Low Complexity PTS and SLM Techniques on PAPR Reduction in SFBC MIMO-OFDM Systems

Burugupalli Kasi Babu, V. Chaitanya Kumar and P. M. K. Prasad

Department of Electronics and Communication Engineering, GMR Institute of Technology, GMR Nagar, Srikakulam District, Razam 532127, Andhra Pradesh, India; kasi241191@gmail.com, chaitu@cdot.in, mkprasad.p@gmrit.org

Abstract

MIMO-OFDM is an attractive technique for higher data rate transmission and even for fading channels. The signals suffer from high PAPR; it is the drawback of MIMO-OFDM. For ease of accessibility, the MIMO-OFDM systems are employed with SFBC. To reduce the PAPR, the traditional PTS scheme employ directly to every transmitter, but high computational complexity is associated with it. In this paper, the proposed PTS schemes and SLM scheme with QPSK and QAM modulated data are divided into several pairs of blocks based on the way in which original data is divided at two antennas and how each pair of sub-block is modified to generate distinguish pair of new sub different blocks. Thus obtained new sub different blocks are clubbed to induce PTS containing same structure and the diverse potential as of the SFBC. Later, selected sequences having the smaller PAPR are selected and transmitted. Simulated results show, the Type-I PTS scheme and SLM scheme with QPSK modulated data signal have almost similar result which achieves superior PAPR response and Bit Error Rate response when correlated with other schemes with QAM and QPSK modulated signals.

Keywords: Peak to Average Power Ratio - PAPR, Partial Transmit Sequences - PTS, Selected Mapping Sequence - SLM, Spatial Frequency Block Code - SFBC

1. Introduction

OFDM is an efficient encoding technique for digital data, when applied on different carrier frequencies, provides robustness opposite to the fading channels. The OFDM and MIMO together which is MIMO-OFDM ended up a standout amongst the most appealing technique for broadband wireless communications. For accessibility and simplicity, the Spatial Frequency Block Code (SFBC) is utilized in MIMO-OFDM frameworks. MIMO-OFDM with SFBC increases its attention to time selective fading channels because of its robustness. The primary drawback in MIMO-OFDM with SFBC is that the signals may experience the ill effects of a high value of PAPR. A high value of PAPR denotes high power inefficiency and moreover, the nonlinearity leads to distortion in in-band, which increases the BER value and radiation in out of band. To tackle this high PAPR issue, numerous PAPR reduction techniques have proposed earlier, such as low complexity PTS\textsuperscript{1–4}, multi-carrier transmission\textsuperscript{5}, Adaptive Partial Transmit Sequences (PTS)\textsuperscript{6}, OFDM\textsuperscript{7–10,13,14}, SFBC MIMO-OFDM\textsuperscript{12}, Selected Mapping Sequence (SLM)\textsuperscript{16}.

The ACE method, in addition is agreeable since it diminishes the peak power of OFDM signals with the extension of some modulation constellation points without any loss of data rate towards the outside of the constellation. For systems like MIMO-OFDM, the method\textsuperscript{5} cooperative PTS (co-PTS) makes use of spatial sub-block partition and then to find the signal, it uses alternate optimization with the low value in Peak to Average Power Ratio (PAPR). In spite of fact that, for MIMO-OFDM frameworks co-PTS scheme is capable of PAPR reduction, for peak power estimation, it must consider all the samples of each signal. In deviance to PTS method, usually the ACE system has superior PAPR reduction for the receiver it does not send any side information data. Furthermore, the ACE technique makes effective use of a complex repeated filtering and clipping with snag in power. Moreover, whenever
the ACE system is smeared on input signal of an individual transmitter in MIMO-OFDM frameworks with SFBC, destroying orthogonality of signals. In this paper, two low complexity PAPR reduction scheme such as PTS and SLM techniques for MIMO-OFDM SFBC systems are propound with QAM & QPSK modulated data. To be specific 16 bit QAM & QPSK modulated data is used for both PTS I&II Techniques. To divide data input blocks evenly into various sub different blocks, these proposed two PTS Schemes use different methods of sub-block partition. The cost function is assessed by adding the time index in sub blocks with same power of samples. Only the samples having cost function value exceeded a predefined threshold value are considered in estimating the PAPR of the test signals. The complexity is thus minimized in peak power estimation by using the selected samples. Simulation results show that the proposed QPSK PTS-I technique and QPSK SLM technique can achieve a good PAPR and QPSK PTS-I has better BER performance compared to other proposed techniques with reduced computational complexity. The entire work is done at Centre for Development of Telematics (C-DOT), Bangalore.

