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Performance Analysis of PAPR Reduction Techniques using PTS and SLM in OFDM System

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***Abstract*— One of the challenging issues for Orthogonal Frequency Division Multiplexing (OFDM) system is its high Peak-to-Average Power Ratio (PAPR). As we are using the linear power amplifier at the transmitter side so it's operating point will go to the saturation region due to the high PAPR which leads to out-band radiation and in-band distortion. This can be avoided with increasing the dynamic range of power amplifier which leads to high cost and high consumption of power at the base station. In this paper we mainly focus on Partial Transmit Sequence (PTS) and Selected Mapping (SLM) method. A simulation result shows the comparison of these methods. SLM and PTS reduce PAPR about 5.6dB and 4.2 dB respectively.**

***Index Terms*– Orthogonal Frequency Division Multiplexing (OFDM), Complementary Cumulative Distribution Function (CCDF), Peak-to-Average Power Ratio (PAPR), Partial Transmit Sequence (PTS) and Selected Mapping (SLM).**

I. INTRODUCTION

ORTHOGONAL Frequency Division Multiplexing (OFDM) is most prominent multicarrier scheme currently used for achieving high bit rates in wireless communication system due to its immunity to multipath fading and impulse noise, and further eliminates the need for equalizers, while efficient hardware implementation can be realized using fast Fourier transform (FFT) techniques.

Despite many advantages, one of major drawback of OFDM system is high peak-to-average power ratio (PAPR). High PAPR signal requires highly linear power amplifier to avoid excessive inter-modulation distortion which results in expensive devices, higher power consumption/lower efficiency [1]. PAPR is a major concern in portable terminals and an important indicator of system performance.

The CCDF of the PAPR

Usually, the level of the amplitude fluctuation of the discrete time OFDM signal is measured in term of the peak factor that indicate the ratio of the peak to the average envelope power of the signal. PAPR is random variable because it is a function of the input data, and the input data is of random nature. Therefore, it is necessary to calculate the average number of times that the envelop of a signal crosses a given level for PAPR calculation. This can be performed by calculating the complementary cumulative distribution function (CCDF) for different PAPR values. The CCDF of the PAPR denotes the probability that the PAPR of a data block exceeds a certain threshold $PAPR_0$.

$$CCDF\left(PAPR\left(x(t)\right)\right) = P_r\left(PAPR\left(x(t)\right) > PAPR_0\right.$$

The cumulative distribution function (CDF) of the PAPR is one of the most frequently used performance measures for PAPR reduction techniques. Then, according to the central limit theorem, the real and imaginary part of OFDM signal are Gaussian distributed while the amplitude and phase have Rayleigh and uniform distribution, respectively [2].

In this paper, Firstly we discuss various issues which are arises due to high PAPR in the OFDM system; some of them are discussed in section II. Then we two promising PAPR reduction techniques, Partial Transmit Sequence (PTS) and Selected Mapping Technique (SLM) for improving PAPR statistics of an OFDM signal have been discussed and analysed in section III. Simulation results show that both techniques provide improved PAPR statistics for OFDM systems with little cost in efficiency are presented in section IV. Finally, Conclusion is drawn in section V.

II. MOTIVATION OF PAPR REDUCTION

Nonlinear HPA and DAC

High Power Amplifier used in the transmitter of communication systems for sufficient transmission power. They have to be operated at or near the saturation region to achieve maximum output power efficiency. All the more, the large variation in signal amplitudes highly affects the HPA efficiency due to their nonlinear characteristics.

High PAPR results in wide variation of OFDM signal amplitudes which due to nonlinear characteristics of HPA results in inter-modulation between the different sub carriers and leads to an increase in bit error rate (BER). To achieve a low BER and less signal distortion, HPA has to have a large dynamic range and work in linear amplifier region. However, these types of HPA are costly and less power efficient. In wireless communication, power efficiency is crucial to achieve small size terminals and adequate area coverage [3]. Therefore, power efficient operation of non-linear HPA is very important.

