ISSN No: 2309-4893
International Journal of Advanced Engineering and Global Technology
Vol-2, Issue-8, August 2014

PAPR Reduction Techniques In OFDM Systems

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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 communications. Signals, which were initially sent in the analog domain, are being sent more and more in the digital domain these days. 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 commonly. In the OFDM system, orthogonally placed sub carriers are used to carry the data from the transmitter end to the receiver end. Presence of guard band in this system deals with the problem of inter symbol interference (ISI) and noise is minimized by larger number of sub carriers. But the large Peak to Average Power Ratio of these signal have some undesirable effects on the system. In this thesis we have focused on learning the basics of an OFDM System and have undertaken clipping and filtering method to reduce the PAPR in the system so that this system can be used more commonly and effectively, Since the very genesis of man, communication has been one of the main aspects in human life .Previously various methods like sign languages were implemented for this purpose. As various civilizations started coming into existence, many innovative ideas came to the minds of the people special birds and human messengers were employed to meet these challenges. As ages rolled by, post system developed and transportation vehicles like trains and ships were used to maintain link between people miles apart. But by the turn of the nineteenth century, a great leap in communication system was observed when wireless communication was introduced. After the advent of wireless communication huge change has been observed in the lifestyle of people. Wireless communication which was initially implemented analog domain for transfer has is now a days mostly done in digital domain. Instead of a single carrier in the system multiple sub carriers are implemented to make the process easier.

Keywords: — orthogonal frequency division multiplexing, peak-to-average power ratio, nonlinear power amplifier.

1. Introduction

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 communications. Signals, which were initially sent in the analog domain, are being sent more and more in the digital domain these days. 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 commonly. In the OFDM system, orthogonally placed sub carriers are used to carry the data from the transmitter end to the receiver end. Presence of guard band in this system deals with the problem of inter symbol interference (ISI) and noise is minimized by larger number of sub carriers. But the large Peak to Average Power Ratio of these signal have some undesirable effects on the system. In this thesis we have focused on learning the basics of an OFDM System and have undertaken clipping and filtering method to reduce the PAPR in the system so that this system can be used more commonly and effectively. Since the very genesis of man, communication has been one of the main aspects in human life .Previously various methods like sign languages were implemented for this purpose. As various civilizations started coming into existence, many innovative ideas came to the minds of the people special birds and human messengers were employed to meet these challenges. As ages rolled by, post system developed and transportation vehicles like trains and ships were used to maintain link between people miles apart. But by the turn of the nineteenth century, a great leap in communication system was observed when wireless communication was introduced. After the advent of wireless communication huge change has been observed in the lifestyle of people. Wireless communication which was initially implemented analog domain for transfer has is now a days mostly done in digital domain. Instead of a single carrier in the system multiple sub carriers are implemented to make the process easier.

The modern day phenomenon of increased thirst for more information and the explosive growth of new multimedia wireless applications have resulted in an increased demand for technologies that support very high speed transmission rates, mobility and efficiently utilize the available spectrum and network resources. OFDM is one of the best solutions to achieve this goal and it offers a promising choice for future high speed data rate systems [1], [2]. OFDM has been standardized as part of the IEEE 802.11a and IEEE 802.11g for high bit rate data transmission over wireless LANs [3]. It is incorporated in other applications and standards such as digital audio broadcasting (DAB), digital video broadcasting (DVB), the European HIPERLAN/2 and the Japanese multimedia mobile access communications (MMAC) [4], [5]. Also, OFDM is the transmission scheme of choice in the physical layer of the worldwide interoperability for microwave access (Wi MAX) and long term evolution (LTE) standards. It has also been used by a variety of commercial applications such as digital subscriber line (DSL), digital video broadcast handheld (DVB-H) and Media FLO [6]. OFDM was first presented in the late 1950's and characterized in the mid 1960's [7], [8]. OFDM converts the frequency selective fading channel into multiple flat fading sub channels, thereby allows the use of simple frequency domain equalizers to overcome the problem. However, OFDM introduces inter symbol interference (ISI) and inter carrier interference (ICI). ISI is the effect adjacent OFDM symbols exert on each other due to delay spread and ICI is the effect subcarriers exert on each other. Both of these problems can be reduced significantly by introducing a guard interval between OFDM symbols.

