International Journal of Ethics in Engineering & Management Education
Website: www.ijeee.in (ISSN: 2348-4748, Volume 1, Issue 4, April 2014)

An Overview of PAPR Reduction Techniques In Concerned with OFDM

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Abstract: **The concept of Orthogonal Frequency Division Multiplexing (OFDM) has been known since 1960. OFDM is a combination of modulation and multiplexing. It is an attractive multicarrier modulation technique for broadband wireless access due to its strong immunity to multipath fading and high spectral efficiency. PAPR is the one of the major drawback of OFDM and it is due to time domain OFDM signal which is sum of several subcarriers. This paper explains the some of PAPR reduction techniques.**

1. INTRODUCTION:

OFDM is a popular multi-carrier modulation technique that offers very high transmission rates and utilizes efficiently the available spectrum and network resources. It is incorporated in many applications and standards such as WLAN, Digital Audio Broadcasting (DAB), Digital video Broadcasting (DVB) [6] and it effectively combat frequency-selective fading usually encountered in wireless channels. The PAPR for the continuous-time signal is the ratio of the maximum instantaneous power to the average power. The peak values computed using discrete-time OFDM may not coincide with the peak value of the continuous-time OFDM signal [7].

Many PAPR reduction techniques [8] are present like signal companding, selective mapping etc. In signal companding scheme, the time-domain OFDM signal encounters a transformation that attenuates high peaks and enhances low amplitudes at the transmitter. Obviously this process will decrease the PAPR. At the receiver, the inverse transformation is applied to reconstruct the uncompanded signal.

The PAPR reduction capability is measured by the complimentary cumulative distribution function (CCDF), which indicates that the probability that PAPR is above a certain threshold. The companding process takes place before the digital-to-analog converter (D/A) and the high power amplifier (HPA). An increase in the PAPR reduction capability inherently leads to degradation in the SER performance. This occurs because channel noise is decompanded at the receiver resulting in a higher number of errors in the recovered data symbols and hence a higher SER. This occurs because channel noise is decompanded at the receiver resulting in a higher number of errors in the recovered data symbols and hence a higher SER. To maintain high transmission rates, wireless communication systems sacrifice SER performance. PAPR.

OFDM is one of the popular multicarrier modulation technique where multiple data symbols are modulated simultaneously by multiple carries by breaking the wide transmission band into narrower, multiple sub-bands. It have one of the serious drawback which is the non-constant signal envelope with high peaks. This high peaks produces signal excursions into nonlinear regions of the high power amplifier at the transmitter.

2. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM)

The idea of OFDM comes from MultiCarrier Modulation (MCM) transmission technique. The principle of MCM describes the division of input bit stream into several parallel bit streams and then they are used to modulate several sub carriers as shown in Figure 2.1. Each subcarrier is separated by a guard band to ensure that they do not overlap with each other. In the receiver side, bandpass filters are used to separate the spectrum of individual subcarriers. OFDM is a special form of spectrally efficient MCM technique, which employs densely spaced orthogonal subcarriers and overlapping spectrums. The use of bandpass filters are not required in OFDM because of the orthogonality nature of the subcarriers.

Hence, the available bandwidth is used very efficiently without causing the InterCarrier Interference (ICI). In Figure 2.1, the effect of this is seen as the required bandwidth is greatly reduced by removing guard band and allowing subcarrier to overlap. It is still possible to recover the individual subcarrier despite their overlapping spectrum provided that the orthogonality is maintained. The Orthogonality is achieved by performing Fast Fourier

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Transform (FFT) on the input stream. Because of the combination of multiple low data rate subcarriers, OFDM provides a composite high data rate with long symbol duration.

Depending on the channel coherence time, this reduces or completely eliminates the risk of InterSymbol Interference (ISI), which is a common phenomenon in multipath channel environment with short symbol duration. The use of Cyclic Prefix (CP) in OFDM symbol can reduce the effect of ISI even more [24], but it also introduces a loss in SNR and data rate.

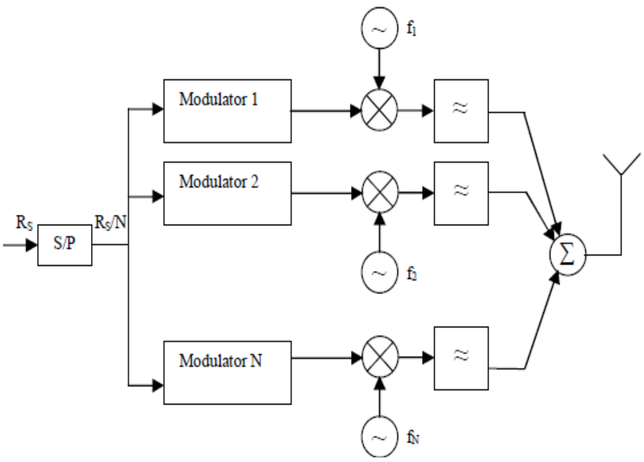

Figure 2.1: Block diagram of Generic MCM Transmitter

3. OFDM SYSTEM IMPLEMENTATION

The principle of OFDM was already around in the 50's and 60's as an efficient MCM technique. But, the system implementation was delayed due to technological difficulties like digital implementation of FFT/IFFT, which were not possible to solve on that time. In 1965, Cooley and Tukey presented the algorithm for FFT calculation [22] and later its efficient implementation on chip makes the OFDM into application. The digital implementation of OFDM system is achieved through the mathematical operations called Discrete Fourier Transform (DFT) and its counterpart Inverse Discrete Fourier Transform (IDFT). These two operations are extensively used for transforming data between the time domain and frequency domain. In case of OFDM, these transforms can be seen as mapping data onto orthogonal subcarriers.

