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Study of Peak-to-Average Power Ratio Reduction Techniques for OFDM Signals

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Abstract: Orthogonal frequency division multiplexing has drawn explosive attention as a new type of high data rate transmission scheme for wireless communication system. The main advantage of OFDM system are spectral bandwidth efficiency and robustness against frequency selective fading or narrowband interference etc. However a critical drawback of OFDM is high peak-to-average-power ratio (PAPR), which results in significant inter modulation, intercarrier interference (ICI), bit error rate (BER) performance degradation and undesirable out of band radiation when an OFDM signal passes through nonlinear devices such as high power amplifier (HPA). This paper reviews the conventional PAPR reduction techniques for OFDM (Orthogonal frequency division multiplexing) signals.

Index Terms**:** Orthogonal frequency division multiplexing (OFDM), peak-to-average power ratio (PAPR), partial transmit sequences (PTS),tone reservation(TR), selected mapping(SLM) .

I INTRODUCTION

OFDM has become an essential technique for high speed wireless communication on system because of its robustness to multipath fading channels and high spectral efficiency. OFDM has been considered as a promising candidate to achieve high rate data transmission in a mobile environment .Especially OFDM has been adopted as a standard for wireless communication systems such as digital audio and video broadcasting, asymmetric-digital-subscriber-line modems and wireless local-area-networks systems [2]. The OFDM systems significantly increases bandwidth efficiency by allowing overlapping of the sub channels , while maintaining orthogonality between them. Moreover, robustness against frequency selective fading channels can be easily achieved [1].

Due to the large number of subcarriers, OFDM systems have a large dynamic signal range with a very high peak-to-average-power ratio (PAPR) . Which causes signal distortion such as in-band distortion and out-of-band radiation due to the nonlinearity of high power amplifiers (HPA) and it also degrades bit error rate (BER) [4]. This problem can be solved by working the amplifier in its linear region, but this solution is not power efficient. This can be made power efficient through some manipulations of the OFDM signal before transmission.

To achieve the above objective several proposals have been studied and their performance have been compared in this paper. For instance, we find partial transmit sequence (PTS), clipping with filtering, optimization with tone reservation (TR) coding and selected mapping (SLM)..

This paper is organised as follows: Section II introduces the OFDM system model and section III represents peak-to-average-power-ratio (PAPR) , PAPR reduction techniques have been discussed in section IV, and finally the section v conclude the paper.

II OFDM - SYSTEM MODEL

Let $A = [\,A_0\ A_1\ A_2 \ldots\ldots A_{N-1}\,]^T$ denotes an input symbol vector in the frequency domain, where N is the number of subcarriers and A_k represents the complex data of the k_{th} subcarriers .The OFDM signal is generated by summing all the N modulated subcarriers each of which is separated by $1/N\ t_s$ in the frequency domain, where t_s represent the sampling period .Then ,a continuous time OFDM signal is defined as

$$a_t = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} A_k e^{j2\pi \frac{k}{Nts} t} , \qquad 0 \le t < Nt_s \quad (1)$$

The discrete time baseband OFDM signal a_n sampled at the Nyquist rate $t = nt_s$ can be given as

$a_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} A_k e^{j2\pi \frac{k}{Nts} n}$, n = 0,1,2…..N-1 (2)

Continuous time baseband OFDM signal can be approximately represented by L times oversampled discrete time baseband OFDM signals .Fig.1 depicts the block diagram of OFDM system utilizing IDFT and filters. In this OFDM system ideal filter is used to remove a portion of out-of- band components , therefore the interference problem can be reduced.

III PEAK-TO-AVERAGE POWER RATIO

The PAPR of the discrete time baseband OFDM signal is defined as the ratio of the maximum peak power divided by the average power of the OFDM signal [3], that is

$$PAPR(a_n) = \frac{\max_{0 \le n \le N-1} |a_n|^2}{Pav(|a_n|)} \quad (3)$$

$$P_{av}(a_n) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} E\{| a_n |^2\} \quad (4)$$

Where E {.} denotes the expected value.

