A Modified PTS Combined with Interleaving and Pulse Shaping Method Based on PAPR Reduction for STBC MIMO-OFDM System

P.MUKUNTHAN and P.DANANJAYAN

Department of Electronics and Communication Engineering
Pondicherry University
Pondicherry Engineering College, Pondicherry-605 014
INDIA.
pdananjayan@pec.edu http://www.pec.edu

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. To overcome this problem, the partial transmit sequence (PTS) based on PAPR reduction by optimally combining signal subblocks and the phase rotation factors is considered. 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 occur simultaneously. In this paper, PAPR reduction schemes based on a modified PTS combined with interleaving and pulse shaping method for STBC MIMO-OFDM system has been presented. The paper analyses the influence of the number of the detected peaks on PAPR reduction performance and on complexity, and then obtain the optimal parameter to achieve better PAPR reduction performance and lower complexity. Simulation results show that the proposed modified PTS with interleaving and the pulse shaping method can obviously improve PAPR performance in the MIMO-OFDM system.

Key-Words: - MIMO-OFDM, PAPR, STBC, Partial Transmit Sequences, Interleaved Subblock Partition Scheme, Raised-Cosine pulse shape

1 Introduction

Future mobile communication systems demands for high data rates and high-quality multimedia services to mobile users. Orthogonal frequency division multiplexing (OFDM) is one of the many multi-carrier modulation techniques, which provides high spectral efficiency, low implementation complexity, less vulnerability to echoes and non-linear distortion. Due to these advantages of the OFDM system, it is vastly used in various communication systems [1-4]. Multiple-antenna communications systems have generated a great deal of interest since they are capable of considerably increasing the capacity of a wireless link [5]. A space-time-frequency coded OFDM system which achieves maximum diversity is proposed in [6, 7]. In [8] space-time codes have been designed for use with OFDM over frequency selective channels, which can achieve spatial diversity by using multiple antennas at the transmitter and receiver and it is promising, since it does not increase the transmit power and the signal bandwidth. Therefore, it has been adopted by many high-speed data transmission standards, such as digital audio broadcasting (DAB), digital video broadcasting (DVB), asymmetric digital subscriber line (ADSL), WLAN (IEEE 802.11a/g) and WiMAX (IEEE 802.16) applications.

The MIMO-OFDM system has several advantages over the single carrier systems such as its robustness against multipath fading and high power spectral efficiency. But the major problem one faces while implementing this system is the high peak-to-average power ratio (PAPR). A large PAPR increases the complexity of the analog-to-digital and digital-to-analog converter and reduces the efficiency of the radio-frequency (RF) power amplifier. For short-range transmissions, and in particular for battery powered devices, it is essential to transmit waveforms with low dynamic range.

This ensures a low PAPR and therefore allows the power amplifier to operate in its linear range without an excessive backoff [9].

There are a number of techniques to deal with the problem of PAPR in MIMO-OFDM system. Some of them are amplitude clipping [10], pre-distortion method [11], interleaved method [12], pulse shaping [13], selective mapping (SLM) [14], and partial transmit sequence (PTS) [15]. Amplitude clipping [10] is the simplest PAPR reduction technique. Clipping reduces the PAPR by limiting the peak power to a predetermined threshold. Interleaving technique has been proposed for reduction of PAPR of an OFDM transmission. 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 [16]. The reduction in PAPR achieved by the pulse shaping technique [13] is obtained at the expense of an increase in the error probabilities of the system, and different pulse shaping waveforms result in different probabilities of errors. SLM and PTS belong to the probabilistic class because several candidate signals are generated and the one with the minimum PAPR is selected for transmission. In SLM [14], one OFDM signal of the lowest PAPR is selected from a set of several signals containing the same information data. SLM is a very flexible scheme and has an effective performance of the PAPR reduction without any degradation. However, SLM technique requires high computational complexity and reduced bandwidth efficiency due to the transmission of side information. These techniques achieve PAPR reduction at the expense of transmit signal power increase, bit error rate (BER) increase, data rate loss, computational complexity increase, and so on.

The ordinary PTS scheme is simple and distortionless, sometimes its computational complexity is burden-some. In the PTS [15] approach, the input OFDM block is partitioned into disjoint subblocks. Each subblock is multiplied by a phase weighting factors (±1, ±j), which is obtained by the optimization algorithm to reduce the PAPR value. However, ordinary PTS requires an exhaustive search over all the phase factor combinations, which results in the search complexity increasing exponentially with the number of subblocks. Hence the modified PTS scheme [17] is proposed to lower the computational complexity which maintains the similar PAPR reduction performance compared with the conventional PTS scheme. Another possible alternative solution is then to exploit other parameters of the OFDM signal. To alleviate the problem of high complexity further an approach [18] 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.

In the previous work, PAPR reduction is jointly optimized in both the real and imaginary parts separately multiplied with phase factors when different subcarriers and subblocks [9] some of the existing single-antenna PAPR reduction based modified PTS with interleaving technique is extended to MIMO-OFDM systems[20].

In MIMO-OFDM system [19], a straightforward way for PAPR reduction is to apply the existing algorithms separately on each transmit antenna. It is effective to reduce PAPR performance, but requires high computational complexity, and large size of side information. Therefore, in this paper, a low complexity PAPR reduction scheme for STBC MIMO-OFDM system based on modified PTS combined with interleaving and pulse shaping method is proposed. As the number of subcarriers are increased, reducing the computational complexity with better PAPR reduction performance when the number of subblocks are increased is the aim of this work.

The rest of this paper is organized as follows. In Section 2, the PAPR in SISO-OFDM and MIMO-OFDM systems, the PTS scheme and pulse shaping are discussed. The detailed description of the interleaving technique is shown in Section 3. The simulation results and discussion are presented in Section 4. Finally, the conclusion is drawn in Section 5.

