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TRELLIS CODED MAPPING FOR PEAK TO AVERAGE POWER REDUCTION IN SFBC MIMO OFDM SYSTEMS

P.N. Kota[1], A.N. Gaikwad[2] and B.P. Patil[3]
[1]*Department of Electronics and Telecommunication Engineering, Sinhgad Institute of Technology, India*
E-mail: [1]prabhukota1@gmail.com
[2]*Department of Electronics and Telecommunication Engineering, Zeal College of Engineering and Research, India*
E-mail: [2]arungkwd47@gmail.com
[3]*Department of Electronics and Telecommunication Engineering, Army Institute of Technology, India*
E-mail: [3]bp_patil@rediffmail.com

Abstract

Space frequency block code orthogonal frequency division multiplexing (SFBC-OFDM) systems has inherit drawbacks of high peak-to average power ratio (PAPR) signals, and constellation shaping with trellis is a promising approach for reducing both peak power and bit error rate of SFBC-OFDM signals. In practice, reliability will improve in SFBC-OFDM by employing coded modulation. In this work, it has been proposed two trellis coded mapping method for SFBC MIMO OFDM system for achieving good error performance as well as reduced PAPR and compared with SLM technique.Based on the simulation results the proposed methods has the capability to provide reduced PAPR and bit error rate in SFBC MIMO-OFDM systems without side information.

Keywords:

Orthogonal Frequency Division Multiplexing (OFDM), Peak-to-Average Power Ratio (PAPR) Reduction, Space Frequency Block Code (SFBC), Trellis Shaping (TS), Zero Force Detection (ZF)

1. INTRODUCTION

In recent years, MIMO combined with OFDM, known as MIMO-OFDM technology is an encouraging contender for modern high-date-rate wireless communication applications due to its ability to support large capacity and robustness to multipath fading. There are many diversity technique adopted in MIMO-OFDM to overcome challenges in time varying channel. Space frequency blocks coding (SFBC) diversity based MIMO-OFDM [1] [2] is reliable solution for time selective fading channels. However, like OFDM based multi-carrier techniques, SFBC SYSTEM has also faced an inherent drawback of high peak-to-average power ratio (PAPR) [3]. High peak-to-average power ratio (PAPR) signal amplifies the signal nonlinearly, which degrades quality of signal and the efficiency of the power amplifier (PA). The overall power consumption determines its Power efficiency of power amplifier. Therefore, it is necessary to reduce the PAPR of generated signals for battery-driven mobile terminals. Literature survey suggest many PAPR reduction algorithm like distortion technique clipping [4] and filtering which degrades performance of system, distortion less technique like reserved tones (TR), tone injection (TI) [5] and active constellation extension (ACE) [6] change constellation points for some subcarriers to reduce the PAPR, and probabilistic solutions [7] [8] [9] approach include symbol selection, partial transmit sequence [10], schemes generate several alternative signal sequences representing the same OFDM signal sequence and select the one with the minimum PAPR among them. Conventional SLM and PTS methods required SI information but [11] [12] [13] some methods are available without side information also. These methods are good PAPR reduction technique but degrade the performance of system in terms of BER.

In the tone Injection technique [14] the basic idea is take large constellation size so that each symbols on the original basic constellation can be represents to several point symbols in the modified constellation, so that it can be select any equivalent representation point on constellation of given symbol to help to reduction of PAPR.

In this paper, Like in tone injection [14] we focus on the constellation expanding based on trellis coded mapping approach developed in for reducing the peak power as well as bit error rate in SFBC MIMO OFDM system. The original constellation expanded using Trellis coded modulation and it will help to shape constellation as well as forward error correction technique for improving bit error rate. This method reduces PAPR as well as the bit error rate. As in many PAPR reduction schemes that involve optimization processes, one challenging issue of the scrambling method is the reduction of bit error rate. This issue will be solved by combined channel coding with Trellis modulation mapping, and this feature is the key focus of this paper.

