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# A REVIEW ON PAPR REDUCTION TECHNIQUES FOR OFDM MULTI-CARRIER SYSTEMS

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**Abstract— orthogonal frequency division multiplexing (OFDM) is one of the most spectrally efficient, robust transmission technique widely used in recent communication systems, and it also remits the problem of multipath environment. The concept of OFDM has been known since 1966, but it only reached sufficient maturity for deployment in standard systems during 1990s. OFDM is an attractive modulation technique for transmitting large amounts of digital data over radio waves. One major disadvantage of OFDM is that the time domain OFDM signal which is a sum of several sinusoids leads to high peak to average power ratio (PAPR). Number of techniques has been proposed in the literature for reducing the PAPR in OFDM systems. In this paper the various techniques proposed for reducing the PAPR have been discussed. The goal is to convey the fundamental ideas and intuitive understanding of the concept introduced. This is done primarily to give an overview of the various techniques known today for PAPR reduction.**

**Index Terms—Orthogonal frequency division multiplexing, peak-to-average power ratio (PAPR), signal scrambling, signal distortion.**

## I. INTRODUCTION

New Technologies and thereby new applications are emerging not just in wired environment but also in the wireless arena. The next generation mobile systems are expected to provide a substantially high data rate to meet the requirements of future high performance multimedia applications. The minimum target data rate for the 4G system is expected to be at 10-20 Mbps and at least 2 Mbps in the moving vehicles. To provide such a high data rate with high spectral efficiency, a new modulation scheme is to be used. A promising modulation technique that is increasingly being considered for adoption by 4G community is OFDM [1]. Existing 3G systems uses single carrier modulation technique whereas OFDM is employed in Digital Television Broadcasting (such as the digital ATV Terrestrial Broadcasting) [2], European Digital Audio Broadcasting (DAB) and Digital Video Broadcasting Terrestrial (DVB-T) [3], Wireless Asynchronous Transfer Mode (WATM) [4] and which is otherwise known as Multicarrier Modulation (MCM) / Discrete Multitone Technique (DMT) sends a high speed data stream by splitting it up to multiple lower speed stream and transmitting it over a lower bandwidth subcarriers in parallel. OFDM has several favorable properties like high spectral efficiency, robustness to channel fading, immunity to impulse interference, uniform average spectral density, capacity to handle very strong echoes and less non-linear distortion. Table 1 depicts different OFDM systems and their properties. OFDM is the modulation technique used in many new broadband communication systems. In recent years OFDM has emerged as the standard of choice in a number of important high data applications.

Table 1: OFDM Systems

| | Hiperlan 2 | DAB | 802.11a/b | DVB-T |
|---|---|---|---|---|
| No. of carriers | 48 Sub-carriers | 1705 subcarriers in 2k DFT | 48 subcarriers in 64 FFT | 1705 subcarriers in 2k DFT, 6817 subcarriers in 8k DFT |
| Modulation Schemes | 16-QAM/ 8PSK | DQPSK | 64-QAM | 64-QAM |
| Capacity | 25 Mbps | 2 Mbps | 54 Mbps | 12-24 Mbps |
| Bandwidth | 25 MHz | 1.526 MHz overall | 20 MHz | 8 MHz RF channel |
| Spectral Region | 5.2 GHz | Band 3: 174-240 MHz Band L: 1452-1492 MHz | 802.11a in 5.8 GHz, 802.11b in 2.4 GHz | VHF / UHF band |
| Technology | WLAN | Broadcasting | Wireless Technology | Broadcasting Technique |

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## II. BASICS OF ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM):

OFDM is a Multicarrier Transmission technique which divides the available spectrum into many carriers each one being modulated by a low data rate stream. OFDM is similar to Frequency Division Multiple Access (FDMA) in that the multiple user access is achieved by sub-dividing the available bandwidth into multiple channels, which are then allocated to users. However, OFDM uses the spectrum much more efficiently by spacing the channels more closely together. This is achieved by making all the carriers orthogonal to one another, preventing interference between the closely channels.

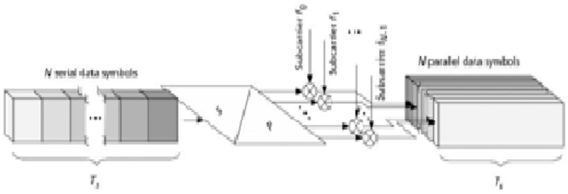

Fig.1. Multicarrier Transmission Technique

A single stream of data is split into several parallel bit streams each of which is coded and modulated on to a subcarrier as shown in Fig.1. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase shift keying) at a low symbol rate, maintaining data rates similar to conventional single carrier modulation schemes in the same bandwidth. Thus the high bit rates seen before on a single carrier is reduced to lower bit rates on the subcarrier.

