PAPR Reduction by CSI-PTS in OFDM System with Low Computational Complexity

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***Abstract*—Orthogonal Frequency Division Multiplexing (OFDM) has been recognized as one of the most promising techniques because it supports high data rate and high performance. In particular, coding over the space-time and frequency domains provided by OFDM will enable a much more reliable and robust transmission over the harsh wireless environment. The main problem associated with OFDM is Peak to Average Power Ratio (PAPR). Several techniques are proposed to overcome the PAPR problem in OFDM. Partial Transmit Sequence (PTS) scheme is one of the most popular distortions-less techniques for OFDM system. In the PTS scheme, one OFDM symbol is partition into disjointed sub-blocks, and each sub-block is multiplied by a phase factor to generate signals with lower PAPR. For data recovery, receiver must have side information (SI) e.g. phase factor, from the transmitter. The disadvantage of PTS technique is that for each OFDM symbol side information bits must send. If side information is affected by noise then receiver does not detect the actual information. In this letter, a novel technique is proposed that is a combination of Complementary Sequence Insertion (CSI) and PTS techniques. In proposed technique increasing number of complementary sequences decreases the transmission efficiency. The conventional PTS requires several Fast Fourier Transform (FFT) operations at the receiver but the proposed technique requires half the FFT operations at the receiver. Unlike the PTS the proposed technique requires, does not require side information bits that increase the bandwidth efficiency of the system. PAPR reduction is better by increasing the length of complementary sequences also the BER is improved. Simulation results are examined with IEEE 802.16-2004 standards. By applying CS of length 16, PAPR reduction about 3 dB at Complementary Cumulative Distribution Function (CCDF) of 0.01% is achieved compared to the simple OFDM system.**

Keywords-PAPR, OFDM, PTS, CSI, SI, CCDF

I. INTRODUCTION

The bandwidth demand in wireless communication system is increased day by day. As the frequency is a dedicated resource for wireless communication and due to limitation on utilization of frequency spectrum, the new transmission formats like Orthogonal Frequency Division Multiplexing (OFDM) is applied to the modern wireless communication systems. OFDM signals have advantages like high spectral efficiency, robustness against multipath propagation effects, high data rate. Despite the advantages of OFDM signals, there are several disadvantages of OFDM signals in which main one is high PAPR. High peak values in OFDM results from the superposition of a large number of usually statically independent sub-channels that can be constructively sum up to high peaks [1]. This high peak values had been considered unavoidable for some time. To overcome this impact, several techniques for reducing PAPR have been proposed. Classification of techniques is based on the distortion introduced by the technique while reducing PAPR. Some techniques do not introduce the distortion so it is called distortion less PAPR reduction technique some examples are Selective Mapping (SLM) and PTS which are in the frequency domain. Clipping Filtering, Companding and PTS techniques are in the time domain. Here a technique is proposed called CSI-PTS which is in the time domain and it is the combination of CSI and PTS [2].

In PTS technique, the OFDM symbols are partitioned into number of dis-joint sub-blocks. IFFT of individual sub-blocks are performed and the resulting signal is multiplied by optimum phase factors that lead to lower PAPR. In PTS technique number of iterative operations need to be performed, therefore, PTS is distortion-less but time-consuming and needs large number of computations [3].

In this paper by applying CSI-PTS technique we show that not only the PAPR be reduced but also the BER is improved by inserting complementary sequences. By applying the proposed CSI-PTS technique, Complexity and processing time also decreased. The proposed technique is valid for any OFDM based system by changing the system parameters. This paper is organized as follows. In section II, we present the OFDM signals generation and PAPR formulation. Section III present generations of complementary sequences and proposed CSI-PTS technique for the PAPR reduction and BER improvement. Section IV and V discuss the simulation results and conclusion respectively.

II. OFDM SYSTEM AND PAPR

OFDM is a multicarrier modulation technique where data symbols modulate a parallel collection of regularly spaced sub-carriers. The sub-carriers have minimum frequency separation required to maintain Orthogonality of the corresponding time domain waveforms, yet the signal spectra corresponding to the different sub-carriers overlap in frequency. The spectral overlap results in a waveform that uses available bandwidth with very high bandwidth efficiency [3].

