TECHNIQUES FOR PAPR REDUCTION IN OFDM SYSTEM

Gurjot Singh Gaba
Deptt. of Electronics & Communication Engg.
Lovely Professional University
Jalandhar, India

Nancy Gupta
Deptt. of Electronics & Communication Engg.
Desh Bhagat Engineering College
Mandi gobindgarh, India

Harsimranjit Singh Gill
Deptt. of Electronics & Communication Engg.
Ludhiana College of Engineering & Technology
Ludhiana, India

***Abstract*- Communication is one of the important aspects of life. With the advancement in age and its growing demands, there has been rapid growth in the field of communication. Initially, the transmission of signals in analog domain was in more demand, but now-a-days, the trend is turning more towards digital signal transmission. The reason being inherent advantages of digital transmission over analog transmission. For better transmission, even single–carrier waves are being replaced by multi–carriers. Multi–carrier systems like CDMA and OFDM are now–a–days being implemented. There are a number of techniques to deal with the problem of PAPR (peak -to -average power). Some of them are clipping, Block coding techniques, Techniques based on phase shifting, Tone injection and reservation. These techniques achieve PAPR reduction at the expense of increase in transmit signal power, rise in bit error rate (BER), data rate loss, more computational complexity and so on.**

***Keywords*— Single-carrier, Multi-carrier, Subcarriers, Orthogonal, PAPR ratio, Spectral efficiency.**

I. Introduction

The OFDM concept is based on spreading the data to be transmitted over a large number of carriers, each being modulated at a low bit rate. In a conventional frequency division multiplexing, the carriers are individually filtered to ensure that there is no spectral overlap. Thereby, resulting in least inter-symbol interference between carriers but with drawback that maximum efficiency of the available spectrum is not utilized. However, if the carrier spacing is chosen such that the carriers are orthogonal over the symbol period, then the symbols can be recovered without interference even with a degree of spectral overlap. The carrier spacing which is equal to the reciprocal of symbol period ensures the maximum spectral efficiency. The inverse Fast Fourier Transform (FFT) process may conveniently result in digital multiplexing of carriers. OFDM is a special case of multicarrier transmission, where a single data stream is transmitted over a number of lower-rate subcarriers (SCs). It is worth mentioning that OFDM can be seen as either a modulation technique or multiplexing technique [1].

One of the main reasons to use OFDM is to increase robustness against frequency selective fading or narrowband interference. In a single-carrier system, a single fade or interferer can cause the entire link to fail, but in a multicarrier system, only a small percentage of the SCs will be affected. Error-correction coding can then be used to correct for the few erroneous SCs. In fact almost 50% bandwidth can be saved by using the overlapping multicarrier modulation technique. To realize this technique, however, crosstalk between SCs should be reduced, so as to achieve orthogonality between the different modulated carriers. The word "orthogonal" indicates that there is a precise mathematical relationship between the frequencies of the carriers in the system. With the ever growing demand of this generation, need for high speed communication has become an utmost priority. Various multicarrier modulation techniques have evolved in order to meet these demands, few notable among them being Code Division Multiple Access (CDMA) and Orthogonal Frequency Division Multiplexing (OFDM) [2].

II. OFDM

Orthogonal Frequency Division Multiplexing is a frequency-division multiplexing (FDM) scheme utilized as a digital multi-carrier modulation method. A large number of closely spaced orthogonal sub-carriers are used to carry data. The data is divided into several parallel streams of channels, one for each sub-carrier. Each sub-carrier is modulated with a conventional modulation scheme (such as QPSK) at a low symbol rate, maintaining total data rates similar to the conventional single-carrier modulation schemes in the same bandwidth. OFDM is one of the many multicarrier modulation techniques, which provides high spectral efficiency, low implementation complexity, less vulnerability to echoes and non-linear distortion. Due to these advantages of the OFDM system, it is vastly used in various communication systems. But the major problem one faces while implementing this system is the high peak -to -average power (PAPR) ratio of the system. A typical OFDM model is shown in fig. 1. A large PAPR increases the complexity of the analog -to-digital and digital- to-analog converter and reduces the efficiency of the radio-frequency (RF) power amplifier. Regulatory and application constraints can be implemented to reduce the peak transmitted power which in turn reduces the range of multi carrier transmission. This leads to the prevention of spectral growth and the transmitter power amplifier is no longer confined to linear region in which it should operate. This has a harmful effect on the battery lifetime. Thus in communication system, it is observed that all the potential benefits of multi carrier transmission can be out - weighed by a high PAPR value .There are a number of techniques to deal with the problem of PAPR. Some of them are amplitude clipping and filtering, coding, partial transmit sequence (PTS), selected mapping (SLM), interleaving etc. These techniques achieve PAPR reduction at the expense of transmit signal power increase, bit error rate (BER) increase, data rate loss, computational complexity increase, and so on.

