Modified PTS Combined with Interleaving Technique for PAPR Reduction in MIMO-OFDM system with Different Subblocks and Subcarriers

P.Mukunthan, and P.Dananjayan

Abstract— **Multiple input multiple output orthogonal frequency division multiplexing (MIMO-OFDM) system have been proposed in the recent past for providing high data-rate services over wireless channels. When combined with space time coding it provides the advantages of space-time coding and OFDM, resulting in a spectrally efficient wideband communication system. However, MIMO-OFDM system suffer with the problem of inherent high peak-to-average power ratio (PAPR) due to the intersymbol interference between the subcarriers. In order to obtain optimal PAPR reduction using the partial transmit sequence (PTS), the total search for the number of subblocks and the rotation factors must be accomplished. As the number of subblocks and rotation factors increases, PAPR reduction improves. The number of calculation increases as the number of subblocks increases, such that complexity increases exponentially and the process delay occurs simultaneously. PAPR reduction is jointly optimised in both the real and imaginary part by the use of fast Fourier transform (FFT) algorithm in the modified PTS scheme. It can be utilized for finding the optimum phase weighting factors, and can achieve the lower PAPR and reduce the computational complexity of MIMO-OFDM system. In this paper, a modified PTS combined with interleaving technique for PAPR reduction using multiple transmit antennas with quadrature phase-shift keying (QPSK) modulation scheme has been presented. The scheme is very efficient and avoids the use of any extra IFFTs as was done in PAPR reduction by ordinary PTS technique. The simulation results show that PAPR performance is improved with the increase in number of subblocks and subcarriers using different transmit antennas.**

Index Terms—**MIMO-OFDM, STBC, PAPR, PTS, interleaving, subblock partition scheme**

I. INTRODUCTION

A multiple-input multiple-output (MIMO) communication system has increased spectral efficiency in a wireless channel. It can provide both high-speed data transmission and spatial diversity between any transmit-receive pair. Alamouti's code is a special space time block code (STBC) for orthogonal frequency division multiplexing (OFDM) system and allows to achieve or approach, channel capacity with two transmit antennas [1]. Moreover, an orthogonal frequency division multiplexing (OFDM) is a multicarrier modulation technology, which can decrease the effect of the noise and interferences efficiently [2]-[7]. OFDM can be used in conjunction with MIMO technique to increase the diversity gain and/or the system capacity by exploiting spatial domain [8]-[10]. Recently space-time coded OFDM systems have been receiving wide spread attention. A space-time-frequency coded OFDM system which achieves maximum diversity is proposed in [11]. In [12] space-time codes have been designed for use with OFDM over frequency selective fading channels, which can achieve spatial diversity technique by using multiple antennas at the transmitter and receiver. The technique is promising, since it does not increase the transmit power and the signal bandwidth. This can be efficiently utilised through STBC MIMO-OFDM systems. However, the above schemes require some side information to be transmitted to the receiver with high reliability, which reduces the spectral efficiency.

Despite its many advantages, MIMO-OFDM suffers with the problem of high PAPR and carrier frequency offset sensitivity [13]. The complex baseband OFDM signal is formed by the superimposition of all subcarriers in the MIMO-OFDM transmitter. The OFDM signal is almost Gaussian distributed and hence exhibits a very large peak-to-average power ratio (PAPR). This major drawback of MIMO-OFDM significantly complicates implementation of the radio-frequency frontend. PAPR reduction technique to reduce the dynamic range of the transmitted OFDM signal has to be done before it is applied to the high power amplifiers (HPAs) used in radio transmitters. This HPA have nonlinear characteristics and cause significant distortion to OFDM signals. Even small amounts of intermodulation distortion can cause undesirable spectral regrowth, which increases the bit error rate (BER) and causes spectral widening, resulting in adjacent channel interference.

One of the first triumphant and most prevalent uses of MIMO-OFDM was in data modems connected to telephone lines. A major confront for high-speed broadband mobile application is inter-symbol interference (ISI) due to time-

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dispersive nature of the terrestrial radio channel. Especially, MIMO-OFDM has been adopted for various wireless communication systems such as wireless local area networks (WLANs), wireless metropolitan area networks (WMANs), digital subscriber lines (DSL), IEEE 802.11, IEEE 802.16, and IEEE 802.15.3a and it is increasingly held that MIMO-OFDM results in an improved uplink performance for fourth generation (4G).

A variety of PAPR reduction techniques such as clipping [14], interleaving method [15], selective mapping (SLM) [16], [17], and partial transmit sequence (PTS) [18], [19] were proposed by researchers to control the PAPR of the transmitted signals in MIMO-OFDM systems. Clipping could be an effective technique for PAPR reduction, but it 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. The interleaved partitioned ordinary PTS scheme has the lowest computational complexity but it has the worst PAPR performance because the generated candidates are not fully independent [15]. In SLM, one OFDM signal of the lowest PAPR is selected in a set of several signals containing the same information data. In PTS, the lowest PAPR signal is made by optimally phase combining the signal subblocks. SLM and PTS are very flexible schemes and provide effective PAPR reduction performance without any degradation. However, both these techniques require much system complexity and computational burden because of the many IFFT stages and complex optimization procedure. Other possible alternative solution is then to exploit other parameters of the OFDM signal. Modified PTS scheme [20] is proposed to lower the computational complexity while maintaining the similar PAPR reduction performance compared with the ordinary PTS scheme. To alleviate the problem of high complexity further an approach [21] has been proposed, in which real and imaginary parts are separately multiplied with phase factors, moreover PAPR is conjointly optimized in real and imaginary parts. Further, the use of Golay complementary sequences is an efficient method to reduce the PAPR for a small number of subcarriers, but it decreases the transmission rate significantly for a large number of subcarriers [22]. Although the Golay complementary sequence reduces the PAPR, the optimal phase weighting factors are determined such that the overall system complexity is increased. But the Golay complementary sequence combined with modified PTS reduces the PAPR and also increases the code rate, thereby enhancing the system performance [23].

