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Transmit-Diversity for Spatial Modulation (SM) and Space-Time Block Codes- A Review

[1]Rahul Saxena, [2]Prof. Rupesh Dubey, [3]Prof. Poonam Lilhare

***Abstract*— Spatial Modulation is the latest developed modulation method in the field of communication. Spatial modulation is a low-complexity scheme for multiple antenna system. The latest research on this shows that SM is useful to achieve the multiplexing gain for the single antenna system, this avoids the inter-channel interference but the spatial modulation is inherently unable to get transmit-diversity. This paper is mainly focused on the concept of SM to design the multiple-antenna wireless system and to get transmit-diversity gain. In other words, SM is a novel modulation technique which combines the high multiplexing gain provided by the spatial modulation and transmit-diversity gain, given by the Space-Time Block Codes (STBCs) technology.**

***Index Terms*—Multiple–Input–Multiple–Output (MIMO) systems, Rayleigh fading channel, Spatial Modulation (SM), STBCs.**

I. INTRODUCTION

In the last decade, the study of wireless communications with multiple transmit and receive antennas has been conducted expansively in the literature on information theory and communications. Multiple-antenna system is a wide area of research. The use of multiple-antenna for wireless communication system has received an upsurge of research interest during the last decade, both in academia and industry [1]. In the realm of many solutions proposed to date, spatial modulation (SM) is a recently proposed modulation scheme that promises a low complexity transmitter and receiver design, along with the improved system performance with respect to many state-of-the-art multiple-antenna solution [2]. Smart antenna wireless communication system providing significant gains in terms of spectral efficiency and link reliability. These benefits translate to wireless network in the form of improved coverage and capacity [3]. With MRC detection algorithm model have BER analysis compared with basics Almouti codes and STBC-SM and OSTBC-SM [4].

The breakthrough idea of SM is to exploit the spatial domain as an additional dimension to convey part of the information bits [5]. Spatial modulation is a recently developed transmission technique which can offer with a very low system complexity, improved data rates compared to Single-input Single-output (SISO) and robust error performance even. The basic idea of SM is to map a block of information bits into two information carrying units: 1) a symbol that is chosen from a complex signal–constellation diagram, and 2) a unique transmit–antenna index that is chosen from the set of transmit–antenna in the antennas. The use of transmitted antenna number as an information-bearing unit increases the overall spectral efficiency by the base two logarithm of the number of transmit antenna. At the receiver, a maximum ratio receiver combining algorithm is used to retrieve the transmitted block of information bits [6]. It combines spatial modulation and space-time block codes (STBCs) to take advantage of the benefits of both while avoiding their drawbacks. SM can achieve a higher capacity than multiple antenna schemes with similar decoding complexity, such as space-time block codes (STBCs), along with smaller bits error probability than Vertical Bell Laboratories Layered Space-Time (V-BLAST) and Almouti scheme [7]. Many researchers have recently started investigating the potential of this technology for receive and transmit diversity. In particular, transmit-diversity is receiving a growing interest due to its suitability for downlink applications with single-antenna and low-complexity mobile units. More specifically many researchers have focused their attentions on a low-complexity implementation of SM, which is known as Space Shift Keying (SSK) modulation [8].

In the recent period, the main research interest has been focused on the application of SM concept to MIMO wireless system, in order to quantify the performance difference with other popular MIMO scheme. In [9], the author have developed an information-theoretic framework to compute the outage and ergodic capacity of SM over Rayleigh fading channels, and have shown that SM offers a capacity gain with respect to STBCs when the number of transmit-antenna in greater than two. Furthermore, a low-complexity decoding scheme has been proposed. In [10] the authors have proposed a new modulation concept that aims at reducing the effect of channel correlation on the performance of SM. As a matter of fact, if, *e.g.*, due to closely–spaced radiating elements, the transmit–to–receive wireless links experience channels correlation, the detector might be unable to distinguish the different transmit–antenna since they will appear almost the same at the receiver. The proposed scheme is called Trellis Coded Spatial Modulation (TCSM). It exploits convolution encoding and Maximum–Likelihood Sequence Estimation (MLSE) decoding to increase the free distance between sequences of spatial–constellation points. Simulation results in [10] have indicated that TCSM can provide better performance than SM and V–BLAST schemes over correlated Rician fading channels, while still guaranteeing the same spectral efficiency.