The paper is organized as follows. In Section 2, the SFBC MIMO OFDM system and SLM based PAPR reduction technique are discussed. Section 3 provides a brief review of the trellis mapping system and proposed two algorithms for SFBC OFDM system. Section 4 evaluates analysis of PAPR reduction capability and performance analysis of in terms of bit-error rate (BER) of the proposed system by computer simulations. Finally, Section 5 will be concluding remark.

2. SYSTEM DESCRIPTION

2.1 SFBC MIMO-OFDM SYSTEM

In this study Alamouti SFBC MIMO-OFDM system adopted. A data symbols is modulated $X = \{X(k)$ where $k = 0, 1,\ldots, N\text{-}1\}$ then this signal separated into two even and odd vectors.

$$X_e = [X(0), X(2),\ldots, X(N-2)]^T$$
$$X_o = [X(1), X(3),\ldots, X(N-1)]^T$$

Then SFBC encoded,

$$X_1 = [X(0), -X^*(1),\ldots, X(N-2), -X^*(N-1)]$$
$$X_2 = [X(1), X^*(0),\ldots, X(N-1), X^*(N-2)]$$

where, $(\cdot)^*$ denotes the complex conjugate operation and N is the number of subcarriers.

The time domain signal x_1, x_2 of two transmitter antennas can be found using IFFT operation as follows:

$$x_i(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_i(k) e^{i2\pi kn/N} \quad (1)$$

where, i = 1, 2 and n = 0, 1,…, N-1.

The PAPR of the SFBC OFDM frame at each antenna is defined by,

$$PAPR_{x_i} = \frac{\max_n \left\{ |x_i(n)|^2 \right\}}{E\left\{ |x_i(n)|^2 \right\}} \quad (2)$$

where, $E\{\cdot\}$ denotes the expectation operation. Therefore the PAPR of SFBC OFDM system is,

$$PAPR = \max_{i=1,2} \left\{ PAPR_{x_i} \right\} \quad (3)$$

In this paper it has been consider two transmitters and one receiver. At the receiver after employing the FFT operation, the received vector $Y = [Y(0), Y(1),…,Y(N\text{-}1)]$ could be expressed as:

$$Y(k) = H_1(k)\, X_1(k) + H_2(k)\, X_2(k) + w_n(k) \quad (4)$$

where, $Y(k)$, $H_1(k)$ and $H_2(k)$ is frequency domain signal obtained by FFT of y, h_1 and h_2, respectively.

$$Y_1 = H_{11}X(0) + H_{21}X(1) + W_1 \quad (5)$$

$$Y_2 = -H_{12}X^*(1) + H_{22}X^*(0) + W_2 \quad (6)$$

H_{ij} is channel coefficient where i represents antenna and j represents subcarriers. W_j represents AWGN noise.

$$\hat{X}_1 = H_{12}^* Y_1 + H_{21} Y_2^* \quad (7)$$

$$\hat{X}_2 = H_{22}^* Y_1 - H_{11} Y_2^* \quad (8)$$

where, $\hat{X}_1$ and $\hat{X}_2$ estimation of signal X. The original data can be recovered after demapping. We assume that subsequent subcarrier have equal response.

2.2 CONVENTIONAL SELECTIVE MAPPING SCHEME (C-SLM)

In Conventional selective mapping scheme with U phase rotation sequences are generated as:

$$B^u = \left\{ e^{j\alpha^u(0)}, e^{j\alpha^u(1)}, ..., e^{j\alpha^u(N-1)} \right\},\ u = 0,1,...,U-1$$

where, $j = \sqrt{-1}$ and $\alpha^u \in [0,2\pi]$. Therefore, the input modulated data X is scrambled by B^u as shown in Fig.1 and generates Alamouti SFBC encoded data into two vectors X_1^u, X_2^u as a frequency domain signals,

$$X_1^u = \begin{bmatrix} X(0)e^{j\alpha^u(0)}, -X^*(1)e^{j\alpha^{u^*}(1)}, ..., \\ e^{j\alpha^u(N-2)}X(N-2), -e^{j\alpha^{u^*}(N-1)}X^*(N-1) \end{bmatrix}$$

$$X_2^u = \begin{bmatrix} X(1)e^{j\alpha^u(1)}, X^*(0)e^{j\alpha^{u^*}(0)}, ..., \\ X(N-1)e^{j\alpha^u(N-1)}, X^*(N-2)e^{j\alpha^{u^*}(N-2)} \end{bmatrix}$$

These signals are converted into time domain signal using IFFT operation, and the two set of minimum PAPR signal transmitted on two antenna. Minimum PAPR signal can be found using Eq.(2) and Eq.(3). Phase rotation sequence B for selected signal should be transmitted to the receiver as the side information bits to recover signal.

