Improved Balanced 2n-PSK STTCs for Any Number of Transmit Antennas from a New and General Design Method

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Improved Balanced 2^n-PSK STTCs for Several Transmit Antennas from a New and General Design Method

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Abstract – **Recently, it has been established that the best space-time trellis codes (STTCs) belong to a specific class of codes. These codes are called "balanced STTCs" because they use the points of the MIMO constellation with the same probability. Therefore, the search of the best codes can be reduced to this class. This paper presents a new and general method to design 2^n-PSK balanced STTCs for any number of transmit antennas. This method is simpler than the first method, which was described only for 4-PSK modulation and can be generalized for any configuration of the space-time trellis encoder. Simulation results of new 4-PSK and 8-PSK balanced codes prove the importance of this class.**

Keywords—**space-time trellis codes, balanced codes, MIMO systems, design method.**

1. INTRODUCTION

The concept of space-time trellis codes (STTCs) was proposed in 1998 by Tarokh et al. [1] by combining time-convolution coding with multiple transmit antennas to improve the data rate and the reliability of wireless communication. In [1], the rank and the determinant criteria were proposed to design STTC in the case of slow fading channel. It was shown in [2] that, for a great product of the number of transmit and receive antennas, the performance for a slow fading channel is determined by the trace criterion.

Based on the above criteria, many codes for 2, 3 and 4 transmit antennas have been proposed [3-7] after a systematic search to decrease the bit and frame error rate. In [8], it has been remarked that the codes achieving the best performance have the same property: the used points of multiple input multiple output (MIMO) constellation are generated with the same probability. Therefore, these codes are referred to as "Balanced space-time trellis codes: B-STTCs" [8-10].

The aim of this paper is to present a general method to design the class of balanced 2^n-PSK STTCs which offers the best performance. Therefore, the systematic search for good codes can be reduced to this class. The rest of this paper is organised as follows. In section 2, the encoder is briefly described. The performance criteria of STTCs are presented in section 3. Section 4 presents the main properties of the balanced codes. In section 5, the general method to design balanced codes is described for any number of transmit antennas and for 2^n-PSK modulations. Some examples to design balanced codes for specific configurations are given. Finally, some new balanced codes which outperform the best known codes are proposed for 4-PSK and 8-PSK modulations.

2. SPACE TIME TRELLIS CODING

We consider the general case of the 2^n-PSK space-time trellis encoder. Fig. 1 shows the encoder for $n=2$.
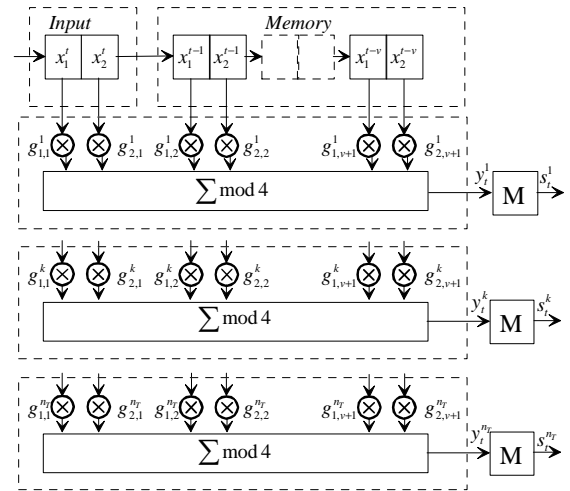

Fig. 1. 4-PSK space time trellis encoder with n_T transmit antennas

This encoder has one input block of n bits and v memory blocks of n bits. At each time $t \in \mathbb{Z}$, the n bits of a block are replaced by the n bits of the previous block. Usually, the state of the encoder is defined by the binary values of v memory blocks of n bits. The ith bit x_i^{t-j+1}, $i = 1 \ldots n$, of the jth block, $j=1...(v+1)$, is associated to n_T multiplier coefficients $g_{i,j}^k \in \mathbb{Z}_{2^n}$, $k = 1 \ldots n_T$, where n_T is the number of transmit antennas. A space-time trellis encoder is thus usually defined by its generator matrix G of $n_T \times n(v + 1)$ coefficients

$$
G = \begin{bmatrix} g_{1,1}^1 & \cdots & g_{n,1}^1 & \cdots & g_{1,v+1}^1 & \cdots & g_{n,v+1}^1 \\ \vdots & & \cdots & & \cdots & & \vdots \\ g_{1,1}^k & \cdots & g_{n,1}^k & \cdots & g_{1,v+1}^k & \cdots & g_{n,v+1}^k \\ \vdots & & \cdots & & \cdots & & \vdots \\ g_{1,1}^{n_T} & \cdots & g_{n,1}^{n_T} & \cdots & g_{1,v+1}^{n_T} & \cdots & g_{n,v+1}^{n_T} \end{bmatrix} \quad (1)
$$

