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A Review of PAPR Reduction Techniques in OFDM

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Abstract: The concept of Orthogonal Frequency Division Multiplexing (OFDM) is an attractive modulation technique for transmitting large amounts of digital data over radio waves. It is recently being used for both wireless and wired communication. OFDM is a form of multi carrier modulation technique with high spectral efficiency, robustness to channel fading, immunity to impulse interference, uniform average spectral density, capacity of handling very strong echoes and less non linear distortion. OFDM is the time domain signal which is a sum of several sinusoids leads to high Peak to Average Power Ratio (PAPR). High PAPR causes saturation in power amplifiers, leading to inter modulation products among the sub carriers and disturbing out of band energy. Several techniques have been proposed to reduce PAPR, such as clipping, windowing, coding, pulse shaping, tone reservation, tone injection, companding, etc. In this paper the various techniques proposed for reducing the PAPR and the selection criteria for choosing these techniques have been reviewed and compared.

Keywords: - Orthogonal Frequency Division Multiplexing (OFDM), Peak-to-Average power ratio (PAPR), Peak Envelope Power (PEP), Selective Level Mapping (SLM), Partial Transmit Sequences (PTS).

I. INTRODUCTION

OFDM is a technique widely used for wireless applications [1]. Due to its multicarrier feature, OFDM systems are more sensitive than single-carrier systems to frequency synchronization errors [2]. OFDM is a special case of FDM. As we know in single carrier modulation channels are frequency selective so they add Inter Symbol Interference (ISI) at the receiver side because channels not having flat response in frequency domain. Even though if we do amplification at the receiver side noise also get amplified so multicarrier modulation is so much popular. OFDM is a multicarrier modulation in which orthogonality allows lot of subcarriers in tight frequency space without interference from each other. Due to limitation of bandwidth in communication we need to divide data stream in too many small bands and also carriers. Then we multiply carriers with data stream then we modulate each carrier at lower data- rate and adding them together for transmission.

OFDM is a form of multicarrier transmission that sends information simultaneously over N orthogonal carriers. It introduces frequency diversity by making the bandwidth of Each carrier smaller than the coherence bandwidth of the channel.

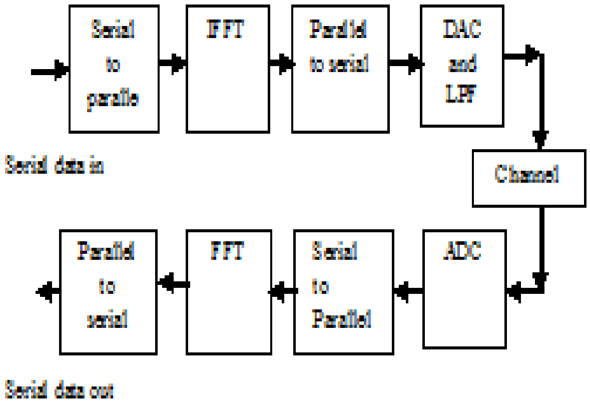

Figure I. Block diagram of OFDM system

OFDM is considered a good candidate for high data rate wireless systems and is currently used for the Hyper LAN II standard [3]. The transmitted signal over a symbol duration T is: [4]

The codeword $\bar{c}$ consists of N symbols chosen from a many modulation method. All of the code words form the set $\bar{c}$. For MPSK

$$c_i = e^{j\frac{2\pi}{M}(a_i)} a_i \varepsilon Z_M \quad \text{(I)}$$

The duration of an OFDM symbol T is N times the duration of the symbols c_i plus the duration of the cyclic prefix or guard band. The complex envelope of the transmitted signal, sampled at 1/T, is:

$$\tilde{s}(\bar{c}, n) = \sum_{i=0}^{N-1} c_i exp(j2\pi ni / N) \quad \text{(II)}$$

This equation can be recognized as the IDFT of the sequence $c_o \ldots c_{N-1.}$

FFT is the efficient algorithm to find the DFT, so in block diagram of OFDM at the transmitter side we are using IFFT block first and at the receiver side we are using FFT block. FFT converts time domain signal in to frequency domain and IFFT is vice versa. In transmitter taking FFT means only multiplying by D-1 block after multiplication we serially convert the parallel signal and transmit it. This whole process is nothing but linear convolution of two signals so there is found overlapping of last L-1 bits to avoid this we can pad zeros or we can cyclic prefix to the original data blocks.