In this paper, modified PTS is combined with interleaving technique for the PAPR reduction in MIMO-OFDM system, where data blocks on an arbitrary subcarrier for different number of transmit antennas are used to lower the maximum PAPR. In the proposed work, PAPR reduction performance can be improved based on different subblocks and subcarriers, which are multiplied by weighting factors. Simulation results presented demonstrate that the proposed PAPR reduction method achieves significantly better PAPR performance with less computational complexity of MIMO-OFDM system.

The rest of this paper is organized as follows. Section II describes a model for the PAPR reduction in MIMO-OFDM system and the principles of modified PTS techniques are introduced. The interleaving technique based on modified PTS is examined in Section III. The simulation results and discussions are presented in Section IV. Finally, conclusions are drawn in Section V.

II. PAPR IN MIMO-OFDM SYSTEM

An OFDM data block with N subcarriers $X_k = \left(X_{0,} X_{1,} .... X_{N-1}\right)$, is formed with each symbol modulating the corresponding subcarrier from a set of subcarriers. In an MIMO-OFDM system, the N subcarriers are chosen to be orthogonal, over the period $0 \le t \le T$ where, T is the original data symbol period, and f_0 =1/T is the frequency spacing between adjacent subcarriers.

The complex baseband OFDM signal for N subcarriers can be written as

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi k f_0 t}, 0 \le t \le T \tag{1}$$

Replacing t=nT_b, where T_b =T/N, gives the discrete time version denoted by

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi kn/LN}, \text{ n=0,1,…, NL-1} \tag{2}$$

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).

The PAPR of the transmitted OFDM signal, $x(t)$, is defined as the ratio between the maximum instantaneous power and the average power, defined by

$$PAPR = \frac{\max_{0 \le t \le T} |x(t)|^2}{E\left[\left|x(t)^2\right|\right]} \tag{3}$$

where $E[\cdot]$ is the expectation operator.

The PAPR of the continuous-time OFDM signal cannot be precisely computed in the Nyquist sampling rate, which corresponds to N samples per OFDM symbol. In this case, signal peaks may be skipped and PAPR estimates are not precise. So, oversampling is necessary.

To evaluate the PAPR reduction performance accurately from the statistical point of view, the complementary cumulative distribution function (CCDF) of the PAPR of OFDM signals is used. CCDF describes the probability of exceeding a given threshold $PAPR_0$ and is represented [24] as

$$CCDF(PAPR(x(n))) = P_r(PAPR(x(n))) > PAPR_0 \tag{4}$$

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

$$P = P_r(PAPR(x(n)) > PAPR_0) = 1-(1-e^{-PAPR_0})^N \tag{5}$$

According to the central limit theorem, the time domain signal samples are mutually independent and uncorrelated and it is not accurate for a small number of subcarriers. The independent assumption in (5) is not true for the oversampling case [25]-[27]. An empirical expression for the CCDF of PAPR can be obtained by approximating the distribution for N subcarriers and oversampling by the distribution for LN, (L > 1) uncorrelated subcarriers without oversampling. Therefore, the CCDF of PAPR computed of the L-time oversampled OFDM signal can be rewritten as

$$P = P_r(PAPR(x(n)) > PAPR_0) = 1 - (1 - e^{-PAPR_0})^{LN} \quad (6)$$

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 [28], i.e.,

$$PAPR_{MIMO-OFDM} = \max_{1 \le i \le M_t} PAPR_i \quad (7)$$

where, $PAPR_i$ denotes the PAPR at the i^{th} transmit antenna. Specifically, since in MIMO-OFDM, M_t LN time domain samples are considered compared to LN in SISO-OFDM, the CCDF of the PAPR in MIMO-OFDM can be written as

$$P_r(PAPR_{MIMO-OFDM} > PAPR_0) = 1 - (1 - e^{-PAPR_0})^{M_t LN} \quad (8)$$

Comparing (8) with (6), it is evident that MIMO-OFDM results in even worse PAPR performance than SISO-OFDM.

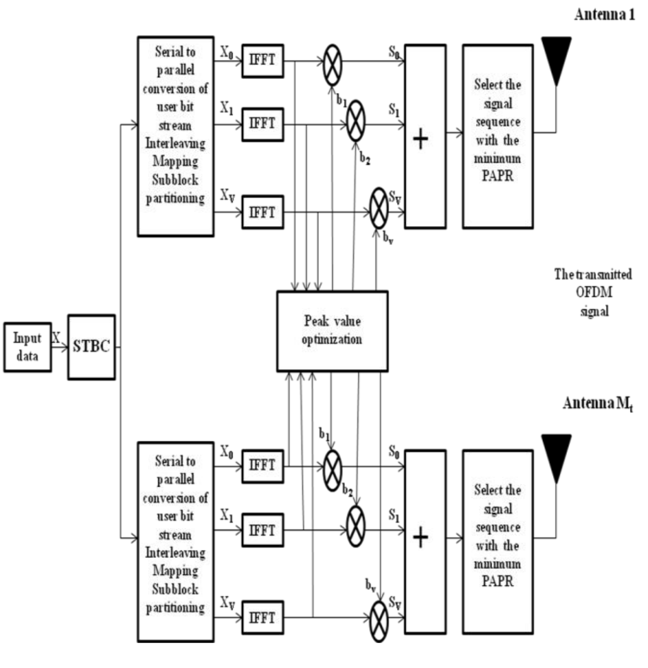

Fig. 1. A typical structure of transmitter for modified PTS combined with interleaved MIMO-OFDM system.

In Fig.1, Consider the data symbol vector $S = [X_0, X_1, ..., X_{N-1}]$ is encoded with space-time encoder into four vectors X_1, X_2, X_3 and X_4,

$$X_1 = [X_0, -X^*_1, ...X_{N-2}, -X^*_{N-1}],$$

$$X_2 = [X_1, X^*_0, ...X_{N-1}, X^*_{N-2}],$$

$$X_3 = [X_2, X^*_1, X_0, ...X_{N-1}, X_{N-2}, X^*_{N-3}],$$

$$X_4 = [X_3, X^*_2, X_1, X_0, ...X_{N-1}, X_{N-2}, X_{N-3}, X^*_{N-4}].$$

The PTS method [12] is divides the input frequency domain symbol S into several sub-blocks, V, by using subblock partition scheme. In general, subblock partition scheme can be classified into 3 categories. The three partition methods are adjacent, interleaved and random.