The encoder outputs for the kth antenna are computed as

$$y_t^k = \sum_{i=1}^{n} \sum_{j=1}^{v+1} x_i^{t-j+1} g_{i,j}^k \quad \mod 2^n \qquad (2)$$

Each encoder output y_t^k is mapped onto a 2^n-PSK signal given by: $s_t^k = \exp\left(j \dfrac{\pi}{2^{n-1}} y_t^k \right)$. Each output signal s_t^k is send to the kth transmit antenna. The modulated streams of all antennas are then transmitted simultaneously.

3. DESIGN CRITERIA

Several design criteria have been proposed in [1, 2] to exploit the spatial diversity and to offer optimal coding gain. The case of slow Rayleigh fading propagation channels is mainly considered in this paper. The n_T dimension transmitted symbols $s_t = \left[s_t^1 s_t^2 ... s_t^{n_T} \right]^T$, where $[\cdot]^T$ denotes the transpose operator, are assumed to be grouped in a frame of length L_f. Traditionally, criteria are derived from the minimization of the pairwise error probability (PEP), i.e. the probability of transmitting the $n_T \times L_f$ dimension coded frame $S_t = \left[s_t \, s_{t+1} ... s_{t+L_f-1} \right]$ and deciding erroneously in favour of another $n_T \times L_f$ dimension coded frame $E_t = \left[e_t \, e_{t+1} ... e_{t+L_f-1} \right]$. The $n_T \times n_T$ product matrix $A = BB*$ is introduced, where $B*$ denotes the hermitian of the $n_T \times L_f$ difference matrix $B = E_t - S_t$.

$$B = \begin{bmatrix} e_t^1 - s_t^1 & ... e_{t+q}^1 - s_{t+q}^1 ... e_{t+L_f-1}^1 - s_{t+L_f-1}^1 \\ ... & ... & ... & ... & ... \\ e_t^{n_T} - s_t^{n_T} & ... e_{t+q}^{n_T} - s_{t+q}^{n_T} ... e_{t+L_f-1}^{n_T} - s_{t+L_f-1}^{n_T} \end{bmatrix} \qquad (3)$$

Let us defined n_R the number of receive antennas. In order to achieve the minimum error probability, if $min(rank(A))n_R \leq 3$ and for slow fading channels, we should maximize the minimum rank and the minimum determinant of the matrix A computed for all pairs of coded frames (E_t, S_t) [1].

In [2], Chen proposed a new criterion which is valid for slow and fast Rayleigh fading channels if $min(rank(A))n_R > 3$. Under this assumption, the PEP is minimized if the sum of all the eigenvalues of the product matrix A is maximized. Because A is a square matrix, the sum of all the eigenvalues λ_k is equal to the trace of the matrix A

$$tr(A) = \sum_{k=1}^{n_T} \lambda_k = \sum_{k=1}^{n_T} \left(\sum_{q=0}^{L_f-1} \left| e_{t+q}^k - s_{t+q}^k \right|^2 \right) \qquad (4)$$

For each pair of coded frames, the matrix A and then $tr(A)$ can be computed. The minimum trace is the minimum of all these values $tr(A)$. When the product $min(rank(A))n_R > 3$, the minimization of the PEP amounts to use a code which has the maximum value of the minimum trace.

4. BALANCED CODES

4.1. What is a "balanced code"?

The concept of "balanced codes" has been proposed in [8-10]. It is based on the observation that the best STTCs proposed in the literature present the same property: the generated symbols of the MIMO constellation are equally probable.

