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# Modified PTS for PAPR Reduction in MIMIO-OFDM Wireless Systems

*By*
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## *Abstract*
Multicarrier modulation is an attractive technique for fourth generation wireless communication. Orthogonal Frequency Division Multiplexing (OFDM) is multi-carrier transmission scheme. Its high PAPR (Peak-to-Average Power Ratio) of the transmitted signal is a major drawback. We propose to reduce PAPR by probabilistic method of modified Partial Transmits Sequence (PTS), using forward error-correcting codes (FECs) such as Golay codes are employed by finding the optimum phase weighting factors and the sub block partition schemes that can achieve the lowest PAPR and computational complexity of MIMO-OFDM wireless systems. Simulation results show that the modified PTS technique achieves better PAPR reduction with reduced computational complexity of PTS scheme in the MIMO-OFDM systems.

## *Keywords:*
Orthogonal Frequency Division Multiplexing (OFDM), Peak–to-Average Power Ratio (PAPR), modified Partial Transmit sequence (MPTS), Multi- Input-Multi Output Antenna (MIMO)

## *1. Introduction*
OFDM is a multi-carrier modulation technique for high data rate wireless communications due to its robustness to frequency selective fading, high spectral efficiency and low computational complexity [1, 2]. OFDM can be used in conjunction with multiple-input multiple-output (MIMO) technique to increase the diversity gain and/or the system capacity by exploiting spatial domain without increase the transmit power and the signal bandwidth [3, 4]. MIMO-OFDM is a key technology for next generation cellular communications (3GPP-LTE, Mobile WiMAX, IMT-Advanced) as well as wireless LAN (IEEE 802.11a, IEEE 802.11n), wireless PAN (MP-OFDM), and broadcasting (DAB, DVB, and DMB). The transmitted signal in an OFDM system can have high peak values in time domain since many subcarrier components are added via an IFFT operation. Therefore, OFDM systems are known to have a high PAPR, it is one of the most detrimental aspects in

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the OFDM system, as it decreases SQNR (signal-to-Quantization Noise Ratio) of ADC (Analog-to-Digital Converter) and DAC (Digital-to- Analog Converter) while degrading the efficiency of the power amplifier in the transmitter. The PAPR problem is more important in the uplink since the efficiency of power amplifier is critical due to the limited battery power in a mobile terminal. In general, even linear amplifiers impose a nonlinear distortion on their outputs due to their saturation characteristics caused by an input much larger than its nominal value. The nonlinear characteristics of HPA (High Power Amplifier), excited by a large input, causes the out-of-band radiation that affects signals in adjacent bands, and in-band distortions that result in rotation, attenuation, and offset on the received signal [5].

A number of techniques were proposed to control the PAPR of the transmitted signals in MIMO-OFDM wireless systems, such as clipping [6], selective mapping (SLM) [7] and partial transmit sequence (PTS) [8]. Deterministic schemes, such as clipping could be an effective technique for PAPR reduction. However, clipping is a nonlinear process and may cause significant in-band distortion, which degrades the BER performance and out-of-band noise, which reduces the spectral efficiency. PTS is probabilistic method which achieves significant PAPR reduction with only a small data rate loss. These techniques achieve PAPR reductions at the expense of transmit signal power increase, BER increase, data rate loss, computational complexity increase and so on.

The conventional PTS scheme is simple and distortion less; sometimes its computational complexity is burden-some. Generally, in PTS, the input data block is divided into disjoint sub blocks. The sub blocks are multiplied by phase weighting factors (±1, ±j) and then added together to produce OFDM symbols or number of candidate signals which ensures the low PAPR. However, Conventional PTS requires an exhaustive search over all the phase factor combinations, which results in the search complexity increasing exponentially with the number of sub blocks.

Hence the modified PTS scheme [9] is proposed to lower the computational complexity which maintains the similar PAPR reduction performance compared with the conventional PTS scheme. A theoretical framework of PAPR reduction by channel coding is given in [10-12] which requires a complex optimization process, particularly when large number of subcarriers is employed.

In this paper, modified PTS is used for the PAPR reduction of the transmitted signal in multiple transmit antenna systems, by determine the optimal phase weighting factors and the sub blocks partition schemes that achieve the lower PAPR and computational complexity of MIMO-OFDM systems by using Forward Error Correcting codes (FECs) such as complementary Golay sequences. The rest of the paper is organized as follows: Section 2 briefly introduces PAPR in MIMO-OFDM systems. Section 3 outlines of PAPR Reduction Code and complementary Golay sequences properties. Modified PTS is presented in section 4. Section 5 presents the simulation results. The conclusions are shown in section 6.

## ***2. PAPR in MIMO-OFDM Systems***

In OFDM modulation technique, a block of k data symbols (one OFDM symbol), $\{x_k$, k = 0, 1,…, k-1} will be transmitted in parallel such that each modulates a different subcarrier from a set {Δf, $N$ = 0, 1,…, $N$-1}. The $N$ subcarriers are orthogonal; the $N$ subcarriers span a bandwidth of $B$ Hz and are separated by a spacing Δf =$B/N$, The continuous-baseband OFDM signal for $N$ subcarriers can be written as $x_{(t)}$

$$x_{(t)} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} x_k e^{j2\pi\Delta f\, k\, t/T} \qquad 0 \le t \le T \tag{1}$$

Where: T is the original data symbol period, and

Δf=1/T is the frequency spacing between adjacent subcarriers.