2 MIMO-OFDM System and PTS Scheme

2.1 PAPR in SISO-OFDM System

In the OFDM modulation technique, a block of N data symbols, $X_k = \left(X_{0,} X_{1,} .... X_{N-1}\right)$, is formed with each symbol modulating the corresponding subcarrier from a set of subcarriers. The N subcarriers are chosen to be orthogonal, with a pulse shape waveform of duration T, and f_0 =1/T is the frequency spacing between adjacent subcarriers.
leave two blank lines between successive sections as here.

In SISO-OFDM system, the time-domain OFDM signal for N subcarriers can be written as

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

where X_k denotes the modulated symbol in the kth subblock.

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

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

where, $x(n)$ is the data symbol at n^{th} subcarrier and L is the oversampling factor.

The PAPR of the transmitted OFDM signal, $x(t)$, is then given as the ratio of the maximum to the average power, written as

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

where $E[\cdot]$ denotes expectation, or time-averaged expectation if x(t) is nonstationary.

The Cumulative Distribution Function (CDF) is one of the most regularly used parameters, which is used to measure the efficiency of any PAPR technique. Normally, the Complementary CDF (CCDF) is used instead of CDF, which is used to measure the probability that the PAPR of a certain data block exceeds the given threshold. By implementing the central limit theorem for a multicarrier signal with a large number of subcarriers, the real and imaginary part of the time domain signals have a mean of zero and a variance of 0.5 and follow a Gaussian distribution.

The CCDF denotes the probability of OFDM signal exceeding a given threshold value $PAPR_0$ is given by

$$CCDF(PAPR(x(n))) = P_r(PAPR(x(n))) > PAPR_0 \quad (4)$$

Since the input to the high power amplifier (HPA) must be a continuous-time signal, the CCDF of the PAPR of x(t) is of interest. Oversampling has been used to approximate the CCDF of the PAPR of the continuous-time OFDM signal by

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

This expression assumes that the Nyquist-rate time domain OFDM signal samples are mutually independent and uncorrelated. This is not true, however, when oversampling is applied. Also, this expression is not accurate for a small number of subcarriers since a Gaussian assumption does not hold in this case. Therefore, the CCDF of PAPR computed of the L-time oversampled OFDM signal can be rewritten as

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

2.2 PAPR in MIMO-OFDM System

A multicarrier system can be efficiently implemented in discrete time using an inverse fast Fourier transform (IFFT) to act as a modulator and an FFT to act a demodulator. Consider the MIMO-OFDM system with M_t transmit antennas that use N subcarriers. With OFDM modulation, a block of N data symbols (one OFDM symbol), $\{X_n, n = 0,1,...,N-1\}$ will be transmitted in parallel such that each modulates a different subcarrier from a set $\{f_n, n = 0,1,...,N-1\}$. The N subcarriers are orthogonal, ie., $f_n = n\Delta f$, where Δf =1=NT and T is the period. The resulting baseband OFDM signal $x_{m,k}$ of a block can be expressed as

$$x_{m,k} = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n e^{j2\pi f_n k}, k = 0,1,....N-1 \quad (7)$$

where, X_n is the transmitted OFDM signal at the n subcarriers of the mth transmit antennas. The PAPR is a characteristic of the input signal and is defined as follows for transmit signal $x(t)$.

$$\text{PAPR=} \frac{\max_{0 \le t \le M\tilde{T}} |x(t)|^2}{\frac{1}{M\tilde{T}} \int_0^{M\tilde{T}} |x(t)|^2 \, dt} \quad (8)$$

where T is the block duration for block transmission

The PAPR of the continuous-time OFDM signal cannot be precisely computed at the Nyquist sampling rate, which corresponds to N samples per OFDM symbol. When this is not the case, the achieved PAPR reduction might be lower and suboptimal [21]. To achieve effective PAPR reduction for this case, signal peaks may be skipped and PAPR estimates are not precise. Usually, the oversampling factor L larger than 4 is used for a PAPR reduction scheme to increase the resolution of discrete-time OFDM signals. However, such an oversampling process would significantly increase the computational complexity.

PTS schemes for SISO systems can be directly applied to each transmit antenna in MIMO-OFDM system achieving almost the same PAPR reduction performance with single transmit antenna. For the entire system, the PAPR is defined as the maximum of PAPRs among all transmit antennas [22], i.e.,

$$PAPR_{MIMO-OFDM} = \max_{1 \le i \le M_t} PAPR_i \quad (9)$$

where $PAPR_i$ denotes the PAPR at the ith transmit antenna.

Specifically, since in MIMO-OFDM, M_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

$$P_r(PAPR_{MIMO-OFDM} > PAPR_0) = 1-(1-e^{-PAPR_0})^{M_t LN} \quad (10)$$

Comparing (10) with (6), it is evident that MIMO-OFDM results in even worse PAPR performance than SISO-OFDM. In practice, a HPA is expected to provide a certain level of power efficiency, which means that for a given HPA and biasing conditions, the average input power has to be above a certain amount. This also requires the input signal PAPR to be less than a threshold $PAPR_0$.

2.3 PTS scheme

The partial transmit sequence scheme [23- 25] is an attractive solution to reduce PAPR in MIMO-OFDM system without any distortion of transmitted signals. In the PTS scheme, the input data block is partitioned into disjointed subblocks. And each subblock is multiplied by phase weighting factors, which obtained with optimization algorithm. If the subblocks are optimally phase shifted, they exhibit minimum PAPR and consequently reduce the PAPR of the merged signal. The number of subblocks *(V)* and the subblock partition scheme determine the PAPR reduction. The main drawback of PTS arises from the computation of multiple IFFTs, resulting in a high computational complexity with the factorial of the product of transmit antennas number and subblocks number.

