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Comparative Study of PAPR Reduction Techniques in OFDM

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Abstract: The need of higher data rate transmission in wireless communication is growing with an extremely rapid pace. These require to be operated in an environment which is characterized by high carrier frequency, data transmission rate and mobility; altogether such an environment can be modeled by a frequency selective fast time varying fading channel. OFDM system is one which attracts every researcher towards it because it has several advantages such as high number of orthogonal sub-carriers, no inter-symbol interference, tolerance in multipath delay spread, frequency selective fading immunity etc. In fact, PAPR in OFDM system is the most detrimental aspect which degrades power and spectral spreading [1]. In this paper, we review and analyze various PAPR reduction techniques and compare their results which describes that some technique mitigate PAPR to a specific extent but at the cost of BER degradation whereas some improve BER but with little amount of PAPR reduction.

Keywords: Orthogonal Frequency Division Multiplexing (OFDM), Peak To Average Power Ratio (PAPR), Bit Error Rate (BER).

I. Introduction

The concept of OFDM was introduced by R.W. Chang in 1966 and was patented in 1970. The principle of of multi-carrier transmission is to divide the entire bandwidth into smaller bandwidths each with a different sub-carrier frequency, such that each of these narrowband signals is immune to frequency selective fading and the data-rates are improved in comparison to single-carrier system as the total bandwidth can be increased significantly. The spectrum of the sub-carriers may overlap but yet can be detected using matched filters with no inter-symbol interference (ISI). This increases spectral efficiency as there is no wastage in bandwidth required to separate two adjacent sub-carriers. Difference in frequency between these sub-carriers will be integral multiples of inverse of symbol time. Such a multi-carrier modulation system is effectively termed as orthogonal frequency division multiplexing. OFDM is vastly used in digital audio broadcasting (DAB), digital video broadcasting-terrestrial (DVB-T), mobile multimedia access communication (MMAC), IEEE802.11a, IEEE802.16 and IEEE802.20 [2]. Though OFDM has many advantages like high spectral efficiency, robustness to channel fading, immunity to impulse interference, capacity to handle very strong echoes and less non-linear distortion it also has disadvantage of high PAPR [4]. It becomes very necessary to mitigate high PAPR otherwise it limits the system performance and require high power amplifier with large dynamic range which is bulky and costlier. in this paper we will study various PAPR reduction techniques and will compare them. This paper is organized as follows. Section II describes, PAPR in OFDM system[3]. Section III describes PAPR reduction techniques. Section IV describes analysis of different techniques. Section V describes conclusion.

II. PAPR IN OFDM

High Peak-to-Average Power Ratio has been recognized as one of the major practical problem involving OFDM modulation. High PAPR results from the nature of the modulation itself where multiple subcarriers / sinusoids are added together to form the signal to be transmitted. When N sinusoids add, the peak magnitude would have a value of N, where the average might be quite low due to the destructive interference between the sinusoids. High PAPR signals are usually undesirable for it usually strains the analog circuitry. High PAPR signals would require a large range of dynamic linearity from the analog circuits which usually results in expensive devices and high power consumption with lower efficiency. The PAPR of any signal is defined as the ratio between the maximum instantaneous power of signal and its average power.

The PAPR of any OFDM signal X(t) is defined as PAPR = P_{peak}/P_{avg} = max $[IX_nI^2]/[IX_nI^2]$
Where X_n is an OFDM signal after IFFT(Inverse Fast Fourier Transform)
E[.] denotes expectation operator, it is an average power
The complex baseband OFDM signal for N subcarriers is represented as

$$X(t) = \frac{1}{\sqrt{N}}\sum_{n=0}^{N-1} X_n\, e^{j2\pi n\Delta f\tau} \quad , 0\leq t \leq NT\ldots\ldots (1)$$

II. PAPR REDUCTION TECHNIQUES

A large number of PAPR reduction techniques have been proposed over a long period during the development of OFDM technology. The main objective of these techniques is to reduce the PAPR of the OFDM signal to an acceptable value before the OFDM signal is sent to the transmitter.

These techniques are categorized as

A) Signal scrambling
B) Signal distortion

A) SIGNAL SCRAMBLING TECHNIQUES

Block Coding Techniques, Selected mapping (SLM) [2][5][8], Partial Transmit Sequence (PTS) [5][6], Tone Reservation (TR) AND TONE INJECTION etc are Signal Scrambling Techniques

1. BLOCK CODING: It is the simple technique to diminish PAPR. Basic idea behind it is to select code words with low peak power after coding from all probable symbols. With N sub-carrier QPSK modulation provides 2N bits and thus N22 messages [7]. If k bit data block is encoded by (n.k) block code with generation matrix G at transmitter and a phase rotator vector b is used to produce encoded output. By separating large information sequence into different sub-blocks and encode these subblocks with system on programmable chips (SOPC) large PAPR reduction can be achieved [7].