The PAPR of the continuous time baseband OFDM signal a_t is defined as the ratio of the maximum instantaneous power divided by the average power of the OFDM signal, it can be expressed as

$$PAPR(a_t) = \frac{\max_{0 \le n \le Nt_s} |a_t|^2}{Pav(|a_t|)} \quad (5)$$

Where $P_{av}(a_t) = \frac{1}{N t_s} \int_0^{N t_s} E\{|a_t|^2\}\, dt$ (6)

And the PAPR of the continuous time passband OFDM signal g_t is also defined as

$$PAPR(g_t) = \frac{\max_{0 \le n \le Nt_s} |g_t|^2}{Pav(|g_t|)} \quad (7)$$

The discrete time baseband OFDM signals, are transformed in to continuous time baseband OFDM signals by a low pass filter called DAC, where the peak power can be increased while maintaining constant average power. Usually, the PAPR of continuous time baseband OFDM signals is larger than that of discrete time baseband OFDM signals by 0.5 – 1.0dB.

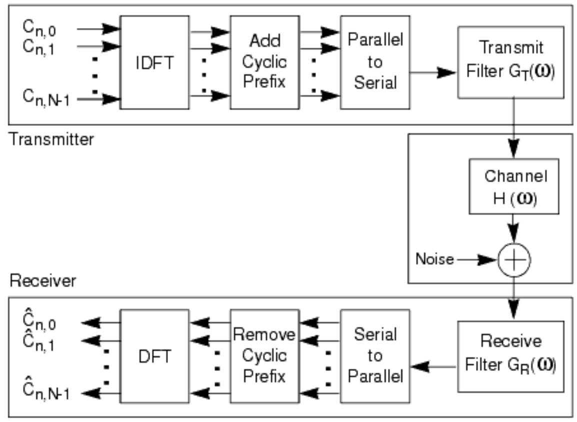

Figure-1: Block diagram of OFDM transmitter and receiver

IV PAPR REDUCTION TECHNIQUES

Numerous techniques have been developed to reduce the PAPR of OFDM signal , high PAPR is the major drawback in multicarrier system . In this section we have discussed different PAPR reduction techniques.

A .Clipping and Filtering

The clipping is one of the easiest technique which is used to reduce the power by setting a maximum level for the
transmitted signal l[10]. Though, this technique has several disadvantages

(a) Due to the in-band distortion caused by clipping technique the performance of the bit error rate may be affected

(b) Also out-of-band radiation , which usually appears with clipping technique could disturb the adjacent channels , However filtering operation can be used to decrease the appearance of the out-of-band radiation but the signal may exceed the maximum level of clipping operation. The outcome of filtering provide a less degraded BER performance.Fig.-2 shows the block diagram of clipping and filtering .The clipped form of passband modulated signal is given as

$$x_c^p[m] = \begin{cases} -A & x^p[m] \le -A \\ x^p[m] & |x^p[m]| < A \\ A & x^p[m] \ge A \end{cases} \quad (8)$$

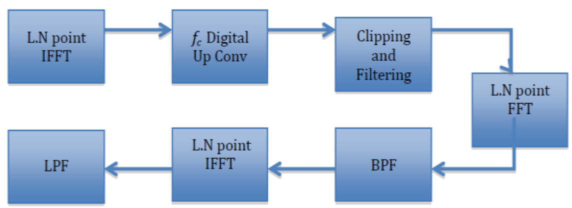

Figure-2: The scheme of clipping and filtering technique for PAPR.

B. Tone Reservation

This technique is basically used for multicarrier transmission and it also shows the reserving tones to reduce the PAPR. This technique includes

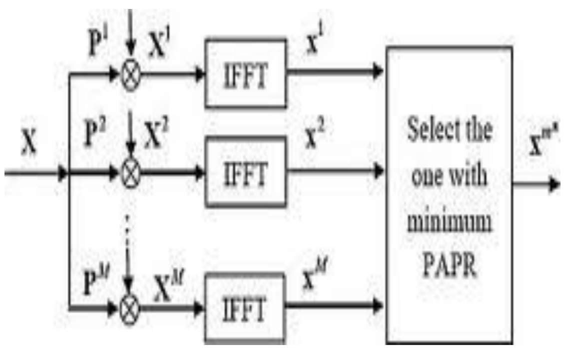

Figure-3: Block diagram of SLM technique

Selective Mapping (SLM) method is used for minimization of peak to average transmits power of multicarrier transmission system with selected mapping [8]. Fig.3 shows the block diagram of SLM technique. Here X represents the input data and X^n represents the output data. It generates a set of favourable blocks at the transmitter end which represent the original information and then chooses the most favourable block for transmission as proposed in [10].Here the input block is given by X=[X(0),X(1),…..X(N-1)] is multiplied with U different phase sequences Pu =[P0u,P1u,….PN-1u]^T to produce a modified data block given by