An important limitation of OFDM is that it suffers from a high Peak-to-Average Power Ratio (PAPR). This forces the power amplifier to have a large input back off and operate inefficiently in its linear region to avoid inter modulation products. High PAPR also affects D/A converters negatively and may lower the range of transmission. PAPR is defined as:

$$PAPR = \frac{\max|s(t)|^2}{E\left[|s(t)|^2\right]} \quad \text{.............................} \quad \text{(III)}$$

Theoretically, the PAPR can be as high as N, but the occurrence of such peaks is rare. The summation of a large number of carriers assumes a Gaussian distribution. The numerator, max|s (t)|^2, is also known as the Peak Envelope Power (PEP). It is also equal to:

$$PEP = \tilde{s}(t)\tilde{s}^*(t) \quad \text{.......................................} \quad \text{(IV)}$$

PAPR reduction is to find the approach that it can reduce PAPR largely and at the same time it can keep the good performance in terms of the High capability of PAPR reduction, Low average power, Low implementation complexity, No bandwidth expansion, No BER performance degradation, without additional power needed these factors. PAPR reduction techniques are divided into two groups like signal scrambling techniques and signal distortion techniques. Signal scrambling techniques are sub divided in to two parts: a) with explicit side information and b) without explicit side information.

With explicit side information further divided in to two parts: 1) coding based and 2) probabilistic schemes.

a. Block coding, sub block coding and block coding with error correction are the coding based techniques.
b. Selective Level Mapping (SLM),Partial Transmit Sequences (PTS) , interleaving, standard arrays of linear block coding, tone reservation, tone injection and active constellation extension are the probabilistic schemes. Signal distortion techniques minimize high peak dramatically by distorting signal before amplification.
c. Signal Clipping, Peak windowing, Envelop scaling, random phase updating, Peak power suppression/peak reduction carrier and Companding.
d. Harmard transform method and Dummy sequence insertion methods are without explicit side information methods.

II. CODING BASED EXPLICIT SIDE INFORMATION TECHNIQUES

A. *Linear Block Coding Techniques:*

The paper by Wilkinson and Jones [5] proposes a block coding scheme for the reduction of the peak to mean envelope power ratio of multicarrier transmission systems in 1995. In block coding the data code words does not contain those which result in excessive peak envelope powers (PEPs). Block coding done via three phases:

a. Selection of suitable sets of code words for any number of carriers, any M-ary phase modulation scheme, and any coding rate.
b. Selection of the sets of code words that enable efficient implementation of the encoding /decoding. c) Selection of sets of code words that also offer error deduction and correction potential.

B. *Sub Block Coding Techniques:*

The paper by Zhang, et.al. [6] proposes the sub-block coding scheme and its two extensions, in the form of redundant bit location optimized sub-block coding and combination-optimized sub block coding, for reducing peak to average power ratio of an OFDM signal. Combination optimized sub-block coding scheme (COSBC) optimizes the combination of the coded sub-blocks, where two coding schemes instead of one is used to encode the same information source.

C. *Block Coding Techniques with Error Correction:*

The paper by Ahn, et.al. [7] Present a new block coding scheme for reduction of peak to average power ratio (PAPR) of an OFDM system, with error correction capability. In block coding approach, the PAPR of the OFDM symbol can be reduced by selecting only those code words with small PAPR.

III. PROBABILISTIC SCHEME BASED EXPLICIT SIDE INFORMATION TECHNIQUES

A. *Active Constellation:*

The paper by Knongold and Jones [8] proposes a technique for PAPR reduction similar to Tone Injection Technique. The main idea of this scheme is easily explained in the case of a multicarrier signal with QPSK modulation in each sub-carrier. The Active Constellation Extension (ACE) idea can be applied to other constellation as well such as QAM and MPSK constellation.