[1]***Rahul Saxena (M.E.4 Sem.)***
Department of electronics & communication, IPS Academy, Indore (M.P.) India,
[2]***Prof Rupesh dubey(Associate Prof. and head of the department)***
Department of electronics & communication, IPS Academy, Indore (M.P.,), India
[3]***Prof. Poonam Lilhare**, **(Asst. Prof.)***
Department of electronics & communication, IPS Academy, Indore (M.P.,), India

II. SPACE-TIME BLOCK CODES

It is well-known that the decoding algorithm must have as low as possible complexity in order to find applications in the real-world of wireless communication systems. Base on this criterion, Alamouti [11] developed a simple and effective transmit technique for two transmit antennas which has remarkably low decoding complexity. Tarokh, Jafarkhani, and Calderbank [12] presented orthogonal designs that can be used as space-time block codes for wireless communications and generalized the Alamouti scheme for more than two transmit antennas. Space–time block coding provides an exceptional link between orthogonal designs and wireless communications. Since this coding scheme achieves full transmit diversity and has a very simple maximum likelihood decoding algorithm at the receiver, Alamouti's space-time block code has been established as a part of the W-CDMA and CDMA-2000 standards.

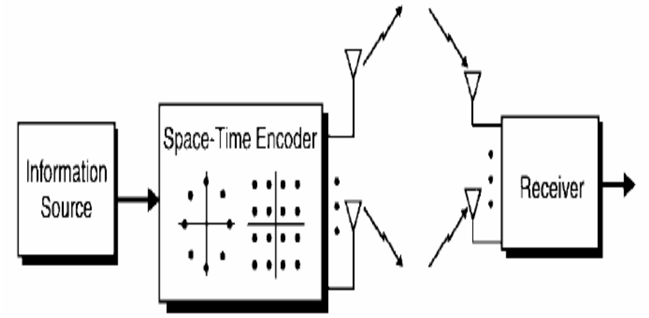

Fig. 1 System block diagram (Adapted from [11])

Orthogonal space-time block codes (O-STBC) achieve high transmit diversity and have a low complexity decoding algorithm at the receiver using any number of transmit and receive antennas.

In a general form, an STBC can be seen as a mapping of n_N complex symbols $\{S_1, S_2, \cdots, S_N\}$ onto a matrix S of dimension $n_t \times N$:

$$\{S_1, S_2, \cdots, S_N\} \rightarrow S \qquad (1)$$

An STBC code matrix **S** taking on the following form:

$$\sum_{n=1}^{nN} \bar{s}_n An + j\tilde{s_n} B_n \qquad (2)$$

Where $\{S_1, S_2, \cdots, Sn_N\}$ is a set of symbols to be transmitted $\bar{s_n}$ = Re $\{ s_n\}$ and $\tilde{s}_n$= Im $\{s_n\}$, and with fixed code matrices $\{A_n, B_n\}$ of dimensions $n_t \times N$ are called linear STBC. The following STBC can be regulated as special cases of these codes.

ALMOUTI CODES

The Almouti code is the first STBC that provides full diversity at full data rate for two transmit antennas [13]. A block diagram of the Almouti space-time encoder is shown in below figure.

