Comparative Analysis of PAPR Reduction Techniques in OFDM using Precoding Techniques

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Abstract— In this modern era, Orthogonal Frequency Division Multiplexing (OFDM) has been proved to be an explicit promising technique for wired and wireless systems because of its several advantages like high spectral efficiency, robustness against frequency selective fading, relatively simple receiver implementation etc. Besides having a number of advantages OFDM suffers from few disadvantages like high Peak to Average Power Ratio (PAPR), Intercarrier Interference (ICI), Intersymbol Interference (ISI) etc. These detrimental effects, if not compensated properly and timely, can result in system performance degradation. This paper mainly concentrates on reduction of PAPR.A comparisons have been made between various precoding techniques against conventional OFDM.

Key words: OFDM, PAPR, ICI, ISI

I. INTRODUCTION

OFDM is basically a combination of both modulation and multiplexing. Multiplexing generally refers to independent signals, those produced by different sources. But in OFDM the question of multiplexing is applied to independent signals and these independent signals are a sub-set of the one main signal. In OFDM the signal itself is first split into independent channels, modulated by data and then re-multiplexed to create the OFDM carrier. OFDM is a special kind of Frequency Division Multiplexing (FDM). To understand the difference between normal FDM and OFDM, let us take an example of water tap and a shower. A general FDM can be considered as water flow coming out of a water Faucet whereas OFDM is analogous to a shower. In a faucet all water comes out like a big stream while in shower the water comes out in combination of little streams.

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier transmission scheme has now became the technology for next generation wireless and wired digital communication systems because of its high speed data rates, high spectral efficiency, high quality service and robustness against narrow band interference and frequency selective fading[1]. Despite of several advantages, the OFDM systems also have some major problems like high Peak to Average Power Ratio (PAPR) of transmitted signal, Synchronization (timing and frequency) at the receiver, Inter carrier interference etc.

This paper mainly deals with high peak to average power ratio reduction techniques. Due to the high Peak to average Power Ratio, the quiescent point of the amplifier used in the transmitter section is forced to enter into the saturation region (non-linear region) resulting in reduction in the efficiency of the HPA. Once the amplifier enters its saturation region ,the amplification process no longer remains linear , moreover the orthogonality between the subcarriers gets lost which leads to Intercarrier Interference(ICI).One way to solve this problem is to force the amplifier to work in its linear range or to increase the dynamic range of the amplifier. Unfortunately, these solutions are not power efficient and cost efficient. Power efficiency is very much necessary in wireless communication as it saves power, provides adequate area coverage etc. Thus inspite of modifying the amplifier characteristic we prefer to reduce peak power swing with respect to the mean power.

II. PEAK TO AVERAGE POWER RATIO (PAPR)

Large envelope fluctuations or High PAPR is another major limitation of an OFDM system. An OFDM signal consists of a large number of independently modulated subcarriers, which when added up coherently, yields a very high amplitude as compared to the average amplitude, resulting in a large peak to average power ratio (PAPR).

The PAPR of the continuous time baseband OFDM transmitted signal x(t) is the ratio of maximum instantaneous power and the average power. By definition,

$$PAPR = \frac{max[x(t)]^2}{E\{|x(t)|^2\}}, for\ 0 \le t \le NT$$

Where, E{.}denotes expectation operator and E{|x(t)|^2}is average power of x(t) and T is an original symbol period.

Since, multiple subcarriers are added in this technique to form the transmitted signal therefore OFDM suffers from high Peak to Average Power Ratio (PAPR) value of the transmitted signal.

Peak-to-average power ratio (PAPR) is directly proportional to the number of subcarriers used for OFDM systems. In other words Any OFDM system with large number of subcarriers will have a large PAPR as these subcarriers add up coherently which results in high peaks.

III. EFFECT OF HIGH PAPR

In the transmitter section, linear power amplifiers are being used so that the quiescent point (Q-point) remains in the linear or active region. But due to high peak to average power ratio, the Q-point starts moving towards the saturation region and hence the clipping of signal takes place which in turn gives rise to in-band and out-of- band distortion. For faithful amplification ,the Q-point must lie in the linear region and to keep the Q-point in the active region, the linear range of the power amplifier have to be increased i.e needs to be operated with huge back-off, which reduces its efficiency and increases the cost factor[2]. If the composite time OFDM signal is amplified by a power amplifier having nonlinear transfer function, the performance of an OFDM System get degrades .Hence, a trade off always lies between non-linearity and efficiency. The high PAPR also results in the increased complexity (number of bits) of DAC and ADC used in the transmitter and receiver section respectively such that large peaks can be represented with good precision. Thus it becomes a prime concern for a telecommunication engineer to develop an efficient algorithm for PAPR reduction.