In general, Subblock partitioning types can be classified into 3 categories; interleaved partition, adjacent partition, and pseudo-random partition. For the interleaved method [12], every subcarrier signal spaced apart is allocated at the same subblock. In the adjacent scheme, successive subcarriers are assigned into the same subblock sequentially. Lastly, each subcarrier signal is assigned into any one of the subblocks randomly in the pseudo-random scheme. It can be noted that the computational complexity of the interleaved subblock partitioning scheme is reduced extensively as compared to that of the adjacent and pseudo-random partition scheme. This subblock partitioning scheme reduces considerably the envelope fluctuations in the transmitted waveform.

A simplified block diagram of STBC MIMO-OFDM system with M_t=2 transmit antennas is illustrated in Fig. 1. A data symbol vector $S=[X_0, X_1, ..., X_{N-1}]^T$ is encoded with space-time encoder takes a single stream of binary input data and transforms it into two vectors S_1 and S_2,

$S_1=[X_0, -X^*_1, ...X_{N-2}, -X^*_{N-1}]^T$,

$S_2=[X_1, X^*_0, ...X_{N-1}, X^*_{N-2}]^T$.

which are fed to the IFFT blocks and sent simultaneously from antennas T_{X1} and T_{X2}, respectively.

Alternative transmit vectors representing the same data can now be constructed by mutually interchanging the corresponding PTSs between the different transmitter branches, provided that the same subcarrier grouping is applied to all branches. Symbol S_1 and S_2 represent the two neighboring OFDM signals in time domain.

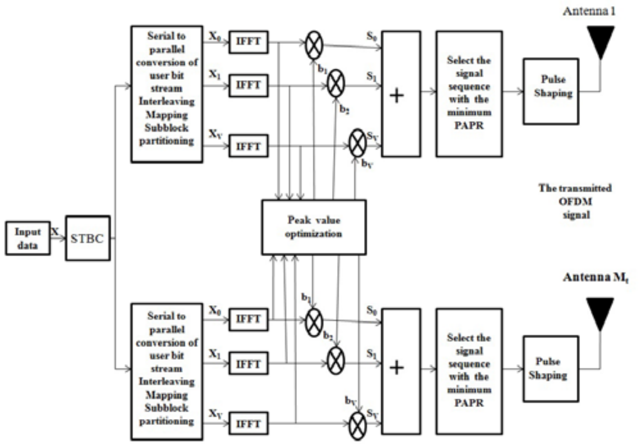

Fig 1. A typical structure of transmitter for modified PTS combined with interleaving and pulse shaping method in STBC MIMO-OFDM system

The objective is to optimally combine the V clusters, which in frequency domain is given by

$$S' = \sum_{m=1}^{V} b_m S_m \tag{11}$$

where, $\{b_m$, m=1, 2,…, V $\}$ are weighting factors and are assumed to be perfect rotations.

In other words, the time domain is given by

$$s = \sum_{m=1}^{V} b_m s_m \tag{12}$$

where, s_m consist of a set of subblocks with equal size and b_m is the phase rotation factor, which are required to inform the receiver as the side information.

In order to increase PTS performance, the size of side information is drastically increased. It means that the total throughput considerably decreases. 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 code word to be transmitted are divided into several subblocks, V, of length N/ V [18].

Mathematically, expressed by

$$A_k = \sum_{v=1}^{V} A_k^{(v)}, \quad v=1, 2, \dots, V \tag{13}$$

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,

$$a_n^{(v)} = IFFT\left\{A_k^{(v)}\right\} \tag{14}$$

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

$$e^{j\theta(v)} \in [0, 2\pi] \tag{15}$$

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

$$\tilde{a}_n = \sum_{v=1}^{V} a_n^{(v)} . e^{j\theta(v)} \tag{16}$$

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, *b*, the MIMO- OFDM symbol with the lowest PAPR is transmitted as given by [18]

$$\tilde{\phi}^2, \tilde{\phi}^3, \ldots \tilde{\phi}^v = \arg\min(\max|\tilde{a}_n|) \tag{17}$$

The weighting 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 PTS method, these phase factors combination correctly maintains the orthogonality between the different modulated carriers. However, the PTS PAPR reduction scheme's performance improvement is achieved at the expense of high complexity and difficult parameter setting problems. Therefore, modified PTS indeed use the potential of MIMO transmission for PAPR reduction. In MIMO communication, data rate or diversity order can be improved by exploiting the spatial dimension [26, 27]. In the same spirit, treating the parallel transmit signals jointly, PAPR reduction may be improved.

2.4 Raised-Cosine pulse shape

A set of time waveforms that reduces the PAPR of OFDM signals was proposed in [28, 29]. However, the reduction obtained was not considerable. Consider a time waveform with constant energy equals to energy signal (Es=1) and uncorrelated symbols within each OFDM block, the maximum PAPR is obtained as follows:

$$PAPR \leq PAPR_{\max} = \frac{1}{N} \max_{0 \leq t \leq T} \left(\sum_{n=0}^{N-1} |P_m(t)| \right)^2 \tag{18}$$

which is a function of the number of subcarriers N and $P_m(t)$ is a pulse shape (time waveform) used at each subcarrier. With large number of subcarriers, the maximum of the PAPR occurs with very low probability.

The cross-correlation function of the OFDM signal is obtained as:

$$R_s(t_1, t_2) = \sum_{n=0}^{N-1} \sum_{m=0}^{N-1} \overline{S_{n,k} S^*_{m,k}} \, p_n(t_1) p^*_m(t_2) e^{j\omega_c(nt_1 - mt_2)} \tag{19}$$

where ω_c is the carrier frequency of the system and the cross-correlation coefficient is zero for all samples separated by multiples of T.