S is partitioned into V disjoint sets, which is represented by the vector,

$$S_m,\ m=1, 2, ..., V \quad (9)$$

In this paper, the codeword vector S is partitioned by using interleaving method. The subblocks or clusters consist of a contiguous set of subcarriers and are of equal size. The objective is to optimally combine the V clusters, which in frequency domain is given by

$$S' = \sum_{m=1}^{V} b_m S_m \quad (10)$$

where, $\{b_m, m=1, 2,\ldots, V\}$ are weighting factors and are assumed to be perfect rotations. Choosing b_m € {1, -1, j, -j} (W=4) is widely used in conventional systems. Where W is a number of allowed phase factors. In other words, the time domain is given by

$$s = \sum_{m=1}^{V} b_m s_m \quad (11)$$

where, s_m consist of a set of subblocks with equal size and b_m is the phase factor, which are required to inform the receiver as the side information. The set of weighting factor for V clusters or subblocks are optimised 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 subblocks, V, of length N/ V. Mathematically, expressed by

$$A_k = \sum_{v=1}^{V} A_k^{(v)},\ v=1, 2, \ldots, V \quad (12)$$

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,

$$a_n^{(v)} = IFFT\{A_k^{(v)}\} \quad (13)$$

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

$$e^{j\theta(v)} \in [0, 2\pi] \quad (14)$$

Applying phase weighting factors to subblocks allows optimization of combining weighted partial transmit sequences. The combined sequence is

$$\tilde{a}_n = \sum_{v=1}^{V} a_n^{(v)} . e^{j\theta(v)} \quad (15)$$

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^{V-1}, the OFDM symbol with the lowest PAPR can be determined by the following equation.

$$\tilde{\phi}^2, \tilde{\phi}^3, ...\tilde{\phi}^v = \arg\min(\max|\tilde{a}_n|) \quad (16)$$

Finally, at each transmitting antenna, there are (V-1) subblocks to be optimised, and the candidate sequence with the lowest PAPR is individually selected for transmitting. The weighting phase rotation parameter set is chosen to minimise 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 $\phi^{(v)} \in (0, 2\pi)$. But finding the best weighting factors is indeed a complex problem. To increase the potential capability of PAPR reduction performance for the modified PTS method, these phase factors combination correctly maintain the orthogonality between the modulated signal subblocks for multiple transmit antennas on an arbitrary subcarrier. The transmit diversity scheme can improve the error performance, data rate, or capacity of wireless communications systems.

III. Interleaved MIMO-OFDM System

Highly correlated data frames of OFDM signals have large PAPRs, which could be reduced, if the long correlation patterns are broken down. A set of fixed permutations (interleaving) is used in OFDM to break these correlation patterns [29], [30]. Some of the existing single-antenna PAPR reduction based modified PTS with interleaving technique is extended to MIMO-OFDM systems [31]. Interleavers are used to produce permuted data blocks from the same data block. The PAPR of (K-1) permuted data blocks and that of the original data block with the lowest PAPR is then chosen for MIMO-OFDM transmission. The uniqueness of the corresponding interleaver is also sent to the receiver as side information. Hence interleaving method is simple to implement and reduces the transmitter complexity when compared with PTS scheme [32]-[34]. If all the K, PAPR computations are done simultaneously and lowest PAPR sequence is selected in one step, the processing delay at the transmitter is significantly reduced. Therefore, it can also be used with high speed data transmissions.

Interleaved MIMO-OFDM is also feasible for spectrum monitoring. Since subcarriers of one subblock are equally spaced, their frequency locations can be determined by capturing one subcarrier with the knowledge of system parameters. Users can monitor the radio activity on one subblock by sensing only one or two subcarriers of the subblock instead of all the subcarriers across the whole frequency band. Interleaving can be used to combat the effect of noise bursts and fading in error correction systems. By interleaving a data frame, the peaks in the associated OFDM signal can be compressed.

For Interleaved MIMO-OFDM, the N subcarriers are partitioned into V groups with each group having Q contiguous subcarriers. Then the k^{th} subcarrier of each group is assigned to the k^{th} user.

$$x^{(k)}(n) = \sum_{m=0}^{\mathrm{V}-1} X_m^{(k)} e^{j(2\pi/N)(mQ+k)n} \tag{17}$$

in which k=0,1,….Q-1 is the index of users

Let $\{x_n : n = 0,1, \ldots, N-1\}$ be data symbols to be modulated. Then, $\{X_k : k = 0, 1,\ldots, N-1\}$ are frequency domain samples after FFT of $\{x_n\}$, $\{\tilde{X}_l : l = 0, 1,\ldots, M-1\}$ are frequency domain samples after subcarrier mapping, and $\{\tilde{x}_m : m=0,1,\ldots, M-1\}$ are time domain symbols after IFFT of $\{\tilde{X}_l\}$ which can be described as follows

Let m=N(q+n), where $0 \le q \le \mathrm{Q}-1$ and $0 \le n \le N-1$

Then,

$$\begin{aligned}\tilde{x}_m\left(=\tilde{x}_{Nq+n}\right) &= \frac{1}{\mathrm{V}}\sum_{l=0}^{\mathrm{V}-1}\tilde{X}_l e^{j2\pi\frac{m}{\mathrm{V}}l} = \frac{1}{\mathrm{Q}}.\frac{1}{N}\sum_{k=0}^{N-1}X_k e^{j2\pi\frac{m}{\mathrm{V}}k} \\ &= \frac{1}{\mathrm{Q}}.\frac{1}{N}\sum_{k=0}^{N-1}X_k e^{j2\pi\frac{Nq+n}{N}k} \\ &= \frac{1}{\mathrm{Q}}\left(\frac{1}{\mathrm{N}}\sum_{\mathrm{k}=0}^{\mathrm{N}-1}\mathrm{X_k e^{j2\pi\frac{n}{N}k}}\right) \\ &= \frac{1}{\mathrm{Q}}x_n\end{aligned} \tag{18}$$

where l denotes a normalized discrete time instance, q is the sub-channel index of the k^{th} user and N is the total number of subcarriers

Here an N-sample interleaved MIMO-OFDM data block is generated by repeating l for Q times. The resulting time symbols $\{\tilde{x}_m\}$ are simply a repetition of the original input symbols $\{x_n\}$ in the time domain [35]-[37]. Therefore, an interleaved MIMO-OFDM system with N subcarriers can be scaled from an OFDM system.