Replacing: t=n $T_b$ , where $T_b$=1/N, gives the discrete time version denoted by

$$x_{(n/L)} = \frac{1}{\sqrt{LN}} \sum_{k=0}^{N-1} x_k e^{j2\pi kn/LN} \qquad n = 0, 1,\dots, NL-1 \tag{2}$$

Where: L is the oversampling factor.

The symbol-spaced sampling sometimes misses some of the signal peaks and results in optimistic results for the PAPR. The sampling can be implemented by an inverse fast Fourier transform (IFFT).

Where $x_{(n)}$ is the transmitted OFDM signal at the $N^{th}$ subcarrier of the ${N_T}^{th}$ transmit antenna theoretically, large peaks in OFDM system can be expressed as Peak-to-Average Power Ratio for one transmit antenna. It is usually defined as

$$\text{PAPR} \overset{\text{def}}{=} \frac{\max \left|x_{i(n)}\right|^2}{E\{\left|x_{i(n)}\right|^2\}} \tag{3}$$

Where E [.] denotes the expected value. Then, the complementary cumulative distribution function (CCDF), which is the probability that the PAPR of an OFDM symbol exceeds the given threshold $\text{PAPR}_0$, can be expressed as:

$$\text{CCDF}(\text{PAPR}(x(n))) = P_r(\text{PAPR}(x(n)) > \text{PAPR}_0) \tag{4}$$

Due to the independence of the n samples, the CCDF of the PAPR of single input single output (SISO) OFDM as a data block with Nyquist rate sampling is given by

$$P_r(\text{PAPR}(x(n)) > \text{PAPR}_0) = 1 - \left(1 - e^{-\text{PAPR}_0}\right)^n \tag{5}$$

This expression assumes that the N time domain signal samples are mutually independent and uncorrelated and it is not accurate for a small number of subcarriers. Therefore, there have been many attempts to derive more accurate distribution of PAPR.

For a MIMO-OFDM system, analysis of the PAPR performance is the same as the SISO case on each single antenna. For the entire system, the PAPR is defined as the maximum of PAPRs among all transmit antennas

$$\text{PAPR}_{MIMO-OFDM} = \max_{0 \le t \le N_T} \text{PAPR}_{N_T} \tag{6}$$

Where, $\mathrm{PAPR}_{N_T}$ denotes that the $N_T{}^{th}$ transmit antenna. Specifically, since in MIMO-OFDM, $N_T$n time domain samples are considered compared to n in SISO-OFDM, the CCDF of the PAPR in MIMO-OFDM can be written as

$$P_r\left(\mathrm{PAPR}\left(\mathrm{x}\left(\mathrm{n}\right)\right) > \mathrm{PAPR}_0\right) = 1 - \left(1 - e^{-\mathrm{PAPR}_0}\right)^{N_T n} \quad (7)$$

Comparing (7) with (5), it is evident that MIMO-OFDM results in even worse PAPR performance than SISO-OFDM

## ***3. PAPR Reduction Code: Golay sequences code***

It was shown in [13] that a PAPR of the maximum 3dB for the 8-carrier OFDM system can be achieved by 3/4-code rate block coding. Here, a 3-bit data word is mapped onto a 4-bit codeword. Then, the set of permissible code words with the lowest PAPRs in the time domain is chosen. The code rate must be reduced to decrease the desired level of PAPR. It was also stated in [13] that the block codes found through an exhaustive search are mostly based on Golay complementary sequence. Golay complementary sequence is defined as a pair of two sequences whose aperiodic autocorrelations sum to zero in all out-of-phase positions [11]. It is stated in [14] that Golay complementary sequences can be used for constructing OFDM signals with PAPR as low as 3dB. [15] showed the possibility of using complementary codes for both PAPR reduction and forward error correction. Meanwhile, [16] shows that a large set of binary length $2^m$ Golay complementary pairs can be obtained from Reed-Muller codes. However, the usefulness of these coding techniques is limited to the multicarrier systems with a small number of subcarriers. In general, the exhaustive search of a good code for OFDM systems with a large number of subcarriers is intractable, which limits the actual benefits of coding for PAPR reduction in practical OFDM systems.

First, let us consider the basic properties of complementary sequence. Two sequences $\mathrm{x}_{1(n)}$ and $\mathrm{x}_{2(n)}$ consisting of -1 or +1 with equal length N

$$\mathrm{x}_1 = [\,\mathrm{x}_0, \mathrm{x}_1, \mathrm{x}_2, \dots\ \mathrm{x}_{N-1}\,] \quad \text{and} \quad \mathrm{x}_2 = [\,\mathrm{x}_0, \mathrm{x}_1, \mathrm{x}_2, \dots\ \mathrm{x}_{N-1}\,]$$

are said to be complementary if the following condition hold on the sum of both autocorrelation functions:

$$\sum_{k=0}^{N-1} \left(\mathrm{x}_{1(n)}\mathrm{x}_{1(n+i)} + \mathrm{x}_{2(n)}\mathrm{x}_{2(n+i)}\right) = \begin{cases} 2\mathrm{N}; & i = 0 \\ 0 & i \neq 0 \end{cases} \quad (8)$$

after taking the Fourier transform on both sides of Eq. (8) the above condition is translated into the following equation.