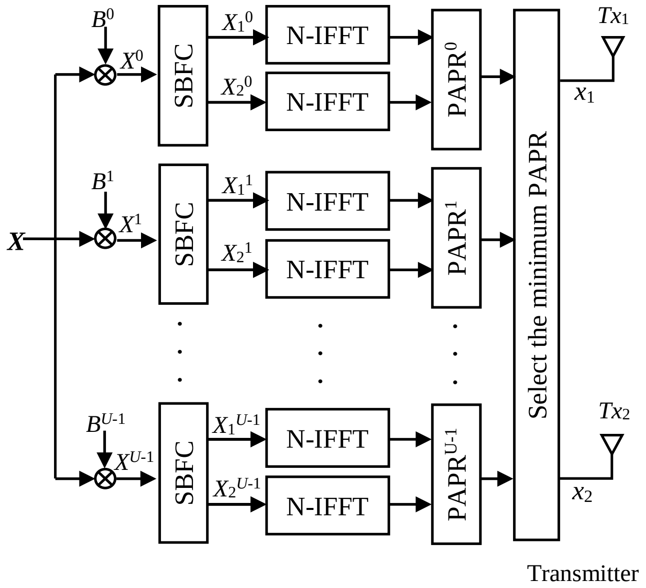
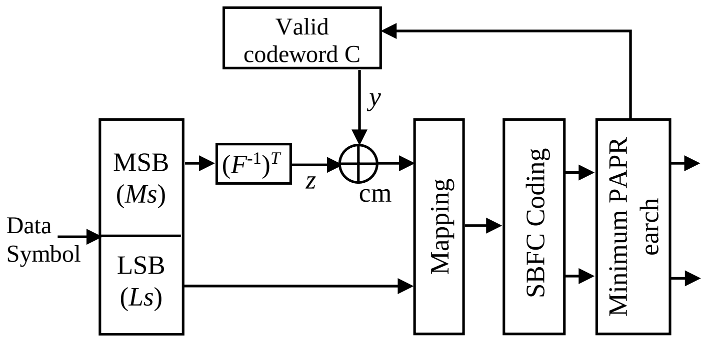


Fig.1. Block diagram of SFBC MIMO OFDM transmitter with SLM PAPR reduction

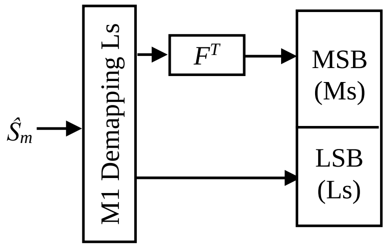
3. PROPOSED TRELLIS SHAPING IN SFBC OFDM SYSTEM

Tellambura [15] has shown that the trellis shaping is applicable to the PAR reduction of OFDM signals. In this paper, we propose a new trellis mapping system with a branch metric based on the autocorrelation of the data sequence designed for the band-limited SFBC OFDM signal. Since the autocorrelation of the data sequence (in frequency domain) and the power spectrum (in time domain) form a Fourier transform pair, minimizing the side lobe of the autocorrelation in the data sequence may help flattening the dynamic range of the band limited OFDM signals. The branch metric of the trellis shaping decoder is devised such that the Viterbi algorithm is applicable for this purpose.

It should be noted that the proposed system does not reduce the bandwidth efficiency, but it also expands the constellation size similar to the Tone Injection method in [16]. While the approach in [16] may typically increase the required average power that reduces the PAR for a given minimum Euclidean distance signal constellation.