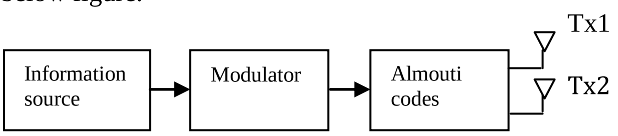

Fig. 2 Block diagram of Almouti space-time encoder

Where,

$$Tx1 = S_1 = [s_1, -s^*{}_2] \qquad (3)$$

$$Tx2 = S2 = [s_2, s^*{}_1] \qquad (4)$$

The information bits are first modulated using an M-ary modulation scheme. The encoder takes the blocks of two modulated symbols s1 and s2 in each encoding operation and hands it to the transmit antennas according to the code matrix

$$S = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \qquad (5)$$

The first row represents the first transmission period and the second row represents the second transmission period. During the first transmission the symbol s_1 and s_2 are transmitted simultaneously from antenna one and antenna two respectively. In the second transmission period, the symbol $-s_2^*$ is transmitted from antenna one and the symbol s_1^* from antenna two.

It is cleared that the encoding is performed in both time (two transmission intervals) and space domain (across two transmit antenna). The two rows and columns of S are orthogonal to each other and the code matrix is orthogonal.

$$ss^H = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix}\begin{bmatrix} s_1^* & -s_2 \\ s_2^* & s_1 \end{bmatrix}$$

$$= \begin{bmatrix} |s_1|^2 + |s_2|^2 & 0 \\ 0 & |s_1|^2 + |s_2|^2 \end{bmatrix}$$

$$= (|s_1|^2 + |s_2{}^2|) I_{2,} \qquad (6)$$

Where I_2 is the (2×2) identity matrix, this property enables the receiver to detect s_1 and s_2 by a simple linear signal processing operation.

Let us look at the receiver side now. Only one receiver antenna is assumed to be available. The channel at time **t** may be modeled by a complex multiplicative distortion $h_1(t)$ for transmit antenna one $h_2(t)$ for transmit antenna two. Assuming that the fading is constant across two consecutive transmit periods of duration **T,** we can write

$$h_1(t) = h_1(t+T) = h_1 = |h_1|e^{j\theta 1}$$
$$h_2(t) = h_2(t+T) = h_1 = |h_2|e^{j\theta 2} \qquad (7)$$

Where $|h_i|$ and θ_i, **i**=1, 2 are the amplitude gain and phase shift for the path from transmit antenna **i** to the receive antenna. The received signal at the time t and t+T can then be expressed as

$$r_1 = s_1 h_1 + s_2 h_2 + n_1$$
$$r_2 = -s_2^* h_1 + s_1^* h_2 + n_2 \qquad (8)$$

Where r_1 and r_2 are the received signal at time **t** and **t+T**, n_1 and n_2 are complex random variables representing receiver noise and interfaces. This can be written in matrix form as:

$$r = Sh + n, \qquad (9)$$

Where, h = [h1, h2] ^{T} is the complex channel vector and n is the noise vector in the receiver.

III. SPACE-TIME BLOCK CODED SPATIAL MODILATION

The basic idea of SM is an extension of two dimensional signal constellation (such as M-ary phase shift keying (M-PSK) and M-ary quadrature amplitude modulation (M-QAM), where M is the constellation size) to a third dimension which is the spatial (antenna) dimension. Therefore the information is conveyed not only by the phase/amplitude modulation (PAM) techniques, but also by the antenna indices. The error performance of SM scheme [14] is improved approximately in the amount of 4 db by the use of the optimal detector under conventional channel assumptions and that SM provides better error performance than V-BLAST. In this technique information is conveyed with an STBC matrix that is transmitted from the combination of the transmit antenna of the corresponding MIMO system. The Almouti code is chosen as the target STBC to exploit. As a source of information, we consider not only the two complexes information symbols embedded in Almouti's code, but also indices of the two transmit antennas employed for the transmission of the Almouti STBC.