So, the major impact of a high PAPR is:

1) Increased complexity in the analog to digital and digital to analog converters.
2) Reduction in the efficiency of radio frequency (RF) power amplifiers.

It has been observed that the effects of nonlinearity depends upon the type of modulation used in OFDM systems, because different modulation schemes give rise to different amplitude and phase of signal, which is ultimately related the peak to average power ratio (PAPR). [3]

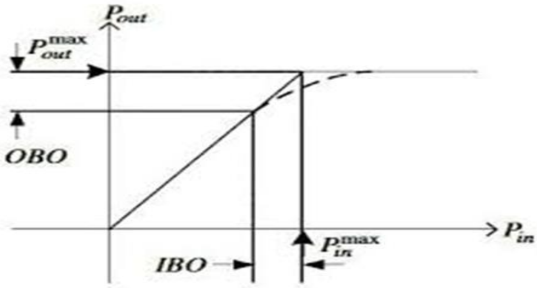

Fig. 1: Input- Output characteristic of an HPA.

A linear amplifier shows non linear distortion in their outputs when its input is much larger than its nominal value. Figure shows the input-output characteristics of high power amplifier (HPA) in terms of the input power and the output power. As illustrated in Figure , the input power must be backed off so as to operate in the linear region describing the nonlinear region by Input Back-Off (IBO) or Output Back-Off (OBO).[4]

IV. Distribution Of PAPR

The Cumulative Distribution Function (CDF) is one of the most regularly used parameters to measure the efficiency of any PAPR technique. Normally, the Complementary Cumulative Distribution Function (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.

CCDF provides an indication of the probability of the OFDM signal's envelope exceeding a specified PAPR threshold within the OFDM symbol and is given by

CCDF [PAPR (xn(t)] = prob [PAPR (xn(t) > δ]

where PAPR (xn(t)) is the PAPR of the nth OFDM symbol and δ is some threshold value.

V. PAPR Reduction Methods

Various techniques have been proposed in the literature for PAPR reduction, each having its own advantages and disadvantages. Among them, some are Clipping and Filtering, Partial Transmit Sequence (PTS), Selected Mapping (SLM), Precoding, Tone Injection (TI),Tone Reservation(TR) ,Companding ,Coding Methods or Hybrid Techniques etc [5].

In this paper , we presented a comparative analysis among various precoding techniques such as Walsh Hadamard Transform (WHT),Discrete Fourier Transform (DFT) and Discrete Hartley Transform(DHT) and on the basis of computer simulation using MATLAB concluded that precoding techniques can reduce PAPR as compared to the conventional OFDM system.

VI. Conventional OFDM System

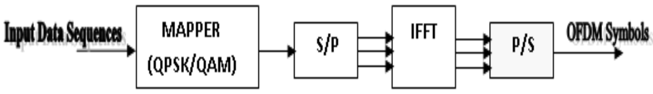

Fig. 2: Block diagram of conventional OFDM transmitter section.

Fig 2 shows the basic block diagram of an conventional OFDM system. ,Here the Mapper transforms the input bit stream into constellation corresponding to various modulation techniques .Here we have performed our simulations considering two modulation techniques: M-QPSK and M-QAM.The baseband modulated symbols are then passed through a serial to parallel converter ,which generates a complex vector of size N. .The complex vector of size N can be written as X = [X0,X1,X2,…….,XN-1]T. This X is then passed through the IFFT block. The IFFT block converts the frequency domain baseband spectrum into its time domain equivalent. After the IFFT operation, the data are transformed and multiplexed to x (n) given by [6].

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{\frac{j2\pi kn}{N}}, \qquad for\ n = 0, 1, 2, 3 \ldots N-1$$

VII. Model for Precoded OFDM System

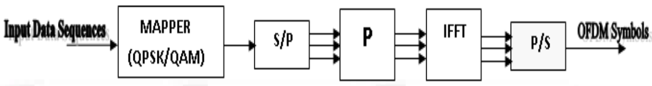

Fig. 3: Block diagram of precoded OFDM transmitter section.

Figure 3 shows a precoded OFDM system. In Precoding method, the modulated data is first multiplied with shaping matrix or precoding matrix before the formation of OFDM symbol (before IFFT) . Different methods like pulse shaping function, discrete cosine transformation (DCT) matrix, Hadamard matrix, Zadoff-chu sequence etc. are used to generate precoding matrix. After that these precoded data are transmitted through IFFT to generate OFDM symbols. Each element of precoding matrix should be carefully designed, so that it can reduce the PAPR.In this model a precoding matrix P of dimension N×N has been implemented before the IFFT to reduce the PAPR.

$$P = \begin{bmatrix} p_{0,0} & p_{0,1} & \cdots & p_{0,N-1} \\ p_{1,0} & p_{1,1} & \cdots & p_{1,N-1} \\ \vdots & & \ddots & \vdots \\ p_{N-1,0} & p_{N-1,1} & \cdots & p_{N-1,N-1} \end{bmatrix}$$

Now the modulated OFDM vector signal with N the subcarriers can be expressed as follows.