2. Background

MIMO utilizes numerous transceivers. As in a given bandwidth MIMO permits more bits/sec, it has high spectral efficiency and also mean while supports more users with data-rate higher. The data rates higher, expanded spectral efficiency and capacity to build data with not using extra transmit power or extra bandwidth, made MIMO particularly appealing for using in wireless communication frameworks. In MIMO wording, the I/p and O/p are attributes a wireless channel, which incorporates the antennas at the receiving end. Performance gains are accomplished as different transmitters transmit the information signals into wireless channel and same signals receive at receiver o/p.

For simplicity, the paper concentrates on MIMO-OFDM frameworks with 2 transceivers. This paper considers the MIMO-OFDM SFBC framework which uses Alamouti method. In systems like MIMO-OFDM SFBC with 2 transceivers, the data input block $X = [X_0, X_1, ..., X_{N-1}]^T$ with the Alamouti space-frequency encoder is encoded into two vectors, as shown below:

$$X_{1,SFBC} = [X_0, -X_1^*, ..., X_{N-2,-}, -X_{N-1}]^T$$

$$X_{2,SFBC} = [X_1, X_0^*, ..., X_{N-1}, X_{N-2}]^T$$

(1)

Where number of subcarriers ‘N’ and $(·)^*$ indicates the complex conjugate function. The continuous-time OFDM signal of Xi for $i = 1, 2$ can be referred as

$$x_i(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_{ik} e^{j2\pi k\Delta f}, 0 \leq t \leq T$$

(2)

Where $X_{ik}$ denotes the modulated kth subcarrier for $k = 0, 1, ..., N-1$ in transmitter $T_x_i$ with $i = 1, 2$, ‘T’ is the symbol duration in OFDM and ‘$\Delta f$’ is the subcarrier frequency gap.

![Figure 1. Diagram of conventional PTS scheme.](image)

The ratio of the maximum power to the average power of $x(t)(2)$ and is denoted as

$$PAPR = \max_{0 \leq t \leq T} \frac{|x(t)|^2}{E[|x(t)|^2]}$$

(3)

Where $E[·]$ signifies the function expected value. The discrete OFDM time signal $x_i = [x_{i0}, x_{i1}, ..., x_{iN-1}]^T$ in transmitter $T_{x_i}$ is usually got by sampling $x(t)$ with the $N/T$ rate and it is as shown below.

$$x_{i,n} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_{ik} e^{j2\pi kn/N}, n = 0,1,...,N-1$$

(4)

(4) Can be computed by performing a N-point IFFT. The PAPR evaluated from the samplings by taking L equal to 4 times oversampling can precisely related to (3). Since the two signals $x_1$ and $x_2$ are correlated and transmitted at
same time from antennas $T_{X_1}$ and $T_{X_2}$, respectively, the PAPR of MIMO-OFDM SFBC networks can be computed together as

$$PAPR\{x_1, x_2\} = \max \{PAPR(x_1), PAPR(x_2)\}$$  \hspace{1cm} (5)

The principal objective is to consolidate sub-blocks ‘M’ in getting the least PAPR in time domain signals. Withholding any significant decrease in the proposed results, one can approximate $b_1 c = 1$ and notice that the number of sub-blocks whose performance can be improved are $M-1$. Hence, the number of combinations to be checked for obtaining the minimum PAPR in order to accomplish the optimal phase factor for each i/p data sequence is $W^{M-1}$. So, the complexity for an optimal set of the phase factors increments exponentially. So, alternate optimization is used in decreasing the number of rotation factor multiplications in order to increase no. of signals and uses spatial sub-block circular permutations between antennas.

