transmitting antennas. Differential decoding ideas require neither CSI estimation nor pilot data transmission but require knowledge about the symbol transmission. For the detection of the received signal, the recovered signal at time t – 1 is utilized to evaluate the channel, and these evaluations are utilized to recognize the transmit data signal at time t [34].

A. Differential Encoding

The encoder evaluates 2 symbols and transmits them utilizing O-STBC, especially for every block of 2b bits. The 2 × 2 transmitting codeword of the O-STBC relies upon the codeword and symbols transmitted in the preceding block. The primary difficulty is: In what way the 2 symbols or respective orthogonal codeword are created in such a manner that the receiver can decrypt/decode the transmitted symbols deprived of path gains.

There are 2 primary ways to deal with this issue. 1st approach is to substitute the PSK modulation scheme with the O-STBC design. Another way is the addition of intermediary step and firstly produce the pair of transmission symbols and afterward transmit them in an orthogonal style as shown in figure 6.1. Firstly, group the 2 transmitted symbols for the l^{th} block in a vector known as symbol vector $S^l = \begin{pmatrix} S_1^l \\ S_2^l \end{pmatrix}$. The S^l For block, l is produced from S^{l-1} and the $2b$ input bits. To illustrate the generation of S^l, considering the below 2 vectors that developed on orthogonal guidelines:

$$\left.\begin{aligned} V_1(S^l) &= S^l = \begin{pmatrix} S_1^l \\ S_2^l \end{pmatrix}, \\ V_2(S^l) &= \begin{pmatrix} (S_2^l)^* \\ (-S_1^l)^* \end{pmatrix} \end{aligned}\right\} \quad (21)$$

Consider, a set V comprises of 2^{2b} unit-length distinctive vectors $P_1, P_2, .., P_{2^{2b}}$. Defining a one-to-one mapping β(•) that maps 2b bits onto V. Then coding begins with the transmission of S^0. For block l, 2bbits are used to select the correspondent vector p^l in V. Considering the transmission of S^{l-1} for the $(l-1)^{th}$ block, evaluating S^l by

$$S^l = P_1^l V_1(S^{l-1}) + P_2^l V_2(S^{l-1}) \quad (22)$$

where P_1^l and P_2^l Are the 1st and 2nd elements of the vector P^l, respectively. Point to be noted that since $v_1(s^{l-1})$ and $v_2(s^{l-1})$ are generated on an orthogonal basis, and P_1^l and P_2^l can be presented as:

$$\left.\begin{aligned} P_1^l &= [V_1(S^{l-1})]^h . S^l \\ P_2^l &= [V_2(S^{l-1})]^h . S^l \end{aligned}\right\} \quad (23)$$

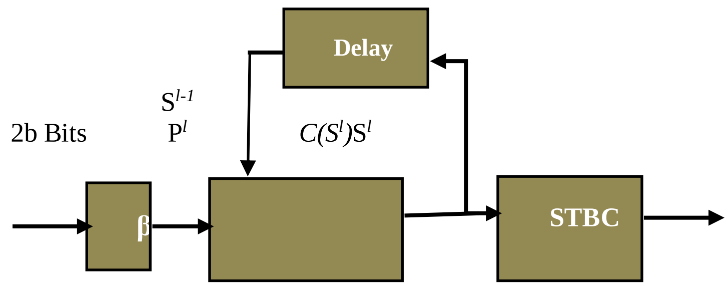

Fig.4 Block diagram of Differential STC

B. Differential Decoding

Now discussing the decoding process of the differential spatial-time modulation, first consider the simple case of the 1×2 MIMO system. Defining a receive vector *R* as follows:

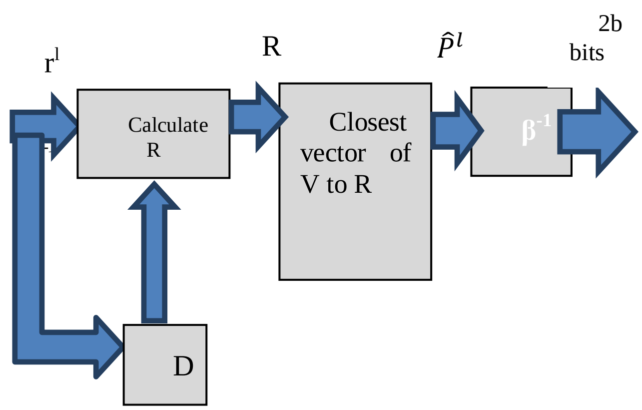

Fig.5 Differential STC decoder

$$R = \begin{pmatrix} (r_1^{l-1})^* r_1^l + r_2^{l-1} (r_2^l)^* \\ (r_2^l)^* r_1^{l-1} - r_1^l (r_2^{l-1})^* \end{pmatrix} \quad (24)$$

Where, r_1^l and r_2^l are received signals for block l, defined as

$$\begin{cases} r_1^l = \alpha_1 s_1^l + \alpha_2 s_2^l + n_1^l \\ r_2^l = -\alpha_1 (s_2^l)^* + \alpha_2 (s_1^l)^* + n_2^l \end{cases}$$

Therefore, the receive vector becomes:

$$R = (|\alpha_1|^2 + |\alpha_2|^2) p^l + n \quad (25)$$

The decoder accurately detects the nearest vector p^l in V and pronounces it as the best estimated transmit vector. The converse mapping $\beta^{-1}(\bullet)$ gives the recovered bits as portrayed in figure 6.2. Finally, for N_r receive antennas, MRC is used. This modulation is less complex because it requires no CSI on either side.

VII. LDC

O-STBCS are increasingly prohibitive for channels with a higher range of antennas. Once decoding complexness isn't a problem, one might style codes that give higher rates or better execution contrasted with O-STBCs. LDC partitions the data stream into sub-streams which are spread in linear combinations over spatial and time dimensions. LDC is a complex spatial-time coding model [4-6,10,35].The LDC achieves the high coding rate by fulfilling the information-theory optimality criteria, i.e., the codes are modeled to maximize the mutual data between the transmitting and receiving signals in a communication system.

A. LDC Encoding

Consider the LDC in the $N_t \times N_r$ antenna system. the propagation channel is consistent for an interval of T symbols, and the receiver has the information about CSI. The transmission matrix sof dimension $T \times N_t$ guides the data transmission onto the receive antennas throughout the interval. The LDC matrix codeword, denoted as C_{LDC}, is transmitted from N_t transmit antennas at T channel uses and performs encoding of Q source data symbols. Assuming that the data stream has to splits into Q sub-streams, generally Q = min (N_r, N_t).T and that $s_1, s_2, \ldots s_Q$ are the complex symbols selected from m-PSK or m-QAM, constellation. The matrix codeword C_{LDC} is presented as:-

$$C_{LDC} = s = \sum_{q=1}^{Q}(\alpha_q A_q + j\beta_q B_q) \quad (26)$$

where $C_{LDC} \in C_{T\times N_t}$ and $A_q \in C_{T\times N_t}$, $B_q \in C_{T\times N_t}$, for q = 1, ...,Q. A_q and B_q are known as dispersion matrices. The complex source data symbols are expressed by real scalars (α_q, β_q) as:

$$S_q = \alpha_q + j\beta_q \quad (27)$$

The coding rate of LDC in terms of bits is as: $R=(Q/T)\log_2(m)$, where m is the size of the constellation. At the physical layer of a communication system, the symbol coding rate often is useful for comparing the spectrum efficiency between different systems. The symbol coding rate is given as :

$$R_{LDC}^{sym} = R_s = \frac{Q}{T\min(N_t, N_r)} \quad (28)$$

Considering a multiple-antenna system,

➢ For narrow-band, flat-fading channels: the transmit (s) and receive (r) signal vectors are related by equation (29) as :

$$r = \sqrt{\frac{\rho}{N}}\, Hs + v \quad (29)$$

where, $X \in C^{N_r}$ signifies the complex receive vector, $s \in C^{N_t}$ denotes the complex transmit vector, $h \in C^{N_r \times N_t}$ denotes the channel matrix, and the additive noise $v \in C^{N_r}$ (noise signal follows the normal distribution function) dispersed in space and time white. The matrix H and vector s are expected to have unit variance entries, indicating:

$E\{tr(HH^*)\} = N_t \times N_r$ and $E\{s^*s\} = N_t$

At the point, CSI is well-known to the receiving side, the eventual channel capacity (often known as the perfect-knowledge capacity) is :

$$C(\rho, N_t, N_r) = \max_{R_s \geq 0, tr(R_s) = N_t} E\log\det(I_{N_r} + \frac{\rho}{N_t} HR_sH^*) \quad (30)$$

where the expected value [E(.)] is taken over the distribution on the H. For the rotational invariant distribution on H, equation (30) becomes:

$$C(\rho, N_t, N_r) = E\log\det(I_{N_r} + \frac{\rho}{N_t} HH^*) \quad (31)$$

➢ For the constant channel: If the channel is consistent for τ = 0,1,2…...T, rewriting the equation (29) in its transposed form as given below

$$X_\tau = \sqrt{\frac{\rho}{N_t}}\, Hs_\tau + v_\tau \; , \quad \tau = 0,1,2\ldots T \quad (32)$$

where, r = received vector = $[r_1, r_2, \ldots r_t]^t$,
s = transmitted vector = $[s_1, s_2, \ldots s_t]^t$,
v = noise vector = $[v_1, v_2, \ldots v_t]^t$.
where t denotes matrix transpose, thus obtain :

$$r^t = \sqrt{\frac{\rho}{N_t}} Hs^t + v^t$$

For convenience, rewrite the above equation as:

$$r = \sqrt{\frac{\rho}{N_t}} sH + v$$

Redefining the channel matrix H of dimension $N_t \times N_r$. The matrix $r \in C^{T\times N_r}$ is the received vector, $s \in C^{T\times N_t}$ is the transmitted vector, and $v \in C^{T\times N_r}$ Is the additive noise vector. Vertical dimension is time, and horizontal dimension is space in r,s, and v. When the rate in bits per channel use is R, at that point, the number of matrices is 2^{RT}. Concerning modeling the signal matrix s, which follows the power constraint $E[tr(ss^*)] = TN_T$ and optimizing the following channel capacity, which is adequately (31) with $R_s = I_{2q}$ condition (31) can be written as :

$$C'(\rho, t, n_t, n_r) = \max_{A_q, B_q} \frac{1}{2T} E\log\det(I_{2N_rT} + \frac{\rho}{N_t} HH^t) \quad , \text{ for } q=1,2,\ldots Q$$

Choose the value of $\{A_q, B_q\}$ that gives the optimum value of $C'(\rho, t, n_t, n_r)$ for high SNR(ρ), subject to one of the following constraints:

- The first constraint is the power constraint which provides $E[trSS^*] = N_tT$ in terms of matrices A_q and B_q :

$$\sum_{q=1}^{Q}(trA_q^*A_q + trB_q^*B_q) = 2N_tT \quad (33)$$

- The 2nd bounds the real and imaginary terms of every single transmitted signal to possess a similar average power in *T* time slots from N_t transmission antennas:

$$A_q^*A_q = trB_q^*B_q = TN_t/Q\, ,\ q=1,2,..Q \quad (34)$$

- The 3rd restricts the real and imaginary terms of every single transmitting signal to possess the similar power in every particular usage of the channel from each transmission antenna:

$$A_q^*A_q = B_q^*B_q = (T/Q).I_{N_t} \quad (35)$$

The difference $C(\rho, N_t, N_r) - C'(\rho, t, n_t, n_r)$ depends on the appropriate choice of t and q. Less difference shows low capacity expense in designing the LDC model. V-BLAST method transmits every signal (α_q, B_q) from 1 transmit antenna in one channel usage. While, in LDC, the dispersion matrices probably transmit a certain combination of each symbol from each and every transmitting antenna at each channel use. This satisfies the requirements of effective coding properties [36].