The binary input data are supposed to be generated by a memory less binary source $S_b = \{0, 1\}$ with equally probable symbols and 2^n-PSK modulation are considered. From a given extended-state $X = \left[x_1 x_2 ... x_L \right]^T \in \mathbb{Z}_2^L$ of the $L = n(v + 1)$ length shift register realized by the input block of n bits followed by the v blocks of n bits, the MIMO symbol $Y = \left[y_1 y_2 ... y_{n_T} \right]^T \in \mathbb{Z}_{2^n}^{n_T}$ generated by the space time trellis encoder shown in Fig. 1 is

$$Y = G\,X \qquad (5)$$

where G is the generator matrix (1). This is a deterministic relation. Therefore, the STTC is defined by a map

$$\Phi : \mathbb{Z}_2^L \rightarrow \mathbb{Z}_{2^n}^{n_T} \qquad (6)$$

which associates to the extended-state X a unique codeword Y. Note that $\Phi(\mathbb{Z}_2^L) \subseteq \mathbb{Z}_{2^n}^{n_T}$ represents the set of generated codewords Y.

By definition, a STTC is balanced if and only if each generated codeword $Y \in \Phi(\mathbb{Z}_2^L)$ has the same number of occurrences $n_0 \in \mathbb{N}^*$.

The number of different codewords generated by relation (5) is given by $card(\Phi(\mathbb{Z}_2^L))$ which is a power of 2.

The code is fully balanced if

$$\left\{ \sum_{j=1}^{j=L} (x_j G_j) \mod 2^n \, / \, x_j \in \{0,1\} \right\} = \mathbb{Z}_{2^n}^{n_T} \qquad (7)$$

where G_j is the jth column of the generator matrix G. In this case: $\Phi(\mathbb{Z}_2^L) = \mathbb{Z}_{2^n}^{n_T}$.

Due to the random memory less source $S_b = \{0, 1\}$, with $p(0) = p(1) = 1/2$, from a given extended-state X, the encoder has only 2^n equally probable next states. The matrix T of the transition probabilities between these states corresponds to a Markov chain. Due to the symmetry of the matrix T, the steady-state probabilities of the extended-states X are all equal. For a balanced code, by using (5), the generated codewords Y are also equally-probable. In other words, the generated symbols of the MIMO constellation are equally probable.

4.2 Properties of balanced STTC

Theorem 1: If a STTC is fully balanced then $L \geq L_{\min} = n.n_T$. One can observe that $L_{\min} = \dim(\mathbb{Z}_{2^n}^{n_T})$.

Theorem 2: Let us consider a fully balanced MIMO code with a $n_T \times L$ generator matrix G. Then, for any additional column matrix $G_{L+1} \in \mathbb{Z}_{2^n}^{n_T}$ the resulting generator matrix $G'=[G\ G_{L+1}]$ corresponds to a new fully balanced code.

Theorem 3: If G is the matrix of a balanced code, each permutation of its columns or/and lines generates the matrix of a new balanced code.

Theorem 4: $C_{[0]} = 2^{n-1}\mathbb{Z}_2^{n_T}$ is a subgroup of $\mathbb{Z}_{2^n}^{n_T}$ such as $v = -v,\ \forall v \in C_{[0]}$. In the case of 4-PSK modulation, each element $v \in C_{[0]}$ can be written as $v = 2p$, with $p \in \mathbb{Z}_2^{n_T}$. The coset $C_{[p]} = p + C_{[0]}$ is called "*relative to* v". So, it is possible to write: $\mathbb{Z}_4^{n_T} = C_{[0]} \bigcup E_1$ where E_1 is the set of the cosets $C_{[p]} \neq C_{[0]}$. In the case of 8-PSK modulation, each element $v \in C_{[0]} = 4\mathbb{Z}_2^{n_T}$ can be written as $v = 2p$, with $p \in 2\mathbb{Z}_2^{n_T}$. For 8-PSK, we note by E_1 the set of cosets which can be written as $C_{[p]} = p + C_{[0]}$ with $p \in 2\mathbb{Z}_2^{n_T} \setminus \left\{ [0\ 0]^T \right\}$. So, each coset $C_{[p]} = p + C_{[0]} \in E_1$ is called "*relative to* v", with $v = 2p \in C_{[0]}$. Each element $q \in E_1$ can be written as $q=2r$, with $r \in \mathbb{Z}_4^{n_T} \setminus 2\mathbb{Z}_2^{n_T}$ and a new set E_2 of cosets $C_{[r]} = r + C_{[0]}$ can be created. Thus, each coset of E_2 is also "relative *to* an element of E_1". Therefore, it is possible to write: $\mathbb{Z}_8^{n_T} = C_{[0]} \bigcup E_1 \bigcup E_2$.