IV. Results and Discussion

The analysis of the modified PTS with interleaving method has been carried out using MATLAB 7.0. The simulation parameters considered for this analysis is summarized in Table I.

TABLE I
SIMULATION PARAMETERS

Simulation Parameters	Type/Values
Number of random OFDM blocks	10000
Number of subcarriers(N)	64, 128, 256, 512, 1024
Number of subblocks(V)	2, 4, 8,16
Oversampling factor(L)	1
Subblock partition scheme	Interleaving
Modulation scheme	QPSK
Phase weighting factor (b)	1, -1, j, -j
Number of transmit Antenna (M_t)	2, 4

In the MIMO-OFDM system under consideration, modified PTS scheme combined with interleaving technique based on different subcarriers and subblocks applied to uncoded information modulated by QPSK modulation scheme was simulated. 10000 OFDM symbols were randomly generated to obtain the CCDFs of PAPR.

Figure 2 illustrates the CCDFs of PAPR of the modified PTS with interleaving technique for different subblocks V=2, 4, 8, 16 when the number of subcarriers is 64 with 2 transmit antennas. From this figure it is observed that the values of PAPR for 2 transmit antennas with different subblocks (V= 2, 4, 8, and 16) are 7.6dB, 5.8dB, 4.8dB, and 4.7 dB respectively when CCDF = 10^{-2}. Modified PTS combined with interleaving technique for different subblocks and 64 subcarriers with 4 transmit antennas is shown in Figure 3. From this figure it is manifested that the values of PAPR for this case are 7dB, 5.2dB, 4dB, and 3.7 dB respectively. From figures 2 and 3 it is inferred that PAPR reduction performance increases with the increase of subblocks.

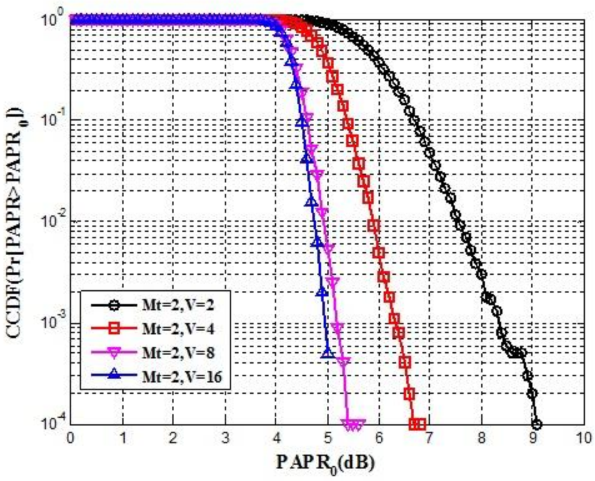

Fig. 2. CCDF of PAPR for different subblocks when N=64 with Mt=2 transmit antenna

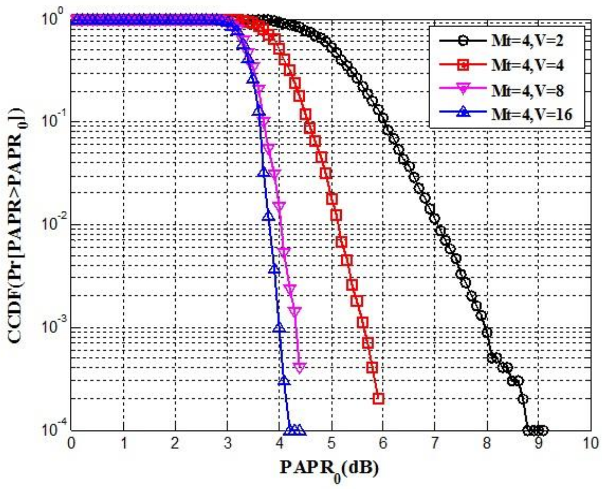

Fig. 3. CCDF of PAPR for different subblocks when N=64 with Mt=4 transmit antenna

Figure 4 shows the CCDFs of PAPR of the modified PTS with interleaving technique when the number of subcarriers is increased to 256 with 2 transmit antennas for different subblocks. From this figure it is observed that for a CCDF of 10^{-2} the values of PAPR are 8.6dB, 7.1dB, 6.4dB, and 6.2 dB for V=2, 4, 8, and 16 respectively. By comparing the Figures 2 and 4 it is evident that PAPR is increased from 5.8 dB to 7.1 dB for 2 transmit antennas as the number of subcarriers is increased from 64 to 256. Increasing the subcarriers increases the data rate but, these carriers add up constructively or destructively and create the potential for a large variation in the signal power envelopes.