A possible solution to reduce the PAPR of the OFDM signals is then to create some correlation between the different OFDM samples of the same block. The new set of pulse shapes indicates that each subcarrier pulse of the OFDM scheme has a different shape and all these pulse shapes are derived from the same pulse (cyclic shifts of the same pulse).This will also reduce the PAPR of the OFDM transmitted signal since the peak amplitude of the different pulse shapes will never occur at the same time instant unless time waveform is a rectangular pulse.

The impulse response of a raised cosine filter is,

$$r(t) = \sin c(\pi \frac{t}{\tilde{T}}) \frac{\cos(\frac{\pi\alpha t}{\tilde{T}})}{1 - \frac{4\alpha^2 t^2}{\tilde{T}^2}} \tag{20}$$

where the parameter α is the roll-off factor which ranges between 0 and 1. Lower values of α introduce more pulse shaping and more suppression of out-of-band-signal components. Pulse shapes are very flexible and can control the correlation between the OFDM block samples without destroying the orthogonality property between the subcarriers of the OFDM modulated signal.

3 Interleaved MIMO-OFDM

Highly correlated data frames of OFDM signals have large PAPRs, which could thus be reduced, if the long correlation patterns are broken down. A set of fixed permutations (interleaving) is used in this technique to break these correlation patterns [30-32]. In this approach K-1 interleavers are used at the transmitter. These interleavers produce K-1 permuted frames of the input data. The minimum PAPR frame of all the K frames is selected for transmission. The identity of the corresponding interleaver is also sent to the receiver as side information. 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.

$$x^{(k)}(n) = \sum_{m=0}^{V-1} X_m^{(k)} e^{j(2\pi/N)(mQ+k)n} \tag{21}$$

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

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

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

$$= \frac{1}{Q}.\frac{1}{N}\sum_{k=0}^{N-1} X_k e^{j2\pi\frac{Nq+n}{N}k}$$

$$= \frac{1}{Q}\left(\frac{1}{N}\sum_{k=0}^{N-1} X_k e^{j2\pi\frac{n}{N}k}\right) \tag{22}$$

$$= \frac{1}{Q}.x_n$$

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.

The resulting time symbols $\{\tilde{x}_m\}$ are simply a repetition of the original input symbols $\{x_n\}$ in the time domain [33]. Therefore, an interleaved MIMO-OFDM system with N subcarriers can be scaled from an OFDM system.

4 Results and Discussion

The analysis of PAPR reduction performance for modified PTS combined with interleaving and pulse shaping method has been carried out using MATLAB 7.0. The simulation parameters considered for this analysis is summarized in Table 1.

Table 1.Simulation parameters

Simulation parameters	Type/Values
Number of OFDM blocks	10000
Number of subcarriers (N)	64,128,256,512,1024
Number of subblocks (V)	2, 4,8,16
Oversampling factor (L)	4
Roll-off factor (α)	0.6
Subblock partitioning scheme	Interleaving
Number of antennas(M_t)	2
Modulation scheme	QPSK
Phase weighting factor (b)	1, -1, j, -j

In the MIMO-OFDM system under consideration, modified PTS technique is applied to the subblocks of input information, which is modulated by QPSK modulation, and the phase rotation factors are transmitted directly to receiver through subblock. The performance evaluation is done in terms of complementary cumulative distribution function (CCDF) of the PAPR, which indicates the probability that the PAPR is larger than $PAPR_0$.

It is shown in Fig.2 that the performance of the modified PTS technique with interleaving and pulse shaping method for STBC MIMO-OFDM system with different number of subcarriers N= 64,128, 256, 512, and 1024. From this figure it is observed that the values of PAPR for N= 64,128, 256, 512, and 1024 become 6.9dB, 7.6dB, 8.2dB, 8.6dB and 9dB respectively when CCDF = 10^{-2}. The PAPR value increases significantly as number of subcarriers used in the MIMO-OFDM transmission increase. This improvement in PAPR is valid for any number of subcarriers of the OFDM signal by using pulse shaping technique.

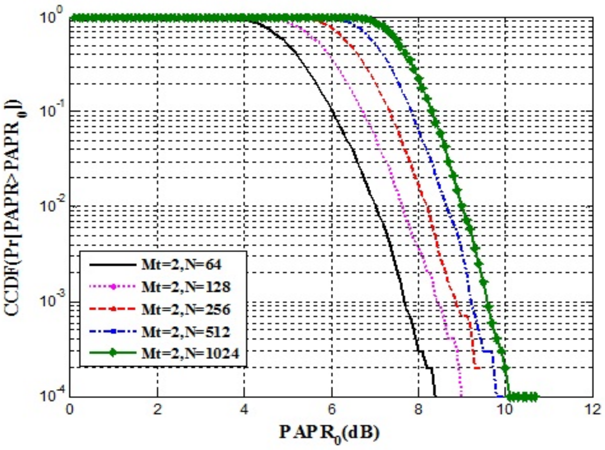

Fig. 2 CCDF of PAPR for different subcarriers N = 64, 128, 256, 512, 1024 when V=4, L=4, α=0.6 and M_t=2

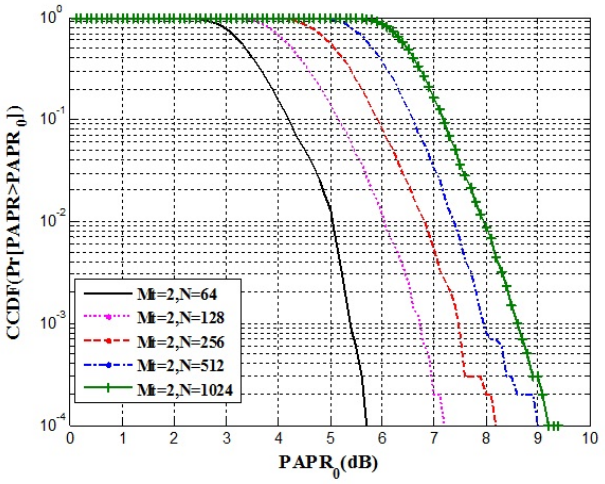

Fig. 3 CCDF of PAPR for different subcarriers N = 64, 128, 256, 512, 1024 when V=8, L=4, α=0.6 and M_t=2