(a)



(b)

Fig.2. Trellis shaping SFBC-OFDM system; (a) transmitter (b) receiver

3.1 PROPOSED METHOD I

The trellis mapping system block diagram is described in Fig.2. The convolutional code is designed as C with code rate $1/n$, generator matrix G and F parity check matrix. In this study simple ½ convolutional code design is consider. Suppose binary data d of length $N * \log M$ is divided into two sub clock of every symbol say Ms and Ls. N is number of subcarrier, MSB and LSB bits are denoted by Ms and Ls respectively. First, Inverse syndrome former $(F^{-1})^T$ is used to encode Ms bits and generate n bit sequence z as follow: $z = Ms\,(F^{-1})^T$

Select y from convolutional valid code word set C and modulo-2 add with z as: $Cm = z \oplus y$, where $y \in C$. The data sequence Ms can be retrieve by the syndrome former as,

$$(z \oplus y)\, F^T = Ms\,(F^{-1})^T F^T \oplus \mathrm{y} \cdot F^T = Ms \oplus 0 = Ms.$$

Since for any valid code ward y:

$$y \cdot F^T = 0 \tag{9}$$

Proposed method has used the “Type-I” constellation mapping from [17], applied, where the constellation in each sub region is designed to employ Gray mapping such that the bit error rate of uncoded system is minimized.

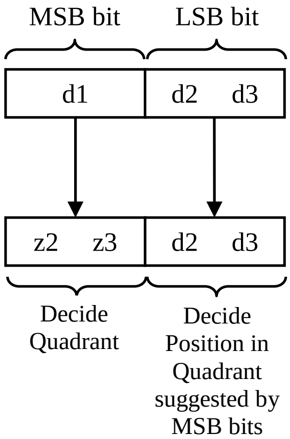


Fig.3. k^{th} symbol mapping using trellis shaping

Trellis shaping of k^{th} data symbol of N subcarrier of OFDM symbol shown in Fig.3. The z_1z_2 is encoded bits of the MSB bit $d_1$of k^{th} data symbol by $(F^{-1})^T$. The role of encode MSB bits will select quadrant and LSB bits locate the point on selected quadrant. This means that MSB bits will play very important role to influence PAR by flipping the most significant bit (MSB) using binary sequence y. According to property of inverse syndrome former Eq.(9) shaping side information need not to be transmitted at the receiver. Now the design of metric calculation used in the (shaping) Viterbi decoder is very crucial to reduce PAR.

In this section, we derive a metric that can be used for reducing the autocorrelation side lobes of SFBC-OFDM data sequence in conjunction with the Viterbi algorithm.

3.1.1 Autocorrelation Function of SFBC - OFDM Symbol:

Representation of the SFBC-OFDM signal from Eq.(1) for two transmitting antenna $i = 1, 2, \ldots$ shows that,

$$x_i^2(n) = \frac{1}{\sqrt{N}} R_{i0} + \frac{2}{N} \sum_{m=0}^{N-1} \left|R_{im}\right| \cos\left(\frac{2\pi mn}{N} + \arg R_{im}\right) \tag{10}$$

where, aperiodic autocorrelation R_{im} is the i^{th} transmitter complex data sequence $A \in Q$ mapper, defined as:

$$R_{im} \triangleq \sum_{k=0}^{N-1-m} X_{k+m} Y_k^* \tag{11}$$

The first term of Eq.(10) is the direct current component, while the second term represents the fluctuation of the SFBC OFDM signal which affects on PAPR .

Now, selecting a code word $y_k \in C$ such that minimizing autocorrelation sidelobes and due to this property, the OFDM signal modulated by this set of sequence results in waveform with little fluctuation or very low PAPR. Hence need to finding optimum y requires the entire search over C. We shall develop a metric design such that the Viterbi algorithm can be applied for the search of y.

