PAPR reduction in OFDM system using T-PTS technique combined with RP-IP separation

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Abstract —**Orthogonal frequency division multiplexing (OFDM) is a robust and effective multicarrier transmission technique for high speed communication in wireless mobile environment and applications. A major challenging issue in application of OFDM is its high peak to average power ratio (PAPR). Partial transmit sequence (PTS) scheme is an attractive technique for PAPR reduction in OFDM systems. An exhaustive search for phase sequences is needed to obtain desirable PAPR performance, which results in high computational complexity. In this paper, a hybrid combination of tree PTS (T-PTS) algorithm and real part-imaginary part separation technique is proposed. The simulation results of the proposed technique show improved PAPR performance with remarkably reduced bit error rate (BER) over all variants of PTS. Also, the technique offers significant reduction in computational complexity over conventional PTS technique.**

Keywords-Orthogonal Frequency Division Multiplexing (OFDM); Peak to average power ratio (PAPR); Partial transmit sequence (PTS).;

I. INTRODUCTION

OFDM is widely implemented in various high speed wireless communication standards because of its favorable properties such as high spectral efficiency, robustness to channel fading, immunity to impulse interference and capability of handling multipath fading. Interestingly, OFDM is a combination of modulation and multiplexing.

This technique is a multicarrier modulation technique, which employs several carriers, within the allocated bandwidth, to convey the information from source to destination. Each carrier may employ one of the several available digital modulation techniques (BPSK, QPSK or QAM) [1].

In OFDM systems, a sampled time-domain sequence

$$x = [x_0, x_1, \dots \dots x_{N-1}]^T$$

is obtained by performing an *N*-point IFFT on frequency-domain sequence

$$X = [X_0, X_1, \dots \dots X_{N-1}]^T$$

$$x_n = \frac{1}{N}\sum_{k=0}^{N-1} X_k W_N^{-nk} \qquad 0 \le n \le N-1 \qquad (1)$$

Where $W_N^{-nk} = e^{(-j2A\pi nk/N)}$, k is the frequency index and n is the time index.

Equation (1) can be thought of as an Inverse Fast Fourier Transform (IFFT) where 'N' is the size of IFFT. The Fourier transform breaks a signal into different frequency bins by multiplying the signal with a series of sinusoids.
Since the OFDM signalx_n, as referred in equation (1), is in time domain, IFFT is the appropriate choice to use at the transmitter, which can also be interpreted as converting frequency domain samples to time domain samples. To acquire the original transmitted signal, FFT is performed at the receiver side [2].

In spite of the several advantages offered by OFDM, there is a limitation of high PAPR, which can be reduced using several techniques such as clipping and filtering, companding, coding, selective mapping (SLM), partial transmit sequence (PTS), tone reservation, tone injection, constellation extension etc. PTS technique improves PAPR statistics of an OFDM signal significantly without any in-band distortion and out-of-band radiation [3].

The conventional PTS offers reduction in PAPR at the cost of higher computational complexity. By using different PTS techniques such as Tree PTS (T-PTS) and RP-IP PTS, better reduction in PAPR and BER can be achieved with considerable reduction in computational complexity.

The technique proposed in this paper is a hybrid combination of tree PTS algorithm with real and imaginary parts separation method for PAPR reduction of OFDM signal. The proposed technique mainly concentrates on reducing the PAPR and BER significantly over that offered by the individual techniques. The computational complexity, which is a major issue for implementation of PTS, is also reduced considerably compared to that of conventional PTS.

II. PEAK TO AVERAGE POWER RATIO

OFDM has several features which make it an attractive modulation scheme for high speed transmission links. However, one major limitation is its high Peak to Average Power Ratio (PAPR). These large peaks cause saturation in power amplifiers at the transmitting end, leading to inter-modulation among the subcarriers, which causes an increase in the out of band (OOB) energy. Hence, to design a cost effective and robust system, it is highly desirable to reduce the PAPR.

The mathematical representation of PAPR of an OFDM signal can be given as –

$$\mathrm{PAPR}[\mathrm{x_n}] = \frac{\max\limits_{0\le n<N} |\mathrm{x_n}|^2}{\mathrm{E}[|\mathrm{x_n}|^2]} \qquad (2)$$

Where E $\{.\}$ denotes average power.
PAPR can be expressed in 'dB' as follows,

$$\mathrm{PAPR\ (dB)} = 10\log_{10}\mathrm{PAPR}(\mathrm{x_n}) \qquad (3)$$

The selection of proper phase sequences to achieve significant PAPR reduction accompanied by low computational complexity is very important in the PTS technique [3].

