Application of PSO Optimized Companding in Peak Average To Power Ratio(PAPR) Reduction In Orthogonal Frequency Division Multiplexing(OFDM)

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ABSTRACT: *Orthogonal frequency division multiplexing (OFDM) modulation using orthogonal subcarriers reduces the delay spread by increasing robustness to multipath fading and can use overlapped bandwidth due to orthogonality on frequency domain. The main drawback of Orthogonal Frequency Division Multiplexing(OFDM) systems is the high peak-to average power ratio (PAPR),which significantly reduces the efficiency of the transmit high power amplifier (HPA). Several methods have been proposed in the literature to reduce the peak power of OFDM signals and substantial gains were reported. This dissertation is focused on analyzing PAPR reduction by undertaking various methods to reduce the PAPR in the system like Selective mapping (SLM), Companding-SLM and Particle Swarm Optimized-Companding (PSO-Companding). The technique PSO-Companding has been proposed which reduces the PAPR in the wireless system.Simulation result shows that the proposed PSO optimized companding method outperforms than the existing methods of PAPR reduction companding and SLM.*

Keywords—*OFDM, peak-to-average power ratio (PAPR), high power amplifier (HPA), SLM,PSO*

1. INTRODUCTION

In recent years orthogonal frequency division multiplexing (OFDM) has gained a lot of involvement in miscellaneous digital communication applications. It is a new ensuring transmission scheme for broadband communications over a wireless channel. In OFDM data is transmitted simultaneously through multiple frequency bands [1].It offers many advantages over single frequency transmission such as high spectral efficiency, robustness to channel fading, immunity to impulse interference, and the capability to handle frequency-selective fading without resorting to complex channel equalization schemes. OFDM also uses small guard interval, and its ability to combat the ISI problem. So, simple channel equalization is needed instead of complex adaptive channel equalization.

In the conventional serial data transmission system, the information symbols are transmitted sequentially where each symbol occupies the entire available spectrum bandwidth. But in an OFDM system, the information is converted to N parallel sub-channels and sent at lower rates using frequency division multiplexing. The subcarrier frequency spacing is selected carefully such that each subcarrier is located on the other subcarriers zero crossing points [2]. This implies that there is overlapping among the subcarriers but will not interfere with each other, if they are sampled at the sub carrier frequencies. This means that all subcarriers are orthogonal.

2. OFDM System

In OFDM the transmit signals are constructed in such a way that the frequency spectra of the individual sub channels are allowed to overlap thereby utilising the frequency spectrum much more efficiently. Mathematically the continuous time representation of the OFDM transmit signalis expressed as:

$$x_m(t) = \frac{1}{\sqrt{N}} \sum_{\frac{-N}{2}+1}^{\frac{N}{2}+1} X_{m,k}.e^{j2\pi k \Delta f t}.w_k(t-m$$

(1)

where $X_{m,k}$ is the mapped (QAM, PSK, etc.) data to be transmitted on the kth subcarrier of the mth transmitted symbol, is the kth subcarrier, Δf is the frequency spacing between subcarriers, and is a rectangular window applied to each subcarrier, is the number of subcarriers, and is the total time of the transmit symbol. To ensure the orthogonal relationship between subcarriers Δf is set as (W is the total bandwidth of the signal).

A discrete time representation of equation (1) can be obtained by sampling the continuous signal. Under the condition that and,the signal can be determined by its samples if sampled at,Under this condition equation (1) then becomes equation (2).

$$x_{m,n} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_{m,k}.e^{\frac{j2\pi n k}{N}} = IDFT\{X$$

(2)

Where 'n' represents the discrete sampling points. This equation describes exactly the IDFT operation.

2.1 Basic OFDM Transceiver Structure

Figure 3.1 shows a baseband transceiver structure for OFDM utilizing the Fourier transform for modulation and demodulation. Here the serial data is modulated to complex data symbols with a symbol rate .The data is then demultiplexed by a serial to parallel converter resulting in a block of complex symbols, The parallel samples are then passed through a point IFFT (in this case no oversampling is assumed) with a rectangular window of length,resulting in complex samples to.Assuming the incoming complex data is random it follows that the IFFT is a set of independent random complex sinusoids summed together. The samples, are then converted back into a serial data stream producing a baseband OFDM transmit symbol of length.A Cyclic Prefix (CP), which is a copy of the last part of the samples is appended to the front of the serial data stream before Radio Frequency (RF) up conversion and transmission. The CP combats the disrupting effects of the channel which introduce Inter Symbol Interference (ISI).