B. *Standard Arrays of Linear Block Codes:*

The paper by Yang et.al. [9] Proposes a method to reduce the PAPR reduction by using the standard arrays of linear block codes. This scheme is a modified version of SLM, in which the transmit signal is selected as a signal with minimum PAPR from differently scrambled signal of the information by a number of random sequences.

C. *Partial Transmit Sequenc (pts):*

Partial Transmit Sequence (PTS) technique has been proposed by Muller and Hubber in 1997 [10]. This method is flexible and effective for OFDM system.

As shown in figure 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.

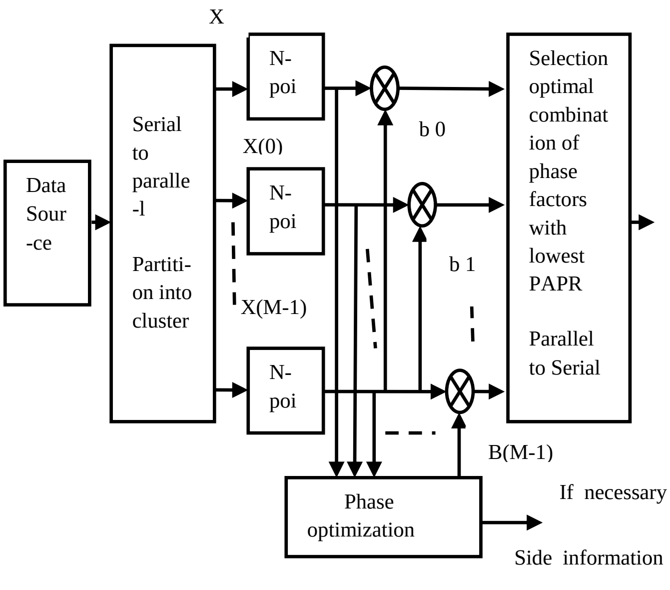

Figure. III. Block diagram of PTS system.

There is no need to send any side information to the receiver of the system, when differential modulation is applied in all sub blocks is simple, fast, and requires a relatively small amount of side information and introduces no distortion.

D. Selective mapping (slm):

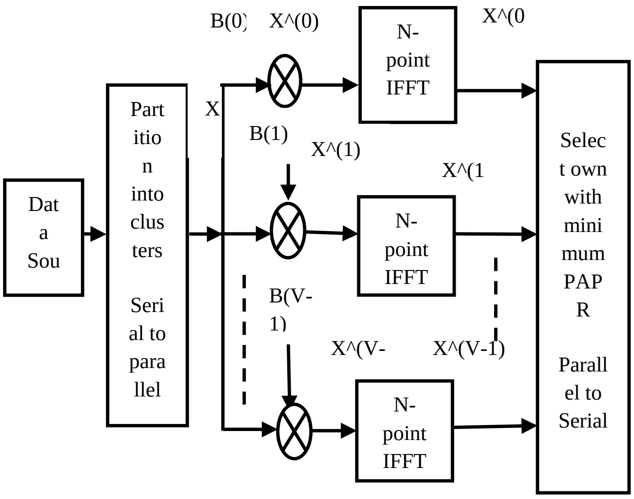

Figure. IV. Block diagram of SLM system

Selective Mapping (SLM) approaches have been proposed by Bauml in 1965 [11]. As shown in figure below in the SLM the input data structure is multiplied by random series and resultant series with the lowest PAPR is chosen for transmission.

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.

Selective Mapping (SLM) uses M different sets of phase factors as the candidates and passes the rotated frequency domain data symbols through an IFFT. Figure above shows the SLM method. Last block of parallel to serial conversion brings output of the system.

E. Tone Reservation (tr):

Tone Reservation (TR) method is proposed for PAPR reduction [12]. The main idea of this method is to keep a small set of tones for PAPR reduction.

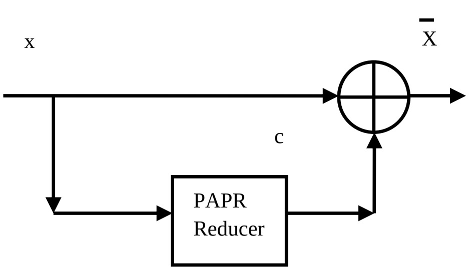

Figure. V. Block diagram of TR method

Reserving tones for PAPR reduction may present a non–negligible fraction of the available bandwidth and resulting in a reduction in data rate.