5. A NEW METHOD TO DESIGN 2^n-PSK STTC WITH SEVERAL TRANSMIT ANTENNAS

In [8-9], a first method to design fully balanced codes has been presented for several transmit antennas and 4-PSK STTC. In [10], a simpler method to design balanced 4-PSK STTC was presented. The general method described in this paper which is based on the method of [10] allows an easier design of balanced codes for any number of transmit antennas and for any 2^n-PSK modulation. Due to Property 2, it is enough to design fully balanced codes with $L = L_{min}$. This general method respects two rules:

- Rule 1: The first no null column G_1 must belong to $C_{[0]}$. Due to the theorem 4, $G_1 = -G_1$, so $H_1 = \left\{ 0,\ G_1 \right\}$ is a subgroup of $\mathbb{Z}_{2^n}^{n_T}$.

- Rule 2: Each new chosen column of G must create a new subgroup H_{i+1} of $\mathbb{Z}_{2^n}^{n_T}$ with $card(H_{i+1}) = 2card(H_i)$.

Thus, in order to obtain a fully balanced STTC, this general algorithm is as follows:

if $i<L_{min}$ columns of G have been already chosen in $\mathbb{Z}_{2^n}^{n_T}$ and $\left\{ \sum_{j=1}^{i} x_j G_j \mod 2^n / x_j \in \{0,1\} \right\} = H_i$ is a subgroup of $\mathbb{Z}_{2^n}^{n_T}$,

then the column G_{i+1} of G must belong to $\mathbb{Z}_{2^n}^{n_T} \setminus H_i$ and must be selected in the cosets *relative to* the vectors which belong to H_i or in the coset $C_{[0]}$. This method ensures that

$$H_{i+1} = H_i \bigcup (H_i + G_{i+1}) \text{ is a subgroup of } \mathbb{Z}_{2^n}^{n_T}.$$

The algorithm ends when $i+1=L_{min}$. The obtained matrix G corresponds to a fully balanced code with $n_0=1$. If necessary, more columns can be added to G to create a fully balanced code with $n_0>1$.

In order to obtain balanced codes (not necessary fully balanced) the algorithm can be ended when H_{i0} is created with $i_0 \leq L_{min}-2$ columns. One can add a new column $G_{i_0+1} \in \mathbb{Z}_{2^n}^{n_T} \setminus H_{i_0}$. Once again, the obtained code is balanced but not fully balanced. If necessary, several elements of H_{i_0} can also be added as columns of the matrix G. The resulting code is also balanced but not fully balanced.

Remark: The main idea of this new method is to generate at each step several new elements of $\mathbb{Z}_{2^n}^{n_T}$ and their opposites. Therefore, there are not discarded elements of $\mathbb{Z}_{2^n}^{n_T}$ (elements that must not be further selected). Thus, this new method to design the B-STTC is simpler than the method described in [8-9].

5.1 Design of fully balanced 4-PSK STTC with 2 transmit antennas

In this case, each generated element belongs to $\mathbb{Z}_4^2$. It is possible to make the partition in cosets: $C_{[p]} = p + C_{[0]}$ with $C_{[0]} = 2\mathbb{Z}_2^2$ and $p \in \mathbb{Z}_2^2$. Thanks to this partition, to generate a balanced code with $L_{min}=4$ columns, we can proceed as follows:

- In agreement with rule 1, the first column G_1 of G must be selected in $C_{[0]}$ (but $G_1 \neq \begin{bmatrix} 0 \\ 0 \end{bmatrix}$), because $C_{[0]}$ contains the vectors with the property : $G_i = -G_i$. Therefore, a subgroup of $\mathbb{Z}_4^2$ is generated: $H_1 = \left\{ 0,\ G_1 \right\}$.