In practice, OFDM signals are generated and detected using the Fast Fourier Transform algorithm. In FDMA each user is typically allocated a single channel which is used to transmit all the user information. The bandwidth of each channel is typically 10-30 kHz for voice communication. However, the minimum required bandwidth for speech is only 3 kHz. The allocated bandwidth is made wider than the minimum amount required to prevent channels from interfering with one another. This extra bandwidth is to allow for signals of neighboring channels to be filtered out and to allow for any drift in the center frequency of the transmitter or receiver. In a typical system up to 50% of the total spectrum is wasted due to the extra spacing between channels. This problem becomes worse as the channel bandwidth becomes narrower and the frequency band increases. Time Division Multiple Access (TDMA) overcomes this problem by using wider band width channels which are used by several users. The subcarriers in an OFDM signal are spaced close as is theoretically possible which maintain orthogonality between them.

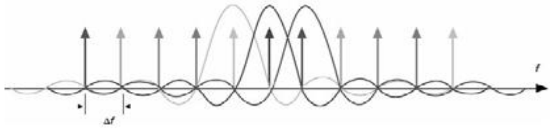
Fig.2. Orthogonality of Subcarriers

The Orthogonality of the carriers means that each carrier has an integer number of cycles over a symbol period. Due to this the spectrum of each carrier has a null at the center frequency of each of the other carriers in the system. This results in no interference between the carriers, allowing them to be spaced as close as theoretically possible. In OFDM scheme, large number of closely spaced orthogonal sub-carriers is as shown in Fig.2.

To generate OFDM successfully the relationship between all the carriers must be carefully controlled to maintain the orthogonality of the carriers. For this reason, OFDM is generated by firstly choosing the spectrum required based on the input data, and modulation scheme used [5]. Each carrier to be produced is assigned same data to transmit. The required amplitude and phase of them are calculated based on the modulation scheme. The required spectrum is then converted back to its time domain signal using an Inverse Fast Fourier Transform (IFFT). The IFFT performs the transformation very efficiently and provides a simple way of ensuring the carrier signals produced are orthogonal.

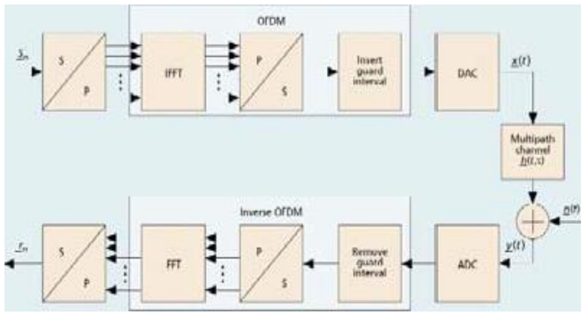

Fig.3. OFDM Transceiver Structure

Fig.3 shows the configuration for a basic OFDM Transmitter and Receiver. The signal generated is at base band and so to generate an RF signal, the signal must be filtered and mixed to the desired transmission frequency.

## III. SOME BASICS ABOUT PAPR PROBLEM IN OFDM

OFDM signal exhibits a very high PAPR, which is due to the summation of sine waves and non-constant envelope. Therefore, RF power amplifiers have to be operated in a very large linear region [6]. Otherwise, the signal peaks get into non-linear region causing signal distortion. This signal distortion introduces inter modulation among the subcarriers and out-of-band radiation. PAPR is a very important situation in the communication system because it has big effects on the transmitted signal. Low PAPR makes the transmit power amplifier works efficiently, on the other hand, the high PAPR makes the signal peaks move into the non-linear region of the RF power amplifier which reduces the efficiency of the RF power amplifier. In addition, high PAPR requires a high-resolution DAC at the transmitter, high-resolution analog to digital converter (ADC) at the receiver [7]. Any non-linearity in the signal will cause distortion such as inter-carrier interference (ICI) and inter symbol interference (ISI).

PAPR of OFDM signal is given by,

$$PAPR = Ppeak/Pavg. = 10\log 10 = \max[|xn|^2]/E[|xn|^2] \quad (1)$$

Where, Ppeak represents peak output power, Pavg. means average output power. E denotes the expected value; xn represents the transmitted OFDM signals. For an OFDM system with N sub-carriers, the peak power of received signalsis N times the average power when phase values are the same. The PAPR of baseband signal will reach its theoretical maximum at

$$(dB) = 10\log N \quad (2)$$

The Complementary Cumulative Distribution Function (CCDF) is used to measure the efficiency of any PAPR reduction technique which helps us to measure the probability that the PAPR of a certain data block exceeds the given threshold [8]. By implementing the Central Limit Theorem for a Multicarrier signal with a large number of sub-carriers, the real and imaginary part of the time domain signals have a mean of zero and a variance of 0.5 and thus follow a Gaussian distribution. Also Rayleigh distribution is followed for the amplitude of the multicarrier signal, whereas a central chi-square distribution with two degrees of freedom is followed for the power distribution of the system.