1.1 BLOCK CODING WITH ERROR CORRECTION : Based upon the idea that block codes can not only reduce PAPR but if well designed can also be utilized to for error correction, the scheme of block coding with error correction was proposed

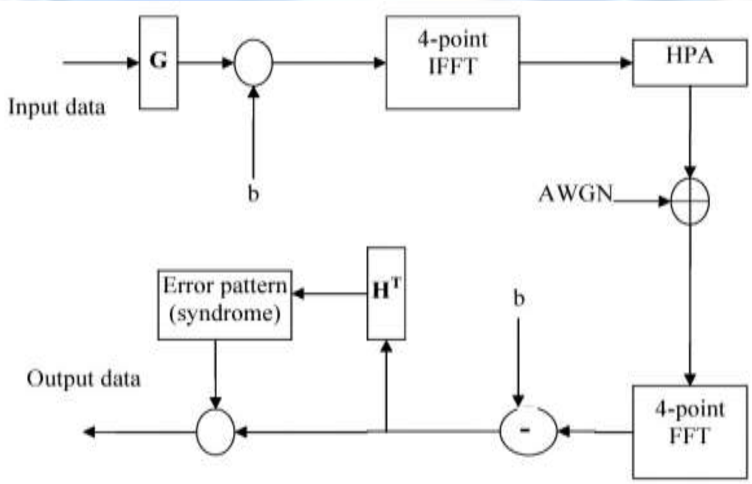

Fig 1: Block coding with error correction.

The authors claim that there is improvement in BER in comparison with uncoded system. But the fact remains that just like block coding this scheme is also not feasible for higher number of sub carriers. Furthermore, there is significant increase in the bandwidth

2. TONE RESERVATION: This is an accurate method for PAPR mitigation. Amount of PAPR mitigation relies on some factor such as number of reserved tones, location of reserved tones, and amount of complexity and allow power on reserved tones. Method shows that reserving a small fraction of tones leads to large mitigation of PAPR with simple operation at transmitter and no complexity at receiver end. There is no need for additional operation and no side information to receiver. It based on summing a data block and time domain signal. A data block is dependent block signal to the original multicarrier signal to minimize high peak. This time domain signal can be calculated simply at the transmitter of system and stripped off at receiver [7]. This scheme takes an edge as no need of side information to send along with message, less complexity. BER is improved to a little extent with tone reservation. One of the advantages with this technique is reduction in complexity

3. TONE INJECTION: This is an additive method, which achieves PAPR Reduction of multicarrier signals with no data rate loss. The basic idea is to increase the constellation size so that each of the points in the original basic constellation can be mapped into several equivalent points in the expanded constellation, Since each information unit can be mapped into one of several equivalent constellation points, these extra degrees of freedom can be exploited for PAPR reduction. The method is called Tone Injection, as substituting the points in the basic constellation for the new points in the larger constellation is equivalent to injecting a tone of the appropriate phase and frequency in the multi-carrier symbol.

4. SELECTIVE LEVEL MAPPING: In this technique the actual transmit signal lowest PAPR is selected from a set of sufficiently different signals which all represents the same information. SLM Techniques are very flexible as they do not impose any restriction on modulation applied in the subcarriers or on their number. Block diagram of SLM Technique is shown in Fig.1 Let's define data stream after serial to parallel conversion as $X=[X_0, X_1\text{--------},X_{N-1}]T$. Initially each input X_n (u) can be defined as equation no.2

$X_n(u) = X_n\, b_n(u)$. . . .(2)

