

Orthogonal Space-Time Block Codes for Four, Five and Transmit Antennas with 4/7 and 5/11 code rates

N.S.Murthy * Dr.S.Sri Gowri** Dr.B.Prabhakara Rao***

* Associate Professor, ECE Dept, VR Siddhartha Engg. College, Vijayawada-7, INDIA

** Professor & HOD, ECE Dept, SRK Institute of Technology, Vijayawada, INDIA

*** Professor, ECE Dept, JNTUK, Kakinada

Abstract –

Orthogonal designs using Space-time block codes has significant role to achieve maximum code rate, bandwidth efficiency and simple decoding algorithm. Alamouti invented two branch diversity Scheme with full code rate. V. Tarokh, H. Jafarkhani, and A. R. Calderbank has proposed three and four transmit antennas with code rates of $\frac{3}{4}$. Complex orthogonal designs of space-time block codes for five, six, seven and eight transmit antennas with code rates $\frac{2}{3}$, $\frac{2}{3}$, $\frac{5}{8}$, and $\frac{5}{8}$ were proposed. In this paper we achieved new matrix of Complex orthogonal STBC for four and five with code rates of 4/7 and 5/11

Index Terms – Diversity, (generalized) complex orthogonal designs, space-time block codes.

I. INTRODUCTION

Since the pioneering work of Alamouti [1] in 1998, orthogonal design has become an effective technique for develop the space-time block codes (STBC). Its code for two transmit antennas has been incorporate as a simple and efficient transmit diversity technique in the wireless standard W-CDMA. Tarokh, Jafarkhani, and Calderbank [2] proposed space-time block coding with orthogonal designs for any numbers of transmit antennas ad the generalizations of Alamouti's scheme for two transmit antennas. The special structure of orthogonal designs guarantees that these codes achieve full diversity and have a simple maximum-likelihood decoding algorithm. In general, there are two criteria for the evaluation of a complex orthogonal designs (CODs) code

- Rate R: $R=k/p$, higher rate means more information carried by the code.
- Block length p: given n and R, a smaller p results less delay in decoding, and we can call it Decoding delay also.

To design “good” “space-time block codes is a challenging problem. Since a space-time block code is a collection of some matrices, even for small block size and a reasonable rate, the set of a space-time block code can be significantly large and therefore, its maximum-likelihood (ML) decoding

may have a high complexity. On the other hand, the performance of space-time block code depends on the diversity of the code. Therefore, a “good” space-time block code should possess two properties: i) the decoding at the receiver is reasonably fast; and ii) the diversity of the code is not small.

Let x_1, x_2, \dots, x_k be information symbols in S. The entries of the complex orthogonal design of G are formed from complex linear combinations of $x_1, x_1^*, x_2, x_2^*, \dots, x_k, x_k^*$ such that the columns of G are orthogonal to each other, where x^* is the complex conjugate of x. The rate of the code is $R = k/p$, which means that each codeword with block length p carries k information symbols. Clearly, for a given k, the smallest possible block length p is k.

II. COMPLEX ORTHOGONAL ESIGNS

We first review the concept of the (generalized) complex orthogonal design and some known designs of rate greater than or equal to $1/2[3]$, [4], [5]–[8].

Definition 1: A generalized complex orthogonal design (GCOD) in variables x_1, x_2, \dots, x_k is a $p \times n$ matrix G such that:

- the entries of G are complex linear combinations of x_1, x_2, \dots, x_k and their complex conjugates $x_1^*, x_2^*, \dots, x_k^*$

- $G^H G = D$, where G^H is the complex conjugate and transpose of G, and D is an $n \times n$ diagonal matrix with the (i, i) th diagonal element of the form

$$l_{i,1} |x_1|^2 + l_{i,2} |x_2|^2 + l_{i,3} |x_3|^2 + \dots + l_{i,k} |x_k|^2$$

Where all the coefficients $l_{i,1}, l_{i,2}, l_{i,3}, \dots, l_{i,k}$ are strictly positive numbers.

The rate of G is defined as $R = k/p$. If

$$G^H G = (|x_1|^2 + |x_2|^2 + \dots + |x_k|^2) I_{n \times n}$$

Then G is called a complex orthogonal design. Tarokh, Jafarkhani, and Calderbank [3] first mentioned that the rate of space-time block codes from generalized complex orthogonal designs cannot be greater than 1, i.e., $R = k/p \leq 1$. Later, it was

proved in [9] that this rate must be less than 1 for more than two transmit antennas. For a fixed number of transmit antennas n and rate R, it is desired to have the block length p as small as possible. The first space-time block code from complex orthogonal design was proposed in Alamouti [3] for two transmit antennas. It is the following 2 x 2 COD in variables x₁ and x₂

$$G_2 = \begin{pmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{pmatrix}$$

the rate of G₂ achieves the maximum rate 1. For n = 3 and n = 4 transmit antennas, there are complex orthogonal designs of rate R = 3/4 [3], for example, for three transmit antennas

$$G_3 = \begin{pmatrix} x_1 & x_2 & x_3 \\ -x_2^* & x_1^* & 0 \\ x_3^* & 0 & -x_1^* \\ 0 & x_3^* & -x_2^* \end{pmatrix}$$

for four transmit antennas, and

$$G_4 = \begin{pmatrix} x_1 & x_2 & x_3 & 0 \\ -x_2^* & x_1^* & 0 & x_3 \\ x_3^* & 0 & -x_1^* & x_2 \\ 0 & x_3^* & -x_2^* & -x_1 \end{pmatrix}$$

