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PAPR Reduction in OFDM using Multiple Phase Sequence

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Abstract

Orthogonal frequency division multiplexing (OFDM) has gained considerable attention in the past couple of years. In our modern world the need for faster data transmission is never-ending. OFDM modulation provides us with a way of more densely packing modulated carriers in the frequency domain than other existing Frequency Multiplexing schemes, thus achieving higher data rates through communications channel. Besides various advantages an important disadvantage of OFDM systems is their high peak-to-average power ratio (PAPR). High PAPR degrades OFDM signals by forcing the analog amplifier to work in the nonlinear region, distorting this way the signal and making the amplifier to consume more power. There are several ways to reduce the PAPR of OFDM signals which can be divided in two groups: the techniques that non-linearly distort the signal and the ones that reduce the PAPR without distorting the signal. In this research, we will give an overview to OFDM technique and identify the PAPR problem characteristically. Some popular PAPR reduction schemes will be introduced and compared. In addition, we introduced an improved scheme having combination of SLM and PTS with a PAPR threshold.

Keywords: *OFDM, PAPR, Multiple Phase Sequence.*

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) has become a popular technique for transmission of signals over wireless channels and it has been adopted in various wireless standards such as digital audio broadcasting (DAB), digital video broadcasting (DVB-T), the IEEE 802.11a [1], local area network (LAN) standard and the IEEE 802.16a [2] metropolitan area network (MAN) standard. In OFDM system, high rate incoming signal is serial to parallel converted to N low rate data streams and each is sent over one of the N orthogonal subcarriers.

OFDM is a bandwidth efficient multicarrier modulation where the available spectrum is divided into subcarriers, with each subcarrier containing a low rate data stream. OFDM has gained a tremendous interest in recent years because of its robustness in the presence of severe multipath channel conditions with simple equalization, robustness against Inter-symbol Interference (ISI), multipath fading, in addition to its high spectral efficiency[3]. However, the Peak-to-Average Power Ratio (PAPR) is a major drawback of multicarrier transmission system such as OFDM.

The advantage of such schemes is that unlimited transmission rates are theoretically possible in highly time dispersive channels. Also, by introducing a guard-period and using differential encoding, reliable transmission over spectrally shaped channels is possible without any equalization. Besides various advantages an important disadvantage of OFDM systems is their high peak-to-average power ratio (PAPR). High PAPR degrades OFDM signals by forcing the analog amplifier to work in the nonlinear region, distorting this way the signal and making the amplifier to consume more power[1][2]. There are several ways to reduce the PAPR of OFDM signals which can be divided in two groups: the techniques that non-linearly distort the signal and the ones that reduce the PAPR without distorting the signal. Several researches have been proposed schemes for reducing PAPR, such as amplitude clipping method, active constellation extension (ACE), coding method, phase optimization, nonlinear transforms, interleaving, Selective Mapping (SLM) and Partial Transmission Sequence (PTS) etc[4].

1.1 PAPR in OFDM

One major drawback of OFDM is the large Peak to Average Power Ratio (PAPR) of the transmitted signal. 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 [4] [5]. Presence of large number of independently modulated sub-carriers in an OFDM system the peak value of the system can be very high as compared to the average of the whole system. This ratio of the peak to average power value is termed as Peak-to-Average Power Ratio. Coherent addition of N signals of same phase produces a peak which is N times the average signal. The major disadvantages of a high PAPR are:

1. Increased complexity in the analog to digital and digital to analog converter.
2. Reduction is efficiency of RF amplifiers. [6]

Therefore, high PAPR increases both the complexity and cost of implementation. In practical systems, commonly available circuits with a finite range and precision are used, thus introducing non-linear distortion to the reconstructed analog signal [7]. To avoid this distortion, for high PAPR, the RF power amplifiers needs to be operated under large back-offs due to the limited linear region. Thus high PAPR reduces the efficiency of RF power amplifiers. With these two effects degrading the system performance, we should try to keep away from high PAPR in the system design. Tons of research has been done on the PAPR reduction for OFDM system.