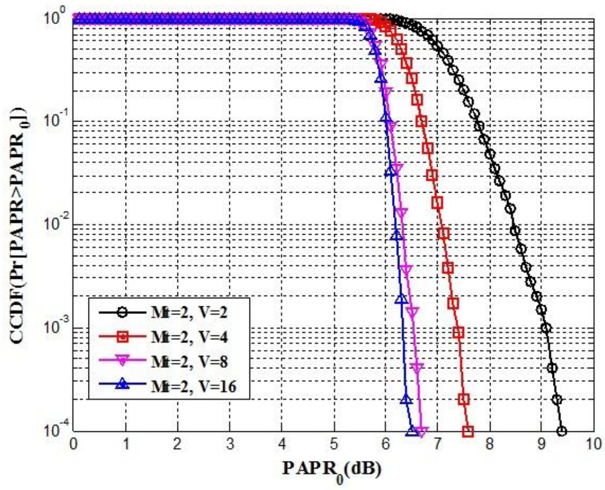

Fig. 4. CCDF of PAPR for different subblocks when N=256 with Mt=2 transmit antenna

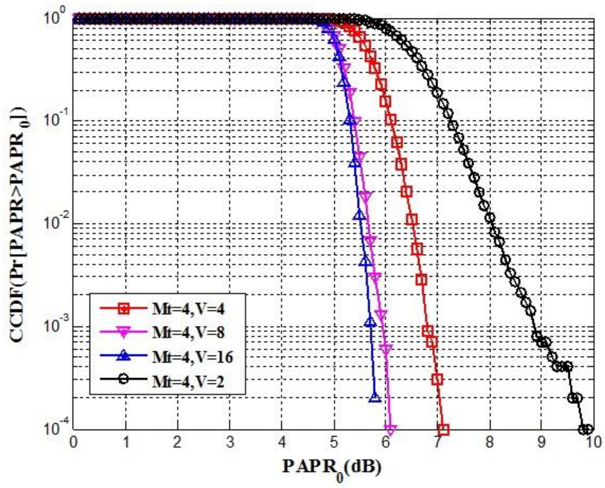

Fig. 5. CCDF of PAPR for different subblocks when N=256 with Mt=4 transmit antenna

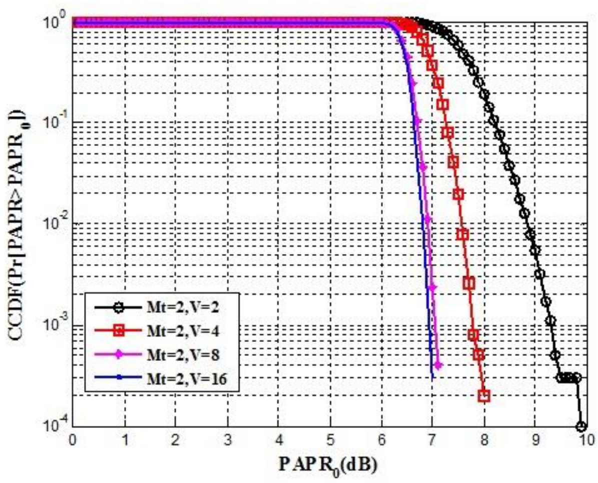

Fig.6. CCDF of PAPR for different subblocks when N=512 with Mt=2 transmit antenna

Figure 5 depicts the PAPR reduction performance of the modified PTS with interleaving technique with 4 transmit antennas. The same parameters considered in Figure 4 are used in this case. From this figure it is observed that the values of PAPR for 4 transmit antennas with different subblocks are 8dB, 6.5dB, 5.6dB, and 5.5 dB respectively. By comparing the Figures 3 and 5 it is evident that PAPR is increased from 5.2 dB to 6.5 dB for 4 transmit antennas when the number of subblocks is 4, and the number of subcarriers is 256 at CCDF of 10^{-2}.

Figure 6 and 7 illustrate the performance of PAPR reduction for the modified PTS with interleaving technique for different subblocks V=2, 4, 8, 16 when subcarriers N=512 with 2 and 4 transmit antennas respectively. Similarly Figure 8 and 9 shows the CCDFs of PAPR of the modified PTS with interleaving technique for different subblocks, when the number of subcarriers is increased to 1024 with 2 and 4 transmit antennas. The results inferred from Figures 6, 7, 8 and 9 are tabulated in Table II. It is obvious that if a system with OFDM signaling uses more antennas, the achievable gain becomes much higher to reduce the peak signal power.

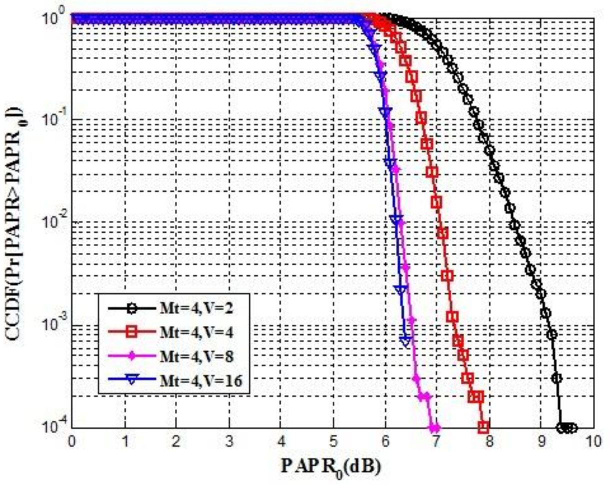

Fig.7. CCDF of PAPR for different subblocks when N=512 with Mt=4 transmit antenna

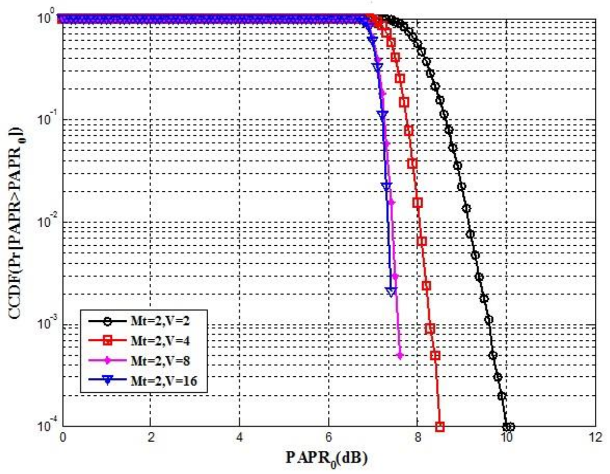

Fig. 8. CCDF of PAPR for different subblocks when N=1024 with Mt=2 transmit antenna

By comparing the Figures 2, 4, 6, and 8 it is evident that PAPR is increased from 5.8 dB to 7.1 dB, from 7.1 dB to 7.6 dB and from 7.6 dB to 8dB for 2 transmit antennas when V=4 subblocks with number of subcarriers increased from N=64 to 256, from N=256 to 512 and from N=512 to 1024 respectively at CCDF of 10^{-2}.