This interval is a cyclic extension of the signal itself concatenated at the beginning of the OFDM symbol, called the cyclic prefix (CP). Detailed discussion of the problems of ISI and ICI and the mitigation techniques used to overcome them are beyond the scope of this survey and will not be discussed further. In the future, OFDM systems are expected to assume greater importance in high speed wireless telecommunications systems, both fixed and mobile. The evolution of the physical layer of such high speed networks points to the use of OFDM systems with a large number of subcarriers with potentially high PAPR. Consequently, mitigation solutions are expected to gain increased interest and spur further research. Although the topic of PAPR reduction has been surveyed in the literature [9]–[12], this survey offers both deeper and wider coverage and includes the most recent literature related to the topic, compared with all the previous surveys. The paper also provides several original contributions via simulation results, complexity analyses and insights into the transmitted power constraint.

Therefore, this survey is well suited to serve as an all in one information source to the topic of PAPR reduction in OFDM systems. Its comprehensive and thorough treatment of the topic makes the paper a valuable tool to new researchers who wish to acquire wide knowledge as well as a categorized guide to extensive contributions available in the literature. This rest of this survey is organized as follows: reviews the basic concepts of conventional OFDM system. presents the PAPR metric and other factors considered in evaluating the performance of PAPR reduction methods.

2. OFDM SYSTEM MODEL AND NOTATION

OFDM system is multi carrier system. The rapid growth in multimedia based applications has triggered an insatiable thirst for high data rates and hence increased demand on OFDM based wireless system that can support high data rates and high mobility. As

ISSN No: 2309-4893
International Journal of Advanced Engineering and Global Technology
Vol-2, Issue-8, August 2014

the data rates and mobility supported by the OFDM system increase, the number of subcarriers also increases, which in turn leads to high Peak To Average Power Ratio (PAPR). OFDM is a multicarrier modulation technology which is used in broadband wireless communication systems like Digital Video Broadcasting (DVB), Digital Audio Broadcasting (DAB) and future 4G systems. It's positive aspects are,

- Immunity to frequency selective fading channels.
- Multipath delay spread tolerance.
- Spectral bandwidth efficiency.

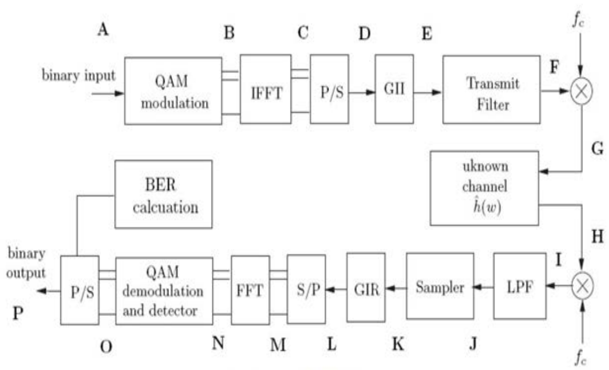

Figure: 1 OFDM Transmitter and Receiver

From above block diagram(Figure: 1) the modelling techniques involved in land mobile systems have also many similarities with those used in other area coverage systems such as sound and TV broadcasting. The convergence of two-way and broadcast, as well as of mobile and fixed systems is making such systems almost indistinguishable, as they try to aim at the same users with offerings of similar services. The similarities between fixed and mobile wireless channels over the frequency bands of interest not only include the mechanisms giving rise to path loss, but also they are subjected to shadowing and multipath effects even though these are normally much milder. Depending on the location and the BS or access point height, cells of larger or smaller size can be created. The classical cellular environment of tall masts above rooftops gives rise to so-called microcells. Propagation in these conditions will take up most of the discussion in this chapter and most of this book. As the BS antenna height becomes smaller and is below the surrounding rooftops, so-called microcells are generated. BSs within buildings give rise to piccolos. Man-made structures [3] such as buildings or small houses in suburban areas, with sizes ranging from a few meters to tens of meters, dramatically influence the wireless propagation channel. In urban areas, the size of structures can be even larger. Likewise, in rural and suburban environments, features such as isolated trees or groups of trees, etc. may reach similar dimensions. These features are similar or greater in size than the transmitted wavelength (metric, dissymmetric, cent metric waves) and may both block and scatter the radio signal causing secular and/or diffuse reflections. These contributions may reach MS by way of multiple paths, in addition to that of the direct signal. In many cases, these echoes make it possible that a sufficient amount of energy reaches the receiver, so that the communication link is feasible. This is especially so when the direct signal is blocked. Hence, in addition to the expected distance power decay, two main effects are characteristic in mobile propagation: shadowing and multipath.

We can identify three levels in the rate of change of the received signal as a function of the distance between BS and MS, namely, very slow variations due to range, slow or long-term variations due to shadowing and fast or short-term variations due to multipath.

