Tone Injection Method for Reduction of Peak-To-Average-Power (PAPR) in OFDM System

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Abstract : Orthogonal Frequency Division Multiplexing popularly known as OFDM is efficient system mainly used for the transmission of large data with higher data rate. But the key problem in any OFDM system is increase in peak-to-average-power ration in OFDM signal which causes low power efficiency and performance degradation in OFDM system. This paper represents the tone injection technique for PAPR reduction. This paper considers three different algorithms of tone injection named as cross entropy, hexagonal constellations and clipping noise and gives he comparative study.

Keywords : Orthogonal Frequency Division Multiplexing(OFDM), Tone Injection (TI), Peak-To-Average Power Ratio (PAPR).

I. INTRODUCTION

OFDM is the Orthogonal Frequency Division Multiplexing system through which orthogonally located sub carriers are being used o carry the data from the transmitting device to the receiving device. OFDM gives the higher data rate, high spectral efficiency , immunity to frequency selective fading channel. It eliminates the inter-symbol interference (ISI) and offers good protection with respect to noise and co-channel interfaces. Due to all these advantages OFDM is used on large scale for many applications which includes Digital Television and Audio Broadcasting, 3G and 4G Mobile communication using LTE, Wireless network communication such as WLAN and Wi MAX, Internet access with DSL etc. But there are also some drawbacks present in OFDM system.

The main problem in the OFDM system is its high peak to average power ratio (PAPR). The peak-to –average-power ratio (PAPR) of the transmitted of OFDM signal requires the transmit power amplifier with an extremely large dynamic range, which significantly reduces the efficiency of the amplifier. Therefore various PAPR reduction techniques are proposed, that can be classified broadly in two groups as signal distortion technique and signal scrambling techniques. One group processes OFDM signals directly, such as clipping and filtering method , companding transform. In this group signal is clipped and filtered or companded to a predefined level and PAPR is reduced at the cost of the bit error rate (BER) increase and out of band radiation[3]. The other group i.e signal scrambling techniques intend to reduce the occurrence of large signals before multicarrier modulation, including probabilistic techniques, tone reservation(TR), tone injection(TI) and coding[3]. But we have to select the PAPR technique that compromise computational complexity, data rate, signal power and bit error rate(BER) to decrease high PAPR of transmitter OFDM signal.

Tone Injection (TI) is a distortion less technique because it gives very low distortion and decrease PAPR efficiently without data rate loss. In addition it does not requires the exchange of side information between transmitter and receiver. Thus PAPR may be effectively decreased by accurately selecting the correct constellation points from the available set of constellation points in TI method. It provides the cyclic extension of constellation. But implementation of TI method needs to solve a high computational complexity which increase as we increase the number of subcarriers. Therefore the suboptimal TI solutions are required.

This paper represents three suboptimal algorithms of tone injection namely cross entropy, hexagonal constellation and clipping noise to decrease the computational complexity of TI technique. The outline of paper is designed as follows. Section II gives the brief introduction of OFDM system and PAPR. Section III describes the tone injection and three selected algorithms namely HC-TI, CE-TI and CN-TI are explained in section IV. In section V comparative analysis of selected algorithms with other methods is shown in the form of graphs. Section VI concludes the paper.

II. OFDM SYSTEM & PAPR DEFINITON

The general block diagram of OFDM system is shown below in fig.1.

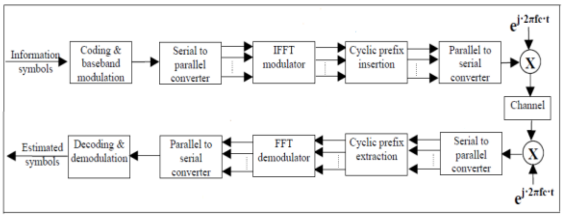

Fig.1: OFDM System

The input data sequence is first modulated by using any modulation technique among the different modulation type. Different modulation schemes such as BPSK, QPSK, QAM can be used. The data symbols are converted into parallel form in N different sub-streams and each sub-stream is modulated with a separate subcarrier. Then all these modulated subcarriers are passed through IFFFT block. IFFT is the main component of OFDM system. Inter-symbol and inter-channel interference can be eliminated by adding cyclic prefix. The cyclic prefix is obtained by copying the last samples of symbols in front of it. Thus cyclic prefix is a circular extension cyclic of IFFT modulated symbols. Cyclic prefix is added after IFFT modulation. OFDM symbol are further converted back into serial form and transmitted through the channel to the receiver. At receiver end all above operation are performed inversely. Received OFDM signal is converted into parallel form and cyclic prefix is removed. Then demodulation is performed to extract the transmitted symbols. After performing FFT data is converted into serial form and demodulate using appropriate modulation scheme that has been used at transmitter to extract the original transmitted data sequence.