3. PTS Schemes with QAM and QPSK Modulated Data

The PAPR issue for MIMO-OFDM SFBC frameworks is determined by the two PTS schemes with QAM & QPSK modulated information. The PTS-I&II schemes with $N_T$ equal to 2 transmitting antennas and $N = 128$ subcarriers is examined. The Type-I scheme utilizes random data and Type-II scheme produces the random test signals in time domain & utilizes the relation among frameworks between the two antennas. The random test signals of the 2 antennas are not generated values in the frequency but rather generated values in time domain to reduce the complexity considering number of properties in time domain system.

3.1 Type-I PTS Scheme with QAM and QPSK Modulated Data

In the PTS-I scheme, SFBC MIMO-OFDM frameworks, conventional PTS scheme is applied for every transmitting antenna. The primary difference between conventional PTS and Type-I PTS scheme is we use rotational factors in PTS Type-I. The i/p data block $X_{i1}$ was initially separated evenly into $M_b$ sub-disjoint blocks, expressed as

$$X_{i,m} = [X_{i,m,0}, X_{i,m,1}, \ldots, X_{i,m,N-1}]^T$$  \hspace{1cm} (6)

Where $I = 1, 2 \& 1 \leq m \leq M_b$. The $C_{i\alpha}$ test signal $X_{i\alpha} = [X_{i\alpha,0} \ldots X_{i\alpha,N-1}]^T$ framed by utilizing sub-blocks of $X_{i,m}$, which is denoted as

$$x_{i\alpha} = \sum_{n=1}^{M_b} b_{i,m,n} IFFT \{X_{i,m,n}\} = \sum_{n=1}^{M_b} b_{i,m,n} IFFT \{X_{i,m,n}\} = \sum_{n=1}^{M_b} b_{i,m,n} x_{i,m,n}$$  \hspace{1cm} (7)

Where $x_{i,m,n} = IFFT\{X_{i,m,n}\}$ and $i = 1, 2$. $b_{i,m,n}$ is rotational factor chosen from set $W = \{e^{j\theta}; i = 0, 1, \ldots, W-1\}$ for interval $1 \leq \alpha \leq C_i$ where $C_i (\leq W^{M_b})$ data signals number for each antenna.

By utilizing min max criterion, from $C$ data signals the optimal output signal $X_{i\alpha}^{opt}$ for $i = 1, 2$ is chosen, indicated as

$$[X_{i1}^{opt}, X_{i2}^{opt}] = \min_{1 \leq \alpha \leq C_i} \{\max \{PAPR(x_{i1}), PAPR(x_{i2})\}\}$$  \hspace{1cm} (8)

To compute optimum signals, only peak power of each data signal is required. In this way, a cost function is assessed for selecting the optimum signals.

![Figure 2. Diagram of PTS-I scheme.](image)

The cost function of an antenna $T_{X_i}$ is characterized as

$$Q_{i,n} = \sum_{m=1}^{M_b} |x_{i,m,n}|^2, n = 0, 1, \ldots, N-1$$  \hspace{1cm} (9)

Where $x_{i,m,n}$ is sample in $X_{i,m}$ situated for $i=1,2$at the time n. To evaluate peak power of data signals, the samples having value cost function more than set threshold value $(\alpha_0)$ is utilized for the antenna $T_{X_i}$. Thus, the computational complexity decreases during the optimization process.
3.2 Type-II PTS Scheme with QAM and QPSK Modulated Data