The theory of space-time block codes was further developed by Weifen Su and Xian-Gen Xia [9]. They defined space time block codes in terms of orthogonal code matrices. The properties of these matrices ensure rate 7/11 and 3/5 for 5 and 6 transmit antenna.

III Existed GCODs of Rates 4/8, 6/8 and 5/13 for n=4 and n = 4 and n=5 Transmit Antennas

G₄ is a 8 x 4 complex orthogonal design as follows:

$$G_4 = \begin{pmatrix} x_1^* & 0 & 0 & -x_4^* \\ 0 & x_1^* & 0 & x_2^* \\ 0 & 0 & x_1^* & -x_3^* \\ 0 & -x_3^* & -x_2^* & 0 \\ 0 & 0 & 0 & 0 \\ x_2^* & x_4^* & 0 & 0 \\ -x_3^* & 0 & x_4^* & 0 \\ x_4 & -x_2 & x_3 & x_1 \end{pmatrix}$$

Where rate R = 4/8 = 0.5, and the block length p (=8) [11]

$$D(1,1)=D(2,2)=D(3,3)=D(4,4)=\sum_{m=1}^4 |x_m|^2$$

$$G_4 = \begin{pmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2 & x_1 & -x_4 & x_3 \\ -x_3 & x_4 & x_1 & -x_2 \\ -x_4 & -x_3 & x_2 & x_1 \\ x_1^* & x_2^* & x_3^* & x_4^* \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ -x_3^* & x_4^* & x_1^* & -x_2^* \\ -x_4^* & -x_3^* & x_2^* & x_1^* \end{pmatrix}$$

Where rate R = 4/8 = 0.5, and the block length p (=8)

$$G_5 = \begin{pmatrix} x_1^* & 0 & -x_2^* & -x_5^* & 0 \\ 0 & -x_1^* & x_4^* & -x_3^* & 0 \\ 0 & 0 & x_5 & -x_2 & 0 \\ 0 & 0 & -x_3 & -x_4 & 0 \\ 0 & 0 & 0 & 0 & -x_1^* \\ x_2 & x_4 & x_1 & 0 & 0 \\ 0 & 0 & 0 & 0 & x_5 \\ x_3^* & x_5^* & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & x_2 \\ 0 & 0 & 0 & 0 & x_3^* \\ -x_4^* & x_2^* & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -x_4^* \\ x_5 & -x_3 & 0 & x_1 & 0 \end{pmatrix}$$

Where rate R = 5/13 [10]

IV. Improved GCOD of Rates 4/7 and 5/11 for n=4

And n=5 Transmit Antennas

$$G4 = \begin{pmatrix} z1 & z2 & z3 & z4 \\ -z2^* & z1^* & 0 & 0 \\ -z3^* & 0 & z1^* & 0 \\ -z4^* & 0 & 0 & z1^* \\ 0 & -z3^* & z2^* & 0 \\ 0 & -z4^* & 0 & z2^* \\ 0 & 0 & -z4^* & z3^* \end{pmatrix}$$

where rate R = 4/7 = 0.57 and the block length p (=7)

$$G5 = \begin{pmatrix} z1 & 0 & 0 & 0 & z2 \\ 0 & z1 & 0 & 0 & z3 \\ 0 & 0 & z1 & 0 & z4 \\ 0 & 0 & 0 & z1 & z5 \\ -z2^* & -z3^* & -z4^* & -z5^* & z1^* \\ -z3 & z2 & 0 & 0 & 0 \\ -z4 & 0 & z2 & 0 & 0 \\ -z5 & 0 & 0 & z2 & 0 \\ 0 & -z4 & z3 & 0 & 0 \\ 0 & -z5 & 0 & z3 & 0 \\ 0 & 0 & -z5 & z4 & 0 \end{pmatrix}$$

where rate R = 5/11 = 0.45 (p=7)

V CONCLUSION

Space-time block codes from (generalized) complex orthogonal designs have two advantages: fast ML decoding and full diversity. It has been proved in [8] that the rate of these space-time block codes must be less than 1 except for the case of two transmits antennas. There is a systematic construction of complex orthogonal designs of rate 1/2 for any number of transmit antennas based on the Hurwitz-Radon theory. The previously known designs of rate larger than 1/2 and less than 1 were given only for three and four transmit antennas with rate 3/4. In this correspondence, we presented generalized complex orthogonal designs of rates 4/7, rate 5/11 for four and five transmit antennas,

respectively. The number of transmitting antenna increases then corresponding BER decreases.

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