On comparing the Figures 3, 5, 7, and 9 it is evident that PAPR is increased from 5.2 dB to 6.5 dB, from 6.5 dB to 7.2 dB and from 7.2 dB to 7.6 dB for 4 transmit antennas when V=4 subblocks with number of subcarriers increased from N=64 to 256, from N=256 to 512 and from N=512 to 1024 respectively at CCDF of 10^{-2}.

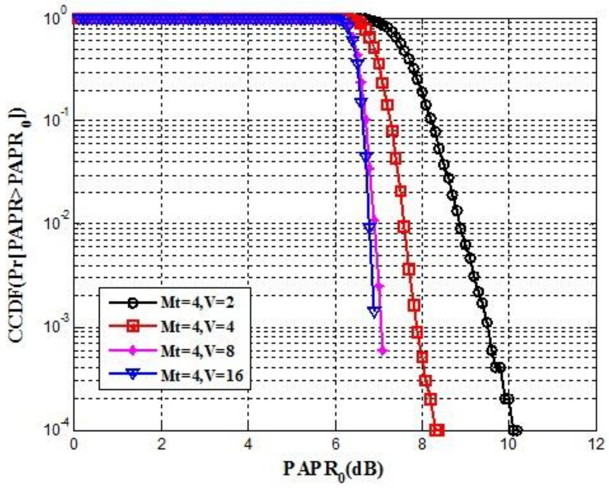

Fig. 9. CCDF of PAPR for different subblocks when N=1024 with Mt=4 transmit antenna

TABLE II: CCDF of PAPR for different subblocks

N / V	The values of PAPR in dB at CCDF of 10^{-2}							
	Mt=2				Mt=4			
	2	4	8	16	2	4	8	16
64	7.6	5.8	4.8	4.7	7	5.2	4	3.7
256	8.6	7.1	6.4	6.2	8	6.5	5.6	5.5
512	8.8	7.6	6.8	6.7	8.4	7.2	6.4	6.3
1024	9.2	8	7.4	7.3	8.8	7.6	6.8	6.7

The impact of the subblock size V on the performance of PAPR reduction is shown in figures 2, 3, 4, 5, 6, 7, 8, 9. To improve the PAPR reduction performance, a shorter subblock size V is desirable so that phases can be adjusted with more flexibility. However, a too small value V will cause a significant degradation of BER performance due to the residual ambiguity. Therefore, the subblock size V should be chosen carefully to reduce the PAPR significantly while maintaining a near-optimal BER performance. Also the PAPR reduction performance increases with increase of subblocks.

Figure 10 shows the performance of the proposed PAPR reduction schemes for different number of subcarriers with 2 subblocks in terms of the CCDF of PAPR. From this figure it is observed that the values of PAPR for 2 transmit antennas with different subcarriers N= 64, 128, 256, 512, and 1024 become 7.6, 8.2, 8.6, 8.8 and 9.2 dB respectively when CCDF = 10^{-2}.

Figure 11 demonstrates the CCDF of PAPR for V=2 subblocks and different number of subcarriers. From this figure it is observed that the values of PAPR for 4 transmit antennas with different subcarriers N= 64, 128, 256, 512, and 1024 become 7, 7.5, 8, 8.4 and 8.8 dB respectively. From Figure 10 and 11 it is inferred that the PAPR value increases significantly as number of subcarriers used in the

MIMO-OFDM transmission increase, but PAPR decreases when the number of transmit antennas increase.

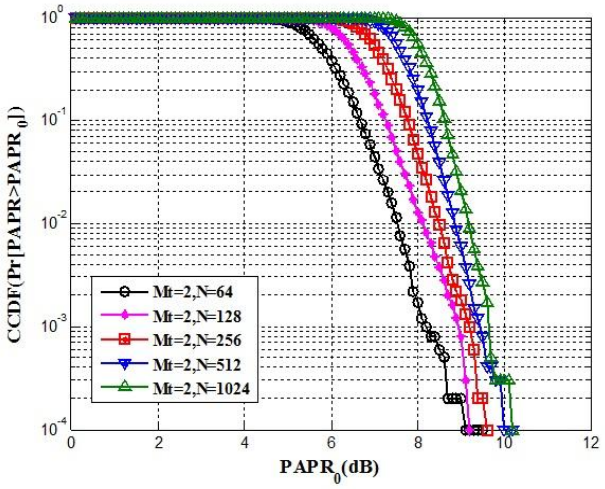

Fig. 10. PAPR reduction performance for different number of subcarriers N= 64, 128, 256, 512, and 1024 when V=2 subblocks with Mt=2 transmit antenna

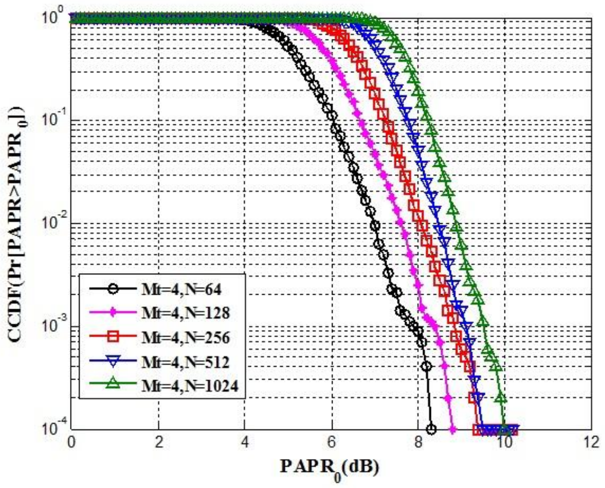

Fig. 11. PAPR reduction performance for different number of subcarriers N= 64, 128, 256, 512, and 1024 when V=2 subblocks with Mt=4 transmit antenna