The high peaks of the OFDM signal due to high PAPR demand enough dynamic range of DACs. For large dynamic range with a given sampling rate if we use low precision DACs they result in high quantization noise causing high BER. While high precision DACs can sustain high PAPR without significantly increasing quantization noise but they become more costly. As OFDM signals with large number of sub carriers have Gaussian distribution, so peak signals occur quite rarely hence it is not preferred to have uniform quantization by the DACs [4]. Therefore, the best solution is to reduce the PAPR before OFDM signals are transmitted into nonlinear HPA and DAC.

Power Saving

A high dynamic range HPA has poor power efficiency. It has been reported that we can save power by PAPR reduction. This power saving which is achieved in this way has direct relationship with the desired average output power. Assuming a linear model of HPA, the power efficiency is:

$$\eta = \frac{0.5}{PAPR}$$

Where η = HPA efficiency and is defined as:

$\eta = P_{out.avg} / P_{DC}$,

P_{DC} = constant amount of power regardless of the input power

$P_{out.avg}$ = average of the output power

In an OFDM signal having 256 sub carriers we require an input back-off (IBO) equivalent to the PAPR at the probability level less than 0.01%, i.e., (25.235). This makes $\eta = 0.5/25.235 \approx 1.98\%$.

Hence we have to reduce the PAPR in OFDM systems in order to avoid this level of power inefficiency [5].

Why We Need to Reduce the PAPR?

Non-linear devices such as high power amplifiers (HPA) and digital to analog converters (DAC) exist in almost all communication links and demand for data transmission over longer ranges. At the same time higher power efficiency of the amplifiers, require the amplifier to operate in a more non-linear region, In general, there is a trade of between linearity and efficiency [5].

In single-carrier modulation the signal amplitude is somehow deterministic, except for the pulse shaping filter effect, so the operating point in the amplifier can be determined accurately without destructive nonlinear impairments. But in the multi-carrier systems like OFDM, the envelope of the time domain signal will change with different data symbols. Accordingly, the input power amplitude will change with a noticeable variance in specified operating point and the non-linearity effect causes distortion.

Moreover, the out-of-band distortion of subcarriers is the result of non-linearity impairments, which causes cross talk since the subcarriers are not orthogonal any more. To estimate the distortion which is caused by non-linearity, it is desired to have a measure of the signal to show its sensitivity to non-linearity. A well-known measure for the multi-carrier signals is peak to average power ratio (PAPR). The higher the PAPR, the more fluctuation in the signal amplitude, so the operating point in the amplifier needs to be set far enough from saturation point and this input back off reduces the efficiency [6].

III. REDUCTION TECHNIQUE IN OFDM SYSTEM

There have been many new approaches developed during the last few years. Several PAPR reduction techniques have been proposed. In these days, most relevant techniques such as Amplitude Clipping and Filtering (ACF), Partial Transmit Sequence (PTS) [7]–[10] and Selected Mapping (SLM) [11]–[13], Block coding, Interleaving, Tone Reservation (TR), Tone Injection (TI) and Active Constellation Extension (ACE) are used widely to reduce PAPR of the OFDM system. In this section, we mainly discuss PTS and SLM techniques for PAPR reduction in OFDM system.

Partial Transmit Sequence (PTS)

Partial Transmit Sequence (PTS) technique has been proposed by Muller and Hubber in 1997 [14]. 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.

PTS is probabilistic method for reducing the PAPR problem. It can be said that PTS method is a modified method of SLM. 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. In this data distortion is very small approximate to negligible [15].

Selected Mapping (SLM) Technique

Selective Mapping (SLM) approaches have been proposed by Bäuml in 1996 [16]. This method is used for minimization of peak to average transmit power of multicarrier transmission system with selected mapping. A complete set of candidate signal is generated signifying the same information in selected mapping, and then most favourable signal is selected in terms of PAPR and 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 the multiplying sequence can be sent as ‘side information.