2. Proposed Work

One major drawback of OFDM is the large Peak to Average Power Ratio (PAPR) of the transmitted signal. There have been many PAPR reduction schemes proposed. SLM, tone injection, tone reservation, constellation extension and partial transmit sequence are all distortion-less PAPR reduction techniques that manipulate the signal in the frequency domain prior to the IFFT.

2.1 Partial Transmit Sequence (PTS):

In PTS approach, the input data block is partitioned into disjoint sub-blocks. The sub-carriers in each sub-block are weighted by phase rotations. The phase rotations are selected such that the PAPR is minimized. At the receiver, the original data are recovered by applying inverse phase rotations. In the PTS technique, an input data block of K symbols is partitioned into disjoint sub-blocks. The subcarriers in each sub-block are weighted by a phase factor for that sub-block. The phase factors are selected such that the PAPR of the combined signal is minimized. In order to implement this idea, the input data block of K symbols is partitioned into M pair wise disjoint blocks X_k, k = 1, ..., Mainly, the total number of subcarriers included in any one of these sub-blocks Xk is arbitrary, but sub-blocks of equal size have been found to be an appropriate choice. All subcarrier positions in Xk, which are already represented in another sub-block.

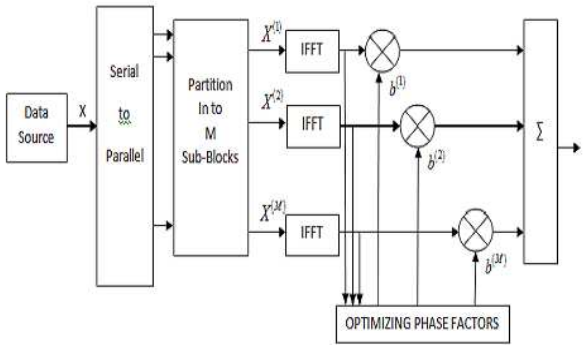

Figure 1: Block diagram of PTS technique [8].

Each sub-block is weighted by a set of rotation factors $b_k(u)$ where u = 1…..U , so that a modified subcarrier vector $\widehat{X} = \sum_{k=1}^{M} X_k b_k(u)$ is obtained, which represents the same information as X, if the set $b_k(u)$ is known for each u and k. The phase factors are selected such that the PAR of the combined signal is minimized (Fig-3). Mathematically, it is expressed as:

$$\{b_1(u), b_2(u), \dots\dots, b_M(u)\} = \operatorname{argmin}_u\left(\max_{0\le n<N_{sL-1}}\left|\sum_{k=1}^{M} \mathrm{IDFT}(X_k).\, b_k(u)\right|\right)$$
(2.1)

Where, $b_u(u) = e^{j\phi(u_k)}, \phi(u_k) \in (0,2\pi)$

Resulting in the optimum transmit sequence

$$\widehat{X}(u_{opt}) = \sum_{k=1}^{M} \mathrm{IDFT}\,(X_k).\, b_k(u)$$

(2.2)

Where u_{opt} is the phase vector that gives the greater reduction. Hence, $U^{(M-1)}$ is the amount of sets of phase factors that are evaluated to find the best case. The total complexity increases exponentially with the number of sub-blocks M. The receiver needs to know the set $b_k(u)$. Hence, an unambiguous representation of it must be transmitted to the receiver. As a consequence, the amount of bits as side information is $\lfloor \log_2 U^{(M-1)} \rfloor$. Figure1 represents the block diagram of PTS algorithm. From the left side of diagram, the data information in frequency domain X is separated into M non-overlapping sub-blocks and each sub-block vectors has the same size N. Hence, we know that for every sub-block, it contains N/M nonzero elements and set the rest part to zero. The argmin(.) is the judgment condition that output the minimum value of function. In this way we can find the best **b** so as to optimize the PAPR performance. The additional cost we have to pay is the extra M-1times IDFTs operation.