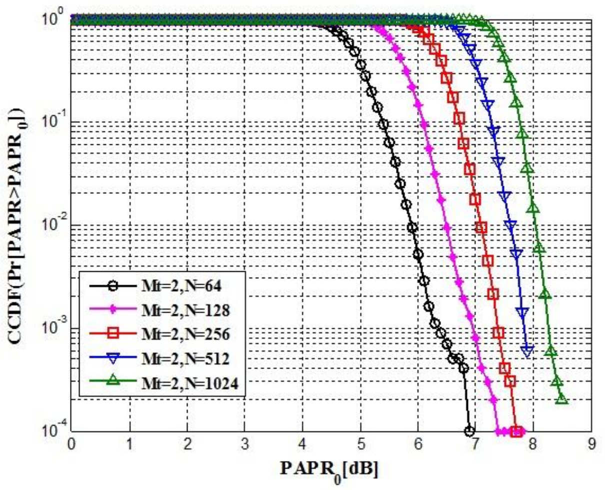

Fig. 12. PAPR reduction performance for different number of subcarriers N= 64, 128, 256, 512, and 1024 when V=4 subblocks with Mt=2 transmit antenna

The impact of the subblock V=4 on the performance of PAPR reduction for different number of subcarriers N= 64,128, 256, 512, 1024 with 2 and 4 transmit antennas respectively are shown in Figure 12 and 13.

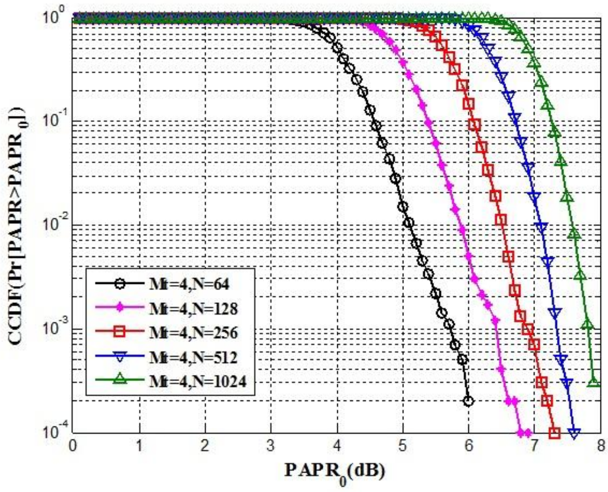

Fig. 13. PAPR reduction performance for different number of subcarriers N= 64, 128, 256, 512, and 1024 when V=4 subblocks with Mt=4 transmit antenna

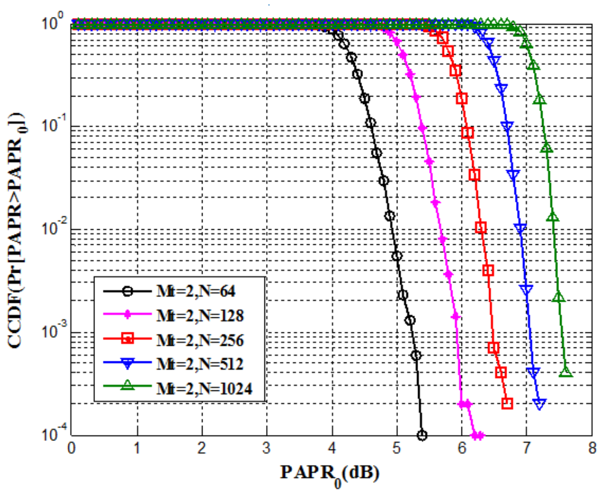

Fig. 14. PAPR reduction performance for different number of subcarriers N= 64, 128, 256, 512, and 1024 when V=8 subblocks with Mt=2 transmit antennas

The force of 8 subblocks on the performance of PAPR reduction for different number of subcarriers with 2 and 4 transmit antennas are shown in Figure 14 and 15. Additionally, in Figures 16 and 17 the CCDF of PAPR are given when the number transmit antennas are increased from Mt=2 and Mt=4 with different subcarriers and subblock size of V=16. Accordingly the results inferred from Figures 14, 15, 16 and 17 are tabulated in Table III.

TABLE III: CCDF of PAPR for different subcarriers

N / V	The values of PAPR in dB at CCDF of 10^{-2}							
	Mt=2				Mt=4			
	2	4	8	16	2	4	8	16
64	7.6	5.8	4.8	4.7	7	5.2	4	3.7
128	8.2	6.6	5.6	5.5	7.5	5.8	4.8	4.6
256	8.6	7.1	6.4	6.2	8	6.5	5.6	5.5
512	8.8	7.6	6.8	6.7	8.4	7.2	6.4	6.3
1024	9.2	8	7.4	7.3	8.8	7.6	6.8	6.7

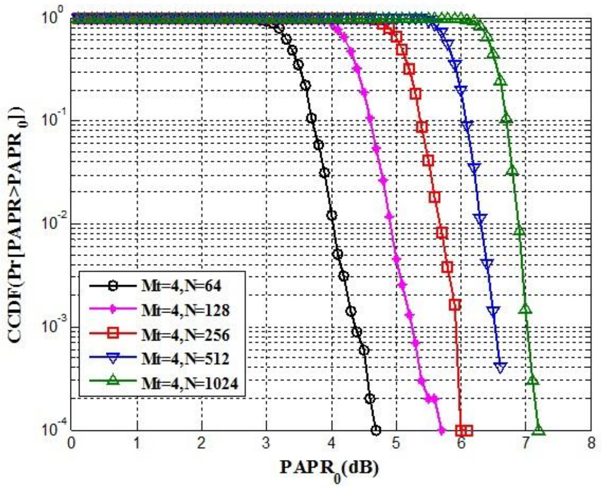

Fig. 15. PAPR reduction performance for different number of subcarriers N= 64, 128, 256, 512, and 1024 when V=8 subblocks with Mt=4 transmit antennas