- The second element G_2 has to create a new subgroup $H_2 = \{0,\ G_1,\ G_2,\ G_1+G_2\}$, where $-G_1$, $-G_2$ and $-(G_1+G_2)$ are included in H_2. There are two solutions to choose G_2:

  - If $G_2 \in C_{[0]} \setminus H_1$, then $-G_2 = G_2$, $-(G_1+G_2) = G_1+G_2$ and $H_2 = \{0,\ G_1,\ G_2,\ G_1+G_2\} = C_{[0]}$ is a subgroup of $\mathbb{Z}_4^2$. This type of code is called [8, 10] *Type II*, i.e. G has 2 columns in $C_{[0]}$ and thus $C_{[0]}$ is totally generated by G_1 and G_2. It remains to select two different cosets and in each coset, one vector must be selected. In fact, because $G_3 \in \mathbb{Z}_4^2 \setminus C_{[0]}$, $H_3 = C_{[0]} \bigcup (C_{[0]} + G_3)$ is a new

subgroup of $\mathbb{Z}_4^2$. Finally, if $G_4 \in \mathbb{Z}_4^2 \setminus H_3$, then $H_4 = H_3 \bigcup (H_3 + G_4) = \mathbb{Z}_4^2$.

– If $G_2 \in C_{[p_1]}$ with $2p_1 = G_1$, then $G_1 + G_2 = -G_2$ and $H_2 = \{0, G_1, G_2, G_1 + G_2\}$ is a subgroup of $\mathbb{Z}_4^2$. If no more vector is selected in $C_{[0]}$, this type of code is called [8, 9] *Type I*. To create a new group $H_3 = H_2 \bigcup (H_2 + G_3)$ without using a new vector of $C_{[0]}$ (else the generator matrix G would correspond to a balanced code of *type II*), the third column of G must be selected in $C_{[p_1]}$ among the two elements that are not generated by the combinations of G_1 and G_2. So, thanks to the combinations between G_1, G_2 and G_3, the group H_3 is equal to $C_{[0]} \bigcup C_{[p_1]}$. The last vector G_4 is selected among the two non generated cosets. Then, *{$G_1, ...G_4$}* is a base of $\mathbb{Z}_4^2$ and thus a fully balanced space-time trellis code for 4-PSK modulation and 2 transmit antennas is obtained.

5.2 Design of fully balanced 8-PSK STTC with n_T transmit antennas

For 8-PSK STTC with 2 transmit antennas, each generated element belongs to $\mathbb{Z}_8^{n_T}$. In agreement with theorem 4, it is possible to make the partition of the set of the cosets: $\mathbb{Z}_8^{n_T} = C_{[0]} \bigcup E_1 \bigcup E_2$ where each coset of E_2 is *relative to* one element of E_1 and each coset of E_1 is *relative to* one element of $C_{[0]}$. Thanks to this partition, in order to generate a balanced code, we can proceed as follows:

- In agreement with rule 1, the first column G_1 of G must be selected in $C_{[0]}$ (but $G_1 \neq \begin{bmatrix} 0 & \cdots & 0 \end{bmatrix}^T$), because $C_{[0]}$ contains the vectors with the property : $G_i = -G_i$. Therefore, a subgroup of $\mathbb{Z}_4^2$ is generated: $H_1 = \{0, G_1\}$.

- The ith column G_i ($i>1$) can be selected either :
  – in $C_{[0]} \setminus H_{i-1}$.
  – or in the coset $C_{[p]} \in E_1 \setminus H_{i-1}$ if and only if $2p \in H_{i-1}$.
  – or in the coset $C_{[q]} \in E_2 \setminus H_{i-1}$ if and only if $2q \in H_{i-1}$.

Thus, each new selected column creates a new subgroup with twice more elements than the previous subgroup.

6. PERFORMANCE OF NEW CODES

In Table 1, the minimum trace of some new balanced codes are compared to the minimum trace of Chen's codes with 3 and 4 transmit antennas. These codes have 32 and 64 states. The new codes have higher values of the minimum trace than the traces of Chen's equivalent codes. The codes noted by

'B' are balanced, those by 'FB' are fully balanced and those noted by 'NB' are not balanced. Each new code is balanced and its trace is greater than the trace of Chen's corresponding code.