An OFMD modulator can be implemented as an N-point Inverse Fast Fourier Transform (IFFT) in a block of N information symbols followed by Digital-to-Analog Converter (DAC) on the IDFT samples [3]. In OFDM systems, a fixed number of successive input data samples are modulated first by using any digital modulation technique such as PSK or QPSK. On digitally modulated samples IFFT operation is performed at the transmitter side that generates orthogonal sub-carriers and superimposes the digitally modulated data on sub-carriers. The time domain complex baseband OFDM signal can be represented as [3]:

$$s_n = \frac{1}{\sqrt{N}} \sum_{K=0}^{N-1} S_K e^{j2\pi \frac{n}{N} K} \qquad n = 0,1,2,3, \dots, N-1 \quad (1)$$

Where s_n represents the n-th signal component in OFDM output symbol, S_K is the k-th data modulated symbol in OFDM frequency domain and N is the number of sub-carriers.

If OFDM symbols carry the same information that means their phase angle will be same. These OFDM symbols transmitted through a non-linear power amplifier those results in out-of-band distortion and in-band distortion. The high peak signals also increase dynamic range of Digital –to-Analog Converter (DAC). In OFMD system after performing the IFFT operation, there will be variation in output envelope. Therefore, the PAPR occurs after performing IFFT operation on digitally modulated samples. PAPR is an important factor in the design of both High Power Amplifier (HPA) and DAC. For generating error free transmission and preventing the PA to work in the nonlinear region, PAPR should be controlled. The PAPR (in dB) of the transmitted OFDM signal can be defined as [4].

$$\mathrm{PAPR} = 10\log_{10}\left\{\frac{\mathrm{P_{peak}}}{\mathrm{P_{avg}}}\right\} \quad (2)$$

Where $\mathrm{P_{peak}}$ and $\mathrm{P_{avg}}$ are the peak and average power of OFDM output symbols, respectively, and they are computed as:

$$\mathrm{P_{peak}} = \max_{0 \le n \le N-1} |S_n|^2 \quad (3)$$

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$$P_{avg} = \frac{1}{N}\sum_{n=0}^{N-1} |S_n|^2 \quad (4)$$

III. PROPOSED CSI-PTS TECHNIQUE

A. CSI-PTS Technique

The block diagram of proposed technique is shown in Figure.1. From this figure, input data symbols X having length N are converted into parallel fashion by using serial to parallel converter. The first step in proposed technique is to generate the complementary sequences with the help of a kernel and then added to the vector of data sub-carriers. The new vector in the frequency domain is then constructed from K-data and L-complementary sub-carriers, respectively. L can be any number less than K. the new vector S is given by:

$$\mathrm{S} = [\mathrm{D_k}, \mathrm{C_l}] \quad (5)$$

Where $\mathrm{D_k}$ the data sub-carrier vector, and $\mathrm{C_l}$ is the complementary sequence vector both the vectors can be represented as:

$$\mathrm{D_k} = \left[\mathrm{D_{k,0}}, \mathrm{D_{k,1}}, \dots, \mathrm{D_{k,N-L-1}}\right], \quad k = 1,2,\dots,K \quad (6) \quad \#$$

$$\mathrm{C_l} = \left[\mathrm{C_{l,0}}, \mathrm{C_{l,1}}, \dots, \mathrm{C_{l,L-1}}\right], \quad l = 1,2,\dots,L \quad (7)$$

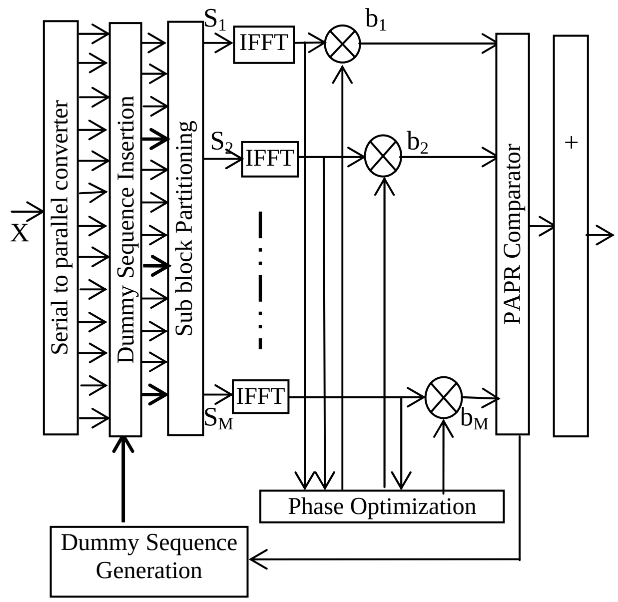

Figure.1. Block Diagram of Proposed CSI-PTS Technique

The new signal vector S is partitioned into M disjoints sub-blocks by adjacent sub-block partition method. This can be represented as:

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$$\mathrm{S_m} = [\mathrm{S_1}, \mathrm{S_2}, \dots, \mathrm{S_M}] \quad (8)$$

Such that

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$$\sum_{m=1}^{M} \mathrm{S_m} = \mathrm{S} \quad (9)$$

And the sub-blocks should be combined to minimize the PAPR in the time domain. In the time domain, the signal $\mathrm{S_m}$ is oversampled W times. Oversampling of $\mathrm{S_m}$ is obtained by taking IFFT of length WL on X_m concatenated with (W-l)N zeros.