In the PTS-II scheme, the relationship between $X_1$ and $X_2$ (1) is utilized and also utilizes adjacent interleaving method for selecting samples. The two information signals $X_1$ and $X_2$ are divided into odd and even parts, which are defined as

$$
X_1^O = \begin{bmatrix} X_0, 0, X_2, \ldots, X_{N-2}, 0 \end{bmatrix}^T
$$

$$
X_1^E = \begin{bmatrix} 0, -X_1^*, 0, \ldots, -X_{N-1}^* \end{bmatrix}^T
$$

$$
X_2^O = \begin{bmatrix} X_1, 0, X_3, \ldots, X_{N-1}, 0 \end{bmatrix}^T
$$

$$
X_2^E = \begin{bmatrix} 0, X_0^*, 0, \ldots, X_{N-2}^* \end{bmatrix}^T
$$

(10)

Where $X_1^*$ and $X_1^O$ represent even and odd parts respectively for $i=1,2$. $X_2^E$ is attained after performing right shift and conjugate operation on $X_2$. Likewise by perform shift left operation, negate operation and conjugate operation on $X_1^O$, the $X_1^E$ is acquired. The above four signals are gets separated into $M$ sub block by utilizing adjacent sub-block partitioned techniques.

Each and every sub block is partitioned as $X_{i,m}$ with $e = 0,1$ and $1 \leq m \leq M$; $i = 1,2$. For instance, if $M=2$, the sub-blocks got from $X_1$ and $X_2^O$ for the antenna $TX_1$ is expressed as

$$
X_{1,1}^O = \begin{bmatrix} X_0, 0, \ldots, X_{N/2-2}, 0, \text{zeros} (N/2) \end{bmatrix}^T
$$

$$
X_{1,2}^O = \begin{bmatrix} \text{zeros} (N/2), X_{N/2}, \ldots, X_{N-2}, 0 \end{bmatrix}^T
$$

$$
X_{1,1}^E = \begin{bmatrix} 0, -X_1^*, \ldots, 0, -X_{N/2-1}^*, \text{zeros} (N/2) \end{bmatrix}^T
$$

$$
X_{2,2}^E = \begin{bmatrix} \text{zeros} (N/2), 0, -X_2^*, \ldots, 0, -X_{N-1}^* \end{bmatrix}^T
$$

(11)

where $(N/2)$ zeros represents the vector containing zeros $N/2$. Likewise, sub-blocks acquired from $X_2$ and $X_2^O$ in transmitting antenna $TX_2$ are denoted as

$$
X_{2,1}^O = \begin{bmatrix} X_1, 0, \ldots, X_{N/2-1}, 0, \text{zeros} (N/2) \end{bmatrix}^T
$$

$$
X_{2,2}^O = \begin{bmatrix} \text{zeros} (N/2), X_{N/2+1}, \ldots, X_{N-1}, 0 \end{bmatrix}^T
$$

$$
X_{2,1}^E = \begin{bmatrix} 0, X_0^*, \ldots, 0, X_{N/2-1}^*, \text{zeros} (N/2) \end{bmatrix}^T
$$

$$
X_{2,2}^E = \begin{bmatrix} \text{zeros} (N/2), 0, X_0^*, \ldots, 0, X_{N-2}^* \end{bmatrix}^T
$$

(12)

At that point, for input data block $X$, the $c$th test signal framed for utilizing the sub-blocks obtained in (10) denoted as

$$
X^c_{i,m} = \text{IFFT}\{ b^{c,0}_{i,m} X^0_{i,m} + b^{c,1}_{i,m} X^1_{i,m} \}
$$

$$
= \sum_{m=1}^{M} \text{IFFT}\{ b^{c,0}_{i,m} X^0_{i,m} + b^{c,1}_{i,m} X^1_{i,m} \}
$$

$$
= \sum_{m=1}^{M} \sum_{e=0}^{1} b^{c,e}_{i,m} \text{IFFT}\{ X^e_{i,m} \} = \sum_{m=1}^{M} \sum_{e=0}^{1} b^{c,e}_{i,m} X^e_{i,m}
$$

(13)