As shown in figure Tone reservation method is based on adding a data block and time domain signal. Optimization requires IFFT operations several times until the predetermined PAPR reduction threshold is achieved, which inevitably reduces the system speed. It also leads to bandwidth sacrifice.

F. Tone injection (ti):

Tone Injection (TI) method has been recommended by Muller, S.H., and Huber, J.B. [13]. This technique is based on general additive method for PAR reduction. Tone Injection method because of replacing the points in the basic constellation for the new points in the larger constellation which corresponds to injecting a tone of the proper phase and frequency in the multi-carrier symbol

G. Interleaving:

The paper by Jayalath and Tellambura, [14] presents interleave based technique for improving the peak to average power ratio of an OFDM signal. The low threshold will force the adaptive interleaving (AIL) to search for all the interleaved sequences, whereas for the large threshold value, AIL will search only a fraction of the interleaved sequences.

IV. SIGNAL DISTORTION TECHNIQUES

A. Clipping and filtering:

Complexity of the ADC and DAC get increased due to PAPR and also reduced efficiency of radio frequency (RF) power amplifier. As shown in figure below in Clipping, the amplitudes of the input signal are clipped to a predetermined value which yields distortion power called clipping noise and expands the transmitted signal spectrum which causes interfering [15].

Clipping causes degradation in the performance of bit error rate (BER) and out-of-band noise, which decreases the spectral efficiency [16].

Filtering can decrease the spectrum growth, filtering after clipping can reduce the out-of-band radiation, but may also cause some peak re-growth, which the peak signal exceeds in the clip level [17]. Iterative signal takes long time and it will increase the computational complexity of an OFDM transmitter [15].

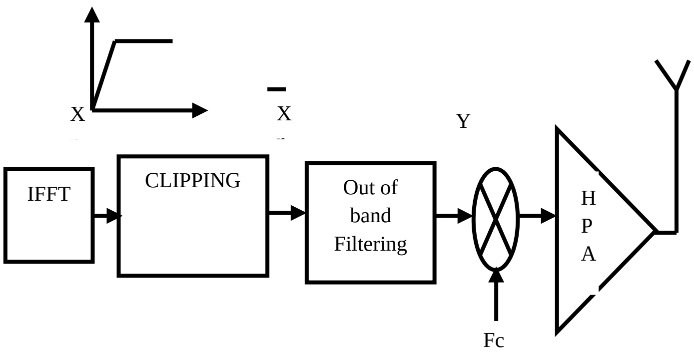

Figure. VI. Block diagram of Clipping and Filtering

Clipping operation is performed to cut high peak amplitudes and frequency domain filtering is used to reduce the out of band signal, but caused peak re-growth [17]. This method clipping distortion, peak regrowth of the signal after digital-to-analog conversion, and out-of-band radiation are observed. [26][27].

B. Peak windowing:

The paper by van Nee and Wild [18] proposes that as large PAP ratios occur only infrequently, it is possible to remove these peaks at the cost of a slight amount of self interference. Peak Windowing technique provides better

PAPR reduction with better spectral properties than clipping. In windowing technique a large signal peak is multiplied with a certain window such as Gaussian shaped window, Cosine, Kaiser and Hamming window.

C. Envelope Scaling:

The paper by Foomooljareon and Fernando, [19] proposed an algorithm to reduce PAPR by scaling the input envelope for some sub carriers before they are sent to IFFT.

The main idea behind the scheme is that the envelopes of all the subcarriers input, with PSK modulation, are equal. To limit the BER degradation, amount of the side information would also be excessive when the number of subcarriers is large.

D. Random Phase Updating:

The paper by Nikookar and Lidsheim, [20] proposes a novel random phase updating algorithm for the peak to average power ratio (PAPR) reduction of the OFDM signal. The random phase update is continued till the peak value of the OFDM signal is below the threshold. After each phase update, the PAPR is calculated and the iteration is continued till the minimum threshold level is achieved or the maximum number of iterations has been reached.