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 any 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 PAPR reduction technique, the data distortion is occurring at a small amount.

IV. SIMULATION AND ANALYSIS

In this section, we are going to evaluate the PAPR performances of a typical OFDM system with 256 subcarriers (namely N = 256) and oversampling factor 4, 8 with QPSK and QAM modulation technique using SLM and PTS technique. We calculate the PAPR reduction in terms of the CCDF of PAPR with the different number of phase sequences. Simulation results of SLM technique in terms of the CCDF of PAPR with different number of phase sequences (U = 2, 4, 8, 16, 32 and 64) and PTS technique in terms of the CCDF of PAPR with different number sub-blocks (K = I, 2, 4, 8, 16, 32 and 64).

Selected Mapping (SLM) Technique

For the SLM technique, we used oversampling factor of 4 for accurate PAPR results with QPSK modulation for different phase sequences (U=2 and 4). It is clearly observed from Fig. 1 that SLM technique performance improve with different phase sequences. PAPR of OFDM system is continuously decreases from 11.9 dB to 10.4dB (in case of U=2) and 9.7dB (in case of U=4) [17].

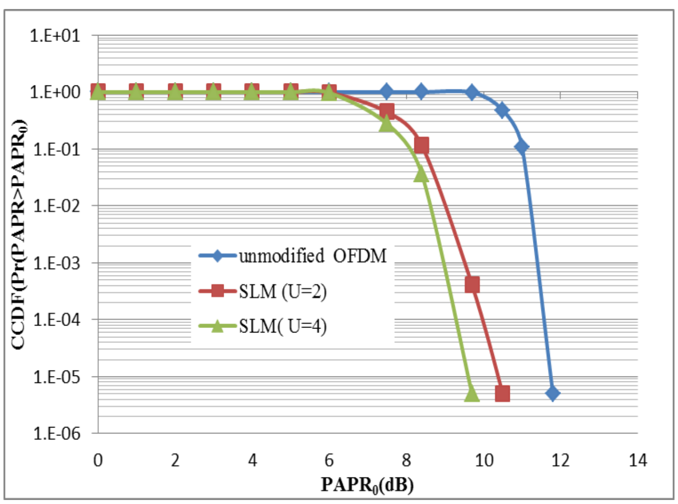

Fig. 1: Comparison of CCDF of PAPR of OFDM system for different phase sequences (U=2, 4) using QPSK modulation

In this section, we also calculate the PAPR reduction in terms of the CCDF of PAPR with QAM modulation technique for different phase sequences phase sequences U (1, 2, 4, 8, 16, 32 and 64), Oversampling factor 8 and number of subcarriers N is set to 256. Figure 2 shows the performance of peak to average power ratio (PAPR) performance with different phase sequences (U = 1, 2, 4, 8, 16, 32 and 64) using QAM modulation. It is clear from the figure 2 that by increasing the number of phase sequences U from 1 to 64, 5.6 dB reduction in PAPR value has been achieved [18], [19].

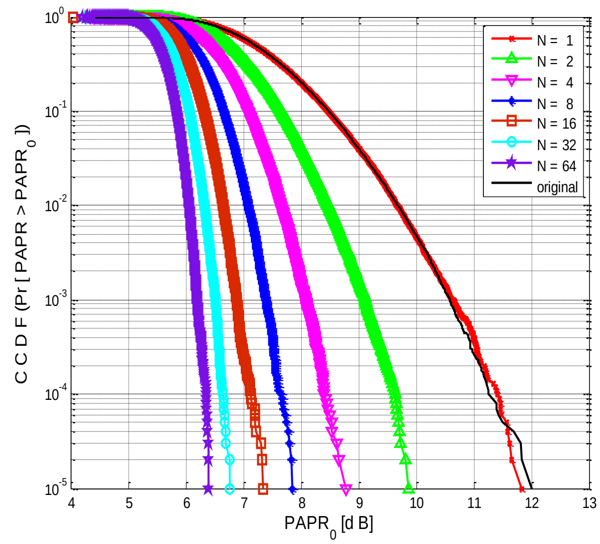

Fig. 2: Comparison of CCDF of PAPR of OFDM system for different phase sequences (U = 1, 2, 4, 8, 16, 32 and 64) using QAM modulation