$$\left|\mathrm{X}_{1(n)}\right|^2 + \left|\mathrm{X}_{2(n)}\right|^2 = 2\mathrm{N} \quad (9)$$

Where $\mathrm{X}_{i(n)}$ is the DFT of $\mathrm{x}_{1(n)}$. Such that

$$\mathrm{X}_{i(n)} = \sum_{k=0}^{N-1} \mathrm{x}_{i(n)}\ e^{j2\pi nkT_S} \quad (10)$$

with the sampling period of Ts. The power spectral density of $\mathrm{X}_{i(n)}$ is given by DFT of the autocorrelation of $\mathrm{x}_{i(n)}$. Note that $\left|\mathrm{X}_{i(n)}\right|^2$ is the power spectral density (PSD) of a sequence $x_{i(n)}$ According to Equation (9), the PSD $\left|X_{i(n)}\right|^2$ is upper-bounded by 2N, which means

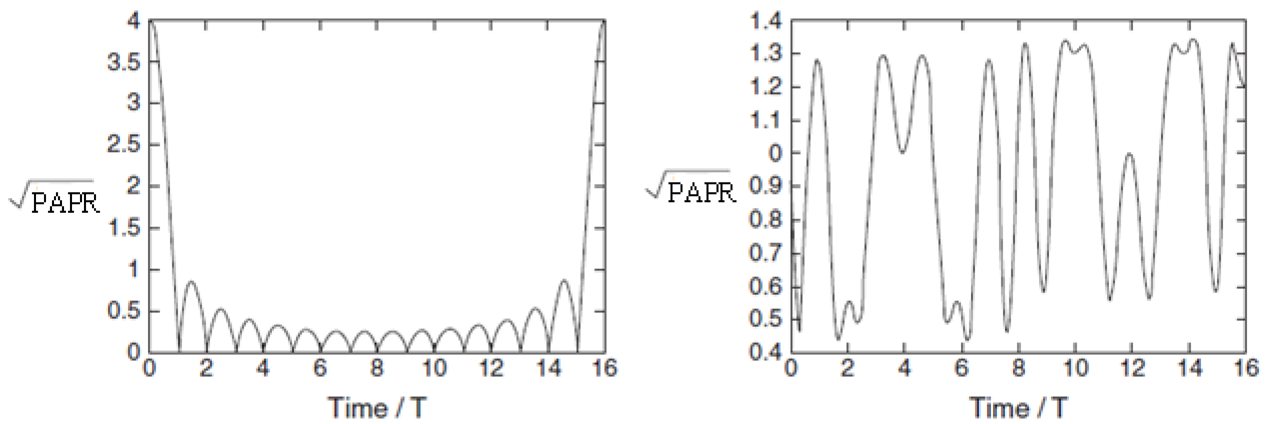
$$\left|X_{i(n)}\right|^2 \leq 2N \tag{11}$$

Since the power of $X_{i(n)}$ is 1, the average of $\left|X_{i(n)}\right|^2$ in Equation (10) is N and thus, the PAPR of $x_{i(n)}$ is upper-bounded by 2N. Because the average power of $X_{i(n)}$is equal to N, assuming that the power of the sequence x is equal to 1, the PAPR of X (f) is bounded as

$$PAPR \leq \frac{2N}{N} = 2 = 3dB \tag{12}$$

Hence, using complementary sequences as input to generate an OFDM symbol, it is guaranteed that the maximum PAPR of 3dB can be achieved. Suppose that a sequence is applied as the input to IFFT. Since the IFFT is equivalent to taking the complex conjugate on the output of FFT and dividing it by N, we can replace $X_{i(n)}$ by the IFFT of $x_{i(n)}$ so that the PAPR can be upper-bounded by 2 (i.e., 3dB). This implies that if the complementary sequences are used as the input to IFFT for producing OFDM signals, the PAPR will not exceed 3dB.

The first and second graphs in Figure 1 illustrate the PAPR of the uncoded OFDM signal with 16-subcarriers and that of the complementary-coded OFDM signal with 16-subcarriers, respectively. It can be seen from these figures that the complementary coding reduces the PAPR by about 9dB.