The optimization is achieved by searching thoroughly for the best phase factor. Theoretically, **b**= $[b_1, b_2,...,b_M]$ is a set of discrete values, and numerous computation will be required for the system when this phase collection is very large. For example, if ϕM contains W possible values, theoretically, **b** will have W^M different combinations, therefore, a total of $M.W^M$ IFFTs will be introduced. By increasing the M, W, the computational cost of PTS algorithm will increase exponentially. For instance, define phase factor b_M contains only four possible values, that means $b_M \epsilon \{\pm 1, \pm j\}$, then for each OFDM symbol, $2.M-1$bits are transmitted as side information. Therefore, in practical applications, computation burden can be reduced by limiting the value range of phase factor **b**= $[b_1, b_2,\ldots,b_M]$ to a proper level. At the same time, it can also be changed by different sub-block partition schemes. There are three kinds of sub-block partitioning method schemes: Adjacent sub-block partitioning, Interleaved sub-block partitioning and Pseudo-random sub-block partitioning.

2.2 Selective Mapping (SLM):

Selective mapping (SLM) is a popular PAPR reduction scheme for OFDM systems. Like PTS, SLM provides good PAPR reduction capability without distorting the shape of the OFDM signal. Frequency domain OFDM signal, after multiplication with phase sequence set, generates a set of alternative OFDM signals and one of them with lowest PAPR is selected for transmission. But, like PTS scheme, it also suffers from the requirement of SI transmission, which results in data rate loss. In SLM based PAPR reduction schemes the PAPR reduction capability increases with the number of alternative OFDM signals. But, by increasing the number of alternative OFDM signals, the computational complexity of system increases due to the increase in number of IFFT operations and the number of multiplications required to multiply the frequency domain OFDM signal with phase sequence.

It has been reported, that SLM based OFDM systems using different types of phase sequence sets, have different PAPR performances for same number of alternative sequences. Hence, for achieving good PAPR reduction and to limit the computational complexity, it is essential to select a good phase sequence set.

For SLM-OFDM system many phase sequence sets to achieve good PAPR reduction capability are proposed. A phase sequence set that achieves minimum correlation between alternative OFDM signal provide best PAPR performance, a phase sequence set is generated randomly from the set of four phase factors { ±1, ±j} , for achieving good PAPR reduction capability, but it requires large number of bits to encode the SI because in an OFDM system with N subcarriers, there are 4^N possible combinations of phase sequences with length N and any one of them can be generated randomly; In order to encode the index of a phase sequence, $\log_2 (4^N)$bits per OFDM symbol are required, which results in high data rate loss. The PAPR reduction in SLM-OFDM system is performed by choosing the rows of Hadamard matrix as phase sequence. The elements of Hadamard matrix are either 1 or -1, therefore they have only two phase factors ∈{1,-1}, but PAPR reduction capability of Hadamard matrix is very limited [9].

In selective mapping (SLM) technique the actual transmit signal lowest PAPR is selected from a set of sufficiently different signals which all represents the same information. SLM Technique is very flexible as they do not impose any restriction on modulation applied in the subcarriers or on their number. Block diagram of SLM Technique is shown in Fig.2.

Lets define data stream after serial to parallel conversion as $X=[X_0, X_1\text{--------}, X_{N-1}]^T$. Initially each input $X_n^{(u)}$ can be defined as equation $x_n^{(u)} = x_n . b_n^{(u)}$.

B(u) can be written as x_n^((u))=[x_0^((u)),x_1^((u)),……,x_(N-2)^((u))]^T

Where n = 0, 1, 2……..,N-1, and u=0,1,2,…U to make the U phase rotated OFDM data blocks. All U phase rotated OFDM data blocks represented the same information as the unmodified OFDM data block provided that the phase sequence is known.

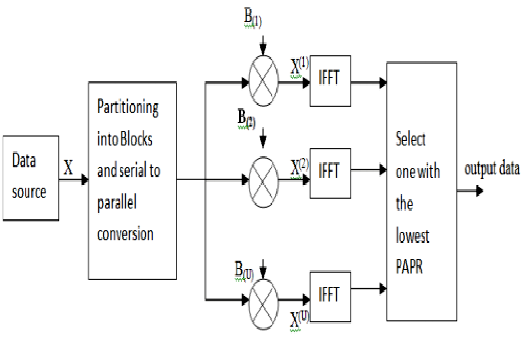

Figure2: Block Diagram of OFDM transmitter with the SLM Technique [10].