The frequencies used in mobile communications are normally above 30MHz and the maximum link lengths do not exceed 25 to 30 km. Macro cells in current 2G (second generation, e.g., GSM) or 3G (third generation, e.g., UMTS) systems are much smaller. It must be taken into account that mobile communications are two-way and that the uplink (MS to BS) is power limited. This is especially so in the case of regular portable, handheld terminals. Furthermore, mobile system coverage ranges are short due to the screening effects of the terrain and buildings in urban areas. This makes frequency reuse possible at relatively short distances. This is also an important feature in mobile networks which require a great spectral efficiency for accommodating larger and larger numbers of users.

Currently 3G wireless systems are being deployed in the 2 GHz band while wireless LANs are beginning to be deployed in the 5 GHz band while, still, the 2.4 GHz band is the most popular for this application. Fixed access systems in licensed bands with ranges of several km to a few tens of km are being deployed in the 3.5 GHz band in Europe while in the Americas their assigned band is closer to 2 GHz. The 5 GHz band will also be used in unlicensed fixed access network applications. Very promising, short-range systems are being proposed at higher frequencies such as in the neighborhood of 60 GHz where gaseous absorption mechanisms dominate.

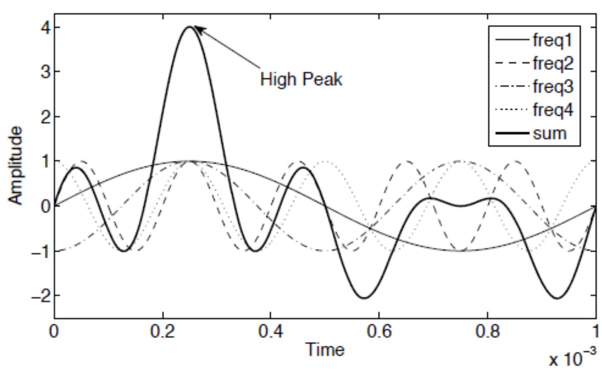

Figure: 2 High peaks in OFDM signal generated by summing multiple sinusoids

Two representative and extreme scenarios may be considered:

(a) The case where a strong direct signal is available together with a number of weaker Multipath echoes, i.e. line-of-sight (LOS) conditions; and
(b) The case where a number of weak multipath echoes is received and no direct signal is Available, non line-of-sight (NLOS) conditions.

Case (a) occurs in open areas or in very specific spots in city centres, in places such as crossroads or large squares with a good visibility of BS. Sometimes, there might not be a direct LOS signal but a strong seculars reflection off a smooth surface such as that of a large building will give rise to similar conditions. This situation may be modelled by a Rice distribution for the variations of the received RF signal envelope: the Rice case. Under these conditions, the received signal will be strong and with moderate fluctuations.

Case (b) will typically be found in highly built-up urban environments. This is a worst case scenario since the direct signal is completely blocked out and the overall received signal is only due to multipath, thus being weaker and subjected to marked variations. The received field strength or the received voltage may be represented in the time domain, r(t), or in the traveled distance domain, r(x).

2.1 CONVOLUTION

Convolution is the process by which the output of a system can be determined. One of the signals is time reversed, shifted, multiplied with another signal and finally integrated to generate the output signal in this process. Mathematically, it is represented as

$$w(t) = v(t) \otimes h(t) = \int_{-\infty}^{+\infty} v(\tau)h(t-\tau)d\tau$$

2.2 DISCRETE FOURIER TRANSFORM

In many occasions signals are available in a set of *N* sample values, taken at regularly spaced intervals, $T_S$over a time period of T_0. So it is desirable to have some approximate idea about the signal spectral content by interpreting its interval space and time period. For this, it is assumed that the signal is periodic (time period T_0.) and the Nyquist criterion is satisfied for sampling period. For simplicity, even number of samples are assumed and symmetrically placed across the origin. The location of sample values are $\pm T_S/2$, $\pm 3T_S/2$ etc. If the waveform to be sampled is *m(t)*, we obtain *m(t)S(t)* after sampling, where S(t) is the sampling function. The amplitude of the spectrum of *m(t)S(t)* is given by:

$$M_n = \frac{1}{T}\int_{-T_0/2}^{T_0/2} m(t)e^{-j2\pi nt/T_0}dt$$

Similarly, the value of M_N can be computed for all *N* samples. The period of the highest frequency component should be $2T_S$. Orthogonal Frequency Division Multiplexing is a special form of multicarrier modulation which is particularly suited for transmission over a dispersive channel. Here the different carriers are orthogonal to each other, that is, they are totally independent of one another. This is achieved by placing the carrier exactly at the nulls in the modulation spectra of each other.