***Uncoded case*** **Complementary-coded case**

***Figure (1):*** *Comparison of PAPR: Uncoded vs. PAPR reduction-coded OFDM system with N=16.*

## 4. Modified Partial Transmit Sequence

### A. conventional PTS

In conventional PTS was introduced in [17] as a PAPR reduction scheme. In PTS, the frequency domain symbols $x_{i(n)}$, get partitioned into D disjoint blocks, $\{x_{i(n)}{}^{(d)}\}_{d=0}^{D-1}$ that are zero-padded to be length N so that

$$x = \sum_{d=0}^{D-1} x_{i(n)}{}^{(d)} \tag{13}$$

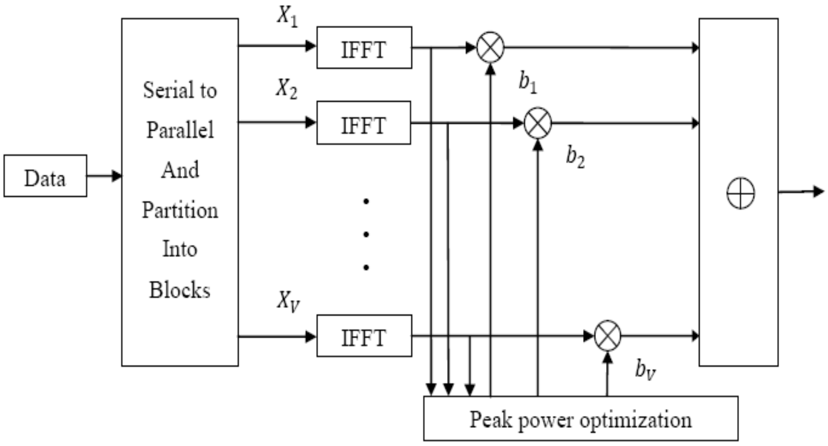
The end goal is to multiply each block by an optimized sequence of phase constants $\{e^{j\varphi^{(d)}}\}_{d=0}^{D-1}$ such that the PAPR is reduced as shown in figure 1. It is assumed that the constants are drawn from a finite set A, where $|A| = P$. The beauty of PTS is that this can be done in the time domain because the IFFT is linear. That is,

$$IFFT\left\{\sum_{d=0}^{D-1} x_{i(n)}{}^{(d)}\ e^{j\varphi^{(d)}}\right\} = \sum_{d=0}^{D-1} IFFT\{x_{i(n)}{}^{(d)}\}\ e^{j\varphi^{(d)}} \tag{14}$$

Therefore, the PAPR can be checked without having to go back and forth between the time and frequency domains. Stated concisely, the goal of PTS is to find $\{e^{j\varphi^{(d)}}\}_{d=0}^{D-1}$ according to

$$\{\varphi^{(d)}\}_{d=0}^{D-1} = \arg mim_{\{\varphi^{(d)}\}_{d=0}^{D-1}}\left[\max\left|\sum_{d=0}^{D-1} IFFT\{x_{i(n)}{}^{(d)}\}\ e^{j\varphi^{(d)}}\right|\right] \tag{15}$$

The weighting factors are assumed to be pure rotations. Without loss of generality, the first weighting factor can be set to unity. Therefore, the optimization problem is to find "D-I" phase values to minimize the PAPR. For instance, consider an OFDM system with 256 carriers, which is divided into 16 clusters. 15 optimal phase values are to be found for each input data vector. Even if the phase values are discredited to 0 and 180, $2^{15}$ phase combinations to be searched to find the optimum. Moreover, [5] shows that taking the peak amplitude of the N-point IFFT output will not give the true peak, and hence over sampling is necessary. Our key modification is as follows. As before, the input complex data vector of N symbols is divided into D clusters; however, only $\frac{D}{2}$ optimized phase values are required. Starting from the first cluster every alternate cluster is kept unchanged and phase values are optimized only for the rest of the blocks. For instance, in the above example, this would mean only 8 phase values to be optimized. If discretized ($0^0$–$180^0$) phase values are used $2^8$ total phase combinations are $2^8$. Corresponding system block diagram is shown in Fig.2. PTS can be quite effective at reducing the PAPR, however, the PAPR reduction capability depends on the size of D and P. effectively, there " $p^D$ mappings" in a PTS scheme at the cost of D IFFT operations. But, as we will discuss above, the mappings are not even approximately independent, thus, the PAPR of one mapping is correlated with the PAPR of another mapping. In terms of PAPR reduction capability, this means that PTS falls well short of a scheme that tests $p^D$ independent signal mappings. Another difficulty for PTS is that side information that can distinguish $p^D$ different mappings must be transmitted, which can take up to $D\log_2 p$ bits. There have been several proposed PTS side information schemes [9]. But there is still a sub-optimal element to PTS where more mappings than necessary are being tried per PAPR reduction which leads to more side information than necessary being transmitted per PAPR reduction. The PTS is one method randomly searches the possible combinations, and there have been several attempts at more elegant solutions [17-18]. But all of these methods increase the complexity of the system by some unspecified amount making a PAPR-to-complexity tradeoff analysis difficult.




***Figure(2):*** *Block diagram of conventional PTS algorithm.*

## B. Modified PTS

In this paper, we use complementary sequence to suppress the PAPR in the MIMO-OFDM systems. Complementary sequences are encoded by the generator matrix $G_N$ and $b_N$ [19]. Let $A_N$ denote the corresponding codeword sequences of length N and u is the integer sequences between [0, M-1] of length k. Then $A_N$ can be written as

$$A_N = u.G_N.b_N \ (mod\ M) \quad (16)$$

Where: $G_N$ is a k × N matrix and

$b_N$ is a phase shift sequence of length N while k is related to $N=2^{k-1}$ for k=3,4,5,…

If the M-ary PSK (Phase shift keying) modulation is used in $i^{th}$ transmit antenna, then the phase sequence of $A_N$ is given by

$$\varphi_i = \frac{2\pi}{M} * a_i + \Delta\varphi \quad (17)$$

Where: $\Delta\varphi$ is the arbitrary phase shift and $a_i$ is the $i^{th}$ sequence of $A_N$.