## IV. PAPR REDUCTION TECHNIQUES

Several techniques have been proposed in the literature to reduce the PAPR. These techniques can mainly be categorized into signal scrambling techniques and signal distortion techniques. Signal scrambling techniques are all variations on how to scramble the codes to decrease the PAPR. Coding techniques can be used for signal scrambling. However with the increase in the number of carriers the overhead associated with exhaustive search of the best code would increase exponentially. More practical solutions of the signal scrambling techniques are block coding, Selective Level Mapping (SLM) and Partial Transmit Sequences (PTS). Signal scrambling techniques with side information reduces the effective throughput since they introduce redundancy.

The signal distortion techniques introduce both In-band and Out-of-band interference and complexity to the system. The signal distortion techniques reduce high peaks directly by distorting the signal prior to amplification. Clipping the OFDM signal before amplification is a simple method to limit PAPR. However clipping may cause large out-of-band (OOB) and in-band interference, which results in the system performance degradation. More practical solutions are peak windowing, peak cancellation, Peak power suppression, weighted multicarrier transmission, companding, etc. Basic requirement of practical PAPR reduction techniques include the compatibility with the family of existing modulation schemes, high spectral efficiency and low complexity.

### A. Signal Scrambling Techniques:

#### 1) Block Coding Techniques

The paper by, Wilkinson and Jones [9] proposes a block coding scheme for the reduction of the peak to mean envelope power ratio of multicarrier transmission systems in 1995. The main idea behind this paper is that PAPR can be reduced by block coding the Data such that set of permissible code words does not contain those which result in excessive peak envelope powers (PEPs). There are three stages in the development of the block coding technique. The first stage is the selection of suitable sets of code words for any number of carriers, any M-array phase modulation scheme, and any coding rate. The second stage is the selection of the sets of code words that enable efficient implementation of the encoding /decoding. The third stage is the selection of sets of code words that also offer error deduction and correction potential.

There are a number of approaches to the selection of the sets of code words. The most trivial brute force approach is sequential searching of the PEP for all possible code words for a given length of a given number of carriers. This is simple and appropriate for short codes because it requires excessive computation. Most sophisticated searching techniques such as natural algorithms can be used for the selection of longer code words. The encoding and decoding, with sets of code words selected from searches, can be performed with a look up table or using combinatorial logic exploiting the mathematical structure of the codes.

#### 2) Selective Mapping (SLM)

The paper, by Bauml et al., [10] proposes a method for the reduction of peak to average transmit power of multicarrier modulation systems with selected mapping in 1996. In selective mapping (SLM) method a whole set of candidate signals is generated representing the same information, and then the most favorable signal as regards to PAPR is chosen and transmitted. The side information about this choice needs to be explicitly transmitted along with the chosen candidate signal.

SLM scheme is one of the initial probabilistic approaches for reducing the PAPR problem, with a goal of making occurrence of the peaks less frequent, not to eliminate the peaks depending on design and number of the phase sequences U. The scheme can handle any number of subcarriers and drawback associated with the scheme is the overhead of side information that needs to be transmitted to the receiver.

3) Partial Transmit Sequence (PTS)

The paper, by Muller and Hubber [11] proposes an effective and flexible peak power reduction scheme for OFDM system by combining Partial Transmit Sequences (PTS) in 1997. The main idea behind the scheme is that, the data block is partitioned into non - overlapping sub blocks and each sub block is rotated with a statistically independent rotation factor. The rotation factor, which generates the time domain data with the lowest peak amplitude, is also transmitted to the receiver as side information.

PTS is also probabilistic scheme of reducing PAPR. PTS scheme can be interpreted as a structurally modified case of SLM scheme and, it is found that the PTS schemes perform better than SLM schemes. When differential modulation is used in each subblock, no side information needs to be transmitted to the receiver.

4) Interleaving

The paper, by Jayalath and Tellambura [12] presents interleave based technique for improving the peak to average power ratio of an OFDM signal. Highly correlated data frames have large PAPR, which could thus be reduced, if long correlation patterns were broken down. The paper proposes a data randomization technique for the reduction of the PAPR of the OFDM system.