3.1.2 Metric Design for Viterbi Algorithm:

The square of the absolute value of the side lobes is minimized by following condition.

$$y = \mathbf{arg} \max_{i=1,2} \mathbf{arg} \min_{y_k \in C_s} \sum_{m=0}^{N-1} \left|R_{im}\right|^2 \tag{12}$$

Recursive process can be used to minimize process. The number of subcarriers controlled by each shaping symbol $y_k \oplus z_k$ denote by n. selection of shaping symbol is chosen according to Eq.(11). At the k^{th} stage the shaping symbol y_k is chosen according to,

$$y_k = \mathbf{arg} \max_{i=1,2} \mathbf{arg} \min_{y_k \in C_s^k} \mu^j \tag{13}$$

where, k is shaping symbol index increases as $k = 1, 2, \ldots, N/n-1$and C^k is a k^{th} set of output encoding symbols of the shaping code C and μ^j is defined as,

$$\mu^j = \sum_{m=1}^{N-1} \left|R_{im}^j\right|^2 \tag{14}$$

where, i is number of transmiting antennas and R^j_m is the a periodic autocorrelation function of the complex data sequence of length j, i.e.

$$A^j \triangleq \{A_0, A_0, \ldots, A_{M-1}\} \in Q_{iM}^j$$

Note that the recursive process terminates at $j = N$ as index j is the total number of subcarriers processed up to the k^{th} stage of both SFBC code and is given by $j = (k+1)n$. For SFBC we consider $n = 1$ and $i = 1, 2$. An additive recursive structure of the metric μ^j in conjunction with the Viterbi algorithm can be easily derived:

For first transmitting antenna $i = 1$

$$R_{1m}^{j} = R_{1m}^{j-1} + \delta_{1m}^{j-1} \tag{15}$$

where, $\delta_{1m}^{j} = A_j A_{j-m}^{*}$ (A belongs to X_1)

For second transmitting antenna i = 2

$$R_{2m}^{j} = R_{2m}^{j-1} + \delta_{2m}^{j-1} \tag{16}$$

where, $\delta_{2m}^{j} = A_j A_{j-m}^{*}$ (A belongs to X_2)

Computed and tabulated beforhand all possible values for δ_{1m}^{j} for i = 1, 2 for computational complexity reduction. Substitute this in Eq.(14). can be expressed in follwing recursive form:

For transmiting antenna 1,

$$\mu_1^{j} = \mu_1^{j-1} + \sum_{m=1}^{j-2} 2\Re\left\{\Re_{m1}^{j-1} * \delta_{m1}^{j-1}\right\} + \sum_{m=1}^{j-2}\left|\delta_{m1}^{j-1}\right|^2 \tag{17}$$

For transmiting antenna 2,

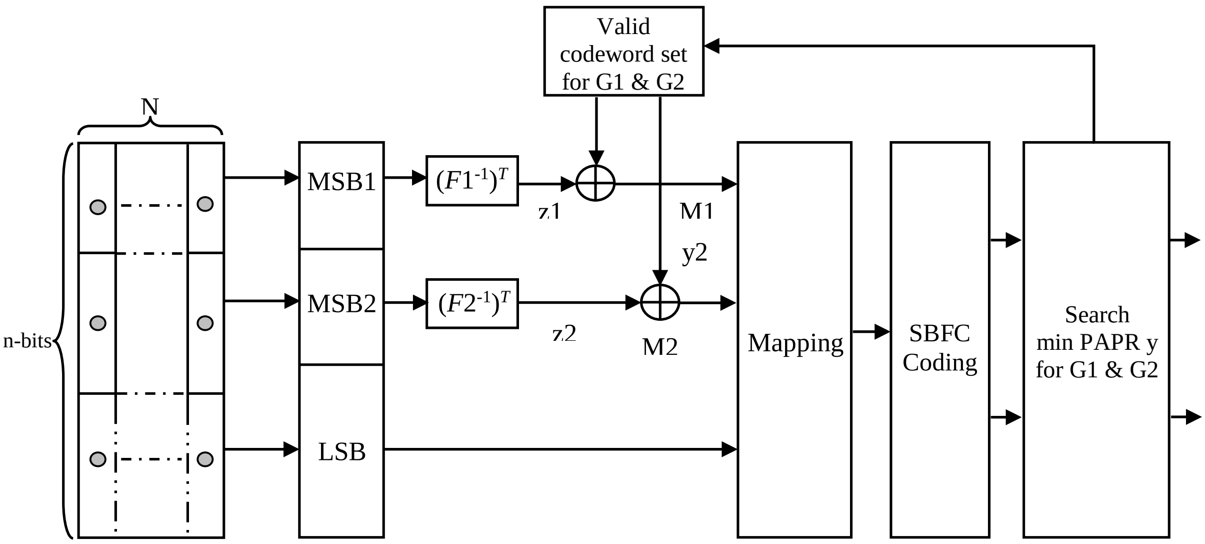
$$\mu_2^{j} = \mu_2^{j-1} + \sum_{m=1}^{j-2} 2\Re\left\{\Re_{m2}^{j-1} * \delta_{m2}^{j-1}\right\} + \sum_{m=1}^{j-2}\left|\delta_{m2}^{j-1}\right|^2 \tag{18}$$