III. PARTIAL TRANSMIT SEQUENCE (PTS)

PTS method is a distortionless probabilistic technique for PAPR reduction. This technique is called distortionless because the quantity with which the actual signal is altered is sent as side information.

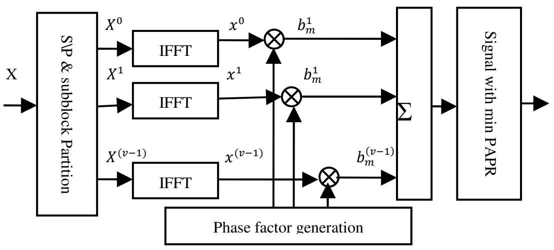

Fig. 1 Block Diagram of Basic PTS

In conventional PTS, the frequency-domain sequence X is firstly partitioned into V disjoint sub-blocks as shown in Fig.1.

$$X^{(v)} = \left[X_0^{(v)}, X_1^{(v)}, \ldots., X_{N-1}^{(v)}\right]^T$$

Where $v = 0,1,\ldots..,V-1$. In every sub-block, only N/V signal points exist and the others are set to zero. Then, V sub-blocks $X^{(v)}$ are combined with a phase factor vector

$b_m = \left[b_m^{(0)}, b_m^{(1)}, \ldots, b_m^{(v-1)}\right]^T$ According to equation (4);

$$X_m = [X_0^m, X_1^m, \ldots., X_{N-1}^m]^T = \left[X_0^{(0)}, X_1^{(1)}, \ldots, X_{N-1}^{(V-1)}\right] b_m \qquad (4)$$

Where the phase factor $b_m^{(v)}$belongs to phase factor set
$\Phi = \left\{e^{j\phi_1}, \ldots, e^{j\phi_w}, \ldots., e^{j\phi_W}\right\}, \phi_w \epsilon [0,2\pi]$, W is the number of elements in the phase factor set, $m = 1,2,\ldots M, M$ is the number of used phase factor vectors. Because the first element in every phase factor vector $b_m^{(0)} = 1$ can be fixed without loss of PAPR performance, the number of phase factor vectors is $M = W^{v-1}$. Generally, in order to reduce the computational complexity, the phase factor set is restricted to$\{1, -1, j, -j\}$.

Subsequently, an N-point IFFT is performed on X_m to generate a time-domain candidate x_m

$$x_m = IDFT(X_m)$$

If M phase factor vectors are used, M time-domain candidates can be obtained. For one OFDM symbol, the number of needed IFFTs is equal to the number of candidates [4-6].

IV. REAL PART-IMAGINARY PART SEPERATION IN PTS

In this method, the real part and imaginary part of the IFFTed signal is multiplied with the corresponding real and imaginary part of the phase vector respectively, this result in increased number of candidate signals (refer Fig. 2). However, the computational complexity is reduced in this technique which is explained further in this section.

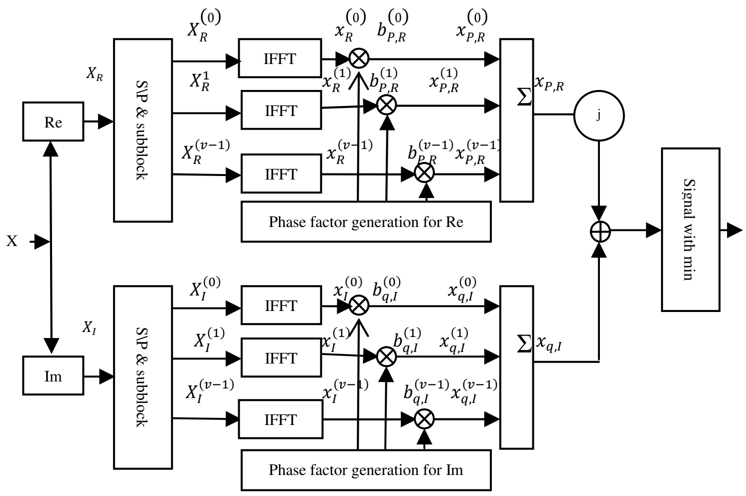

Fig. 2 Block Diagram of RP-IP PTS

In this method, the number of required IFFTs is $2M$. If M is larger, the computational complexity of IFFTs is considerably high. For one OFDM symbol,

$2V$ sets of N-points IFFTs are needed, which include, V sets of IFFTs for real part operation, and V sets of IFFTs for imaginary part operation. In conventional PTS, IFFT is performed on the modulated signal which is a complex quantity whereas here a real valued signal is processed; hence number of multiplications needed for IFFT are reduced. The complexity of $2V$ real-to-complex IFFTs is nearly the same as that of V complex IFFTs, as parallel operations are performed [7].