TABLE 1: 4-PSK Balanced STTCs
with 3 and 4 transmit antennas

n_T	States	Code	G		Trace
3	32	Chen [7, 11]	$\begin{bmatrix} 0 & 2 & 2 & 1 & 1 & 2 & 0 & 2 \\ 2 & 2 & 3 & 2 & 2 & 3 & 0 & 0 \\ 2 & 0 & 3 & 2 & 2 & 1 & 0 & 0 \end{bmatrix}$	FB	24
		New 1	$\begin{bmatrix} 2 & 1 & 2 & 3 & 2 & 3 & 0 & 2 \\ 2 & 3 & 0 & 2 & 2 & 1 & 0 & 0 \\ 2 & 1 & 2 & 1 & 0 & 0 & 0 & 2 \end{bmatrix}$	FB	26
	64	Chen [7, 11]	$\begin{bmatrix} 0 & 2 & 3 & 2 & 3 & 0 & 3 & 2 \\ 2 & 2 & 1 & 2 & 3 & 0 & 2 & 0 \\ 2 & 0 & 0 & 2 & 2 & 3 & 1 & 1 \end{bmatrix}$	B	28
		New 2	$\begin{bmatrix} 2 & 3 & 2 & 3 & 2 & 1 & 2 & 1 \\ 0 & 2 & 0 & 2 & 2 & 3 & 0 & 2 \\ 2 & 1 & 0 & 2 & 2 & 3 & 2 & 1 \end{bmatrix}$	FB	32
4	32	Chen [7, 11]	$\begin{bmatrix} 0 & 2 & 2 & 1 & 1 & 2 & 0 & 2 \\ 2 & 2 & 3 & 2 & 2 & 3 & 0 & 0 \\ 2 & 0 & 3 & 2 & 2 & 1 & 0 & 0 \\ 2 & 1 & 2 & 0 & 1 & 0 & 0 & 2 \end{bmatrix}$	NB	36
		New 3	$\begin{bmatrix} 2 & 3 & 2 & 1 & 2 & 1 & 0 & 2 \\ 0 & 2 & 2 & 1 & 2 & 3 & 0 & 3 \\ 2 & 3 & 2 & 3 & 0 & 0 & 0 & 2 \\ 2 & 1 & 0 & 2 & 2 & 1 & 0 & 0 \end{bmatrix}$	B	36
	64	Chen [7, 11]	$\begin{bmatrix} 0 & 2 & 3 & 2 & 3 & 0 & 3 & 2 \\ 2 & 2 & 1 & 2 & 3 & 0 & 2 & 0 \\ 2 & 0 & 0 & 2 & 2 & 3 & 1 & 1 \\ 1 & 2 & 2 & 0 & 2 & 1 & 3 & 2 \end{bmatrix}$	NB	38
		New 4	$\begin{bmatrix} 1 & 2 & 2 & 0 & 3 & 2 & 1 & 2 \\ 3 & 2 & 3 & 2 & 2 & 0 & 3 & 2 \\ 2 & 0 & 1 & 2 & 3 & 2 & 3 & 2 \\ 1 & 2 & 2 & 0 & 2 & 0 & 2 & 0 \end{bmatrix}$	FB	40

In Table 2, 8-PSK Chen's codes and new corresponding codes are shown for 3 transmit antennas/16 states and 4 transmit antennas/8 states. The two new codes have higher values of the minimum trace than the traces of Chen's equivalent codes.

The performance of each code is evaluated by simulation in a slow Rayleigh fading channel. The channel fading coefficients are independent samples of a complex Gaussian process with zero mean and variance 0.5 per dimension. These channel coefficients are assumed to be known at the decoder. Each frame consists of 130 4-PSK symbols or 198 8-PSK symbols. For the simulation, there are 2 receive antennas. The decoding is performed by the Viterbi's algorithm. Figure 2 shows the performance of the 4-PSK 32 states and 64 states codes for 3 transmit antennas given in Table 1. In the same way, the performance of 4-PSK STTC with 32 states and 64

states for 4 transmit antennas is shown in figure 3. Figure 4 shows the performance of the new 8-PSK and the corresponding Chen's codes of Table 2.