In the right-hand side of Eq.(17)and Eq.(18), the third term is a function of the power of subcarrier symbols, which remains constant for the mapping regardless of the chosen path. Therefore, it can be omitted for mapping strategies without average power reduction capability.

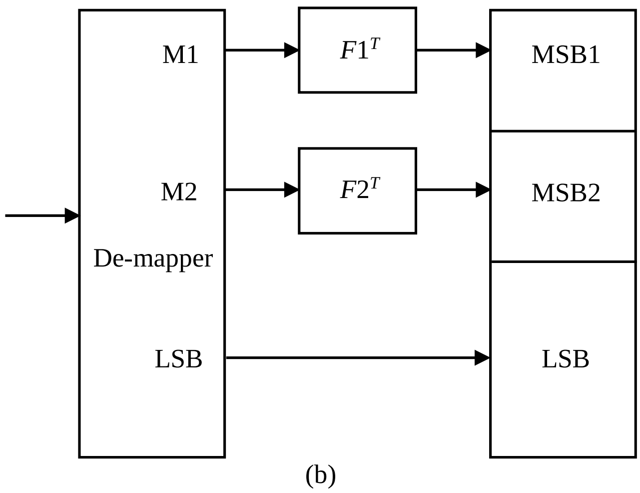
After the minimum path for each state is chosen by the Viterbi algorithm, the autocorrelation can be revised based on Eq.(15) and Eq.(16), where $\Re_{m1,2}^{j-1}$ and $\delta_{m1,2}^{j-1}$ are those attributed to the chosen path.

This value can be used for the recursive calculation of the next metric μ_1^{j+1} in Eq.(17) and μ_2^{j+1} in Eq.(18). Note that, unlike the conventional Viterbi decoder for convolutional codes, the calculation of Eq.(17) and Eq.(18) requires that each state should store and refer to all the past subcarrier symbols associated with the chosen path.

Thus, the complexity of metric calculation required for the proposed algorithm is considerably higher than that of a typical Viterbi decoder. But in SFBC system symbols and their complex conjugate symbols on successive subcarriers. So y can be search on every two subcarriers i.e. we need only N/2 search.



(a)



(b)

Fig.4. Two level trellis shaped SFBC OFDM System (a) Generation (b) Degeneration

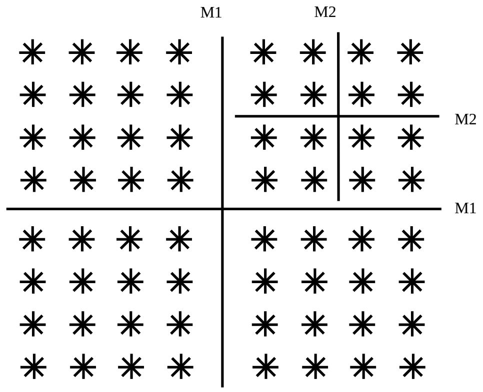


Fig.5. Two Level Search Constellation

3.2 PROPOSED METHOD II

The Trellis shaping bit are forward error correction parity bits, helps to detect and correct data at receiver but these bits help to shape constellation in such a way that to reduce PAPR just like in tone injection method. This means transmitting a certain amount of redundant data which is help to reduce PAPR as well as BER, while decodable at the receiver. As this data is encoded using a Convolutional, or Trellis code, the underlying method is termed Trellis mapping.