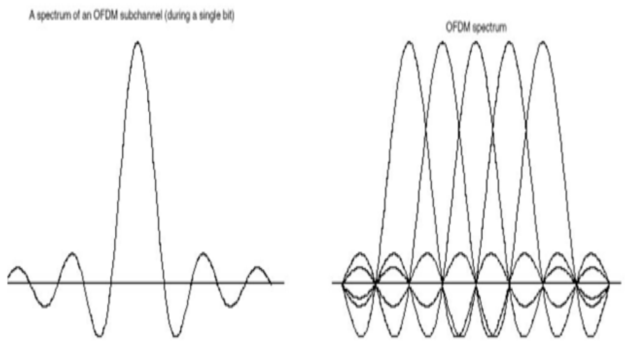

Figure: 3 OFDM Spectrum

2.3 ORTHOGONALITY

Two periodic signals are orthogonal when the integral of their product over one period is equal to zero.

For the case of continuous time:

$$\int_0^T \cos(2\pi n f_0 t)\cos(2\pi m f_0 t)dt = 0,$$

For the case of discrete time:

$$\sum_{k=0}^{N-1} \cos\left(\frac{2\pi kn}{N}\right)\cos\left(\frac{2\pi km}{N}\right)dt = 0,$$

where *m≠n* in both cases.

2.4 INVERSE DISCRETE FOURIER TRANSFORM

By working with OFDM in frequency domain the modulated QPSK data symbols are fed onto the orthogonal sub-carriers. But transfer of signal over a channel is only possible in its time-domain. For which we implement IDFT which converts the OFDM signal in from frequency domain to time domain. IDFT being a linear transformation can be easily applied to the system and DFT can be applied at the receiver end to regain the original data in frequency domain at the receiver end. Since the basis of Fourier transform is orthogonal in nature we can implement to get the time domain equivalent of the OFDM signal from its frequency components. Usually, in practice instead of DFT and IDFT we implement Fast Fourier Transformation for an N-input signal system because of the lower hardware complexity of the system.

2.5 ADVANTAGES & DISADVANTAGES OF AN OFDM SYSTEM

- **Advantages**

➢ Due to increase in symbol duration, there is a reduction in delay spread. Addition of guard band almost removes the ISI and ICI in the system.

➢ Conversion of the channel into many narrowly spaced orthogonal sub carriers render it immune to frequency selective fading.

➢ As it is evident from the spectral pattern of an OFDM system, orthogonally placing the sub carriers lead to high spectral efficiency. Can be efficiently implemented using IFFT.

- **Disadvantages**

➢ These systems are highly sensitive to Doppler shifts which affect the carrier frequency offsets, resulting in ICI.

➢ Presence of a large number of sub carriers with varying amplitude results in a high Peak to Average Power Ratio (PAPR) of the system, which in turn hampers the efficiency of the RF amplifier.

3. PEAK TO AVERAGE POWER RATIO

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.

$$\mathrm{PAPR}(a_n) \triangleq \frac{\max\limits_{0\le n\le N-1} |a_n|^2}{P_{av}(a_n)}$$

$$P_{av}(a_n) = \frac{1}{N}\sum_{n=0}^{N-1} \mathrm{E}\{|a_n|^2\}$$

The major disadvantages of a high PAPR are

1. Increased complexity in the analog to digital and digital to analog converter.

2. Reduction is efficiency of RF amplifiers.

Large PAPR leads to damage of High Power Amplifier (HPA). Reduction of PAPR improves life span of HAP. High PAPR of OFDM signals, especially with higher carrier frequencies and higher order modulations brings new challenges for its implementations. High PAPR demands HPA with better efficiency. Hence, PAPR should be maintained as low as possible. To reduce PAPR Different Techniques are available.

3.1 PAPR REDUCTION TECHNIQUES

PAPR reduction techniques vary according to the needs of the system and are dependent on various factors. PAPR reduction capacity, increase in power in transmit signal, 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.

The PAPR reduction techniques on which we would work upon and compare in our later stages are as follows.

3.2 DIFFRENT TYPE OF PAPR REDUCTION TECHNIQUES

- **CLIPPING AND FILTERING:** A threshold value of the amplitude is set in this process and any sub-carrier having amplitude more than that value is clipped or that sub carrier is filtered to bring out a lower PAPR value.
- **SELECTIVE MAPPING:** In this a set of sufficiently different data blocks representing the information same as the original data blocks are selected. Selection of data blocks with low PAPR value makes it suitable for transmission.
- **PARTIAL TRANSMIT SEQUENCE:** Transmitting only part of data of varying sub-carrier which covers all the information to be sent in the signal as a whole is called Partial Transmit Sequence Technique.
- **TONE INJECTION:** In this technique the constellation size is increased so that each point in the original complex plane constellation is mapped onto several other points in the expanded constellation prior to IDFT processing. This extra degree of freedom facilitates a reduction in PAPR. Substituting a point in the original constellation for one in the expanded one is equivalent to injecting a tone with proper frequency and phase to the OFDM signal and hence the name of this method.