Where $x^e_{i,m} = \text{IFFT}\{ X^e_{i,m} \} = [ x^e_{i,m,0}, x^e_{i,m,1}, \ldots, x^e_{i,m,N-1} ]^T$ represents the IFFT of sub-block $X^e_{i,m}$; $1 \leq m \leq M$; $e = 0,1$ and $i = 1,2$. $b^{c,e}_{i,m}$ is rotation factor of sub-block $x^e_{i,m}$ for $1 \leq c \leq C$. By utilizing (8), the output signal $X^c_{i,m}$ for $i = 1,2$ are computed. In the PTS-II scheme with various modulated data, the cost function $Q_{i,n}$ of the sample in the transmitting antenna $TX_i$ located at time $n$ is characterized by

$$
Q_{i,n} = \sum_{m=1}^{M} \left( |x^0_{i,m,n}|^2 + |x^1_{i,m,n}|^2 \right)^2, n = 0,1,\ldots, N-1
$$

(14)

Where $x^0_{i,m,n}$ and $x^1_{i,m,n}$ are samples of $x^0_{i,m}$ and $x^1_{i,m}$. Moreover, by utilizing the property of time domain signal $x^0_{i,m}$ and $x^1_{i,m}$ has the form,

$$
\hat{x}^0_{i,m} = \begin{bmatrix} \hat{x}^0_{i,m,0}, \hat{x}^0_{i,m,1}, \ldots, \hat{x}^0_{i,m,N-1} \end{bmatrix}^T
$$

$$
\hat{x}^1_{i,m} = \begin{bmatrix} \hat{x}^1_{i,m,0}, \hat{x}^1_{i,m,1}, \ldots, \hat{x}^1_{i,m,N-1} \end{bmatrix}^T
$$

(15)

For $1 \leq m \leq M$ and $i = 1,2$, where $\hat{x}^e_{i,m}$ indicates the vector which contains set of first half of elements of $x^e_{i,m}$ for $e = 0,1$. Hence, it can be simple to calculate the cost function vector $Q = [Q_{i,0}, Q_{i,1}, \ldots, Q_{i,N-1}]^T$ is of the form...
\[ Q_i = \begin{bmatrix} Q_1 & Q_2 \end{bmatrix} \]  

Where \( Q_i \) signifies the first half of elements of \( Q_i \). Hence, it’s required to calculate only \( Q_{i,n} \) for \( n = 0, 1, \ldots, N/2 - 1 \) by (14). And, sub-blocks of \( X_{2,m,n} \) can be calculated from \( f_{i,n} \). Since, \( Q_{i,n} \) is produced by time domain signals \( x_{i,m,n} \), the relation among \( Q_1 \) and \( Q_2 \) can get by performing the IFFT linear & shift properties, which is representing shown below.

\[ Q_2 = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ 0 & 0 & \cdots & 1 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 1 & \cdots & 0 \end{bmatrix} Q_1 = JQ_1 \]  

(17)

From equations (16) and (17), only \( N/2 \) components of \( Q_i \) are processed by (14). In this manner, the overhead to generate cost function gets reduced. The cost functions in \( Q_1 \) and \( Q_2 \) are utilized to choose samples. A vector called flag \( f_i = \begin{bmatrix} f_{i,0}, f_{i,1}, \ldots, f_{i,N-1} \end{bmatrix} \) for \( i = 1, 2 \) is utilized for storing examined results of the cost function \( Q_{i,n} \) and set threshold value \( \alpha_{TH} \), in which the elements of \( f_i \) are characterized as

\[ f_{i,n} = \begin{cases} 1, & \text{if } Q_{i,n} \geq \alpha_{TH} \\ 0, & \text{if } Q_{i,n} < \alpha_{TH} \end{cases} \]  

for \( n = 0, 1, \ldots, N - 1 \)  

(18)

At last, the samples \( X_{i,n} \) with \( f_{i,n} = 1 \) was only used in peak power estimating of data signals.

### 4. SLM Scheme with QAM and QPSK Modulated Data

The fundamental idea of SLM technique is to generate test signals based on many OFDM symbols and then selecting one with the lower PAPR value for transmission. Conventionally, the transmission of side information is necessary to find out the signal selected for transmission.