In method I, Sign Bit Shaping is the simplest form of Trellis Shaping. Only the first 2 bits of the transmitted constellation are modified by the shaping code, while the rest remain unaffected i.e. $z = Ms(F^{-1})^T$. If this constellation is labelled using standard Grey mapping, then the first two bits are in charge of the sign of the real and imaginary parts of the symbol, and are thus called the sign bits. So symbols change one quadrant to another depends on selection of y. i.e. $Cm = z \oplus y$. As the code word does not affect the information transmitted, so it can be chosen to minimize the transmit power. In this method it has been only changed the quadrant of symbol to minimize peak power but the reduction is up to certain limit. So, proposed method II, finds second level search of symbol within quadrant for reducing the PAPR. The block diagram of transmitter and receiver is shown in Fig.4.

In this method, two ½ convolutional code generator matrix G_1 and G_2 and their parity check matrix F_1 and F_2 are designed respectively where $y_1 \in C_1$, $y_2 \in C_2$ and C_1 and C_2 are valid set of codeword generated by G_1 and G_2 respectively. The most significant bits MSB_1 and MSB_2 shown in Fig.4 encoded as:

$$z_1 = MSB_1\,(F_1^{-1})^T \tag{19}$$

$$z_2 = MSB_2\,(F_2^{-1})^T \tag{20}$$

Search y_1 and y_2 from their valid code ward set and modulo-2 add with z_1 and z_2 respectively as shown follow: $M_1 = z_1 \oplus y_1$ and $M_2 = z_2 \oplus y_2$.

In this method two most significant bits i.e. M_1 will be select first level quadrant by proper selection of y_1 using minimum power search Viterbi algorithm metric like in proposed I and then in selected quadrant by M_1 made 4 regions as shown in Fig.5. **Error! Reference source not found.**The M_2 bits will select sub quadrant. The M_2 bits will decide sub quadrant by proper selection of y_2 and remaining LSB bits will locate symbol position according to type 1 constellation [17]. This method is applicable for higher modulation like 128 QAM, 256 QAM, etc. The two convolutional codes C_1, C_2 used in this method can be same.

In SLM technique the set of phase select minimum PAPR signal. Side information needed for detection of original signal at receiver. Here in this trellis shaping technique set of 256 constellation point as phase set so 128 QAM constellation map on 256 constellation point according to selection of y_1, y_2 and LSB bits.

4. RESULT ANALYSIS

In this section, we evaluate the performance of the proposed trellis shaping approach by computer simulation. In the simulation, the band-limited SFBC-OFDM signal is generated by oversampling factor of 4. As a shaping encoder, a simple 4-state convolutional code with maximum free distance is employed. However shaping performance may not significant effect for the choice of convolutional codes.

As figure of the complementary cumulative distribution function (CDF) of the peak to average power is obtained in Fig.6 with 256 subcarriers and each subcarrier is modulated by the 256-QAM (rectangular) constellation with Gray mapping. In the simulation following set of parameter are considered OF SFBC MIMO OFDM system for result analysis.

4.1 PAPR REDUCTION

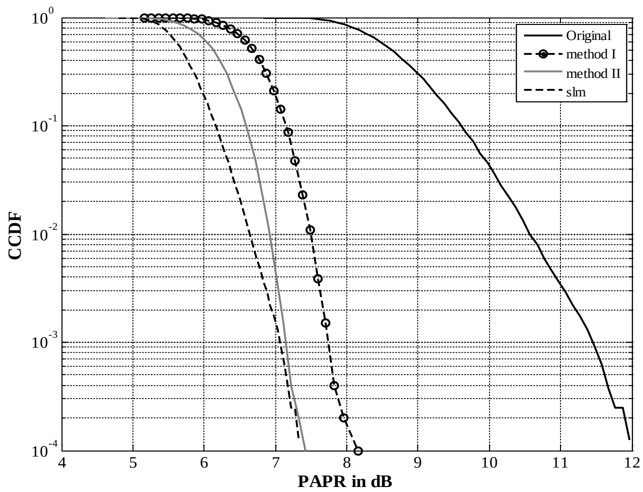


Fig.6. Complementary cumulative distribution of the 256-QAM-modulated 256-subcarrier SFBC OFDM signals using the 4-state trellis shaping