A large set of binary complementary pairs of length $2^m$ can be obtained from the $2^{nd}$ order cosets of the well-known $1^{st}$ order Reed-Muller code R(1, m). This Reed-Muller code results in low PAPR in addition to its error-correcting capability. The $r^{th}$ order

Reed-Muller code is designated as R(r, m), where m is the parameter related to the length of the code, n=$2^m$ and 0 ≤ r ≤ m. Half of the codes of R(r, m) are complements of the other half. R(1, m) is also known as a bi-orthogonal code since it can be obtained from the generator matrix of an orthogonal code by adding all-ones codeword to it [16].

Consider the data symbol vector $x = [\, x_{0,} \, x_{1,} \, x_{2,} \ldots \; x_{N-1} \,]$ is encoded with space-time encoder into two vectors $x_1 and \;\, x_2$

$x_1 = [\, x_{0,} \, -x_1^* \, , \ldots \; x_{N-2}, -x_{N-1}^*],\; x_2 = [\, x_{1,} \, -x_0^* \, , \ldots \; x_{N-1}, -x_{N-2}^*]$

Encode the data blocks by using Reed Muller code. Define the codeword as a vector,

$s_1 = \; [\, c_{0,} \, -c_1^* \, , \ldots \; c_{N-2}, -c_{N-1}^*]^T, s_2 = [\, c_{1,} \, -c_0^* \, , \ldots \; c_{N-1}, -c_{N-2}^*]^T$

Where, C is an encoded set of code words for any number of carriers. S to be transmitted is divided into several sub-blocks, V, by using sub block partition scheme. In general, sub block partition scheme can be classified into 3 categories. The three partition methods are adjacent, interleaved and random. S is partitioned into M disjoint sets, which is represented by the vector

$s_m$, m=1, 2... M (18)

In this work, the codeword vector S is partitioned by using adjacent method. Assume that the sub blocks or clusters consist of a contiguous set of subcarriers and are of equal size. The objective is to optimally combine the M sets, which in frequency domain is given by

$$S' \; = \sum_{m=1}^{M} b_m s_m \qquad (19)$$

Where: {$b_m$, m=1, 2,… M} are weighting factors and are assumed to be perfect rotations. In other words, the time domain is given by

$$s \; = \sum_{m=1}^{M} b_m s_m \qquad (20)$$

Where: $s_m$ is the phase factor, which is required to inform the receiver as the side information. The set of weighting factor for V clusters or sub blocks are optimized in the time domain so as to achieve the better PAPR performance. PTS generates a signal with a low PAPR through the addition of appropriately phase rotated signal parts. The codeword to be transmitted are divided into several sub blocks, V, of length N/V. Mathematically, expressed by

$$A_k \; = \sum_{v=1}^{V} A_k^{(v)} \qquad v=1, 2,\ldots V \qquad (21)$$

All subcarriers positions in $A_k^{(v)}$ which are occupied in another subblock are set to zero. Each of the blocks, v, has an IFFT performed on it,

$$a_n^{(v)} \; = IFFT \; \{ A_k^{(v)} \} \qquad (22)$$

The output of each block except for first block which is kept constant, is phase rotated by the rotation factor as given by

$$e^{j\theta(v)} \in [0, 2\pi] \qquad (23)$$

The blocks are then added together to produce alternate transmit signals containing the same information as given by

$$a_n^- = \sum_{v=1}^{V} a_n^{(v)} \; e^{j\theta(v)} \quad (24)$$

Each alternate transmit signal is stored in memory and the process is repeated again with a different phase rotation value. After a set number of phase rotation values, W, the OFDM symbol with the lowest PAPR is transmitted as given by

$$\tilde{\varphi}^2 \;, \tilde{\varphi}^3 \,, \ldots \, \tilde{\varphi}^v = \; arg \;\; mim(max|a_n^-|) \quad (25)$$

The weighting rotation parameter set is chosen to minimize the PAPR. The computational complexity of PTS method depends on the number of phase rotation factors allowed. The phase rotation factors can be selected from an infinite number of phases $\varphi^{(v)} \epsilon\ [0,2\pi]$. But finding the best weighting factors is indeed a complex problem. To increase the potential capability of PAPR reduction performance for the PTS method, these phase factors combination correctly maintain the orthogonality between the different modulated carriers. The coding method adds pattern of redundancy to the input data in order to reduce the PAPR. In MIMO communication, data rate or diversity order can be improved by exploiting the spatial dimension. In the same spirit, treating the parallel transmit signals jointly, PAPR reduction may be improved. A modified PTS technique with forward error correcting codes such as Golay complementary sequences with Reed-Muller code is proposed to provide better PAPR reduction in the MIMO-OFDM systems with lower computational complexity as shown in Figure3.