The algorithm is described as mentioned in below steps:

1. To produce sequence symbols \( L_0, L_1, \ldots, L_i \) the constellation points BPSK or M-QAM are mapped to input sequence of data bits.
2. Sequences are divided into blocks of length ‘N’.
3. Every block \( L_i = [L_{0,i}, L_{1,i}, \ldots, L_{N-1,i}] \) is multiplied by 'I' different phase vector sequence.
4. A set of 'I' different data OFDM blocks \( L^{(i)} = [L_{0,i}, L_{1,i}, \ldots, L_{N-1,i}] \), \( i = 1, 2, \ldots, I \).
5. Convert \( L^{(i)} \) into signal time domain to get \( l^{(i)} = \text{IDFT}[L^{(i)}] \).
6. Choose the best from \( l^{(i)} \), \( i = 1, 2, \ldots, I \); which has low PAPR and transmit to receiver.

After removing the first column and first row of matrix A, we will get the Riemann matrix as follows

\[ A(c, d) = \begin{cases} c - 1, & \text{if 'c' divides 'd'} \\ -1, & \text{otherwise} \end{cases} \]

If the size of Riemann matrix (R) is \( K \times K \), then the (B) normalized matrix entries will be \( (1/K) \times R \). The side information is never required to send to receiver for this technique because the receiver can generate the Riemann matrix since it has a particular structure. Moreover, extra scaling \( 1/K \) required in order to obtain normalized matrix.

![Figure 4. Block diagram of SLM.](image-url)

The following below CCDF represents the probability that PAPR exceeds ‘m’ threshold,

\[ F_{Z_{\text{max}}} (m) = P(M_{\text{max}} > m) = 1 - P(M_{\text{max}} < m) = 1 - F_{Z_{\text{max}}} (m) \]  

(19)

The CCDF of PAPR will be of form, when each mapping considered as statically independent

\[ P(M_{\text{max}} > m) = F(m)^N = (1 - (1 - e^{-m})^N) \]  

(20)

where \( M \) is any real no which is the threshold value.

### 5. Simulation Results

This paper has simulations for evaluating PAPR reduction and BER performances of the suggested schemes. The assumed data for simulations were 16-bit QAM, 16-bit QPSK modulated contained with N equal to 128
sub-carriers. For selecting the true PAPR value, we do oversampling by a factor of L equal to 4 for SFBC MIMO-OFDM signals. Here L equal to 4 times oversampling used for obtaining discrete time signals.

Figure 5 illustrates comparison of PAPR reduction performance with 2 Transmitting antennas for the type-I & II PTS schemes with different modulated data signals which are QAM and QPSK and SLM scheme with QPSK modulated data signal. It indicates that the SLM scheme with QPSK modulated signal has almost a good PAPR reduction performance when compared with type-I&II PTS schemes with QAM and QPSK modulated signal.

Figure 5. Analogy for PAPR type-I,II PTS and SLM.

Figure 6 shows the Bit Error Rate performance of SFBC MIMO-OFDM signal with both PTS and SLM Techniques. It has been observed from the figure 6 that the BER of the Type-I&II PTS with QPSK modulated signal is approximate $10^{-3}$ at SNR = 5 dB and the BER is increased to $10^{-4}$(approx.) at the SNR = 5 dB with Type-I & II PTS with QAM modulated signal. The BER value for SLM scheme is $10^{-3}$(approx.) at the SNR = 5 dB. Out of all techniques the Type-I PTS with QPSK modulated data signal gives good BER Performance.

6. Conclusion

For reducing the transmitted signals PAPR value in MIMO-OFDM SFBC systems, the SLM scheme and PTS schemes which are of low-complexity are proposed with 16-bit QAM and QPSK modulation. In MIMO-OFDM SFBC systems with 2 transmitting antennas, Simulation results show the Type-I PTS scheme and SLM scheme with QPSK modulated data signal have almost similar result which attains best PAPR response and Bit Error Rate response as compared to with other schemes with QAM and QPSK modulated signals.