The impact of the subblock V=8 on the performance of PAPR reduction for different number of subcarriers N= 64,128, 256, 512, 1024 with 2 transmit antennas is shown in Fig. 3 at CCDF = 10^{-2}. From this Fig. 3 it is observed that the values of PAPR for 2 transmit antennas for different subcarriers N= 64, 128, 256, 512, and 1024 become 5, 6, 6.8, 7.4 and 7.9 dB when CCDF = 10^{-2}. By comparing the Figures 2 and 3 it is evident that PAPR is decreased from 8.2 dB to 6.8 dB for 2 transmit antennas when N=256 subcarriers with number of subblocks increased from V=4 to 8 at CCDF of 10^{-2}. The PAPR value increases significantly as number of subcarriers used in the MIMO-OFDM transmission increase, but PAPR values decreases as the number of subblocks increases.

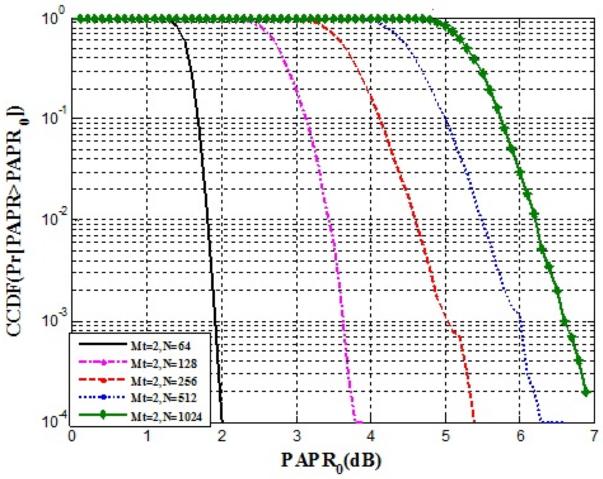

Fig. 4 CCDF of PAPR for different subcarriers N = 64, 128, 256, 512, 1024 when V=16, L=4, α=0.6 and M_t=2

The impact of the subblock V=16 on the performance of PAPR reduction for different number of subcarriers N= 64, 128, 256, 512, 1024 with 2 transmit antennas is shown in Fig. 4 at CCDF = 10^{-2}. From this Fig. 4 it is observed that the values of PAPR for 2 transmit antennas for different subcarriers N= 64, 128, 256, 512, and 1024 become 1.8, 3.4, 4.6, 5.6 and 6.3dB respectively when CCDF = 10^{-2}. By comparing the Figures 2, 3 and 4 it is evident that PAPR is decreased from 8.2 dB to 6.8 dB and from 6.8 dB to 4.6 dB for 2 transmit antennas when N=256 subcarriers with number of subblocks increased from V=4 to 8 and from V=8 to 16 at CCDF of 10^{-2}. The PAPR value increases significantly as number of subcarriers used in the MIMO-OFDM transmission increase, but PAPR values decreases as the number of subblocks increases.

Fig.5 shows the CCDFs of PAPR performance of the modified PTS based on interleaving and pulse shaping method in MIMO-OFDM system with different number of subblocks V=2, 4, 8, and 16 for a random data of block size 10000 with N=256 subcarriers, spreading factor β=4, oversampling factor L=4 and roll-off factor α=0.6. It can be seen from the figure that as the subblock size is increased from 2 to 4, 8, and 16, the PAPR is reduced to 8.8 dB, 8.2dB, 6.8 dB and 4.6 dB respectively when CCDF=10^{-2}, resulting in PAPR performance improvement as the number of subblocks increases.

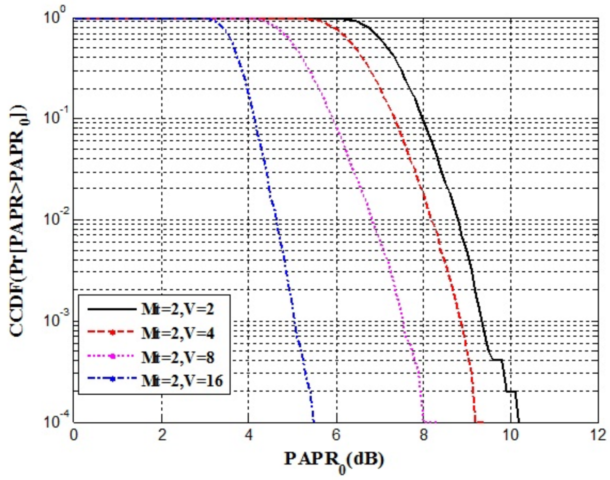

Fig.5 CCDF of PAPR for different subblocks V= 2, 4, 8, 16 when N=256, L=4, α=0.6 and M_t=2