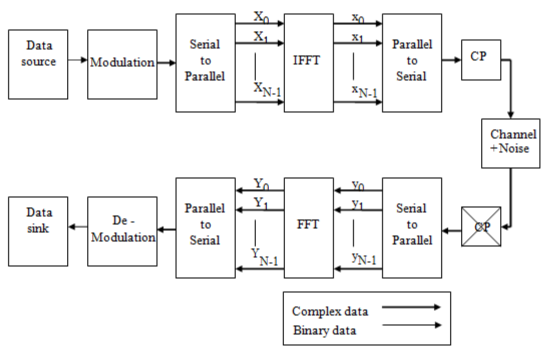

Figure 1: Basic block diagram of OFDM transceiver [35]

In the receiver the whole process is reversed to recover the transmitted data, the CP is removed prior to the FFT which reverses the effect of the IFFT. The complex symbols at the output of the FFT, are then demodulated and the original bit steam recovered [35].

Mathematically the demodulation process (assuming no CP and no channel impairments) using the FFT is as shown in

3. Peak to Average Power Ratio (PAPR)

Due to Presence of large number of independently modulated sub-carriers in an OFDM system the peak value of the signal power can be very high as compared to the average value. 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 power.

$$Y_{m,k} = FFT\{x_{m,n}\}$$

$$= \frac{1}{N}\sum_{n=0}^{N-1} x_{m,n} e^{-j2\pi nk/N}$$

$$= \frac{1}{N}\sum_{n=0}^{N-1}\sum_{d=0}^{N-1} X_{m,d} e^{j2\pi n(d-k)/N}$$

$$= \frac{1}{N}\sum_{d=0}^{N-1} X_{m,d} \sum_{n=0}^{N-1} e^{j2\pi n(d-k)/N}$$

$$= \frac{1}{N}\sum_{d=0}^{N-1} X_{m,d}\, N\delta[d-k]$$

$$= X_{m,k}$$

The major disadvantages of a high PAPR are:

Increased complexity in the analog to digital and digital to analog converter.

- Reduction is efficiency of RF amplifiers.

In other words, PAPR is the relation between the maximum power of a sample in a given OFDM transmit symbol divided by the average power of that OFDM symbol. The PAPR of OFDM is defined as the ratio between the maximum power and the average power, The PAPR of the OFDM signal X (t) is defined as:

$$PAPR = \frac{P_{peak}}{P_{average}} = \qquad (3)$$

where = An OFDM signal after IFFT (Inverse Fast Fourier transform).

E [.] = Expectation operator, it is an average power. The complex baseband OFDM signal for N subcarriers can be represented as:

$$X(t) = \frac{1}{\sqrt{N}}\sum, (0 \le t \le NT) \qquad (4)$$

Where, denotes the complex symbol modulating the n^{th} carrier,N is the number of subcarriers, and T is the duration of an OFDM symbol. Subcarriers are spaced apart.

3.1 Cumulative Distribution Function

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 helps us to measure the probability that the PAPR of a certain data block exceeds the given threshold (0-13dB). The CDF of the amplitude of a signal sample is given by:

$$F(z) = 1 \quad \exp(-z) \qquad (5)$$

The CCDF of the PAPR of the data block is desired is our case to compare outputs of various reduction techniques. This is given by:

$$P(PAPR > z) = 1 - P(PAPR \le z)$$
$$= 1 - F(z^N)$$
$$= 1 - (1 - \exp(-z))^N$$

3.2 PAPR Reduction Techniques

There have been many new PAPR reduction techniques developed during the last few years. Few of PAPR reduction techniques have been discussed in this thesis. These techniques are divided into two groups, (1) signal scrambling techniques and (2) signal distortion techniques. The signal scrambling techniques are:

1. Selected Level Mapping (SLM)
2. Partial Transmit Sequences (PTS)
3. Companding

Signal scrambling techniques work with coding which minimize the effective throughput since they commence redundancy. Signal distortion techniques introduce band interference and system complexity. Signal distortion techniques minimize high peak dramatically by distorting signal before amplification. PAPR reduction techniques vary according to the needs of the system and are dependent on various factors. Following factor are taken into account before using PAPR reduction technique:

- Increase in power in transmit signal
- Loss in data rate
- Complexity of computation
- Increase in bit error rate

1. Selected Mapping (SLM)

Selected Mapping (SLM) approaches have been proposed by Bauml in 1996 [5]. This method is used for minimization of peak to average transmit power of multicarrier transmission system with SLM. A complete set of signal under test is generated signifying the same information in SLM, and then the most favorable signal is selected having least PAPR and it is then transmitted. In the SLM, the input data structure is multiplied by random series and resultant series with the lowest PAPR is chosen for transmission. To allow the receiver to recover the original data with the multiplying sequence can be sent as 'side information'[5].