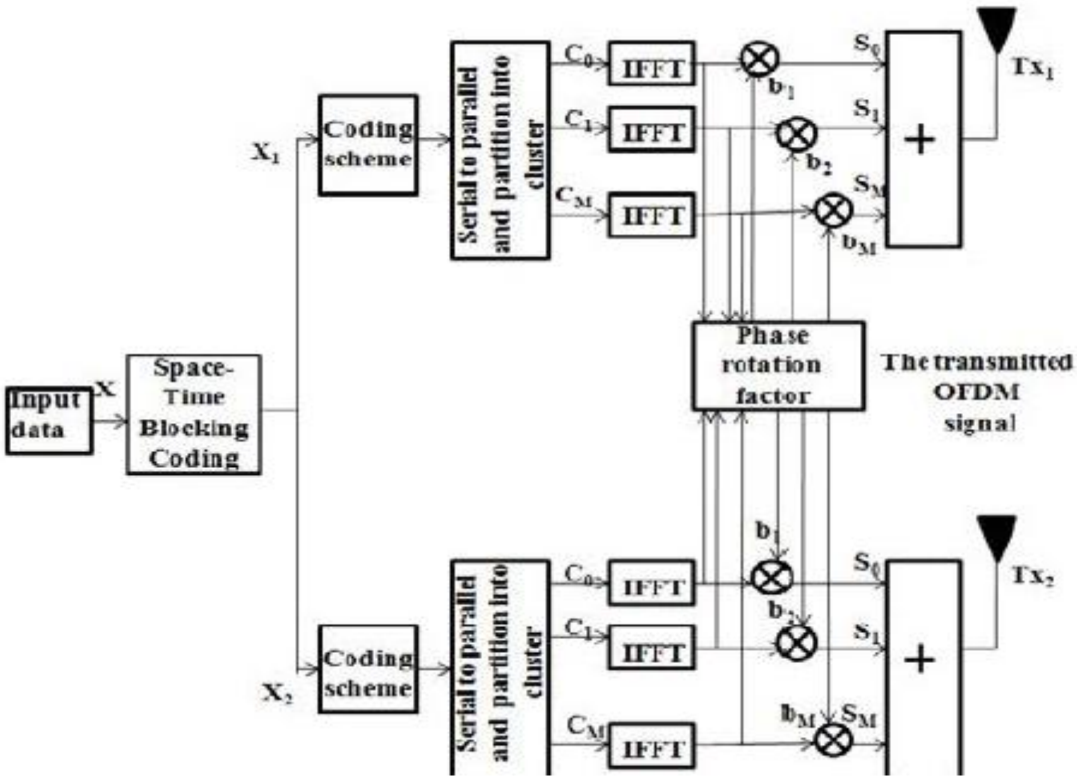



***Figure (3):** Block diagram of the modified PTS scheme of MIMO-OFDM system.*

## *5. Simulation Results*

The analysis of the modified PTS with forward error correcting codes such as Golay complementary sequences with Reed-Muller code have been carried out using MATLAB 7.0. The simulation parameters considered for this analysis is summarized in Table 1. In the MIMO-OFDM systems, modified PTS technique is applied to the subblocks of uncoded information, which is modulated by QPSK and the phase rotation factors are transmitted directly to receiver through subblock. The performance evaluation is done in terms of complementary cumulative distribution function.

**Table (1): Simulation parameters**

| Simulation parameters | Type/Value |
|---|---|
| Number of subcarriers | 64, 128, 256, 512, 1024 |
| Number of sub blocks | 2, 4,8,16 |
| Oversampling factor | 4 |
| Number of antennas | 2×2 |
| Modulation Scheme | QPSK |
| Phase factor | 1, -1, j, -j |

Figure 4, shows the CCDFs of PAPR performance of the MPTS based MIMO-OFDM signal for different number of sub blocks for a random data of block size 1000 with N=256. It can be seen from the figure that as the sub block size is increased from 2 to 4, 8, 16 and 32; the PAPR reduces from 10.8 dB to 10 dB, 8.8 dB, 8.3 dB and 7.5 dB respectively at $10^{-2}$ CCDF, resulting in significant improvement. Obviously, as the number of independent sequences increase, the PAPR performance becomes better.

Figure 5, Shows complementary cumulative distribution (CCDF) of Pr(PAPP > $PAPP_0$) for conventional (uncoded) PTS and modified (coded) PTS with 4 partitions with 3 phase values and 8 partitions with 4 and 7 phase values. Results indicate that the modified PTS scheme performs better than the conventional PTS scheme with 4 partitions with 3 phase values and 8 partitions with 4 and 7 phase values.