Table.1. System Parameters

Convolutional code rate	½ simple design
Number of Transit	2
Receive Antennas	2
Modulation	256 QAM
Channel	AWGN + Rayleigh fading
Channel estimation	Yes
Number of subcarriers	256
Oversampling Factor	4
Detection Method	ZF

As observed in Fig.6, the proposed shaping can significantly mitigate the occurrence of high peak power, and the method II offers better performance than the method I. SLM and method II have very little difference. It is observed that the method I shaping can achieve a PAP reduction of approximately 4 dB at 10^{-4} CCDF. SLM and Method II give same PAPR reduction above 7 dB.

Table.2. Comparison of different PAPR algorithms

Method	PAPR at 10^{-3} dB	BER at SNR 20 dB
Original	11.4	10^{-2}
SLM	7.1	$10^{-1.9}$
Proposed I	7.7	$10^{-2.9}$
Proposed II	7.12	$10^{-3.3}$

4.2 BER PERFORMANCE

The BER performance of the SFBC OFDM system with 2 transmitters and one receiver is shown in Fig.7. In the following simulation, ZF detection and the Rayleigh fading channels is used. Note that the proposed method-I is used 256-QAM with sign-bit shaping can transmit 7 bits per subcarrier, which is equivalent to that of 128-QAM without shaping. For method-II two levels sign-bit shaping is used. So in the method-II, 256-QAM with two level of bit shaping is used. It will transmit 6 bits per subcarrier, which is equivalent to that of 64-QAM without shaping. Due to trellis shaping method I & II give better performance than original SFBC system and SLM technique. Method I & II have approximately same bit error rate upto 20 dB and then Method I degrade performance. Due to higher modulation SLM and simple SFBC OFDM technique degrade performance than proposed methods.

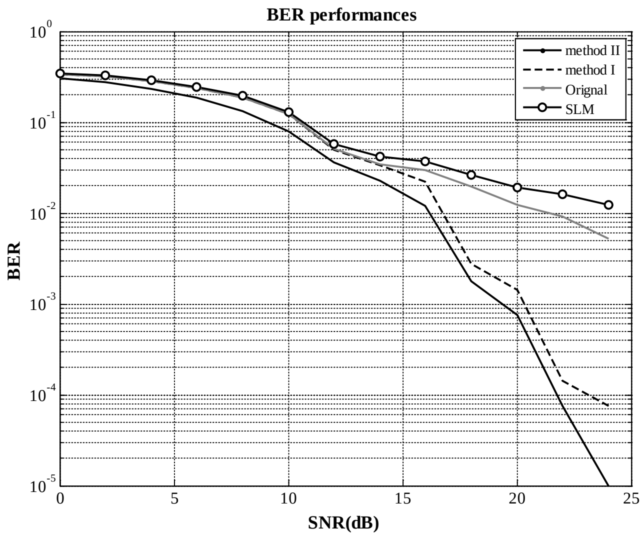


Fig.7. BER performances with 256-QAM over Rayleigh fading channel

The Table.1 shows comparative study of all algorithms. SLM and method II give same PAPR 7 dB but method II give better performance than SLM. Method I and II transmit 1 and 2 bit less per symbol respectively than SLM technique and SLM technique required side information But It is interesting to note that for method I & II no side information is required to detect the signal at receiver.

5. CONCLUSION

Proposed trellis mapped method II give good PAPR reduction with reduced bit error rate. In proposed method no side information needed to be transmitted to the receiver to recover original data. In SFBC system for every two subcarrier once it needs to search of y i.e. for N subcarrier only $N/2$ search in every level. So, search complexity of two level trellis shaping is same as one level trellis shaping in simple OFDM system.

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