One of the preliminary probabilistic methods is SLM method for reducing the PAPR problem. The good side of selected mapping method is that it doesn't eliminate the peaks, and can handle N number of subcarriers. The drawback of this method is the overhead of side information that requires to be transmitted to the receiver of the system in order to recover information. In this a set of sufficiently different data blocks representing the information same as the original data blocks are selected. Selection of data blocks with low PAPR value makes it suitable for transmission[5].

2. Partial Transmit Sequence (PTS)

Partial Transmit Sequence (PTS) technique has been proposed by Muller and Hubber in 1997 [6]. This proposed method is based on the phase shifting of sub-blocks of data and multiplication of data structure by random vectors. This method is flexible and effective for OFDM system. The main purpose behind this method is that the input data frame is divided into non-overlapping sub blocks and each sub block is phase shifted by a constant factor to reduce PAPR[6].

PTS is probabilistic method for reducing the PAPR problem. PTS method works better than SLM method. The main advantage of this scheme is that there is no need to send any side information to the receiver of the system, when differential modulation is applied in all sub blocks. Transmitting only part of data of varying sub-carrier which covers all the information to be sent in the signal as a whole is called Partial Transmit Sequence Technique [6].

3. Companding Technique

Any invertible function with compression feature can be used for companding. Here one can apply the invertible transformation, so as to recover the signal back at the receiver. First a quadrature demodulator generates the estimate of transformed signals with the help of receiver signal level control and low pass filter[15]. Using the inverse function of compression, the nonlinear distortion introduced by the compressor is corrected after reconstruction at the receiver with an expander [15].

4. Particle Swarm Optimization

Particle Swarm Optimization (PSO) is a technique used to explore the search space of a given problem to find the settings or parameters required to maximize or minimize a particular objective.

This technique, first described by James Kennedy and Russell C. Eberhart in 1995[34], originates from two separate concepts: the idea of swarm intelligence based off the observation of swarming habits by certain kinds of animals (such as birds and fish); and the field of evolutionary computation [34]. The PSO algorithm works by simultaneously maintaining several candidate solutions in the search space. During each iteration of the algorithm, each candidate solution is evaluated by the objective function being optimized, determining the fitness of that solution. Each candidate solution can be thought of as a particle “flying” through the fitness landscape finding the maximum or minimum of the objective function. Initially, the PSO algorithm chooses candidate solutions randomly within the search space. It should be noted that the PSO algorithm has no knowledge of the underlying objective function, and thus has no way of knowing if any of the candidate solutions are near to or far away from a local or global maximum or minimum [34].

The original PSO algorithm was inspired by the social behavior of biological organisms, specifically the ability of groups of some species of animals to work as a whole in locating desirable positions in a given area, for example birds flocking to a food source. This seeking behavior was associated with that of an optimization search for solutions to non-linear equations in a real-valued search space [34].

The most common implementations of PSO, particles move through the search space using a combination of an attraction to the best solution that they individually have found, and an attraction to the best solution that any particle in their neighborhood has found.

In PSO, a neighborhood is defined for each individual particle as the subset of particles which it is able to communicate with. The first PSO model used a Euclidian neighborhood for particle communication, measuring the actual distance between particles to determine which were close enough to be in communication. This was done in imitation of the behavior of bird flocks, similar to biological models where individual birds are only able to communicate with other individuals in the immediate vicinity.

5. System Model

1. *PSO Optimized Companding*

The compander consists of compressor and expander. Any invertible function with compression feature can be used for companding [12].

Compression improves the quantization resolution of small amplitude signals at the cost of lowering the resolution of large signals. This also introduces quantization noise; however, the effect of the quantization noise due to reduction in resolution of the peaks is relatively small as the peaks occur less frequently. The compression algorithm as shown in (4.1) amplifies the signals of lower amplitude with the peaks remaining unchanged [12].

In companding, the OFDM signal is compressed at the transmitter and expanded at the receiver. Compression is performed according to the well-known μ-Law[12]:

$$y = V \frac{\log\left[1+\mu\frac{|x|}{V}\right]}{\log(1+\mu)} \mathrm{sgn}(x) \qquad (6)$$

where V is the peak amplitude of the signal, and x is the instantaneous amplitude of the input signal. Decompression is simply the inverse of (4.1).