Xn = IFFT { P Xn}

VIII. Discrete Fourier Transform (DFT) Precoding

For generating the precoding matrix using DFT function, the size of DFT precoder is kept same as IFFT size. The DFT of a sequence of length N can be defined as:

$$X(k) = \sum_{n=0}^{N-1} x(n) \cdot e^{-j2\pi nk} \qquad k = 0, 1, \ldots, N-1$$

And IDFT for the above can be written as

$$x(n) = 1/N \sum_{n=0}^{N-1} X(K) \cdot e^{-j2\pi nk} \qquad k = 0, 1, \ldots, N-1$$

And

$$p_{mn} = e^{-j2\pi mn} / N\ , k = 0,\ 1,\ \ldots,\ N\text{–}1$$

Here the 'm' and ' n' are integers from 0 to N-1 and the precoding matrix is of size N x N given by

$$P = \begin{bmatrix} p_{0,0} & p_{0,1} & \cdots & p_{0,N-1} \\ p_{1,0} & p_{1,1} & \cdots & p_{1,N-1} \\ \vdots & & \ddots & \vdots \\ p_{N-1,0} & p_{N-1,1} & \cdots & p_{N-1,N-1} \end{bmatrix}$$

IX. THE DISCRETE HARTLEY TRANSFORM (DHT) PRECODING

The DHT is also a linear transformation of data. In DHT, real numbers[xo,x1,…..,xN-1] are transformed into N real numbers . According to [4], the N-point DHT can be defined as follows:

$$H_k = \sum_{n=0}^{N-1} x_n \left[\cos\left(\frac{2\pi nk}{N}\right) + \sin\left(\frac{2\pi nk}{N}\right)\right]$$

$$= \sum_{n=0}^{N-1} x(n) \cdot cas\left(\frac{2\pi nk}{N}\right)$$

Where,
cas ϴ=cosϴ +sin ϴ and k=0 ,1,…..N-1

$$p_{m,n} = cas\left(\frac{2\pi mn}{N}\right)$$

X. DISCRETE WALSH HADAMARD TRANSFORM (WHT) PRECODING

This is the simplest and linear transformation. WHT does not increase the complexity of the system. Walsh functions are the basis for Walsh transform. Walsh functions are orthogonal and have only +1 and -1 values [5] . In general, the Walsh transform can be generated by the Hadamard matrix as follows:

$$H_{2^k} = \begin{bmatrix} H_{2^{k-1}} & H_{2^{k-1}} \\ H_{2^{k-1}} & -H_{2^{k-1}} \end{bmatrix}$$

For k=1,2,3….. and H_1=1 for k=0

Here in this case the H matrix of eq. becomes precoding matrix.

XI. SIMULATION RESULS

In this section we have compared the various precoding techniques mentioned in the above section with 16-QAM for subcarriers N=64 and found that Discrete Fourier Transform outperforms the other conventional precoding techniques.

A. PAPR Reduction Results With 16-QAM Modulation

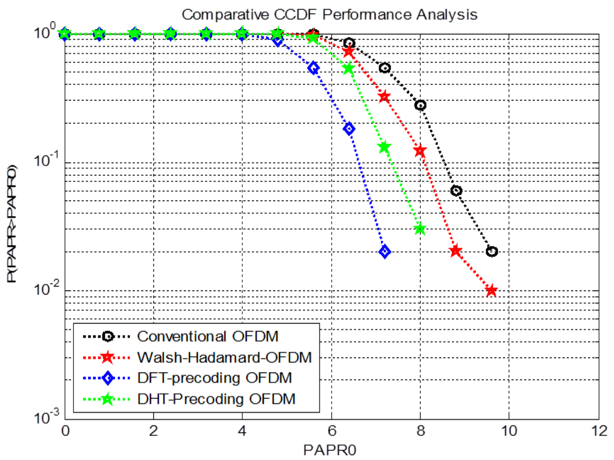

Fig. 4: PAPR reduction results for 16-QAM.

S. No.	PAPR Reduction Technique	PAPR (dB)
1	Conventional OFDM	9.7211
2	DWT Precoding	8.9343
3	DHT Precoding	8.5462
4	DFT Precoding	7.5067

Table 1: Obtained PAPR values for conventional OFDM and various precoding techniques for 16-QAM and number of subcarriers=64.

XII. CONCLUSION

Here, we analyzed performance of various precoding techniques. The precoding technique is quite simple to implement and has no boundations on the system parameters like modulation order, number of subcarriers etc. The Discrete Fourier Transform gives a better PAPR reduction performance than other other precoded techniques.

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