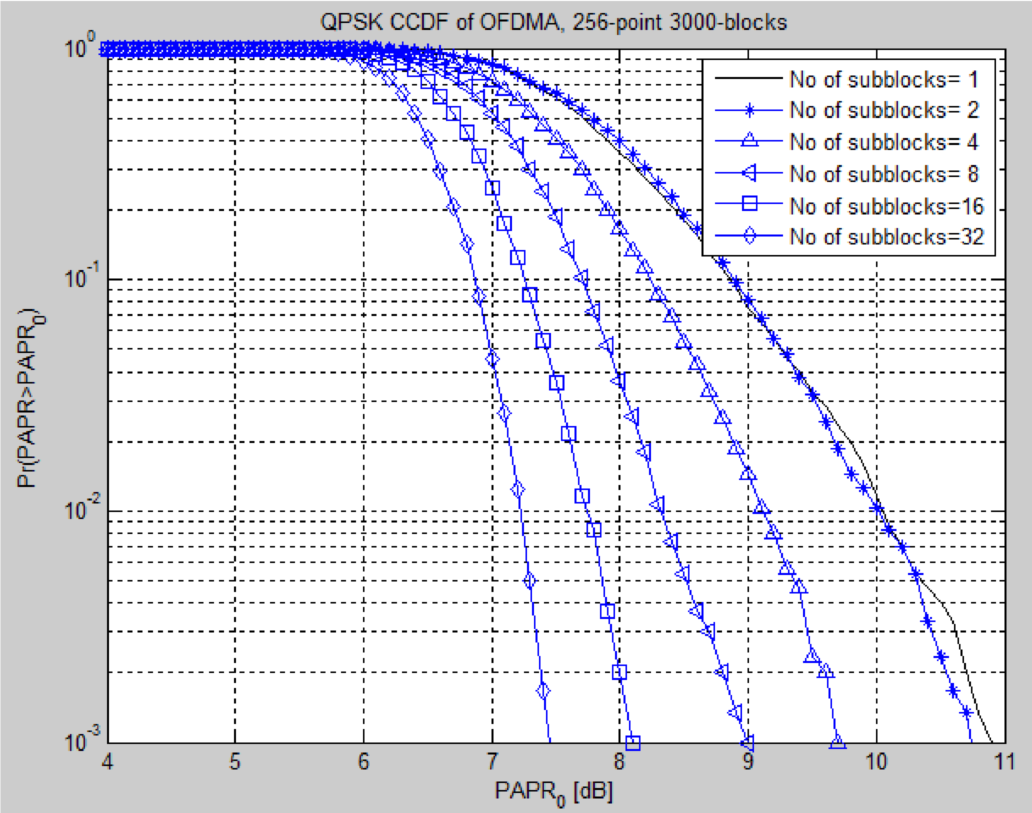



***Figure (4):*** *PAPR performance of MPTS technique with number of sub blocks varies.*

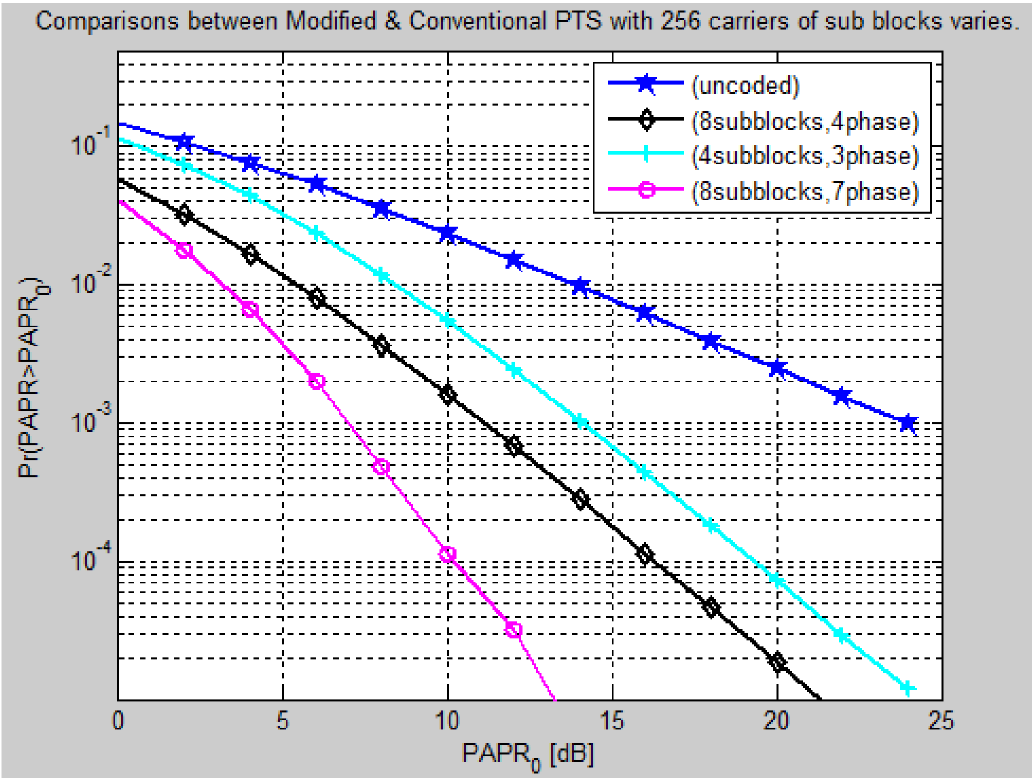



***Figure (5):*** *comparisons between Modified& Conventional PTS with 256 carriers.*

## *6. Conclusions*

In this paper, we introduce PAPR reduction technique based on modified PTS in MIMO-OFDM systems. This approach, which combines the PTS technique with Golay complementary sequences divide the subcarriers of OFDM into several disjoint sub blocks resulting in significant performance gain in terms of PAPR reduction with low complexity. As a result, the CCDF of PAPR exhibits a steeper decay, increased by a factor equal to the number of transmit antennas. The employment of MIMO configuration improved the capacity and the performance of the OFDM system. The simulation results indicated that the modified PTS has a PAPR reduction capability more than that of the conventional PTS technique. In this paper, the side information is assumed not to be erroneous for analyzing the pure effect of multiple candidates. we conclude that the more the candidates, not only the better PAPR reduction performance, but also the better error performance under the assumption of side information transmission without error, and at the expense of computational complexity for n IFFT circuits.