Generally data symbols are modulated by using phase shift keying (PSK) modulation or quadrature amplitude modulation (QAM) and then transmitted using N different subcarriers in typical OFDM system. Let the input data block is represented using vector $\mathbf{X} = [X_0, X_1, \cdots, X_{N-1}]^T$ where N denotes the number of subcarriers in OFDM. Then the OFDM signal consisting of N subcarriers is given by

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi k \Delta f t}, \; 0 \le t < NT, \qquad [4]$$

In above equation $j = \sqrt{-1}$, NT is data block period and Δf denotes subcarrier spacing. The peak value of OFDM signal can be very large due to presence of large number of separately modulated subcarriers as compared to average of complete system. The peak to average power ratio (PAPR) is defined as the ratio of peak value to the average power value of OFDM system. Thus PAPR of transmitted signal is given by

$$PAPR = \frac{\max_{0 \le t < NT} |x(t)|^2}{1/NT \int_0^{NT} |x(t)|^2 dt} \qquad [4]$$

III. TONE INJECTION

The purpose of Tone Injection Technique is to increase constellation size by mapping the points from original constellation into various equivalent points in the expanded constellation. And this is responsible for PAPR reduction. It allows data tones and peak reduction tones to be overlapped. As this technique is similar to multicarrier signal where tones of equal frequency with phase are injected. Hence this technique is called as Tone Injection (TI).

Specifically, by merging the data signal with PAPR reduction signal we can produce the signal which is to be transmitted in time domain with decrease PAPR.

$$\begin{aligned} \tilde{x}[n] &= x[n] + c[n] \\ &= \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} (X[k] + C[k]) e^{j2\pi kn/NL} \end{aligned} \qquad [7]$$

Where $\{C[k]\}_{k=0}^{N-1}$ and $\{c[n]\}_{n=0}^{N-1}$ these terms show the frequency domain and the relative time domain respectively. As in frequency domain the data tones and peak reduction tones(PRTs) are not separated orthogonally. So at receiver we have to eliminate the effect of C[k]. In this method, we can construct signal with reduced PAPR as C[k]=p[k].D + jq[k].D where to minimize the PAPR p[k] and q[k] are selected. Here D is a constant selected as a positive real number. We can discard C[k] at the receiver by applying modulo-D operation on the real and imaginary parts at the output of the frequency-domain equalizer[FEQ]. This can be shown as

$$\bar{X}[k] = X[k] + C[k] = X[k] + p[k] \cdot D + jq[k] \cdot D$$
[7]

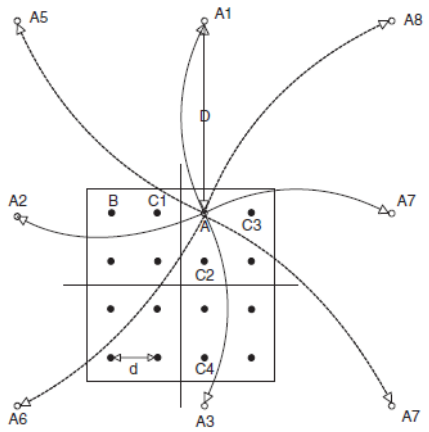

Fig.2 :Expanded constellation of 16-QAM for TI Method[7]

Above fig2. shows expanded constellation diagram of 16-QAM used in TI technique. Here, original QAM and expanded QAM symbols are denoted by the black and white points respectively.

IV. SUBOPTIMAL ALGORITHMS FOR TONE INJECTION

1. TI with hexagonal constellation (HC-TI)

In tone injection technique it is possible to get PAPR reduction without any increase in signal power [1]. In order to achieve, so the number of signal point `in given area can be exceeded using hexagonal constellation in place of quadrature amplitude modulation(QAM) and the remaining degree of freedom can be accessed for PAPR reduction with any increase in signal power in TI technique.

In this method there is no change in amplitude of equivalent points and the average power of signal points is either less or almost equal to the square of QAM constellation without any change in data rate. In TI technique the PAPR reduction capability with hexagonal constellation depends on representation for symbols with at least one or more than one representation, and the number of subcarriers with data symbols provided with more than representation.