B. LDC Decoding

An essential property of LDC is its linearity in the variables (α_q, β_q) and linear dispersion matrices, thus leading to V- BLAST-like decoding method. To analyze the linearity concept, it is essential to elaborate the codeword equation as:

$$r = \sqrt{\frac{\rho}{N_t}} sH + v$$
$$= \sqrt{\frac{\rho}{N_t}} \sum_{q=1}^{Q} (\alpha_q A_q + j\beta_q B_q) H + v \qquad (36)$$

Illustrating the above equation and decomposition of the matrices of eq(36) into real and imaginary parts, thus obtain the system of equations :

$$\underbrace{\begin{bmatrix} r_{R,1} \\ r_{I,1} \\ \vdots \\ r_{R,N_r} \\ r_{I,N_r} \end{bmatrix}}_{\triangleq r} = \sqrt{\frac{\rho}{N_t}} H \underbrace{\begin{bmatrix} \alpha_1 \\ \beta_1 \\ \vdots \\ \alpha_Q \\ \beta_Q \end{bmatrix}}_{\triangleq s} + \underbrace{\begin{bmatrix} v_{R,1} \\ v_{I,1} \\ \vdots \\ v_{R,N_r} \\ v_{I,N_r} \end{bmatrix}}_{\triangleq v} \qquad (37)$$

where the equivalent channel matrix H is of dimension $2N_rT\times2Q$, given as below:

$$H = \begin{bmatrix} A_1 h_1 & B_1 h_1 & \dots A_Q h_1 & B_Q h_1 \\ \vdots & \vdots & \ddots \ \vdots & \vdots \\ A_1 h_{N_r} & B_1 h_{N_r} & \dots A_Q h_{N_r} & B_Q h_{N_r} \end{bmatrix} \qquad (38)$$

There is a linear relationship between the transmit and receive vectors s and r, respectively, as given below:

$$r = \sqrt{\frac{\rho}{N_t}}\, Hs + v$$

From equation (36), we realize that there is linearity between s and r, and the equivalent H is well-known to the receiving side due to the fact that the original H and the A_q, B_q matrices are well-known to the receiver. The receiver basically utilizes (38) to detect H. The equations amongst transmitter and receiver aren't underdetermined on the condition that $Q \leq N_rT$. The systematic and efficient realization of the decoding schemes normally necessitates $O(Q^3)$ calculations.

The advantages of LDC are:

- It can be utilized for any order of MIMO system;
- Easy and straightforward to encode;
- It can be decoded in numerous ways, inclusive of linear-algebraic techniques like V-BLAST, sphere decoding.

VIII. CONCLUSIONS

STC is a signal processing structure to utilize the advantages of MIMO channels in a wireless communication network. STC has the capability of improving the diversity gain and data rates of the system. It comes in two different ways. STTC improves the diversity and coding gain. However, the decoding complexity is high as it requires the vector form of the Viterbi decoder. STBC follows the linear processing and combining algorithm for encoding and decoding, respectively. It provides high transmit diversity without any compromise in bandwidth and with a simple decoding unit. Also, decrease the bit error rate(BER) of a communication system at a definite SNR.

Alamouti coding scheme is the most popular O-STBCs that give full diversity with full data rate for 2 transmission antennas. The multiplexing gain is limited to 1. It is an optimal transmission scheme without CSIT (full spatial diversity and no capacity penalty) for 1×2 MISO. It uses ML decoding that can be performed symbol-by-symbol quite easily.

QO-STBC presents a full coding rate at the price of low spatial diversity. This scheme decodes the pairs of transmit symbols individually to provide a high coding rate.

The encoding and decoding methods of LDCs are simple, and this coding technique can be utilized in any configuration of multiple antennae systems and fulfill the information theoretical-optimality property. It can be modeled in conjunction with channel coding techniques to achieve most of the channel capacity of the wireless network. This coding scheme estimates the channel matrix in transmit precoding unit at the BS and uplink receive decoding unit at the BS to allow a trade-off between diversity and spatial multiplexing and thus improves the performance of multiple antenna wireless communication systems.

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All paragraphs must be indented. All paragraphs must be justified, i.e., both left-justified and right-justified.

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