V. TREE PTS TECHNIQUE (T-PTS)

Conventional PTS becomes impractical for implementation in high speed data transmission systems because of its very high computational complexity. An exhaustive search for the appropriate phase sequence has to be performed.
The Tree PTS technique reduces the number of computations required to obtain the optimum phase sequence for an OFDM symbol.

Following steps are followed for Tree PTS:

1. The modulated symbols are partitioned into M disjoint subblocks.
2. Initially the phase vector is set to {1 1... 1}.
3. As the phase values are restricted to {1,-1,j,-j}, we alter the phase vector for the first subblock to these values.
4. PAPR values are calculated for each combination and the minimum PAPR value is found.
5. Select the phase value which gives the minimum PAPR.
6. Fix this Phase value for first subblock.
7. Repeat the steps 4 to 6 till the M^{th} subblock.

The following example illustrates the execution of the above algorithm:

Consider first subblock out of M subblocks. Calculate PAPRs of the OFDM signals after rotating phase of the first subblock using W phase factors. $PAPR_1$ is the PAPR value obtained after multiplication of first subblock with first phase vector. Similarly other PAPR values are obtained.

{+1 1 1…1}=>$PAPR_1$
{-1 1 1…1}=> $PAPR_2$
{+j 1 1…1}=> $PAPR_3$
{-j 1 1…1} => $PAPR_4$

Minimum PAPR is obtained from the above four values.
Min. {$PAPR_1$, $PAPR_2$, $PAPR_3$, $PAPR_4$}
Let $PAPR_3$ be the minimum value obtained and hence fix '+j' as phase value for first subblock.

Similarly, other phase values are obtained for other subblocks. Final phase sequence is traced according to tree algorithm [8] [9].

8.3467

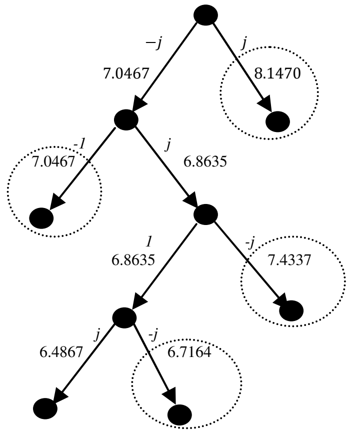

Fig. 3 Tree structure of the proposed T-PTS scheme

Example shown in Fig. 3 may help to understand the details of the T-PTS Scheme. Initially, consider the $PAPR_1$ (8.3467dB) with all phase factors as 1's, now by changing the first value of phase factor as $\{1, -1, j, -j\}$, four PAPR values are obtained, out of which the minimum value is selected. The original PAPR of OFDM signal in this example is 8.3467 dB. This PAPR is reduced to 7.0476 dB by selecting $-j$ in the first subblock, and reduced to 6.8635 dB by selecting j in the second subblock. The value of PAPR is maintained in the third subblock obviously by selecting 1 and finally it is reduced to 6.4869dB by selecting j in the fourth subblock. Thus the final decision of phase factors for minimum PAPR is $\{-j, j, 1, j\}$.

VI. PROPSED TECHNIQUE

High computational complexity, due to search of phase vectors through a high-dimensional vector space, is a potential problem for practical implementation of PTS. To address the complexity issue, a hybrid combination of T-PTS along with Real part (RP) – Imaginary part (IP) separation is proposed in this work. This technique adaptively generates the real and imaginary phase factors separately by using Tree searching algorithm. The phase vector is chosen such that the real part of the signal is multiplied with real part of the phase vector and similar operations are done for imaginary part of the IFFTed signal. The possible combinations for real phase vector will be: $\{1, -1\}$

Similarly, for imaginary phase vector possible combinations are given as: $\{j, -j\}$
Following steps are followed in this hybrid technique:

1. The modulated signals are partitioned into M subblocks.
2. IFFT operation is performed on each subblock.
3. Separate real and imaginary parts of all subblocks. Let them be called RP and IP.