The paper also proposes an adaptive technique to reduce the complexity of the scheme. The key idea in adaptive interleaving is to establish an early terminating threshold i.e. the search is terminated as soon as the PAPR value reaches below the threshold, rather than searching all the interleaved sequences. 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.

The most important aspect of this method is that it is less complex than the PTS method but achieves comparable results. Therefore, higher order error correction method should be used in addition to this scheme.

B. Signal Distortion Techniques:

1) Clipping & Filtering

The paper, by May and Rholing, [13] proposes the method of PAPR reduction by manipulating the OFDM signal with a suitable additive correcting function. In this approach, the amplitude peaks are corrected (or signal is modified) in such a way that a given amplitude threshold of the signal is not exceeded after the correction.

The OFDM signal is corrected by adding it with a corrective function k(t). This correction limits the signal s(t) to A0 at positions of tn of amplitude peaks. This method produces no out-of-band interference and causes interference of the OFDM signal with minimal power. If the OFDM signal is not oversampled, then the correction scheme is identical with clipping and each correction of an amplitude peak causes interference on each sub carrier and the power of the correcting function is distributed evenly to all sub carriers. To apply this correcting scheme, the signal s(t) is oversampled by a factor of four and normalized so that the signal power is one. Then the signal is corrected with k(t). For the correction the amplitude threshold A0 is set according to the input bakeoff. After the correction, the signal is limited to the amplitude A0 in order to take into account the limitation of amplitude peaks which may have remained. The signal can be corrected by multiplicative Gaussian function or additive sinc function. The interesting part of the scheme is that it can be used for any number of subcarriers and it does not need any redundancy. The PAPR is reduced at the cost of small increase in the total in-band distortion.

## V. PAPR REDUCTION USING NULL SUBCARRIERS

There are two techniques which reduces the PAPR value of OFDM system using null subcarriers. Those techniques are switching null subcarriers [14] and shifting null subcarriers [15].

The PAPR of OFDM system can be reduced by reordering the null-subcarriers and data-subcarriers. This technique switches/shifts the ‘innermost’ null subcarriers among different data-subcarriers to minimize the PAPR. Fig.4 shows both the techniques implemented in IEEE 802.11a standard OFDM symbol. These techniques are CSI-free pre-processing algorithms, which can be compatible with most existing OFDM standards, and which can complement many other PAPR-reduction algorithms.

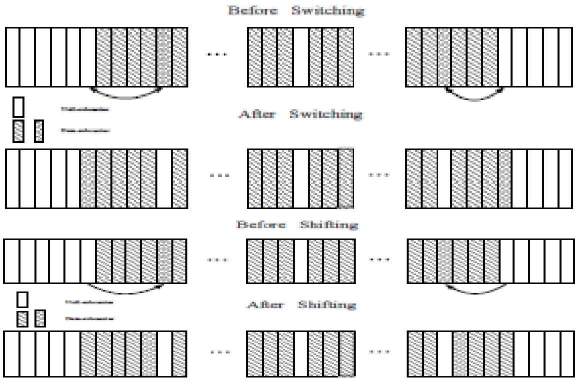


Fig. 4 Null Subcarriers Switching/ Shifting technique for PAPR reduction in OFDM signal

Many of the PAPR reduction techniques don't consider the effect of the components in the transmitter such as the transmitter filter, digital to analog converters (D/A) and transmit power amplifier. In practice PAPR reduction techniques can be used only after careful performance and cost analysis for realistic environment. Table 2 depicts the comparison of different types of PAPR reduction schemes and its necessary parameters.

Table 2: Comparison of PAPR Reduction Techniques

| Type/ Parameter | Distort-ionless | Power Increase | Data Rate loss |
|---|---|---|---|
| Clipping & Filtering | No | No | No |
| Block Coding | Yes | No | Yes |
| Partial Transmit Sequence(PTS) | Yes | No | Yes |
| Selective Mapping | Yes | No | Yes |
| Interleaving | Yes | No | Yes |
| Tone Reservation | Yes | Yes | Yes |
| Tone Injection | Yes | Yes | No |
| Active Constellation | Yes | Yes | No |
| Switching/Shifting | Yes | No | No |

## V. CONCLUSIONS

Most of the above techniques are unable to achieve simultaneously a large reduction in PAPR with low complexity, with low coding overhead, without performance degradation and without transmitter and receiver symbol handshake.

Its basic requirement includes the compatibility with the Family of existing modulation scheme, high spectral efficiency and low complexity. There are many factors to be considered before 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 correctly chosen according to various system requirements.

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