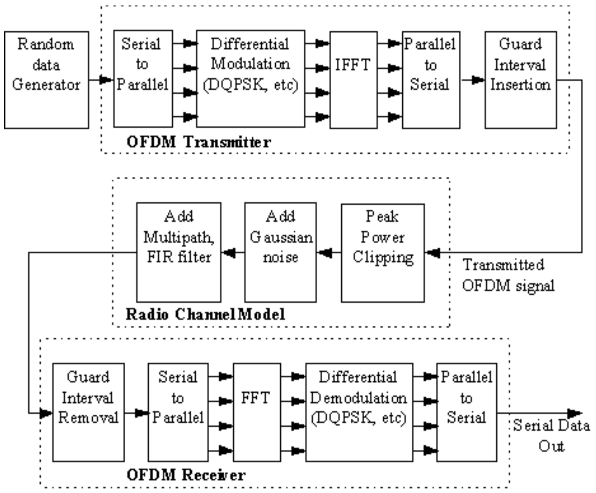

Figure 1. OFDM Model used for simulations

III. PEAK-TO-AVERAGE POWER RATIO

PAPR occurs when, in a multi-carrier environment, the different sub-carriers are out of phase with each other. Thus, at each instant they are offset with respect to each other at different phase values. However, there may come a point when all of them achieve the maximum value simultaneously; this will cause the output envelope to suddenly shoot up. Thus, causes a 'peak' in the output envelope. Due to presence of large number of independently modulated sub-carriers in an OFDM system, the peak value of the system can be very high as compared to the average of the whole system. This ratio of the peak to average power value is termed as Peak-to-Average Power Ratio. Coherent addition of N signals of same phase produces a peak which is N times the average signal.

A. Disadvantages of high PAPR:

1. Increased complexity: Complexity is increased in the analog to digital and digital to analog converter.

2. Reduction in efficiency of RF amplifiers: This forces the power amplifier to have a large input back off and operate inefficiently in its linear region to avoid inter modulation products. When the OFDM signal with high PAPR passes through a non-linear device, (power amplifier working in the saturation region), the signal will suffer significant non-linear distortion. This non-linear distortion will result in in-band distortion and out-of-band radiation. The in-band distortion causes system performance degradation and the out-of-band radiation causes adjacent channel interference (ACI) that affects systems working in the neighbour bands. To lessen the signal distortion, it requires a linear power amplifier with large dynamic range. However, this linear power amplifier has poor efficiency and is also expensive.

The crest factor or peak-to-average ratio (PAR) or peak-to-average power ratio (PAPR) is a measurement of a waveform, calculated from the peak amplitude of the waveform divided by the RMS value of the waveform.

$$C = \frac{|x|_{peak}|}{x_{rms}} \quad (1)$$

It is therefore a dimensionless Quantity. While this quotient is most simply expressed by a positive rational number, in commercial products it is also commonly stated as the ratio of two whole numbers, e.g., 2:1. In signal processing applications it is often expressed in decibels (dB). The minimum possible crest factor is 1, 1:1 or 0 dB.

B. PAPR of a Multicarrier Signal:

Let the data block of length N be represented by a vector X=$[X_{0,} \; X_1, \ldots, X_{N-1}]$. Duration of any symbol X_k in the set X is T and represents one of the sub-carriers $\{f_{n,} \, n = 0,1, \ldots, N-1\}$ set. As the N sub – carriers chosen to transmit the signal are orthogonal to each other, so we can have f_n =nΔf, where, nΔf =1/NT and NT is the duration of the OFDM data block X. The complex data block for the OFDM signal to be transmitted is given by:

$$X(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n . e^{j2\Pi n \Delta f t}, \; 0 <= t <= NT \quad (2)$$

The PAPR of the transmitted signal is defined as:

$$PAPR = \frac{\max |x(t)|^2}{E[|x(t)|]^2} \quad (3)$$

Reducing the *max|x(t)|* is the principle goal of PAPR reduction techniques. Since, discrete- time signals are dealt with in most systems, many PAPR techniques are implemented to deal with amplitudes of various samples of *x(t)*. Due to symbol spaced output in the first equation, some of the peaks missing can be find which can be compensated by oversampling the equation by some factor to give the true PAPR value.

IV. PAPR REDUCTION TECHNIQUES

PAPR reduction techniques vary according to the requirement of the system and are dependent on various factors such as PAPR reduction capacity, increase in transmit signal power, loss in data rate, complexity of computation and increase in the bit-error rate at the receiver end are various factors which are taken into account before adopting a PAPR reduction technique of the system.

Many techniques have been suggested for PAPR reduction, with different levels of success and complexity. The interested reader is referred to the survey by Han and Lee and other papers for further reading. A few well-known and analysed techniques will be summarized in the subsequent sections.

A. Clipping

Amplitude clipping is considered as the simplest technique which may be under taken for PAPR reduction in an OFDM system. A threshold value of the amplitude is set in this case to limit the peak envelope of the input signal. Signal having values higher than this pre-determined value are clipped and the rest are allowed to pass through un-disturbed:

$$\mathbf{B(x)} = \left\{ \begin{matrix} x, \\ Ae^{j\emptyset(x)}, \end{matrix} \right\} |\,\mathbf{x}\,| <= \mathbf{A} \qquad (4)$$

where, *B(x)* = the amplitude value after clipping.
x = the initial signal value.
A = the threshold set by the user for clipping the signal.