4. Initially, set the phase vector as all ones $\{1, 1, \ldots, 1\}$.
5. While finding phase vector for a particular subblock, keep all phase vectors equal to '1' for RP and 'j' for IP.
6. For the first subblock, change the phase vectors from '1' to '-1' for RP and 'j' to '-j' for IP.
7. Four combinations of the phase vectors along with the first subblock are obtained as follows:

Combination no. 1: RP * 1 + IP *
Combination no. 2: RP*-1 + IP *
Combination no. 3: RP * 1 + IP *
j
Combination no. 4: RP * -1 + IP*
j

8. Add the newly formed version of the fi subblock with the other subblocks which are ke unchanged and find PAPR of the combination.
9. Find minimum PAPR out of the above fo combinations and select phase vect corresponding to that symbol accordingly.
   For example, if Combination no. 3 gives le PAPR for a particular subblock, then the pha vector for that subblock becomes $\{1, -j\}$.
10. Thus, PAPR reduction is due to the change in t considered subblock only, as other subblocks are kept unchanged.
11. Fix the obtained phase value for the first subblock and accordingly alter the phase vector.
12. Repeat the steps 3 to 8 upto the Mth subblock.
13. The final phase vector approaches the optimum PAPR value at the end of Mth subblock.

VII. SIMULATION RESULTS

System specifications used for unmodified OFDM, conventional PTS, RP-IP separation PTS, T-PTS and proposed Hybrid PTS technique are specified in Table I [10]. The simulation is performed using MATLAB.

During transmission, the OFDM data block is sent first and the side information related to that particular data block follows on a separate set of frequencies. This keeps the PAPR of the data signal unaltered even after addition of side information to the transmitted signal.

TABLE I

Sr. No.	Simulation Parameters	Parameter Values
1	Number of input bits	1,00,000
2	Modulation for data symbols	16 QAM
3	Modulation for side information	8 QAM
4	No. of bits per symbol	4
5	Oversampling Rate	4
6	No. of sub-blocks (M)	4
7	IFFT/FFT size for OFDM symbols (N)	256
8	IFFT/FFT size for side information	16

The execution time taken for conventional PTS is the highest of all, as it searches for all possible combinations of the phase vectors thereby increasing the computational complexity. In this work, the proposed technique offers nearly 40 times reduction in computational complexity over conventional PTS.

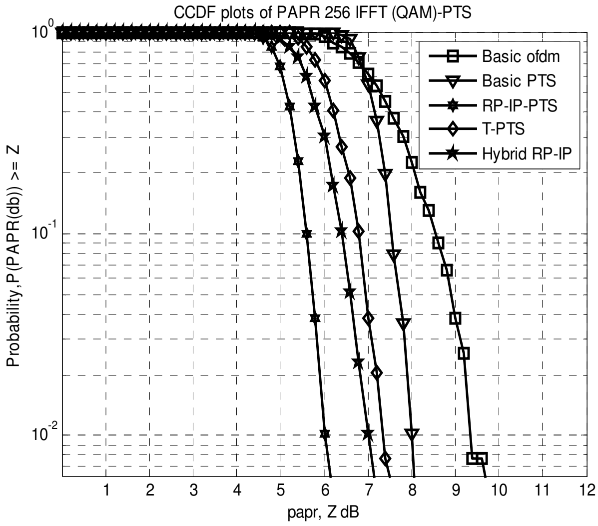

Fig. 4. CCDF plots for different PTS techniques

interpreted from Fig. 4 that the proposed technique shows PAPR reduction better than that of the basic PTS and T-PTS. A PAPR reduction of nearly 3 dB is obtained, as compared to that of basic OFDM.

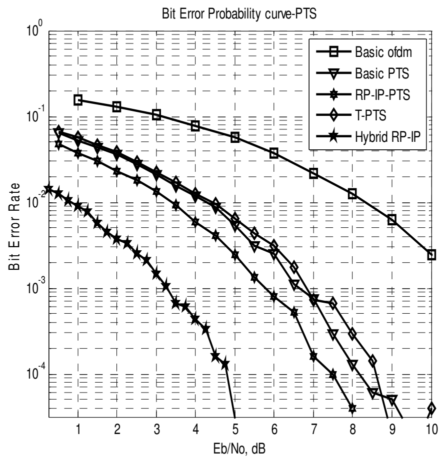

Fig. 5. BER plots for different PTS techniques

The proposed technique shows excellent performance in reception of the data even after it is passed through the AWGN channel. As compared to the other techniques considered in this experimentation, maximum reduction in the BER is offered by the proposed technique (as shown in Fig. 5).

In an OFDM system, PAPR of the system is one of the major concerns, but accurate reception of data is equally important. At the same time, the computational complexity of the PTS system has to be reduced so as to make the system practicaly realisable. All these aspects are precisely taken care of in the proposed technique in this paper.

VIII. CONLCUSION

In this paper, a modification in the conventional PTS scheme is proposed. The proposed technique of hybrid combination of Tree-PTS and RP-IP separation shows a significant reduction in PAPR as compared to that offered by individual techniques. Computational complexity is reduced by a large factor than the conventional PTS. The proposed technique offers better BER performance than that of all variants of PTS techniques under consideration.

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