After applying the SLM technique, the complex envelope of the transmitted OFDM signal becomes $x(t) = \frac{1}{\sqrt{N}}\sum_{n=0}^{N-1} x_n e^{j2\pi n\Delta f t}, 0 \le t \le NT$ here $\Delta f = \frac{1}{NT}$, NT is the duration of an OFDM data block.

Output data of the lowest PAPR is selected to transmit. PAPR reduction effect will be better as the copy block number U is increased. SLM method effectively reduces PAPR without any signal distortion. But it has higher system complexity and computational burden. This complexity can less by reducing the number of IFFT block [10].

2.3 Proposed Algorithm:

The proposed algorithm can be described in following steps:

Step-1: The sequence of data bits is modulated using QPSK to produce sequence symbols I0, I1……….
Step-2: These symbol sequences are divided into blocks of length 256(/N). Here, N(256) is the number of sub-carriers.
Step-3: Take IFFT and multiply each sub-block by choosing the random phase sequence from [1 -1 j –j].
Step-4: Output of Each block is multiplied (point wise multiplication) by U different phase sequence vector from [1 -1 j –j].
Step-5: Transform the output of each block into time domain by taking IFFT.
Step-6: Select the one, which has the minimum PAPR.

3. Result

In this section the PAPR reduction performance of the proposed technique is analyzed. This Proposed technique is also compared with the SLM technique. Simulation has been done in MATLAB and following parameters have been considered for simulation purpose:

Table 1: Simulation Parameters

Simulation parameters	**Type/Value**
Number of subcarriers (N)	256
Number of sub blocks (M)	2,4,8,16
Oversampling factor(L)	4
Modulation Scheme	QPSK
Phase factor	[1,-1,j,-j]

In simulations, an OFDM system is considered with number of sub-carriers (N=256), over-sampling factor (*L*=4) and QPSK Modulation. The sub-carriers are divided into M=2, 4, 8, 16 Sub-blocks with contiguous sub-carriers, respectively. The phase factor is chosen as {1,-1, j, -j}.

Figure1 to Figure 4 show the graphs for the complement cumulative distribution function (CCDF) of PAPR in original SLM and Proposed technique for the different cases of M=2,4,8,16 sub-blocks respectively.

CCDF of PAPR

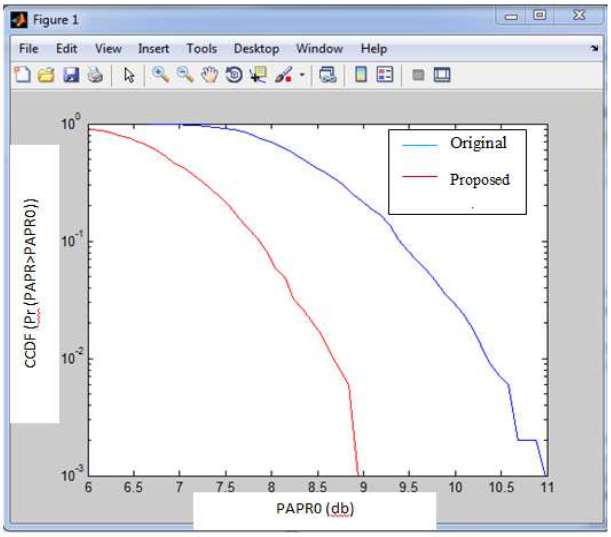

Figure 1: CCDF of PAPR in proposed technique versus original technique with M=2 sub blocks (N=256, L=4, QPSK modulation)

CCDF of PAPR

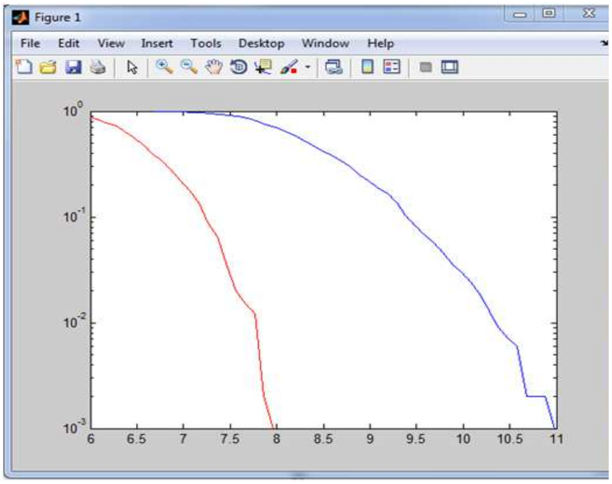

Figure 2: CCDF of PAPR in proposed technique versus original technique with M=4 sub blocks (N=256, L=4, QPSK modulation)