Optimized S_m is obtained by multiplying S_m with the phase factor $b_m = e^{j\theta_m}, \quad m = 1,2,\dots,M$. The resulting time-domain OFDM signal can be expressed as:

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

After multiplying with phase factors, the objective is to find the optimum signal $S'(b)$ with the lowest PAPR. To optimize $S'(b)$ further the process is performed by choosing the optimization parameter $\tilde{b}$ with the following condition:

$$\tilde{b} = \text{avg}\min\left(\max_{0\le k\le N-1}\left|\sum_{m=1}^{M} b_m S_{m,k}\right|\right) \quad (11)$$

After finding the optimum $\tilde{b}$ the optimum signal $S'(b)$ is transmitted to the next block. Now the PAPR of $S'(b)$ is checked whether it is in the acceptable threshold of PAPR. If the value of PAPR is below the $PAPR_{th}$ signal is transmitted otherwise return back to the CSI block to generate complementary sequences again. The process will continue until the PAPR value is less than# $PAPR_{th}$.

We should notice that here N=K+L which means that there is no change in the length of the input signal after addition of complementary sequences. The sub-block partition method applied for proposed CSI-PTS technique is adjacent sub-block partition because of its simplicity and it gives better results as compared to pseudo-random and interleaving methods [4].

B. Generating Complementary Sequences

Here in this section a brief description on CSI is provided. Two sequences a and b are complementary sequences with each other if the sum of their autocorrelation is null except in zero [5].

Several, coding techniques are given for generating a set of complementary sequences, based on some starting complementary pair, the kernel. For complementary sequence of length 2, for instant a possible kernel includes the pair 1,1 and 1,-1. The basic coding rules for generating complementary codes for this kernel are as follows:

1. Interchange both codes;
2. Reversing and conjugating second code;
3. Phase-rotating second code;
4. Phase-rotating elements of even order in both codes;
5. Phase-rotating first code;
6. Reversing and conjugating first code;

When rule 1 to 4 is applied, the following 16 different codes are obtained.

TABLE I. DIFFERENT CODES WITH RULE 1 TO 4 APPLIED

1	1	1	-1		1	1	j	-j
1	1	-1	1		1	1	-j	j
1	-1	1	1		1	-1	J	j
1	-1	-1	-1		1	-1	-j	-j
1	j	1	-j		1	j	J	1
1	j	-1	J		1	j	-j	-1
1	-j	1	J		1	-j	-j	1
1	-j	-1	-j		1	-j	J	-1

C. Computational Complexity

While selecting any PAPR reduction technique computational complexity is the important criteria. In the proposed technique $N=2^n$ is the number of sub-carriers and $W=2^w$ is the oversampling factor, and then number of complex multiplication n_{mul} and complex addition n_{add} of the conventional PTS scheme are given by:

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$$n_{mul} = 2^{n+w-1}(n+w)M \quad (12)$$

$$n_{add} = 2^{n+w-1}(n+w-1)M \quad (13)$$

M is the number of sub-blocks. The main contribution of proposed CSI-PTS technique is that the overall system complexity of the proposed system is reduced. The number of complex multiplication and number of complex addition at the receiver side of the system is:

$$n_{mul} = 2^{n+w-l-1}(n+w-l-1)M \quad (14)$$

$$n_{add} = 2^{n+w-l}(n+w-l-1)M \quad (15)$$

At the receiver side, all the inserted complementary sequences are discarded. Therefore, FFT operations performed at the receiver side is less as compared to the conventional PTS technique. It is also to be noticed that the cyclic prefix does not have any impact on PAPT and therefore it is not considered here [6].