Xu=[Xu[1],Xu[2],……Xu[N-1]]^T (9)

The IFFT of U independent sequences are taken to produce the time domain sequences

xu= [xu(0),xu(1),….xu(N-1)]^T among which the only one with the lowest PAPR is selected for transmission. The amount of PAPR reduction for number of set of reservation of tones. By knowing the number of tones, reserved tones can be used to minimize the PAPR of OFDM signal [13]. This technique basically depends on the amount of complexity of the signals. If the number of tones is small then reduction in PAPR may represent non negligible samples of available bandwidth. The main advantage of tone reservation is that no process is needed at receiver end and also there is no need to transmit the side information along with the transmitted signal. In this technique many number of loop are used and the signal will pass from each loop.

C.Selected Mapping(SLM) Technique

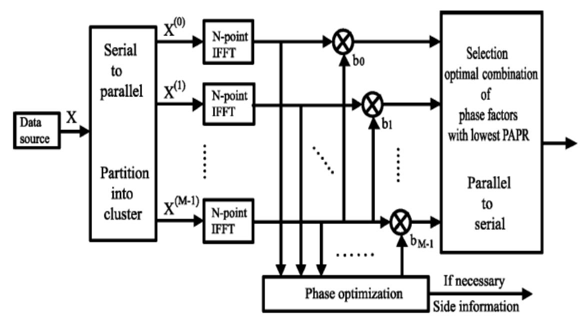

Figure-4: Block diagram of PTS technique

SLM depends on the the proper design of the phase sequences and also on the number of phase sequences U [9]. When using SLM technique the original symbol vector at the receiver end can be recover by transmitting the side band information at the transmitter end. U IFFT operations are required for the implementation of SLM technique.

D.Partial Transmit Sequence

The partial transmit sequence (PTS) is a powerful PAPR reduction technique for OFDM signals .The block diagram of the PTS scheme is shown in fig.-4. In the given fig.-4, X is the input data which is partitioned into M disjoint sub-blocks. The sub-carriers 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[18]. The input data X divided into M disjoint sub-block is expressed as

$$X^m = X_0^m , X_1^m \dots\dots X_{N-1}^m, m = 1,2 \dots . M \qquad (10)$$

The original signal of sub block is given as

$$X= \sum_{m=1}^{M} X^m \quad (11)$$

The sub-block partition techniques are of three type, named as interleaved partition, adjacent partition, and random partition. The interleaved partition has the worst PAPR reduction performance the random partition technique is the best choice for PAPR reduction of OFDM signals. To combine the PTSs the Complex phase factors are introduced . The set of phase factors is denoted as a vector $b = [b_{1,} b_{2......} b_{M,}]$ (12)

To minimize the PAPR we have to find the optimum set of phase factor as the phase factors are introduced to combine the PTSs. The relationship between the phase factor and partial transmit sequence (PTS) given as

$$x' = \sum_{m=1}^{M} IFFT\{X^m . b^m\} = \sum_{m=1}^{M} b^m . IFFT\{X^m\}$$

$$x' = \sum_{m=1}^{M} b^m . x^m\} \quad (13)$$

Where $b^m = \Theta$, $\Theta = \{e^{j\theta_1}, e^{j\theta_2} ...... e^{j\theta_V}\}$ (14)

Here Θ represents the set which includes V phase factor and x^m is called partial transmit sequence.

V CONCLUSION

The high PAPR (peak-to-average power ratio) is considered to be one of the major drawbacks of OFDM (orthogonal frequency division multiplexing) because the power efficiency decreases because of the large signal fluctuation. All the potential benefits of OFDM transmission are reduced by high PAPR value. In this paper the conventional PAPR reduction techniques such as tone reservation (TR), clipping and filtering, selected mapping (SLM) technique and partial transmit sequence (PTS) have been discussed . Each technique have some advantage and disadvantage but for the better PAPR reduction performance SLM and PTS techniques provide better performance because in these techniques the input data is divided in to sub-blocks and as the number of sub block increases ,PAPR of OFDM signals decreases . Although many PAPR reduction technique have been developed but none of them satisfies commercial requirements or has been adopted as a standard for wireless communication systems. But for high data rate OFDM system PAPR reduction technique with low computational complexity can be applied.

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