In (4.1), µ is known as compression ratio and its value is given as 1, 2, 3, 4… and so on. To optimize the performance of system, Particle Swarm Optimization is used. PSO optimizes the value of µ for lowest PAPR.

To accomplish this, PSO operates summation of different PAPR values for the respective value of µ. Moreover, the optimization held on the basis of a particular value of µ on which it gets minimum peak.

2. Selected Mapping (SLM) Companding

In selected mapping (SLM) technique [13] the actual transmit signal lowest PAPR is selected from a set of sufficiently different signals which all represents the same information. SLM Techniques are 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 Figure 4.3.

Let us define data stream after serial to parallel conversion as $X=[X_0, X_1........., X_{N-1}]^T$. Initially each input can be defined as equation:

$$x_n^{(u)} = X_n . b_n^{(u)}$$

where

$$B^{(1)} = [b_{1,0}, b_{1,1}, \dots \dots . b_{1,N-1}]^T$$

$$B^{(2)} = [b_{2,0}, b_{2,1}, \dots \dots . b_{2,N-1}]^T$$

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....

$$B^{(U)} = [b_{u,0}, b_{u,1}, \dots \dots . b_{u,N-1}]^T$$

and,

$$X^{(1)} = [X_0 b_{1,0}, X_1 b_{1,1}, \dots . X_{N-1} b_{1,N-1}]^T$$

$$X^{(2)} = [X_0 b_{2,0}, X_1 b_{2,1}, \dots . X_{N-1} b_{2,N-1}]^T$$

::::

....

$$X^{(U)} = [X_0 b_{u,0}, X_1 b_{u,1}, \dots . X_{N-1} b_{u,N-1}]^T$$

And can be written as,

$$x_n^{(u)} = [x_0^{(u)}, x_1^{(\qquad (8)$$

where $n = 0,1$

and ( ) to make the phase rotated OFDM data blocks. All phase rotated OFDM data blocks represented the same information as the unmodified OFDM data block provided that the phase sequence is known.

After applying the SLM technique, the complex envelope of the transmitted OFDM signal becomes,

$$x^{u}(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} , \qquad (9)$$

where , and 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 minimized by reducing the number of IFFT block.

6. Result

6.1 Simulation Parameters

Table 1: Simulation parameters

Parameter	**Value**
Number of bits per OFDM symbol	52
Number of symbols	10000
FFT size	64
Number of data subcarriers	52
SNR Range	0-12dB
Modulation Schemes	BPSK, QPSK, 16-QAM and 64 QAM

Table 2: Simulation parameters for PAPR

Modulation Schemes	**RateID**
BPSK	0
QPSK	(1, 2)
16-QAM	(3, 4)
64-QAM	(5, 6)
Parameters	**Value**
Cyclic Prefix	¼
N_0 (Number of iterations)	100

Simulation is carried out using MATLAB2010a.

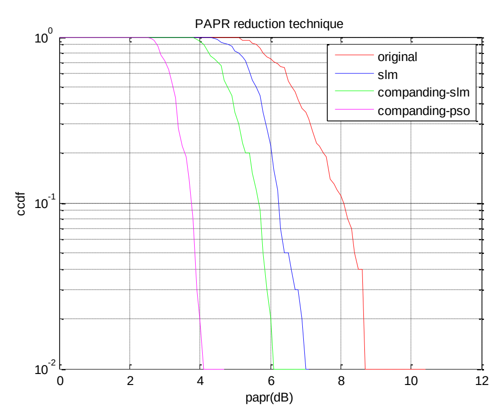

Figure 2: Standard CCDF v/s PAPR calculation graph with QPSK

The above simulation result shows the comparative graph between CCDF and PAPR with QPSK for original signal, SLM, Companding-SLM and Companding-PSO.The X axis indicates the PAPR value and Y axis represents CCDF. It can be observed by above graph that the Companding-PSO outperforms than other methods.