In order to perform frequency domain data into time domain data, IDFT correlates the frequency domain input data with its orthogonal basis functions, which are sinusoids at certain frequencies. In other ways, this correlation is equivalent to mapping the input data onto the sinusoidal basis functions. In practice, OFDM systems employ combination of fast fourier transform (FFT) and Inverse fast fourier transform (IFFT) blocks which are mathematical equivalent version of the DFT and IDFT.

At the transmitter side, an OFDM system treats the source symbols as though they are in the frequency domain. These symbols are feed to an IFFT block which brings the signal into the time domain. If the N numbers of subcarriers are chosen for the system, the basis functions for the IFFT are N orthogonal sinusoids of distinct frequency and IFFT receive N symbols at a time. Each of N complex valued input symbols determines both the amplitude and phase of the sinusoid for that subcarrier. The output of the IFFT is the summation of all N sinusoids and makes up a single OFDM sysmbol. The length of the OFDM symbol is NT where T is the IFFT input symbol period. In this way, IFFT block provides a simple way to modulate data onto N orthogonal subcarriers.

At the receiver side, The FFT block performs the reverse process on the received signal and bring it back to frequency domain. The block diagram in Figure 3.1 depicts the switch between frequency domain and time domain in an OFDM system.

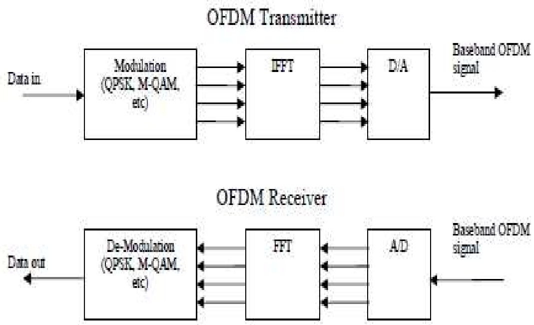

Figure 3.1 Basic OFDM Transmitter and receiver

4. PAPR IN OFDM SYSTEM

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 (for e.g. power amplifier has to operate with larger back-off to maintain linearity). The PAPR of the transmit

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signal x(t) is the ratio of the maximum instantaneous power and the average power.

$$PAPR = \max_{0 \leq t \leq T} \frac{[x(t)]^2}{E\{|x(t)|^2\}} \quad (1)$$

where E{.} denotes expectation operator.

High PAPR / crest factor could cause problems when the signal is applied to a transmitter which contains non-linear components such as High Power amplifier (HPA) in the Transmitter chain. The PAPR has the worst case value PAPRWC which depends on the no. of subscribers N.

The non-linear effects on the transmitted OFDM symbols are spectral spreading, inter-modulation and changing the signal constellation. In other words, the nonlinear distortion causes both in-band and out-of-band interference to signals. The inband interference increases the Bit Error Rate (BER) of the received signal, while the out-ofband interference causes adjacent channel interference through spectral spreading. A better solution is to prevent the occurrence of such nonlinear distortion by reducing PAPR of the transmitted signal with some manipulation of the OFDM signal itself.

5. PAPR REDUCTION TECHNIQUES

Several techniques have been proposed in the literature to reduce the PAPR. These techniques can mainly be categorized in to 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. Golay complementary sequences, Shapiro-Rudin sequences, M sequences, Barker codes can be used efficiently to reduce the PAPR. 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 Inband 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-ofband (OOB) and in-bandinterference, 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.

5.1 Partial Transmit Sequence

The Muller and Hubber, [2] 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 performs better than SLM schemes. When differential modulation is used in each subblock, no side information needs to be transmitted to the receiver

5.2 Selected Mapping:

The paper, by Bauml et.al., [1] proposes a method for the reduction of peak to average transmit power of multicarrier modulation systems with selected mapping in 1996. In selected 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. 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.

5.3 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.

5.4 CLIPPING & FILTERING:

The paper, by May and Rholing, [3] proposes the method of PAPR reduction by manipulating the OFDM signal with a suitable additive correcting function. In this approach, theamplitude peaks are corrected 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 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 inband distortion.

5.5 *Peak Windowing*:

The paper, by van Nee and Wild [4] 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. Clipping is one example of a PAPR reduction technique creating self interference. Peak Windowing technique provides better PAPR reduction with better spectral properties than clipping. Peak windowing can achieve PAPR around 4dB for an arbitrary subcarriers, at the cost of slight increase in BER and out-of-band (OOB) interference.

In windowing technique a large signal peak is multiplied with a certain window, such as Gaussian shaped window, cosine, Kaiser and Hamming window. Since the OFDM signal is multiplied with several of these windows, the resulting spectrum is a convolution of the original OFDM spectrum with the spectrum of the applied window. Ideally the window should be as narrow band as possible, on the other hand the window should not be too long in the time domain because that implies that many signal samples are affected increasing the BER. With windowing method, PAPR can be reduced down to about 4dB, independent of the number of sub carriers. The loss of SNR caused by the signal distortion is limited to about 0.3dB. A backoff relative to maximum output power of about 5.5dB is required in order to keep undesired spectra distortion at least 30dB below the in-band spectral density.

5.6 Companding:

The paper, by Wang et.al, [5] proposes a simple and effective companding technique to reduce the PAPR of OFDM signal. The OFDM signal can be assumed Gaussian distributed, and the large OFDM signal occurs infrequently. So the companding technique can be used to improve OFDM transmission performance. _-law companding technique is used to compand the OFDM signal before it is converted into analog waveform. 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. OFDM signal also exhibit similar characteristic where high peaks occur infrequently. Companding technique improves the quantization resolution of small signals at the price of the reduction of the resolution of large signals, since small signals occur more frequently than large ones.

Due to companding, the quantization error for large signals is significantly large which degrades the BER performance of the system. So the companding technique improves the PAPR in expense of BER
performance of the system.

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