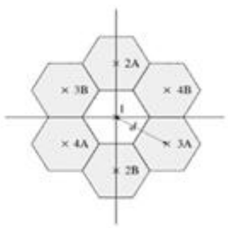

Fig.3: hexagonal constellation with 7 point[1]

Fig.4: hexagonal constellation with 91 point[1]

In Fig.3, In 4-QAM, symbol '1' has 1 representation and symbol '2', '3' and '4' has 2 representation in 7-HEX. At the receiver end if either of the two signals i.e. '2A' or '2B' is received then 2 will be taken into consideration. One choice can be made without any obstruction between the two points in order to reduce PAPR in the transmit signal.The91 signal points(91-HEX) of hexagonal constellation shown in Fig.4.

Steps for tone injection with hexagonal algorithm are as follows[1]:

Step 1: Naming the subcarrier indices depending on the position of subcarrier having more than one representation as A= {a1, a2,……,aN_{TI}}

Step2: Computation of PAPR of the output signal by setting iteration count j=0, and then choosing the initial representation for all positions in A,

Step3: Increment J by 1 with subcarrier ij and then choosing the representation with lowest PAPR in all are possibilities and the other subcarriers being fixed.

Step 4: If $j<N_{TI}$, go to step 3 otherwise end.

2.Cross Entropy based TI (CE-TI)

The Cross Entropy algorithm is used to reduce PAPR and the mathematical complexity. The purpose behind this algorithm according to the Kullback-Leibler distance is to sustain a distribution of possible solutions and improve this distribution adaptively. Where Kullaback-Leibler distance is nothing but cross entropy i.e. distance between the associated density and the optimal importance sampling density[2]. Because of this we can constructs a erratic sequence of solution which can meet to the finest solution. This method consists of two iterative phases. In the first phase, according to a particularize sampling distribution which is generated on the basis of the previous iteration we have to induce random samples. Second phase is to create better scoring samples for the next iteration for this reform the parameters on the basis of samples which scores best[6]. In the CE based TI algorithm only those constellation points are shifted who located on the outer ring and those constellation points are not shifted who closer to the original of the original constellation, because if we shift those points then outcome is a great power rise.

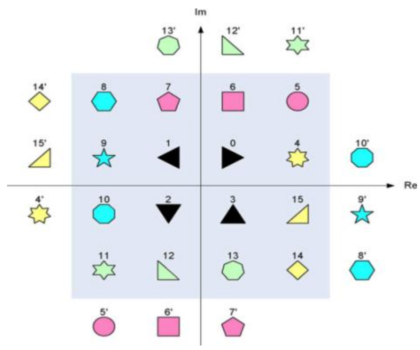

Fig 5 : Expanded constellation for 16-QAM with CE algorithm[2]

Above Fig 5. shows that the original 16-QAM represent by constellation points inside the gray box and the expanded constellation points of the relative original ones are represent by the constellation points outside the gray box. As shown in the Fig 5. shifted constellation points are situated on the outer ring and the relative constellation points are almost uniform about the origin.

Proposed CE algorithm to search for the finest ω* is as follows[2]:

Step1: First we keep the iteration counter t:=1 then set the probability vector $P^{(0)} = \{P_m^{(0)}\}_{m=0}^{N-1}$ with $P_m^{(0)} = 1/2$ for all m. Here P_m is for the probability of the m^{th} input symbol. The symbol m is select to be shifted to its expanded constellation, and the super index of P denotes the iteration index.

Step2: To produce uneven samples i.e. $\{ \omega^{(q)}\}_{q=1}^{Q}$ we are going to use density function $f(\omega;p^{(t-1)})$. Here Q denotes sample size. Where every element of w is lookalike an autonomic Bernoulli Random Variable with the probability distribution, $P(I_m(\omega)=1) = 1-P(I_m(\omega) = 0) = p_m$ for m= 0,...,N -1 and on the basis of indicator function $I_m \in \{0,1\}$ we decide to shift the m^{th} symbol or not.

Step 3: According to this $C_{sel}(\omega) = \max|x_n(\omega)|^2$ we find out the set of performance values $\{Csel(\omega^{(q,t)})\}^{Q}_{q=1}$ and arrange them in ascending order. Then put $\gamma^{(t)} = C_{sel}^{(\lceil \rho Q \rceil)}$ here ρ indicates the fraction of best samples, where [.] this shows the operation of ceiling.

Step 4: Find out the parameter $^{P(t)}$ on the basis of,

$$p_m^{(t)} = \frac{\sum_{q=1}^{Q} I_{\{C_{sel}(\boldsymbol{\omega}^{(q,t)}) \leq \gamma^{(t)}\}} I_m\left(\boldsymbol{\omega}^{(q,t)}\right)}{\sum_{q=1}^{Q} I_{\{C_{sel}(\boldsymbol{\omega}^{(q,t)}) \leq \gamma^{(t)}\}}}$$

Where

$$I_{\{C_{sel}(\boldsymbol{\omega}^{(q,t)}) \leq \gamma^{(t)}\}} = \begin{cases} 1, & \text{if } \; C_{sel}\left(\boldsymbol{\omega}^{(q,t)}\right) \leq \gamma^{(t)} \\ 0, & \text{otherwise.} \end{cases},$$

which is an indicated variable.