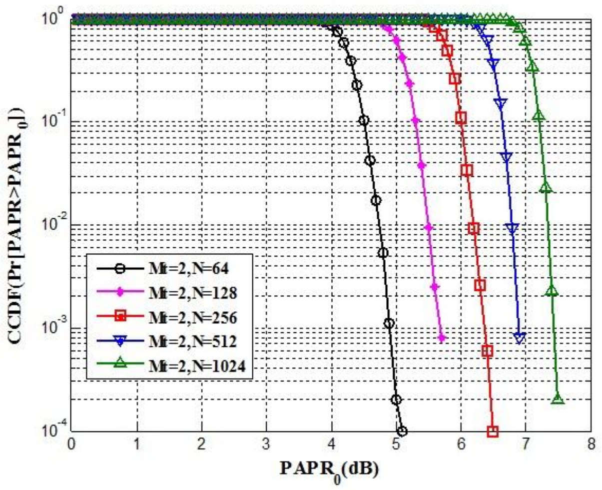

Fig. 16. PAPR reduction performance for different number of subcarriers N= 64, 128, 256, 512, and 1024 when V=16 subblocks with Mt=2 transmit antennas

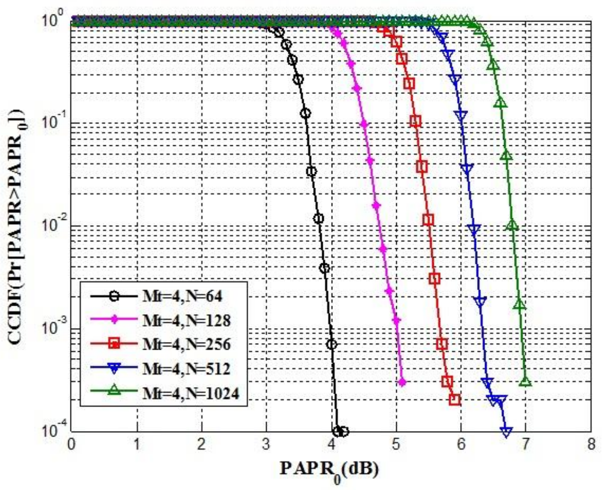

Fig. 17. PAPR reduction performance for different number of subcarriers N= 64, 128, 256, 512, and 1024 when V=16 subblocks with Mt=4 transmit antennas

By comparing of the PAPR reduction performance with different subblocks in Figures 10, 12, 14 and 16 it is clear that PAPR is decreased from 8.6 dB to 7.1 dB, from 7.1 dB to 6.4 dB and from 6.4 dB to 6.2 dB for 2 transmit antennas when N=256 subcarriers with number of subblocks increased from V=2 to 4, from V=4 to 8 and from V=8 to 16 at CCDF of 10^{-2}.

From the Figures 11, 13, 15 and 17, the PAPR reduction performance improvement increases as the number of subblocks increases. It is observed that PAPR values decreased from 8dB to 6.5dB, from 6.5dB to 5.6dB and from 5.6dB to 5.5dB for 4 transmit antennas when N=256 subcarriers with number of subblocks increased from V=2 to 4, 8 and 16 at CCDF of 10^{-2} for 4 transmit antennas.

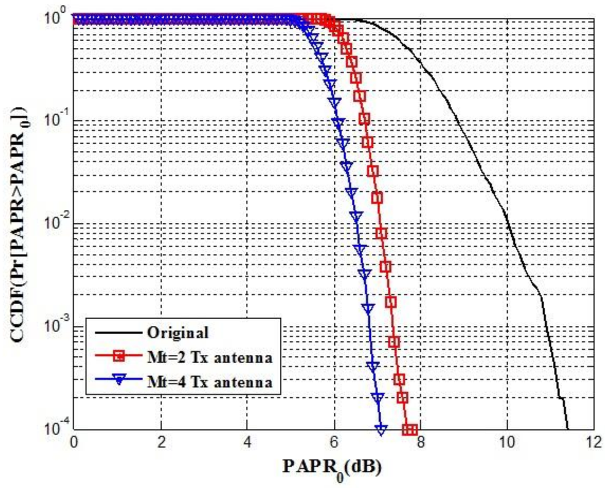

Fig. 18. Comparison of PAPR reduction performance for 256 subcarriers and 4 subblocks with 2 and 4 transmit antennas

In Figure 18 it is shown that the CCDF of PAPR by modified PTS technique combined with interleaving technique for Mt=2 and Mt=4 antennas are improved by 7.1 dB and 6.5 dB compared to ordinary MIMO-OFDM signal when CCDF $=10^{-2}$. The CCDF of PAPR of the unmodified OFDM signal is also shown for comparison purpose. The results show that the unmodified OFDM signal has a PAPR of 10 dB at CCDF $=10^{-2}$. In the considered range of $PAPR_0$ this variant of MIMO PTS performance of PAPR gets worse for an increasing number of transmit antennas. In contrast, the modified interleaved PTS is able to exploit the multiple transmit antennas in order to reduce the PAPR.

V. Conclusion

This paper proposed a modified PTS with interleaving method to reduce the peak-to-average power ratio for MIMO-OFDM system. The method avoids the use of any extra Inverse Fast Fourier Transformations (IFFTs) as was done in PAPR reduction by ordinary PTS technique but instead is based on a proper selection of the different subcarriers and subblocks. It has been shown that the PAPR performance of modified PTS can be improved by using the interleaved subblock partition scheme. As the number of subblock increases better performance is achieved but, the complexity is increased. By interleaved subblock partitioning method combined with modified PTS method is simple to implement and reduces the transmitter complexity can be optimized. This proves to be a promising solution. Unfortunately, the PAPR problem in OFDM gets worse where more transmit antennas are present. Ordinary PTS and modified PTS also suffer from this problem. The modified PTS combined with interleaving technique utilizes the multiple transmit antennas, to achieve better PAPR performance. As the number of subcarriers increases the computational complexity reduction ratio increases. Therefore, the proposed scheme becomes more efficient for high data-rate MIMO-OFDM system.

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