The problem in this case is that due to amplitude clipping, distortion is observed in the system which can be viewed as another source of noise. This distortion falls in both in-band and out-of-band. Filtering cannot be implemented to reduce the in-band distortion and error performance degradation is observed here. On the other hand, spectral efficiency is hampered by out-of -band radiation. Out-of-band radiation can be reduced by filtering after clipping but this may result in some peak re-growth. A repeated filtering and clipping operation can be implemented to solve this problem. The desired amplitude level is only achieved after several iteration of this process.

B. Block coding techniques

Block coding simply suggests using codes in a given coding technique which have a low PAPR. For example, consider an R (3, 4) coding technique and input code words of 6 bits in length. There are 256 possible output code words out of which, say, 150 code words have low PAPR. Thus, smaller input words can be handled, which can be mapped into one of those 6 bit inputs which generate the low PAPR code words. The obvious side-effect of this technique is to reduce coding efficiency. Even more problematic is that a general search of a large code-word space to compute the PAPR of each output code word is very expensive computationally; for large block codes it is simply out of the question. It has been found that Golay complementary codes have very attractive PAPR (almost 2) and it is possible to generate golay complementary code pairs from ordinary Reed-Muller block codes. However, this technique is severely limited in that it can only handle a small number of sub-carriers and is thus not frequently used [4].

C. Techniques based on phase shifting

Tarokh and Jafarkhani propose a method where, instead of transmitting S, they transmit SΦT where Φ is a vector of optimally chosen phase shift angles $\{\emptyset_0, \emptyset_1, \ldots, \emptyset_{M-1}\}$. There is no direct method for computing the optimal phase shift vector Φ; however, there are iterative algorithms to compute them for different modulation techniques. Tarokh and Jafarkhani have reported results for 48 sub-carriers, which in practice is a fairly good block size for OFDM type systems. The authors demonstrate a PAPR reduction of 4.22dB for 8PSK modulation. Phase shifting can also be done in blocks, instead of individual sub-carriers. This technique also goes by the name partial transmit sequences. In this technique, S is broken into a set of blocks, $\{S_0, S_1, \ldots, S_{c-1}\}$ of size k = S/C , and then the entire block is weighted using an optimal weight vector B ={b0, b1, …., bc–1}. Block partitioning can be interleaved, adjacent, or pseudo-random. The obvious bottleneck is again the search time taken to find an optimal weight vector. To reduce the possible number of combinations, the phase shift values are taken from P = ej2□l/c, l = 0, 1.., c–1. This also means that the side-information to be transmitted about the phase shifts used is limited to clog (l). For l = 0, there is no shift. One technique, called iterative flipping, works as follows:

Start with an initial vector {1,1,1,1,1,1,1} Fix the first value b0 to 1, and then search for optimal setting for the second value b1, which yields the lowest PAPR.

After finding the optimal value of b1, fix it and go on to b2. For c=2, the second term is obtained by flipping the sign of the first term, hence the term iterative flipping. This method is a heuristic search and obviously does not give the global optimum. Han and Lee have suggested an improvement where instead of changing just one index at one time, they search for the optimum out of all possible vectors with up to r changes from the current one i.e. a Hamming Distance of r.

An alternative to this method, known as Selective Mapping is to construct K different phase shift vectors $\Psi_m = \{\psi_{0m}, \psi_{1m}, \ldots \psi_{mM-1}\}$. For each input block of N symbols, K candidate blocks are generated by multiplying the input block with the k possible sets of phase shifts Ø * k. The output block S Ø k* T with the least PAPR is transmitted. Here k* is the index of the optimal phase shift vector for this particular input block [4]. In all the above techniques, it is necessary to transmit side information to the receiver about the transformation affected on the original block. This side information is an overhead, since it consumes bandwidth and energy to transmit it. .

V. CONCLUSION

Multicarrier systems are proving better in transmission than single carrier systems. OFDM is a digital multi-carrier modulation method where a large number of closely spaced orthogonal sub-carriers are used to carry data. High PAPR ratio results in many drawbacks of the multi-carrier systems. Thereby, many PAPR reduction techniques such as clipping, block coding techniques along with phase shifting techniques have been discussed in this paper.

REFERENCES

[1] W.R. Davis, N. Zhang, K. Camera, D. Markovic´, T. Smilkstein, M.J. Ammer, E. Yeo, S. Augsburger, B. Nikolic´, and R.W. Brodersen, "*A Design Environment for High Throughput, Low Power Dedicated Signal Processing Systems*," IEEE Journal of Solid State Circuits, vol. 37, no. 3, pp. 420-431, March 2002.

[2] J.E. Volder, "The *CORDIC Trigonometric Computing Technique*," IRE Transactions on Electronic Computers, vol. 8, no. 3, pp. 330-334, 1959.

[3] J. G. Proakis and M. Salehi, "*Communication Systems Engineering*," New Jersey: Prentice Hall, 1994.

[4] S.C. Thompson, "*Constant envelope OFDM phase modulation: spectral containment, signal space properties and performance*," Military Communications Conference, MILCOM 2004, vol. 2, pp. 1129-1135, 2004.