Step 5: Now reform $P^{(t)}$ smoothly by $P^{(t)} = \lambda \times P^{(t)} + (1 - \lambda) \times P^{(t-1)}$. Here, smoothing parameter is denoted by λ with $0 < \lambda \leq 1$.

Step 6: Set the t := t=1, if the stopping criterion is not achieved and jump to Step 2. Where stopping criterion is the number of iterations which is previously defined.

3.TI with clipping noise (CN-TI)

In CN-TI algorithm, the optimal equivalent constellation is obtained by using clipping noise. Here all the samples of original signal which are higher than threshold value of PAPR are taken as clipping noise and mean square error of this clipping noise is obtained. The inherent power increase can be effectively reduced by this method[3].

The FFT of clipped part which is found is calculated and resultant sequence is used to find Ck by increasing points in original constellations[3]. The step by step explanation of CN-TI algorithm is given below.

1. Apply an IFFT to input data block Xk to obtain x.

2. Find Cclip by clipping all |x[n]|>=A in magnitude.

3. Obtain FFT of above Cclip equation.

4. Project the value obtained from step 3 onto allowable extension directions and for each sub channel and select Ck extension vector.

5. Compute highest magnitude sample

E=max |Xi[n]|

6. Determine sub channel k which provide highest peak reduction in PAPR

k = arg min max |x[n]|2

7. Compute

$X_{i+1}[n] = x_i[n] + C[n]$

Where

$$c[n] = \frac{1}{\sqrt{NL}} C_k e^{j2\pi i}$$

8. Update i = i+1 and if required PAPR level or a maximum iteration count are not get then go to step 2 again and again until it gets. Otherwise stop PAPR reduction.

V. SIMULATION RESULTS

PAPR performance can be evaluated by calculating complementary cumulative distributive function (CCDF). Expected outcomes of selected suboptimal algorithms of TI are shown below.

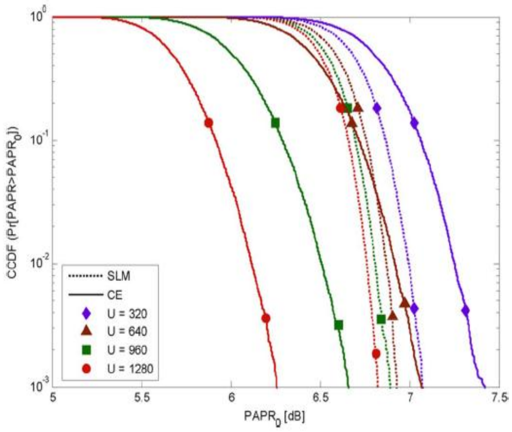

Fig.6.1: Comparison of CE-TI and SLM techniques with 64-QAM and N=256 on the basis of PAPR reduction performance [2]

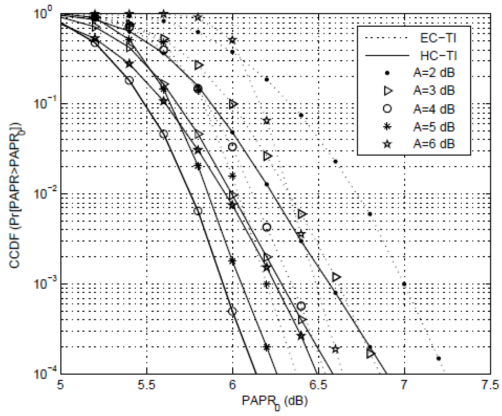

Fig 6.2: CCDFs of different PAPR threshold comparison of clipping noise TI with extended constellation (EC-TI) and with hexagonal constellation (HC-TI) schemes with eight iterations, 64QAM, and 256 subcarriers.[4]

V. CONCLUSION

- This paper represents the three suboptimal algorithms namely hexagonal constellation TI, cross entropy based TI and clipping noise based TI for tone injection technique to reduce PAPR in OFDM system.

- Using hexagonal constellation (HC-TI) we can achieve PAPR reduction without power increase and it is easily applied when constellation size is small.
- Cross entropy method reduces the computational complexity. It gives significant PAPR reduction and also obtain optimal computational complexity.
- The clipping noise based TI easily determines the optimal equivalent constellation. It minimizes number of FFTs requirement. Also the inherent power increase can be effectively avoided by this method.

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