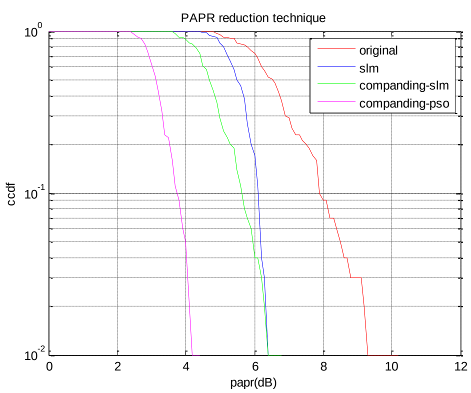

Figure3: Standard CCDF v/s PAPR calculation graph with QAM 16

The above simulation result shows the comparative graph between CCDF and PAPR with QAM-16 for original signal, SLM, Companding-SLM and Companding-PSO.The X axis indicates the PAPR value and Y axis represents CCDF. It can be observed by above graph that the Companding-PSO outperforms than other methods.

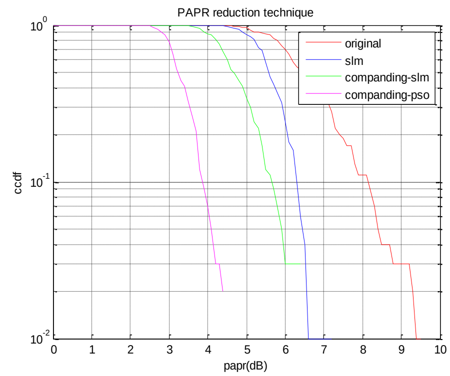

Figure 4: Standard CCDF v/s PAPR calculation graph with QAM-64

The above simulation result shows the comparative graph between CCDF and PAPR with QAM-64 for original signal, SLM, Companding-SLM and Companding-PSO.The X axis indicates the PAPR value and Y axis represents CCDF. It can be observed by above graph that the Companding-PSO outperforms than other methods.

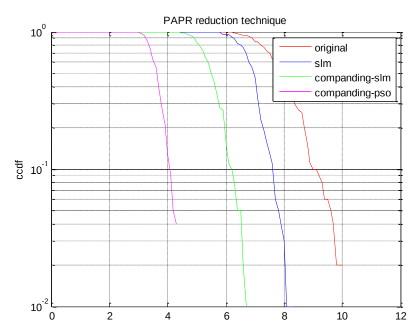

Figure 5: Standard CCDF v/s PAPR calculation graph with FFT-256

The above simulation result shows the comparative graph between CCDF and PAPR with FFT-256 for original signal, SLM, Companding-SLM and Companding-PSO.The X axis indicates the PAPR value and Y axis represents CCDF. It can be observed by above graph that the Companding-PSO outperforms than other methods.

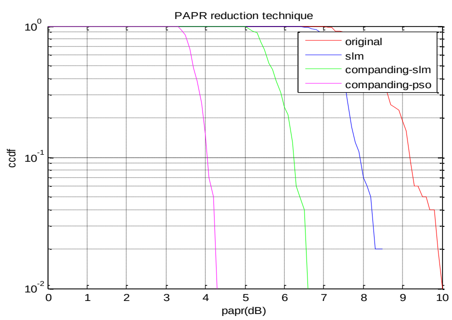

Figure 6: Standard CCDF v/s PAPR calculation graph with FFT-512

The above simulation result shows the comparative graph between CCDF and PAPR with FFT-512 for original signal, SLM, Companding-SLM and Companding-PSO.The X axis indicates the PAPR value and Y axis represents CCDF. It can be observed by above graph that the Companding-PSO outperforms than other methods.

7. Conclusion and Future Work

Orthogonal frequency division multiplexing (OFDM) signals have a generic problem of high peak to average power ratio (PAPR) which is defined as the ratio of the peak power to the average power of the OFDM signal. The drawback of the high PAPR is that the dynamic range of the power amplifiers (PA) & digital-to-analog (D/A) converters required during the transmission and reception of the signal is higher. As a result, the total cost of the transceiver increases, with reduced efficiency. After analyzing some specific algorithms, propose a hybrid algorithm by combining theCompanding technique, Selective Mapping (SLM), Companding-SLM and Particle Swarm Optimized-Companding, which includes an idea of the PAPR constraint, along with the implementation and analysis of the proposed algorithmfor PAPR reduction of the OFDM signals. This algorithm is implemented and tested in the OFDM transceiver designed using MATLAB. The simulation result conclude that the output obtained by Companding-PSOtechnique reduces the PAPR drastically as compared to other schemes. Here, by using SLM technique cost increased but at the same time PAPR reduced.

Future Work

Future research will concentrate on investigating and quantifying further the influence of PAPR as a function of different modulation mapping schemes, OFDM subcarrier levels, and phasing schemes.

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