## *References*


[1] Tao Jiang and Yiyan Wu, "An Overview: Peak-to-Average Power Ratio Reduction Techniques for OFDM Signals", IEEE Transactions on Broadcasting, Vol. 54, No. 2, June 2008, pp. 257-267.

[2] S.H.Muller and J.B.Huber, "A Novel Peak Power Reduction Scheme for OFDM", Proceedings of IEEE International Symposium on Personal, Indoor and Mobile Radio Communication, Marina Congress Center, Helsinki, Finland, September 1997,Vol. 3, pp.1090–1094.

[3] Zhefeng Li and Xiang-Gen Xia, "PAPR Reduction for Space-Time-Frequency Coded MIMO-OFDM Systems using Chu Sequences", IEEE Transactions on Wireless Communications, Vol.7, No. 4, April 2008, pp. 1195-1202.

[4] Jing Gao, Jinkuan Wang and Yun Wang, "A Low Complexity PAPR Reduction technique for STBC MIMO-OFDM System", Proceedings of International Conference on Wireless Communications, Networking and Mobile Computing, Shanghai, September 2007, pp.109-112.

[5] Yong Soo Cho, Jaekwon Kim, Won Young Yang, Chung G. Kang," MIMO-OFDM WIRELESS COMMUNICATIONS WITH MATLAB", John Wiley & Sons Pte Ltd, 2010.

[6] R. O'Neill and L.N. Lopes, "Envelope Variations and Spectral Splatter in Clipped Multicarrier Signals", Proceedings of International Symposium on Personal, Indoor and Mobile Radio Communications, Toronto, Ont., Canada, September 1995, Vol.1, pp. 71–75.

[7] Yung-Lyul Lee, Young-Hwan You, Won-Gi Jong-Ho Paik and Hyoung-Kyu Song "Peak-to-Average Power Ratio Reduction in MIMO OFDM System using Selective mapping", IEEE Communications Letters, Vol.7, No.12, December 2003, pp.575-577.

[8] Jun Hou, Jianhua Ge and Jing Li, "Peak-to-Average Power Ratio Reduction of OFDM Signals using PTS Scheme with Low Computational Complexity", IEEE Transactions on Broadcasting, Vol.57, No.1, September 2010, pp. 143-148.

[9] Jayalath, A. D. S. and Tellambura, C., "Side information in PAR reduced PTS-OFDM signals", Personal, Indoor and Mobile Radio Communications conference, vol. 1, pp. 226 - 230, Sept. 2003.

[10] Vahid Tarokh and A.R,Calderbank, "Space-Time Codes for High Data Rate Wireless Communication: Performance Criterion and Code Construction", IEEE Transactions on Information Theory, Vol.44, No.2, March 1998.

[11] M.J.E. Golay, "Complementary Series", IRE Transactions on Information Theory, Vol.7. No.2, April 1961, pp. 82-87.

[12] Hideki Ochiai and Hideki Imai, "Forward Error Correction with Reduction of Peak to Average Power Ratio of QPSK Multicarrier Signals", Proceedings of IEEE International Symposium on Information Theory, Ulm, Germany, June 1997, pp.120.

[13] Wilkinson, T.A. and Jones, A.E.," Minimization of the peak-to-mean envelope power ratio of multicarrier transmission scheme by block coding", IEEE VTC'95, Chicago, vol. 2, July 1995, pp. 825–829.

[14] Popovic, B.M., "Synthesis of power efficient multitone signals with flat amplitude spectrum", IEEE Trans. Comm., 1991, pp. 1031–1033.

[15] Van Nee, R.D.J., "OFDM codes for peak-to-average power reduction and error correction", IEEE GTC, London, vol. 2, Nov. 1996, pp. 740–744.

[16] J.A. Davis and J. Jedwab, "Peak-to-Mean Power Control in OFDM, Golay Complementary Sequences, and Reed–Muller Codes", IEEE Transactions on Information Theory, Vol. 45, No. 7, November 1999, pp. 2397-2417.

[17] Jayalath, A. and Athaudage, C., "On the PAR reduction of OFDM signals using multiple signal representation", IEEE Communications Letters, vol. 8, pp. 425 - 427, July 2004.

[18] A.E. Jones, T.A. Wilkinson and S.K. Barton, "Block Coding Scheme for Reduction of Peak to Mean Envelope Power Ratio of Multicarrier Transmission Schemes", IEEE Electronics Letters, Vol. 30, No. 25, December 1994, pp.2098-2099.

[19] Xu Yan, Wang Chunli Jr., and Wang Qi, "Research of Peak-to-Average Power Ratio Reduction Improved Algorithm for MIMO-OFDM system", World Congress on Computer Science and Information Engineering, California, USA, April 2009, Vol.1, pp.171-175.