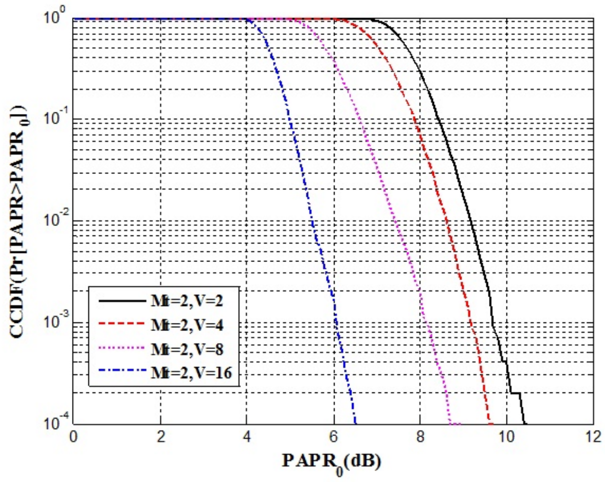

Fig.6 CCDF of PAPR for different subblocks V= 2, 4, 8, 16 when N=512, L=4, α=0.6 and M_t=2

Fig. 6 illustrate the CCDFs of PAPR of the modified PTS with interleaving and pulse shaping method for different subblocks V=2, 4, 8, 16 when subcarriers N=512 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 become 9.1 dB, 8.6 dB, 7.4 dB, and 5.6 dB respectively when CCDF = 10^{-2}. By comparing the Figures 5, and 6 it is evident that PAPR is increased from 8.2 dB to 8.6 dB for 2 transmit antennas when V=4 subblocks with number of subcarriers increased from N=256 to 512 at CCDF of 10^{-2}. From this figure it is shown that PAPR reduction performance increases with increase of subblocks.

Fig.7 shows the CCDFs of PAPR of the modified PTS with interleaving technique for different subblocks V=2, 4, 8, 16 when subcarriers N=1024 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 become 9.4, 9, 7.9, and 6.3 dB respectively when CCDF = 10^{-2}. By comparing the Figures 5, 6, and 7 it is evident that PAPR is increased from 8.2 dB to 8.6 dB, and from 8.6 dB to 9 dB for 2 transmit antennas when V=4 subblocks with number of subcarriers increased from N=256 to 512 and from N=512 to 1024 respectively at CCDF of 10^{-2}. From this figure it is shown that PAPR reduction performance increases with increase of subblocks.

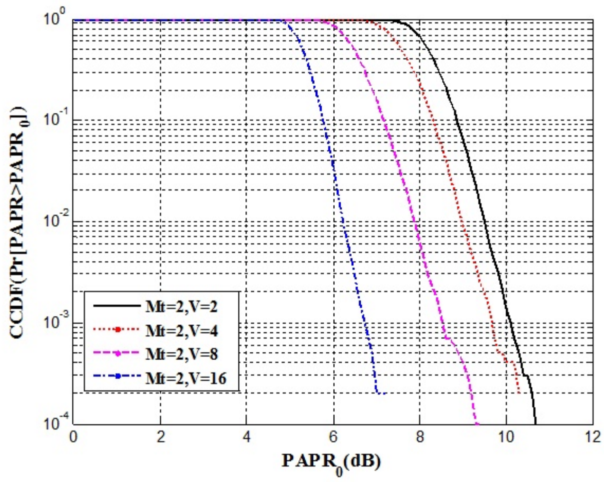

Fig.7 CCDF of PAPR for different subblocks V= 2, 4, 8, 16 when N=1024, L=4, α=0.6 and M_t=2

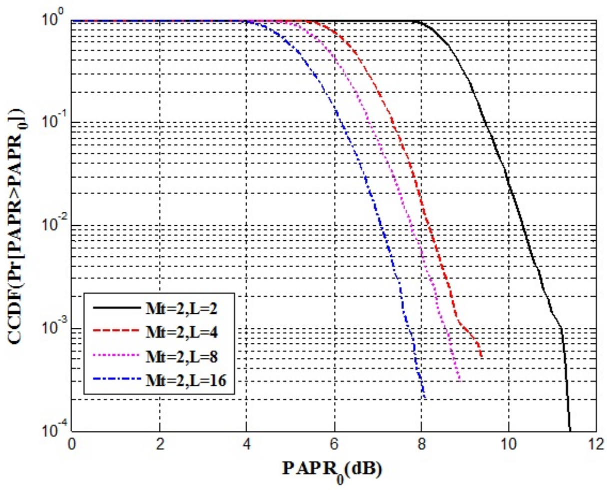

Fig.8 CCDF of PAPR for different oversampling factor L= 2, 4, 8, 16 when N=256, V=4,α=0.6 and M_t=2

Fig. 8 illustrates the complementary cumulative distribution function of the PAPR of the MIMO-OFDM signal for the case of N=256 subcarriers and V=4 subblocks and for different oversampling factor

(L) increased from 2 to 4, 8, and 16. If L is increased, improved performance can be obtained. Of course, this occurs at an increasing level of complexity. Increasing L beyond 4 seems to bring very little improvement in performance.

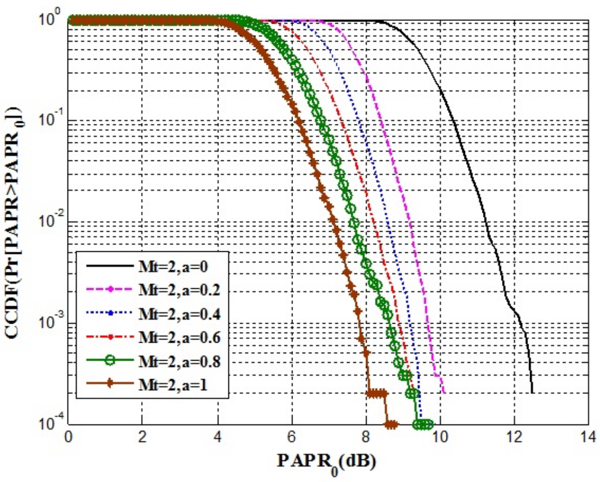

Fig. 9 Analysis of PAPR by altering roll-off factor α=0, 0.2, 0.4, 0.6, 0.8, and 1 for N= 256 when V=4, L=4 and M_t=2

Fig. 9 illustrates the complementary cumulative distribution function of the PAPR of the OFDM signal for the case of N=256 subcarriers and V=4 subblocks and for different roll-off factors. As the roll-off factor α increases from 0 to 1, PAPR reduces significantly for MIMO- OFDM system. This implies that there is a tradeoff between PAPR performance and out-of-band radiation since out-of-band radiation increases with increasing roll-off factor. It is observed that the proposed broadband pulse shapes provide considerable gain in PAPR for the OFDM signal when compared to that of ordinary MIMO-OFDM signal. By using pulse shaping filter with high roll off factor significant reduction of PAPR occurs but price paid is increased bandwidth requirement. So an optimal value of roll-off factor is chosen according to application.