$B_n(u)$can be written as

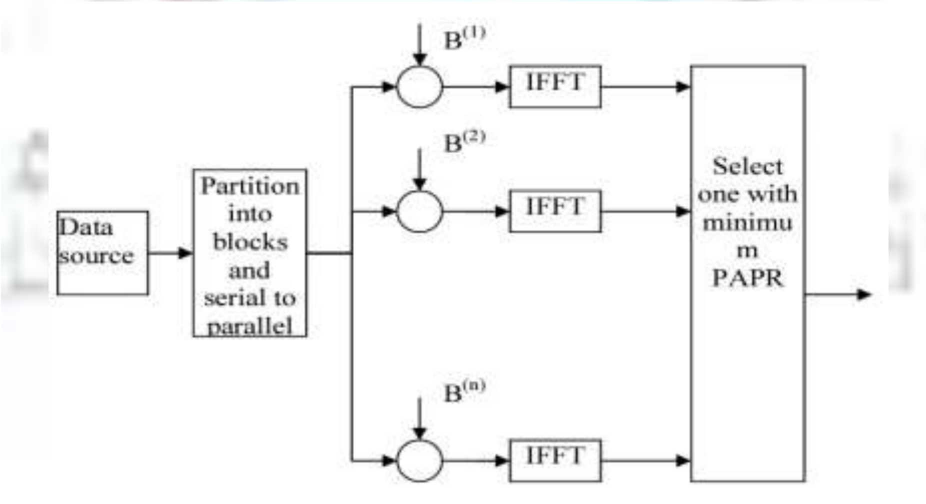

Fig 2: Block diagram of Selective level mapping

$X_n(u) = [X_0(u)..X_1(u)\ldots\ldots\ldots..X_{N-2}(u)\}^T$ …..(3)

Where, n = 0, 1, 2-------N-1, and u = 0,1,2...U to make the U phase rotated OFDM data blocks. All U phase rotated OFDM data blocks represented the same information as the unmodified OFDM data block provided that the phase sequence is known.

After applying the SLM technique, the complex envelope of the transmitted OFDM signal becomes

$$X(t) = \frac{1}{\sqrt{N}}\sum_{n=0}^{N-1} X_n\, e^{j2\pi n\Delta f\tau} \quad , 0\leq t \leq NT$$

Here Δt = 1/NT, NT is the duration of an OFDM data block. Output data of the lowest PAPR is selected to transmit .PAPR reduction effect will be better as the copy block number U is increased. SLM method effectively reduce PAPR without any signal distortion. But it has higher system complexity and computational burden. This complexity can less by reducing the number of IFFT block

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5. PARTIAL TRANSMIT SEQUENCE: In this technique, initially partitioning of the data block into non-overlapping sub-blocks is done. Then these sub-blocks are rotated with rotation factors which are statistically independent. Subsequently the information about rotation factor, which generates the lowest peak amplitude in time domain data, is transmitted to the receiver. The block diagram of PTS:

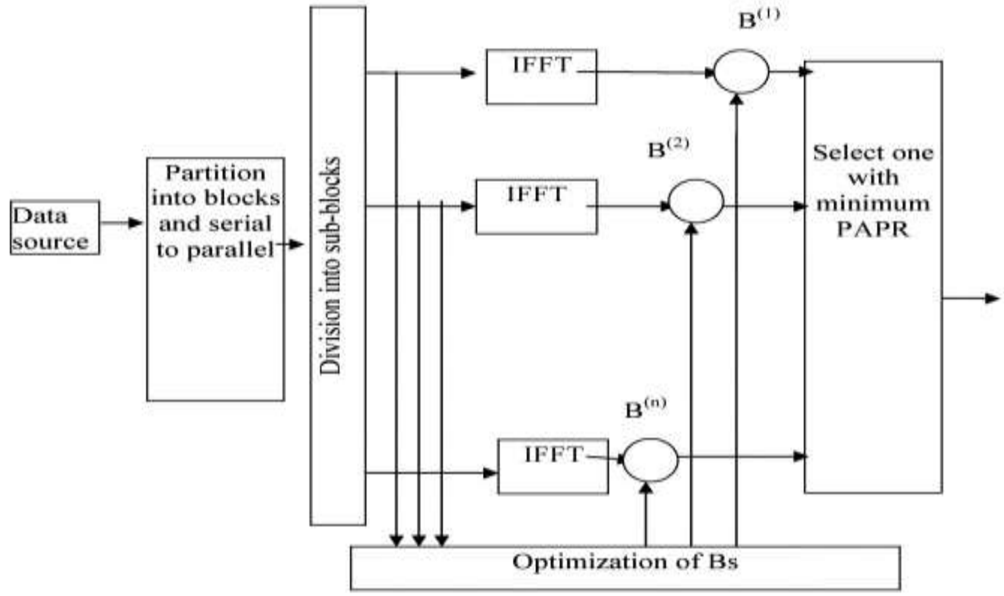

Fig 3: Block diagram of Partial transmit sequence

The simulation results of PTS for PAPR reduction are better as compared to SLM. The need for transmission of side information can also be overcome if differential modulation is employed for each sub block and block partitioning is known in the receiver

B) SIGNAL DISTORTION TECHNIQUES :

Clipping and Filtering [2][9][10], Peak Windowing [11], Envelope Scaling etc. are signal distortion techniques.