The computational complexity reduction ratio (CCRR) of CSI-PTS technique over conventional PTS technique is defined as:

$$CCRR = \left(1 - \frac{\text{Complexity of CSI} - \text{PTS Scheme}}{\text{Complexity of the Conventional PTS}}\right) \times 100\% \quad (16)$$

D. System Performance

In conventional PTS, OFDM signal does not experience distortion however the signal applied to power amplifier could exhibit distortion if PAPR exceed the expected value. In proposed technique addition of complementary sequences causes transmission efficiency to change as follows:

$$T.E = \frac{K}{K+L} \times 100\% \quad (17)$$

Where K is the number of sub-carriers and L is the number of complementary sequences. Thus, in proposed technique efficiency of power amplifier increases and decreases cost of the system.

E. Side Information

Side information is another important factor while selecting the distortion- less PAPR reduction techniques. Side information bits are those bits that have to be transmitted to the receiver to recover the original data blocks. In conventional PTS technique, number of side-information bits are $\lceil \log_2 P^{m-1} \rceil$ where P is the number of allowed phase factors. By applying CSI-PTS technique the number of side information bits is reduced [4]. For example if the conventional PTS has m=4 and p=4, then the number of side information is 6 bits, but in case of CSI-PTS, the number of side information is 2 bits which are according to m=2 and p=4 values.

IV. SIMULATION RESULTS

The proposed system is simulated with parameters as shown in table 1.2. Complementary sequence of length 4, 8 and 16 are used. 256 data sub-carriers are available for simulation out 256 data sub-carriers maximum 64 sub-carriers are used for complementary sequences. Complementary sequences not only responsible to reduce the PAPR but also improve the BER result.

TABLE II. SYSTEM PARAMETERS

Sr.No	Parameter	Specification
1	IFFT	256
2	Complementary sequences	4,8,16
3	Oversampling Factor	4
4	Sub-carriers	256
5	Sub-block partition Method	Adjacent

The proposed CSI-PTS is simulated for parameter specified in Table II. But depends on the application by changing the length of complementary sequences the proposed system is used for any application with compromise between bandwidth efficiency and data rate.

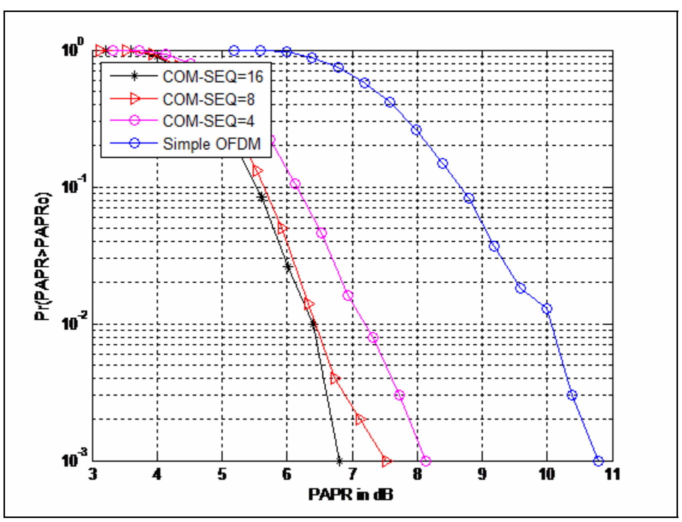

Figure 1. PAPR Analysis of CSI-PTS

From figure 1. We can observed that the increasing the length of complementary sequence gives optimized results. As shown in the result more than 3 dB PAPR reduction is achieved by inserting the complementary sequence of length 4. To reduce the PAPR more than 3 dB length of complementary must be increased but it affects the data rate of the system.

TABLE III. PAPR RESULT ANALYSIS

Technique Used	Simple OFDM	CSI-PTS		
		CS=4	*CS=8*	*CS=16*
PAPR in dB	10.79	8.12	7.52	6.80

Table III. shows the PAPR results obtained for the proposed technique. From the results 6.80 dB PAPR is achieved for complementary sequences of length 16. 4 bB PAPR reduction is achieved as compared to the simple OFDM system. For complementary sequence of length 4 and 8 the achieved PAPR is 8.12 dB and 7.52 dB respectively. Thus, increasing the length of complementary sequences gives better PAPR results but it affects the data rate of the system. Thus, there is a compromise between PAPR and data rate of the system while selecting the length of complementary sequences.