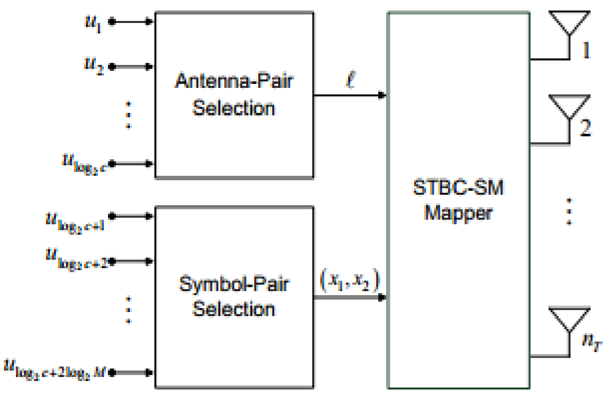

Fig. 3 Block diagram of STBC-SM transmitter

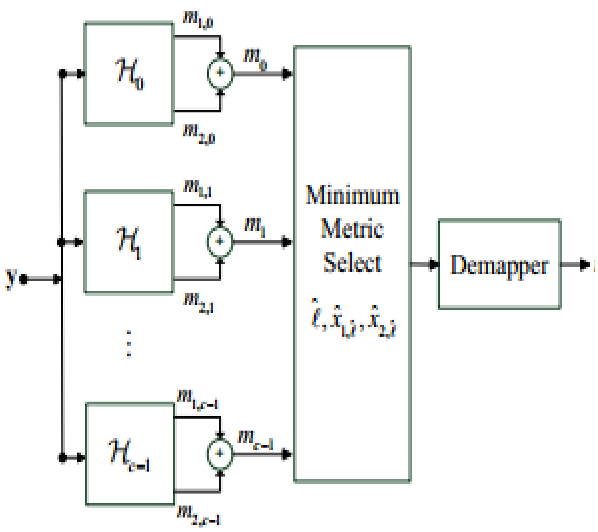

Fig. 4 Block diagram of STBC-SM receiver

A general technique is presented in figure 3 and 4 for constructing the STBC-SM for any number of transmitting antenna. A low-complexity maximum likelihood ML detector is derived for the STBC-SM system, to decide on the transmitted symbols as well as on the indices of the two transmitted antennas that are used in STBC transmission. It is observed [14] that STBC-SM scheme has significant performance advantage over the SM with an optimal decoder, due to its diversity advantage.

IV. SIMULATION RESULTS

In this section, we present simulation results for STBC-SM system with different number of transmit and receive antenna The bit-error-rate (BER) performance of these system was evaluated for various spectral efficiencies as a function of the average SNR per receive antenna. All performance comparisons are made for a SNR of the range from 0 to 20 db.

A) The below graph is plotted for one transmit-antenna and two receive-antenna. This system is designed for a packet size of 1000 bits using QPSK modulation in Rayleigh fading environment for signal to noise ratio ranging from 0 to 20 db. There are total 100 packets are transmitted.

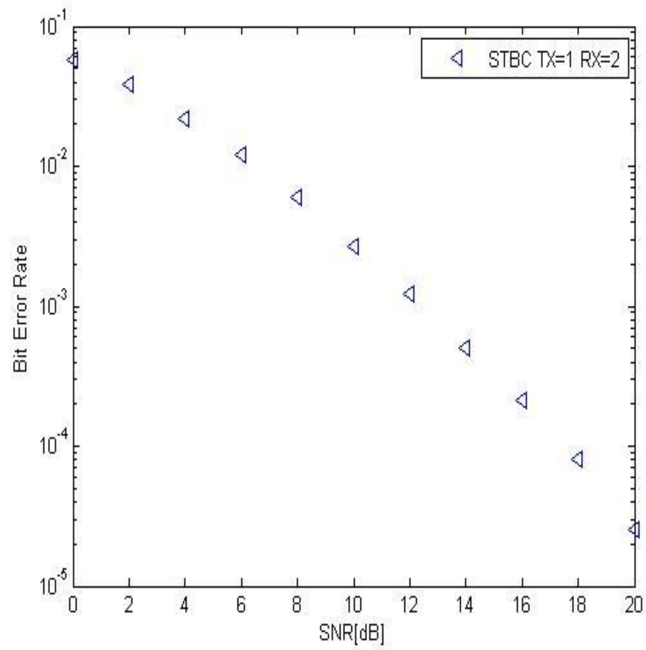

Fig. 5 BER performance of STBC for one Transmitter and two receivers

The above result shows the BER performance of STBC system for single transmitter and two receiver antennas for Rayleigh fading channel. As we can see that BER decreases exponentially with increase in SNR. The maximum value of BER is $10^{-1.3}$ for SNR= 0 db which decrease to $10^{-4.8}$ with SNR=20db.