1. CLIPPING AND FILTERING: The simplest technique of PAPR reduction is clipping whose fundamental process to clip the part of signal which is out of allowed region with high peak [9]. Clipping is expressed as

$$C(x) = \begin{cases} x, & |x| \leq A \\ A, & |x| > A \end{cases}$$

A = Positive real number represent clip level .
This is the simple algorithm to mitigate PAPR by removing the signal component that exceeds some unchanging amplitude called clip level. It is a non-linear process which causes in-band noise, which demotes performance of BER and out of band noise which further reduces the spectral efficiency. Filtering after clipping can demote out of band radiation but cause peak re-growth which may exceed clip level. To avoid peak re-growth iterative clipping and frequency domain filtering can be used.

2. PEAK WINDOWING: With this technique it is possible to remove larger peaks at the rate of a little amount of interference when large peaks arise infrequently. It mitigates PAPR at cost of increases BER (bit-error-rate) and out-of-bands radiation. It provides better PAPR mitigation with better spectral properties[11]. In this method multiply large signal peak with a specific window such as Gaussian shaped window, Kaiser, cosine, and hamming window which results a spectrum of convolution of original OFDM spectrum with spectrum of window. The window size should be narrow otherwise it affects number of signal sample which cause increasing BER. PAPR level will decrease to 4db with this technique from number of independent subcarrier [7]. SNR limited to 0.3db due to signal distortion. Back off Pmax of about 5.5 dB require to keep in band spectral density to at-least 30db below.

3. ENVELOPE SCALING: Objective of this algorithm is to mitigate PAPR by scaling. Input envelope for few subcarrier before IFFT operation. Here 256 subcarriers with QPSK modulation technique are used to make sure envelope for all subcarrier are equal. According to algorithm input envelope in some sub-carrier is scaled to attain the smallest amount of PAPR at IFFT output. Thus, at receiver there is no need of side information for decoding purpose. PAPR reduces to 4db with same algorithm. If QAM is used number of sub-carrier will large then need to send excessive side information otherwise BER demote in large amount.

C) ANALYSIS OF REDUCTION TECHNIQUES

There are a number of parameters or factors which are considered for the PAPR reduction techniques [4]. Not all the criteria can be fully satisfied by any of the existing PAPR reduction techniques. A tradeoff is required between these factors to select the most appropriate technique depending on the system under consideration. The factors are as listed below:

1. **PAPR Reduction capability**: The PAPR reduction capability is described by the reduction of PAPR value (in dB) after the technique is applied to OFDM transmission system. It is measured by CCDF graph.

2. **Power Increase in transmit signal:** The technique must not increase the total power level that is being transmitted. If it does happen, the increment in power has to be within a permissible limit.

3. **BER increase at the receiver:** The technique must not introduce unwanted errors into the transmitted bit stream, such that the overall BER at the receiver is increased. In other words the technique must not distort the signal.

4. **Loss in data rate:** The technique may use some extra bits and this may result in a loss of data rate. The loss is acceptable up to certain value dependent on the system under consideration

5. **Computational complexity:** The technique may satisfy all the other criteria but at the cost of a very high computational complexity. If this complexity is exceedingly high, the technique might not be suitable for hardware implementation as it will incur higher cost, power and time which are not desirable in speedy networks based on OFDM.

Table 1: **COMPARISON CHART OF REDUCTION TECHNIQUES** [12]

TECHNIQUES	DISTORTION LESS	POWER INCREASE	DATA RATE LOSS	BER IMPROVED	COMPUTATIONAL COMPLEXITY	SIDE INFORMATION
BLOCK CODING	YES	NO	YES	YES	MEDIUM	NO
PTS	YES	NO	YES	YES	VERY HIGH	YES
SLM	YES	NO	YES	YES	HIGH	YES
TR/TI	YES	YES	NO	YES	MEDIUM	NO
CLIPPING	NO	NO	NO	NO	LOW	NO
PEAK WINDOWING	NO	YES	NO	NO	LOW	NO
ENVELOPE SACLING	YES	NO	YES	NO	LOW	NO

V. CONCLUSION

In this paper, we have analyzed various PAPR reduction techniques and also compared these techniques for different parameters. There are many factors to be considered before a specific PAPR reduction technique is chosen. These factors include PAPR reduction capacity, Power increase in transmit signal, BER increase at the receiver, loss in data rate, computational complexity increase and so on. No specific PAPR reduction technique is the best solution for all multi carrier transmission. Rather the PAPR reduction technique should be carefully chosen according to various system requirements but an overall observation shows that SLM is the most effective technique to mitigate PAPR to great extent and also improve BER performance of the system.

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