7. References

1. Ku S–J. A Low-complexity PTS-based schemes for PAPR reduction in SFBC MIMO-OFDM systems. Institute of Electrical and Electronics Engineers (IEEE) Transactions on Broadcasting. 2014 Dec; 60(4):650–8.
2. Ku S–J, Wang C–L, Chen C–H. A reduced-complexity PTS-based PAPR reduction scheme for OFDM systems. Institute of Electrical and Electronics Engineers (IEEE) Transactions on Wireless Communication. 2010 Aug; 9(8):2455–60. Crossref
3. Hou J, Ge J, Li J. Peak-to-average power ratio reduction of OFDM signals using PTS scheme with low computational complexity. Institute of Electrical and Electronics Engineers (IEEE) Transactions on Broadcasting. 2011 Mar; 57(1):143–8. Crossref
4. Wang S–H, Li C–P. A low-complexity PAPR reduction scheme for SFBC MIMO-OFDM systems. Institute of Electrical and Electronics Engineers (IEEE) Signal Processing Letters. 2009 Nov; 16(11):941–4. Crossref
5. Wang L, Liu J. Cooperative PTS for PAPR reduction in MIMO-OFDM. Electronics Letters. 2011Mar; 47(5):351–2. Crossref
6. Han H, Lee JH. An overview of peak-to-average power ratio reduction techniques for multicarrier transmission. Institute of Electrical and Electronics Engineers (IEEE) Wireless Communications. 2005 Apr; 12(2):56–65. Crossref
7. Müller SH, Huber JB. OFDM with reduced peak-to-average power ratio by optimum combination of partial transmit sequences. Electronics Letters. 1997 Feb; 33(5):368–9. Crossref
8. Cimini LJ, Sollenberger NR. Peak-to-average power ratio reduction of an OFDM signal using partial transmits
sequence. Institute of Electrical and Electronics Engineers (IEEE) Communications Letters. 2000 Mar; 4(3):86–8. Crossref

9. Wu Y, Zou WY. Orthogonal frequency division multiplexing: A multi-carrier modulation scheme. Institute of Electrical and Electronics Engineers (IEEE) Transactions on Consumer Electronics. 1995 Aug; 41(3):392–9. Crossref

10. Lim DW, Heo SJ, No JS, Chung H. A new PTS OFDM scheme with low complexity for PAPR reduction. Institute of Electrical and Electronics Engineers (IEEE) Transactions on Broadcasting. 2006 Mar; 52(1):77–82. Crossref

11. Jayalath ADS, Tellambura C. Adaptive PTS approach for reduce of peak-to-average power ratio of OFDM signal. Electronics Letters. 2000 Jul; 36(14):1226–8. Crossref

12. Latinovic Z, Bar-Ness Y. SFBC MIMO-OFDM peak-to-average power ratio reduction by polyphase interleaving and inversion. Institute of Electrical and Electronics Engineers (IEEE) Communications Letters. 2006 Apr; 10(4):266–8. Crossref

13. Müller SH, Huber JB. OFDM with reduced peak-to-average power ratio by optimum combination of partial transmit sequence. Electronics Letters. 1997 Feb; 33(5):368–9. Crossref

14. Lee KF, Williams DB. A space-frequency transmitter diversity technique for OFDM systems. In the Proceedings of the Institute of Electrical and Electronics Engineers (IEEE) Global Telecommunications Conference (GLOBECOM). 2000 Nov 27 – Dec 1; 3:1473–7. Crossref

15. Alamouti SM. A simple transmit diversity technique for wireless communications. Institute of Electrical and Electronics Engineers (IEEE) Journal on Selected Areas in Communications. 1998 Oct; 16(8):1451–8. Crossref

16. Wang C–L, Ouyang Y. Low-complexity selected mapping schemes for peak-to-average power ratio reduction in OFDM systems. Institute of Electrical and Electronics Engineers (IEEE) Transactions on Signal Processing. 2005 Dec; 53(12):4652–60. Crossref