Fig. 10 shows the comparison between the modified PTS without interleaving and modified PTS with interleaving for MIMO-OFDM system. When the parameters are set with N=256 subcarriers, V=4 subblocks, oversampling factor L=4 and roll-off factor α=0.6, interleaved subblock partitioning method to reduce hardware complexity of IFFT with little performance degradation. It can be seen that the PAPR of modified PTS without interleaving method is 9.2 dB, modified PTS with interleaving method is 8.9 dB and modified PTS with interleaving and pulse shaping is 8.2 dB at CCDF of 0.6, respectively. From this figure it is concluded that combined modified PTS with interleaving and pulse shaping method results in a significant PAPR reduction compared to the other schemes.

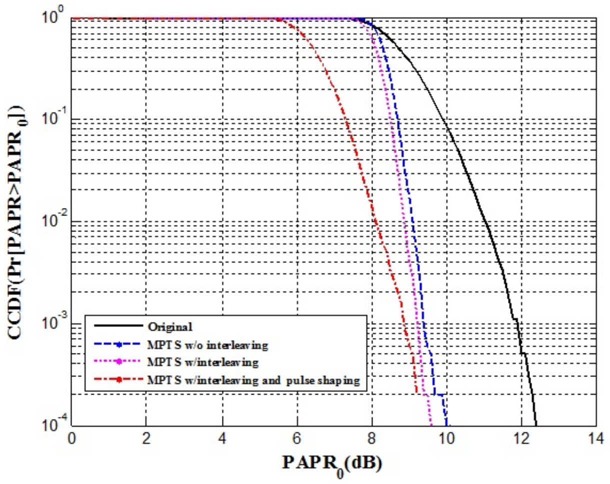

Fig.10 Comparison of Original, MPTS with and without interleaving, and MPTS with interleaving and pulse shaping method for MIMO-OFDM system with N= 256,V=4, L=4, α=0.6 and M_t=2

5 Conclusion

This paper proposes a modified PTS with interleaving and pulse shaping method to reduce the peak-to-average power ratio for MIMO-OFDM transmission. 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 can be improved up to 2.8 dB by using a modified PTS combined with interleaving and pulse shaping method compared with the original signal. Simulation results to illustrate the performance of the modified PTS combined with interleaving and pulse shaping method for STBC MIMO-OFDM system is an effective scheme to achieve a better tradeoff between PAPR reduction and computational complexity. Since the computational complexity reduction ratio increases as the number of subcarriers increases, the proposed scheme becomes more suitable for the high data rate MIMO-OFDM system such as a digital multimedia wireless broadband mobile communication system.

References:

[1] R.V. Nee and R. Prasad, *OFDM for Wireless Multimedia Communications*, London, Artech House, Boston, 2000.

[2] S. Hara and R.Prasad, *Multicarrier Techniques for 4G Mobile communications*, Artech House, Boston, 2003.

[3] Haitham J.Taha and M.F.M. Salleh, "Multi-carrier transmission techniques for wireless communication systems: A survey", *WSEAS Transactions on Communications*, Vol. 8, No. 5, May 2009, pp. 457-472.

[4] S.H. Muller and J.B. Huber, "A novel peak power reduction scheme for OFDM", in *Proceedings of International Symposium on Personal, Indoor, and Mobile Radio Communication*, Finland, Vol. 3, 1-4 September 1997, pp. 1090–1094.

[5] Xu Yan, Wang Chunli Jr., and Wang Qi, "Research of Peak-to-average power ratio reduction improved algorithm for MIMO-OFDM system", in *Proceedings* of *World Congress on Computer Science and Information Engineering*, Los Angeles, USA, Vol. 1, March 31-April 2, 2009, pp. 171-175.

[6] Jing Gao, Jinkuan Wang and Yun Wang, "A low complexity PAPR reduction technique for STBC MIMO-OFDM system", in *Proceedings of International Conference on Wireless Communications, Networking and Mobile Computing*, Shanghai, 21-25 September 2007, pp. 109-112.

[7] A.S.Hiwale and A.A.Ghatol, "Capacity and performance analysis of space-time block codes in raylaigh fading channals", *WSEAS Transactions on Communications*, Vol. 6, No. 12, December 2007, pp. 861-866.

[8] Zhiqiang Liu, Yan Xin and Georgios B.Giannakis, "Space-time-frequency coded OFDM over frequency-selective fading channels", *IEEE Transactions on Signal Processing*, Vol. 50, No. 10, October 2002, pp. 2465-2476.

[9] P.Mukunthan and P.Dananjayan, "PAPR reduction of an OFDM signal using modified PTS combined with interleaving and pulse shaping method", *European Journal of Scientific Research*, Vol. 74, No. 4, May 2012, pp. 475-486.

[10] Shang-Kang Deng, Mao-Chao Lin, "Recursive Clipping and Filtering with bounded distortion for PAPR reduction", *IEEE Transactions on Communication*, Vol. 55, No.1, January 2007, pp. 227-230.