E. Peak Reduction Carrier:

The paper by Tan and Wassell, [21] proposes the use of the data bearing peak reduction carriers (PRCs) to reduce the effective PAPR in the OFDM system. The technique involves the use of a higher order modulation scheme to represent a lower order modulation symbol. So there exists a tradeoff between PAPR reduction and BER performance when selecting the constellation of the PRCs.

F. Companding:

The paper by Wang et.al, [22] proposes a simple and effective companding technique to reduce the PAPR of OFDM signal. The OFDM signal, after taking IFFT, is companded and quantized. After D/A conversion, the signal is transmitted through the channel. At the receiver end then the received signal is first converted into digital form and expanded. Companding is highly used in speech processing where high peaks occur infrequently. Due to companding, the quantization error for large signals is significantly large which degrades the BER performance of the system.

G. Dummy Sequence Insertion:

The paper by Ryu, et.al. [24] Proposes a scheme for PAPR reduction in OFDM transmission using dummy sequence insertion (DSI) method. Dummy sequence is added into the input data for the PAPR reduction before IFFT stage. PAPR threshold technique is combined into this DSI method. If the PAPR of IFFT output is lower than a certain prescribed PAPR threshold level, the IFFT output data is transmitted. Otherwise, dummy sequence is inserted to lower the PAPR. The DSI method demonstrates improved BER performance as compared to the conventional PTS and has higher transmission efficiency for PAPR reduction than the conventional block coding. DSI method using complimentary sequence is better than the other methods.

Table I. Comparison of methods result wise

Method	Power increase	Implementation complexity	Bandwidth expansion	BER degradation
Clipping	No	Low	No	Yes
Block Coding	No	Low	Yes	No
PTS/ SLM	No	High	Yes	No
NCT	No	Low	No	No
TR/TI	Yes	High	Yes	No
Peak windoing	No	High	Yes	No
Harmard transform	No	Low	Yes	No

H. Hadamard transform:

The paper by Park et.al. [23] Proposes a scheme for PAPR reduction in OFDM transmission using Hadamard transform. Hadamard transform based scheme reduces the occurrence of the high peaks comparing the original OFDM system. The idea to use the Hadamard transform is to reduce the autocorrelation of the input sequence to reduce the peak to average power problem and it requires no side information to be transmitted to the receiver.

V. CONCLUSIONS

In this paper some PAPR reduction techniques for multicarrier transmission have been discussed.

Table II. Comparison of methods characteristic wise

Method	Modulation Technique	Parameter's details	% BER found (PAPR)
Tone Reservation by Deep Clipping	QPSK	Clip ratio=1.4	For 50 sub carrier= 8dB For 10 sub carrier= 10dB
Turbo Coding and SLM	128 subcarriers	----	7dB from 70% to 0.25% dB
Tone Injection with Aggressive Clipping	64 channel, 16-QAM	10 to 5 symbpl chips	5.10dB
Interactive Clipping and Filtering	QPSK, QAM	----	0.5dB without peak reduction
PTS with Low Complexity	256-sub.carr. QPSK	Depends on PTS	8% to 2% of conventional PTS
Phase Reversal	QPSK, QAM	N=256	0.45dB to 0.7dB of QAM
Clipping and Filtering	QPSK	Clipping Ratio=1.4, CF tones 128 at 99.99%	Reach to 9 dB from 13dB
DCT-SLM with Clipping	QPSK	For N=64	3.2 dB (DCT-SLM) 2.2 dB (SLM),for V=4
SLM with side Information	QPSK	For N=64,128,512,1 024, etc.	o/p back off= 1,….6 dB
Improved SLM	16- QAM	N=256, M=32	3dB is typical, upto 1.2 dB we can achieve.

BER increase, computational complexity increase and so on. No specific PAPR reduction technique has been the best solution for all multicarrier transmission system. Many techniques to reduce the PAPR have been proposed all of which have the potential to provide substantial reduction in PAPR at the cost of loss in data rate, transmit signal power increase, BER increase, computational complexity increase and so on.

No specific PAPR reduction technique has been the best solution for all multicarrier transmission system. It has been suggested that the PAPR reduction technique should be carefully chosen according to various system requirements. Clipping and Partial Transmit Sequence are more practical than other techniques.

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