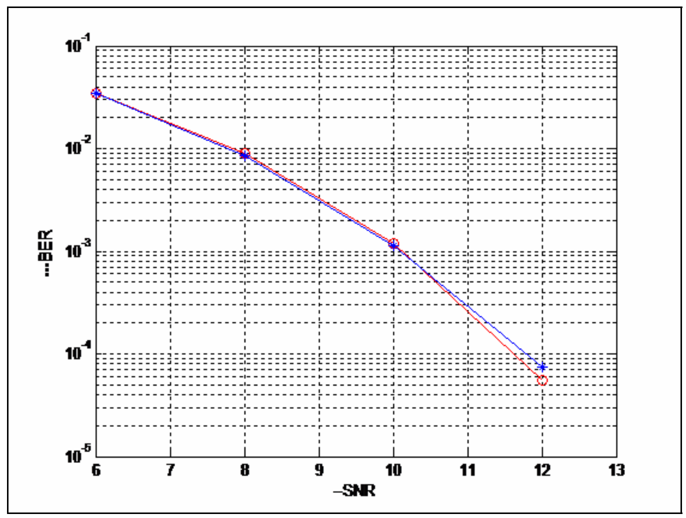

Figure 2. BER Analysis for CSI =4

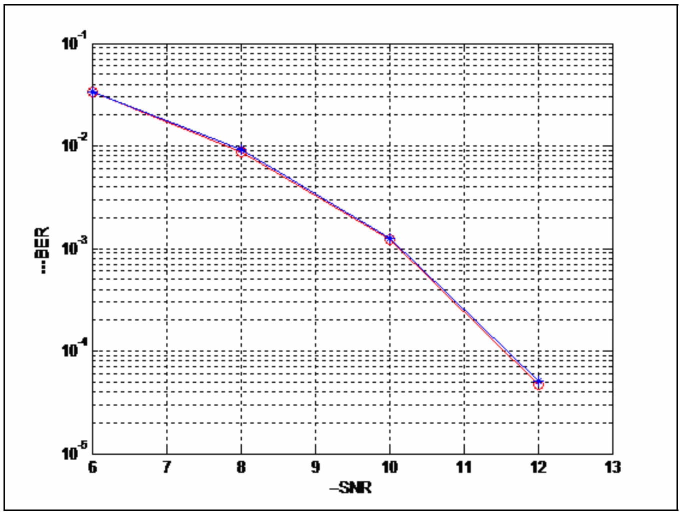

Figure 3. BER Analysis for CSI=8

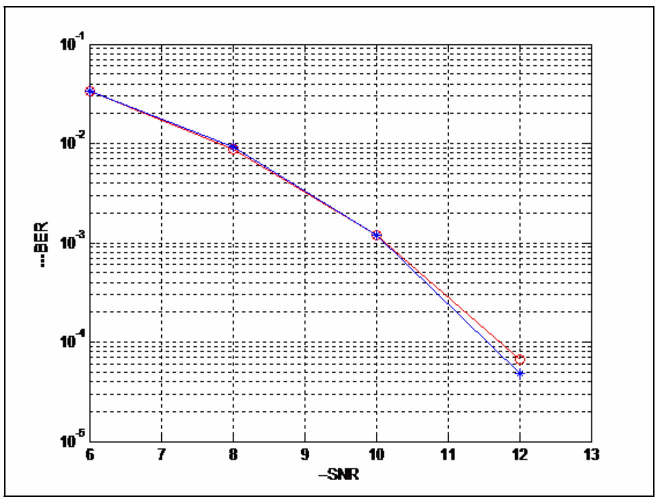

Figure 4. BER Analysis for CSI=16

TABLE IV. BER RESULT ANALYSIS

SNR (dB)	BER (dB) 10^{-5}			
	Simple OFDM	***CSI-PTS***		
		CS=4	***CS=8***	***CS=16***
12	6.64	5.46	5.68	6.84

From the BER analysis results, we can observed that the increasing the length of complementary sequences the BER of the system. For simple OFDM system, the achievable BER is 6.6 X 10^{-5} dB. By inserting the complementary sequence of 4, and 8 the achievable BER is 5.46 X 10^{-5} dB and 5.68 X 10^{-5} dB respectively. Thus, complementary sequences are not only reduces the PAPR but improve, the BER. But the problem is that inserting large number of complementary sequence affects the BER results, even though, reduces the PAPR that is observed in BER result obtained for complementary sequence having length 16.

V. CONCLUSION

A new distortion less PAPR reduction technique based on the combination of Complementary sequences and PTS is proposed in this paper. In this technique, the complementary sequences are added to the OFDM signal and after that, the PTS technique is applied. By applying this technique, the overall complexity of the system is reduced. The proposed technique not only reduces the PAPR but also improves the BER.

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