Partial Transmit Sequence (PTS)

PTS is important probabilistic scheme for PAPR reduction; the alternative OFDM signals generated by PTS are interdependent. PTS divides the frequency vector into some sub-blocks before applying the phase transformation. The PAPR reduction performance of OFDM system with PTS technique is described for different number of sub-blocks (K=2, 4). Amount of PAPR reduction in PTS technique depends on the number of sub-blocks K and selection of phase factors. Oversampling factor 4 is used for accurate PAPR estimation from samples of IFFT output for all cases.

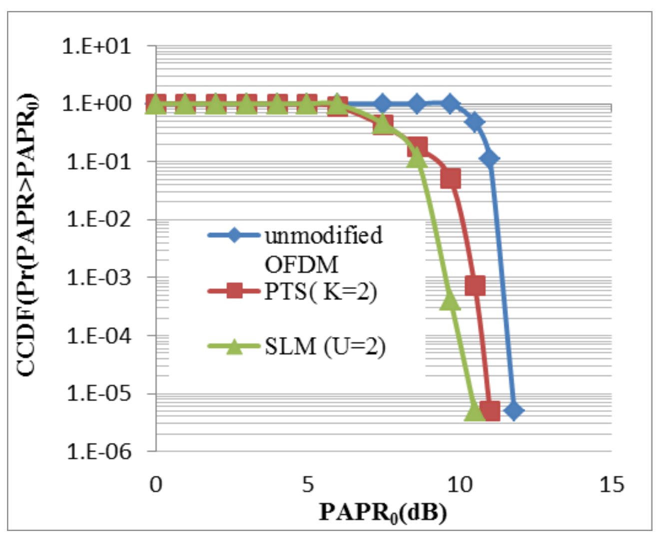

Fig. 3: CCDF of PAPR in unmodified OFDM system and OFDM system with SLM technique for U=2 Phase sequences and PTS for K=2 Sub-blocks using QPSK modulation

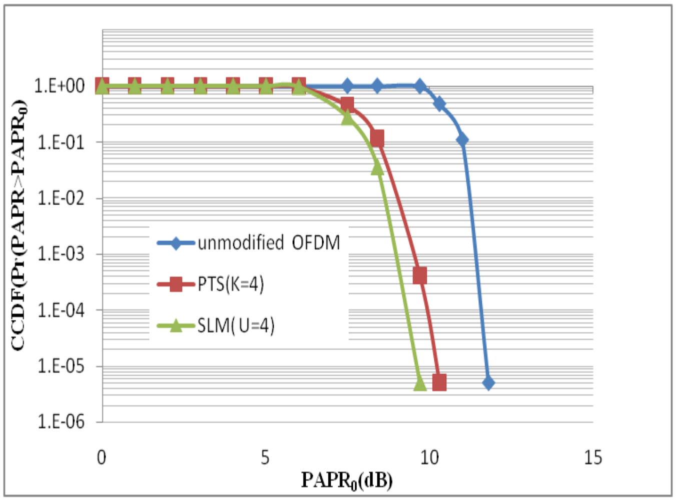

Fig. 4: CCDF of PAPR in unmodified OFDM system and OFDM system with SLM technique for U=4 Phase sequences and PTS for K=4 Sub-blocks using QPSK modulation