[11] Chhavi Sharma, Shiv Kumar Tomar, and A.K.Gupta, "PAPR reduction in OFDM system using adapting coding technique with pre distortion method", *WSEAS Transactions on Communications*, Vol. 10, No. 9, September 2011, pp. 255-262.

[12] S.G.Kang, J.G.Kim, "A novel subblock partition scheme for partial transmit sequence OFDM", *IEEE Transactions on broadcasting*, Vol. 45, No. 3, September 1999, pp. 333-338.

[13] S. Ben Slimane, "Peak-to-average power ratio reduction of OFDM signals using pulse shaping", in *Proceedings of Vehicular Technology Conference*, USA, Vol. 4, 24-28 September 2002, pp. 889-893.

[14] 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.

[15] D.Phetsomphou, S.Yoshizawa, and Y.Miyanaga, "A partial transmit sequence technique for PAPR reduction in MIMO-OFDM systems", in *Proceedings of 10th International Symposium on Communications and Information Technologies*, Tokyo, Japan, 26-29 October 2010, pp. 672-676.

[16] G.Lu, P. Wu and C. Carlemalm-Logothetis, "Enhanced Interleaving partitioning PTS for peak-to-average power ratio reduction in OFDM systems", *IEEE Electronics Letters*, Vol.42, No.17, August 2006, pp.983-984.

[17] Z.Xiuyan and T.Guobin, "The research of improved PTS method for peak-to-average power ratio reduction", in *Proceedings of 3rd international conference on wireless, mobile and multimedia networks*, Beijing, China, 26-29 September 2010, pp. 104-107.

[18] P.Mukunthan and P.Dananjayan, "Modified PTS with FECs for PAPR reduction of OFDM signals", *International Journal of Computer Applications*, Vol. 11, No. 3, December 2010, pp. 38-43.

[19] S. M. Alamouti, A simple transmit diversity technique for wireless communications, *IEEE Select Areas in Communications*, Vol. 16, No. 8, October 1998, pp.1451-1458.

[20] P.Mukunthan and P.Dananjayan, "PAPR reduction based on a modified PTS with interleaving and pulse shaping method for STBC MIMO-OFDM system", in *Proceedings of Third International Conference on Computing, Communication and Networking Technologies*, SNS College of Engineering, Coimbatore, Tamilnadu, India, 26th to 28th July 2012. (Accepted)

[21] M.Sharif, M.Gharavi-Alkhansari, and B.H. Khalaj, "On the peak-to-average power of

OFDM signals based on oversampling", *IEEE Transactions on Communications*, Vol. 51, No. 1, January 2003, pp.72-78.

[22] Harish Reddy and Tolga M.Duman, "Space-time coded OFDM with low PAPR", in *Proceedings of Global Telecommunications Conference*, San Francisco, USA, 1-5 December 2003, pp.72-78.

[23] L.J. Cimini, and N.R. Sollenberger, "Peak-to-average power ratio reduction of an OFDM signal using Partial Transmit Sequences", *IEEE Communications Letters*, Vol. 4, No. 3, March 2000, pp.86-88.

[24] Chintha Tellambura, "Improved phase factor computation for the PAP reduction of an OFDM signal using PTS", *IEEE Communications Letters*, Vol. 5, No. 4, April 2001, pp. 135-137.

[25] Xiuyan Zhang, Yubo Duan, and Guobin Tao, "The research of peak-to-average power ratio performance by optimum combination of partial transmit sequences in MIMO OFDM system", in *proceedings of the 3rd International Congress on Image and Signal Processing*, Yantai, China, Vol. 9, 16-18 October 2010, pp. 4476-4479.

[26] M.Haridim, H.Matzner, V.Neder, D.Ezri, "Analysis of a fixed-complexity sphere decoding method for spatial multiplexing MIMO", *WSEAS Transactions on Communications*, Vol. 8, No. 3, March 2009, pp. 353-362.

[27] D. Tse, P.Viswanath, *Fundamentals of Wireless Communication*, Cambridge University Press, Cambridge, UK, 2005.

[28] H.G.Myung, Junsung Lim and D.J. Goodman, "Peak-to-average power ratio of single carrier FDMA signals with pulse shaping", in *Proceedings of 17th International Symposium on Personal, Indoor and Mobile Radio Communication*, Helsinki, Finland, 11-14 September 2006, pp.1-5.

[29] Mohamed Adnan Landolsi and Ganiyn B. Hussain, "Pulse shaping in Non-coherent DLL tracking of CDMA signals", *WSEAS Transactions on Communications*, Vol.7, No. 12, December 2008, pp. 1246-1252.

[30] S. Zid and R. Bouallegue, "Low-complexity PAPR reduction schemes using SLM and PTS approaches for Interleaved OFDMA", in *Proceedings of International Conference on Ultra Modern Telecommunications &Workshops*, Saint Petersburg, Russia, 12-14 October 2009, pp.1-5.

[31] A.D.S, Jayalath and C.Tellambura, "The use of Interleaving to reduce the peak-to-average power ratio of an OFDM signal", in *Proceedings of Global Tele communications Conference* , San Francisco, CA, Vol. 1, 27 November-1 December 2000, pp.82-86.

[32] J.Sarawong, T.Mata, P.Boonsrimuang and H.Kobayashi, "Interleaved partitioning PTS with new phase factors for PAPR reduction in OFDM systems", in *Proceedings of 8th International Conference on Electrical Engineering / Electronics, computer, Telecommunications and Information Technology*, Khon Kaen, Thailand, 17-20 May 2011, pp.361-364..

[33] U.Sorger, I. De broeck and M.Schnell, "Interleaved FDMA - A new Spread-Spectrum Multiple-Access scheme", in *Proceedings of International Conference on Communications*, Atlanta, Georgia, USA, Vol.2, 7-11 June 1998, pp.1013-1017.