CCDF of PAPR

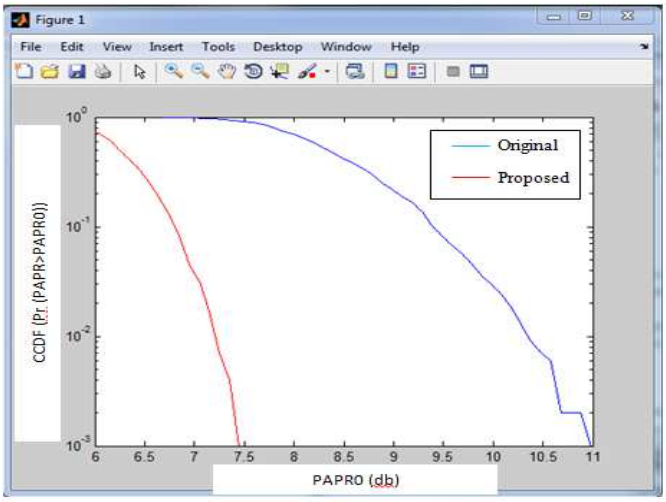

Figure 3: CCDF of PAPR in proposed technique versus original technique with M=8 sub blocks (N=256, L=4, QPSK modulation)

CCDF of PAPR

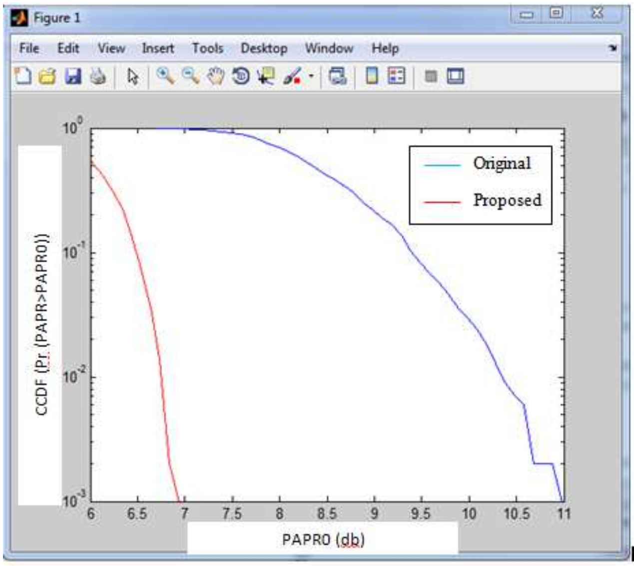

Figure 4: CCDF of PAPR in proposed technique versus original technique with M=16 sub blocks (N=256, L=4, QPSK modulation)

4. Conclusion

OFDM is a very attractive technique for multicarrier transmission and has become one of the standard choices for high – speed data transmission over a communication channel. It has various advantages; but also has one major drawback: it has a very high PAPR. A high PAPR brings disadvantages like an increased complexity of the analog to digital (A/D) and digital to analog (D/A) converters and reduced efficiency of radio frequency (RF) power amplifiers. The proposed scheme is used for PAPR reduction in OFDM system and compared the proposed scheme with original scheme. The simulation results show that the proposed scheme offer better PAPR reduction. The simulation result show that as the number of sub blocks increases, the performance increases. The Proposed technique offer better PAPR reduction performance compared with the existing techniques. It has been investigated that the performance of proposed technique gives better results for 2, 4, 8 sub-blocks and equivalent result for 16 sub-blocks. It can be seen that the results for 2, 4, 8 sub-blocks are better while for 16 sub-block results are comparable with existing results. Although the proposed scheme offers better PAPR reduction, further research work can be carried out to reduce the PAPR combining the filtering or clipping in the scheme.

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