TABLE 2: 8-PSK Balanced STTCs
with 3 and 4 transmit antennas

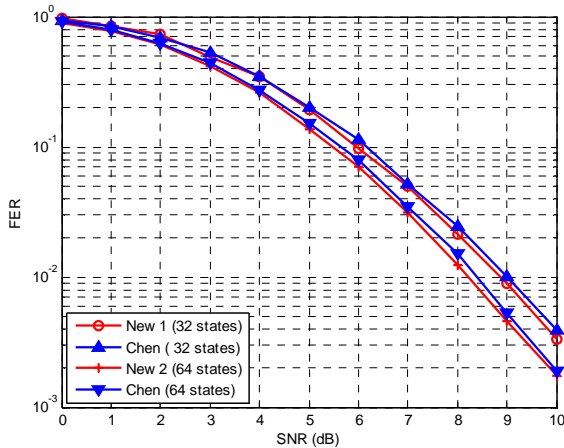| n_T	States	Code	G	Trace
3	16	Chen [11]	$\begin{bmatrix} 2 & 4 & 7 & 3 & 6 & 0 & 0 & 0 & 4 \\ 4 & 0 & 2 & 7 & 6 & 7 & 0 & 0 & 4 \\ 2 & 4 & 2 & 2 & 4 & 6 & 0 & 0 & 0 \end{bmatrix}$	14
		New 5	$\begin{bmatrix} 4 & 2 & 0 & 0 & 4 & 1 & 0 & 0 & 6 \\ 4 & 2 & 3 & 4 & 6 & 7 & 0 & 0 & 4 \\ 0 & 4 & 2 & 4 & 2 & 5 & 0 & 0 & 0 \end{bmatrix}$	15.17
4	8	Chen [11]	$\begin{bmatrix} 2 & 4 & 0 & 3 & 2 & 4 \\ 1 & 6 & 4 & 4 & 0 & 0 \\ 3 & 2 & 4 & 0 & 4 & 2 \\ 7 & 2 & 4 & 5 & 4 & 0 \end{bmatrix}$	16.58
		New 6	$\begin{bmatrix} 0 & 4 & 2 & 4 & 2 & 5 \\ 4 & 6 & 1 & 0 & 0 & 4 \\ 4 & 2 & 3 & 4 & 6 & 0 \\ 4 & 6 & 5 & 0 & 4 & 6 \end{bmatrix}$	17.17

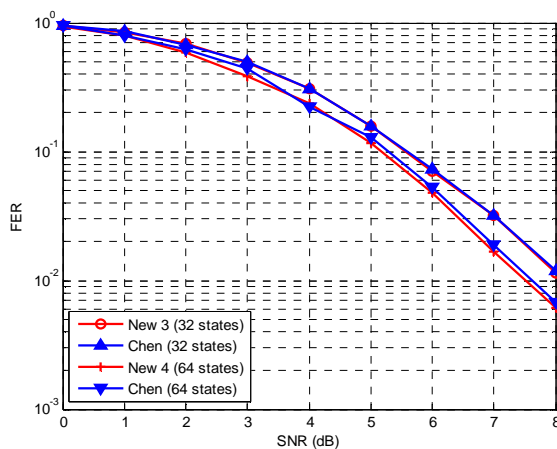Fig. 2. Performance of 4-PSK STTC with 3 Tx / 2 Rx antennas

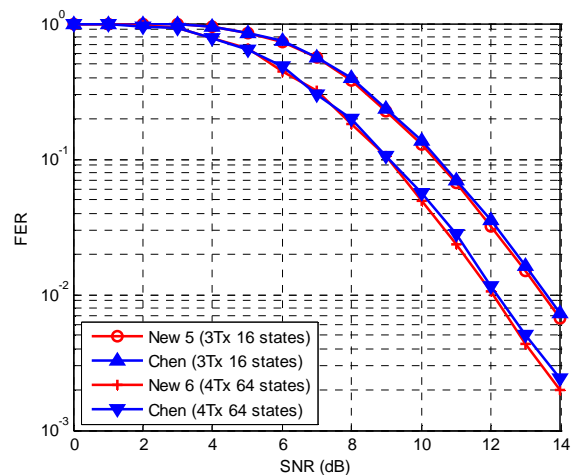Fig. 3. Performance of 4-PSK STTC with 4 Tx/ 2 Rx antennas

Fig. 2. Performance of 8-PSK STTC with 3 Tx & 4 Tx / 2 Rx antennas

7. CONCLUSION

This paper presents a new and simpler method to design balanced space-time trellis codes. It has been shown that the best codes belong to this class. The balanced codes generate the points of the MIMO constellation with the same probability. This new and general method allows to design the balanced STTCs for 2^n-PSK modulations and n_T transmit antennas. The search for the best codes can be reduced to the class of balanced codes. Furthermore, several new balanced 4-PSK and 8-PSK codes for 3 and 4 transmit antennas which outperform the best previously published codes have also been proposed.

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