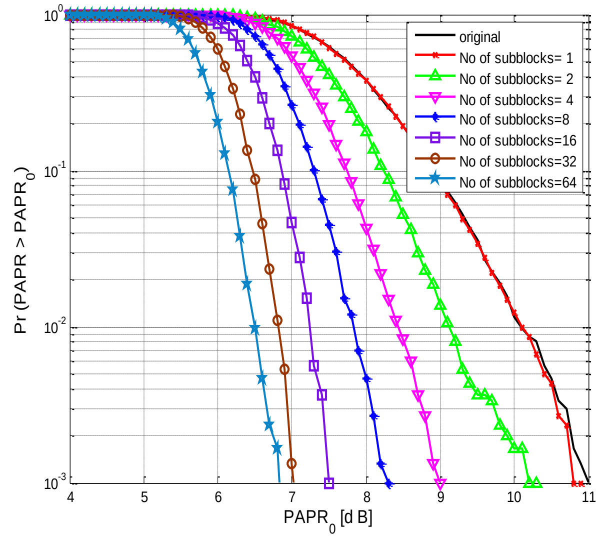

Fig. 5: PAPR performance for PTS technique with different sub-blocks (K = 1, 2, 4, 8, 16, 32, 64)

However, the signal amplitude is approximately Rayleigh distributed with 32 number of sub-carriers [20]. Simulation results related to CCDF of PAPR in original OFDM system with PTS technique for particular case of 32 sub-carriers when different number of sub-blocks (K= 2, 4).

Further simulation results from the curve in Fig. 3 showed that the SLM technique performs better than PTS and provide PAPR reduction of 1.5 dB whereas in case of PTS 1dB is obtained for K=2 sub-blocks and Fig. 4 showed that the using SLM technique provide PAPR reduction of 2.3 dB whereas in case of PTS 1.6dB is obtained for K=4 sub-blocks.

In this section, we also calculate the PAPR reduction in terms of the CCDF of PAPR with QAM modulation technique with different number of sub-block (V = 1, 2, 4, 8, 16, 32 and 64), Oversampling factor 8 and FFT size N is set to 256 using PTS technique. In this, K = 1 is the original OFDM signal. The CCDF curve for K =1 is almost same as that of original signal. The PAPR of the original (OFDM) signal is 11 dB, PAPR is reduced to 10.2 dB, when PTS technique is applied with K = 2. So, reduction in PAPR is about 0.8 dB with the partition of OFDM signal in two (K = 2) disjoint sub-block in PTS technique and PAPR is reduced to 9 dB at K =4 and so on as shown in Fig. 6. Fig. 5 showed that the PAPR reduction performance is significantly improved as the number of sub-blocks are increased with K = 1, 2, 4, 8, 16, 32 and 64 respectively.

A total of 4.2 dB improvement in the PAPR performance has taken place as numbers of sub-block are varied from 1 to 64.

V. CONCLUSIONS

OFDM is a very attractive technique for communications due to its spectrum efficiency and channel robustness. One of the serious drawbacks of OFDM systems is that the composite transmit signal can exhibit a very high peak power when the input sequences are highly correlated. In this paper, two typical techniques to reduce PAPR have been analyzed. PAPR performance of PTS and SLM is analyzed and compared in detail for varying number of sub-blocks (K=2, 4) and SLM for different number of phase sequences (U=2, 4). PTS technique exhibits better performance for case K=4 sub-blocks than K=2 sub-blocks. In case of OFDM system, PAPR values are 11.9 dB for original OFDM and 10.9dB, 10.4dB for K=2, 4 respectively. Thus, it can be concluded that the performance of PTS technique is continuously improved as number of sub-blocks increases.

Further in this paper, another PAPR reduction technique SLM is also implemented in OFDM system with different phase sequences. Simulation results show that SLM technique also reduces PAPR of OFDM system from 11.9 *dB to* 9.7 *dB* for different number of phase sequences i.e., 10.4dB and 9.7 dB for U=2, 4. It has been observed that the SLM technique provides better PAPR reduction than PTS technique however with increased in computational complexity of the system.

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