B) This graph is plotted for the STBC-1x2, STBC-1x4, STBC-2x1 and STBC-2x2 antennas respectively. This system is designed for a packet size of 1000 bits, using QPSK modulation in Rayleigh fading environment; total numbers of packets are 100 to be transmitted.

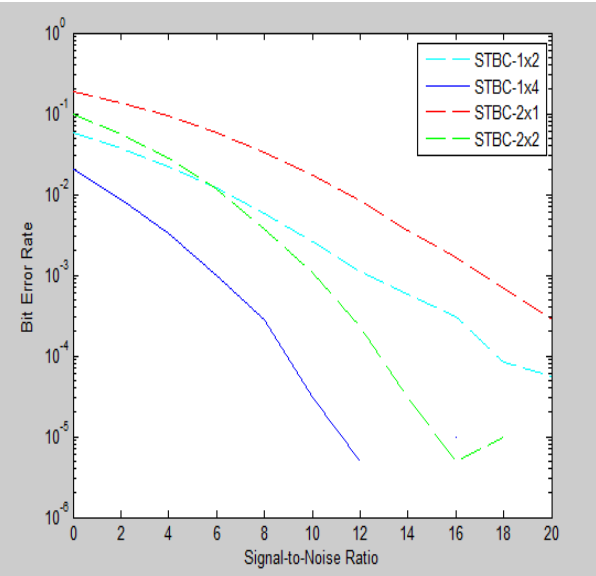

Fig. 6 BER performance of STBC for various numbers of transmitter and receiver antennas

According to the above diagram, the STBC-1x4 and STBC-2x 2 systems have better performance than other two. In the STBC system with one transmit and four receive antennas, the maximum value of BER is $10^{-1.8}$ for the initial value of SNR (SNR=0). The value of BER decreases to $10^{-5.4}$ when SNR=12 db.

In the same manner, STBC system with two transmitter and two receiver antennas also has a good performance. Here the initial value of BER=$10^{-1.0}$ when SNR=0 db. The value of BER decreases to $10^{-5.3}$ with respect to SNR=16 db.

In other two cases, STBC system with one transmitter and two receivers and two transmitters with one receiver has comparable poor performance. In STBC-2x1, BER=$10^{-0.9}$ for SNR=0 db. It decreases to BER=$10^{-3.2}$ when SNR=20 db.

V. CONCLUSION

STBC-SM system produces full transmit-diversity along with spectral efficiency. We have compared the performance of the system with various parameters. In this paper, we have reviewed the encoding and decoding process for the Almouti codes. We have provided the simulation result to compare the performance of different STBC codes chosen for a fixed number of transmit antennas, specifying the best code that assures a maximum diversity gain and a minimum BER. In this paper, a new modulation/coding technique is reviewed and studied here. This technique takes advantage of SM and STBC technologies to design transmit diversity and high rate modulation scheme.

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Rahul Saxena has completed his B.E. in electronics & communication engineering in 2006 from SRITS Datia (RGPV University Bhopal, M.P.). He is pursuing his M.E. in digital communication from IPS Academy, Indore. At present he is in 4th and final semester of M.E.

Prof. Rupesh Dubey is working as a Associate prof. and head of the department (Electronics & Communication) IPS Academy, Indore (M.P.). He has received his B.E. and M.E. degree in electronics & communication engineering. He has more than ten years of experience as associate prof. and head of the department. He has published many papers in various reputed journals, national and international conferences.

Prof. Poonam Lilhare is working as a Asst. Prof (electronics & communication) in IPS Academy, Indore (M.P.). She has received his B.E. and M.E. degree in Electronics & communication engineering. She has more than five years of experience as Asst. Prof.