4. CLIPPING AND FILTERING

One of the simplest signal distortion methods is the method of clipping the high peaks of the OFDM signal prior to passing it through the PA. This method employs a clipper that limits the signal envelope to a predetermined clipping level (CL) if the signal exceeds that level otherwise, the clipper passes the signal without change [71], as defined by,

$$T(x[n]) = \begin{cases} x[n] & \text{if } |x[n]| \le CL \\ CL\ e^{j\angle x[n]} & \text{if } |x[n]| > CL\ , \end{cases}$$

Where x[n] is the OFDM signal, CL is the clipping level and ∠x[n] is the angle of x[n]. Clipping is a nonlinear process that leads to both in band and out of band distortions [8]. While the latter one causes spectral spreading and can be eliminated by filtering the signal after clipping, the former can degrade the BER performance and cannot be reduced by filtering [5]. However, oversampling by taking longer IFFT can reduce the in band distortion effect as portion of the noise is reshaped outside of the signal band that can be removed later by filtering.

Form the Figure 4 filtering the clipped OFDM signal can preserve the spectral efficiency by eliminating the out of band distortion and, hence, improving the BER performance but it can lead to peak power re growth. References [2], [5], [12] propose various repeated clipping-filtering procedures to reduce the overall peak power re growth. In [53], the authors investigate the effect of clipping on the performance of OFDM systems for a frequency selective fading channel. The impact of clipping on PAPR reduction and channel capacity is studied in [5]. Reference [2] presented a modified repeated clipping and filtering scheme which limits the distortion on each tone of the OFDM to achieve both low PAPR and low BER with fast convergence. In [3], the authors developed an optimized repeated clipping and filtering method which determines an optimal frequency response filter for each iteration using convex optimization.

The filter is designed to minimize signal distortion such that the PAPR is below a specified threshold. The authors claimed that the method achieves a desired PAPR reduction after only 1 or 2 iterations, whereas the conventional clipping and filtering method requires about 8 to 16 iterations to achieve a similar PAPR reduction. To demonstrate the effect of clipping on BER, we have conducted computer simulations, the results from which are shown in Fig. (9). OFDM symbols of 1024 subcarriers are considered in our simulations with a symbol structure that follows the Wi MAX standard in the down link partial use subcarrier (DL-PUSC) mode. Data subcarriers are modulated with QPSK data symbols and no coding or any other form of diversity is considered. The SSPA model is used with p = 2 and xsat ≈ max|x[n]|.

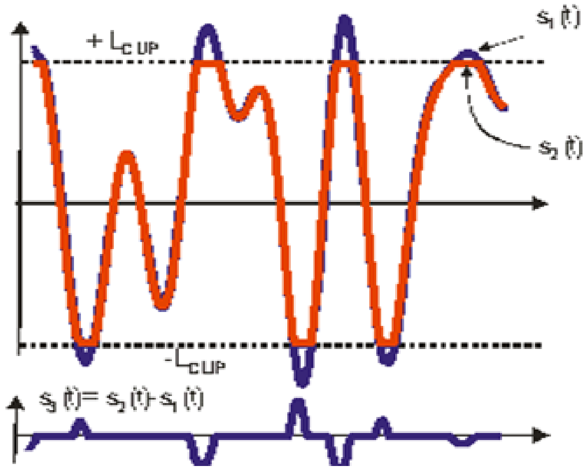

Figure: 4 Clipping and Filtering of Signal

The Stanford university interim (SUI)-1 fading channel model [4] is used and additive white Gaussian noise (AWGN) is added. At the receiver, perfect channel estimation is assumed. The simulations are conducted for the OFDM signal without clipping and when clipping is used with a clipping ratio (CR) of 1dB and 5dB. The CR is related to the clipping level by the expression

$$CR = 20\log_{10}\left(\frac{CL}{E[x[n]]}\right)$$

where E[x[n]] is the average of the OFDM signal x[n]. The results presented in Fig. 9 show that as the CR is reduced, the CL is lowered down and more parts of the OFDM signal are clipped and hence, the BER is increasing and the empirical CCDF is decreasing. Below we can showing the output wave form of the Clipping and Filtering PAPR reduction technique.

ISSN No: 2309-4893
International Journal of Advanced Engineering and Global Technology
Vol-2, Issue-8, August 2014

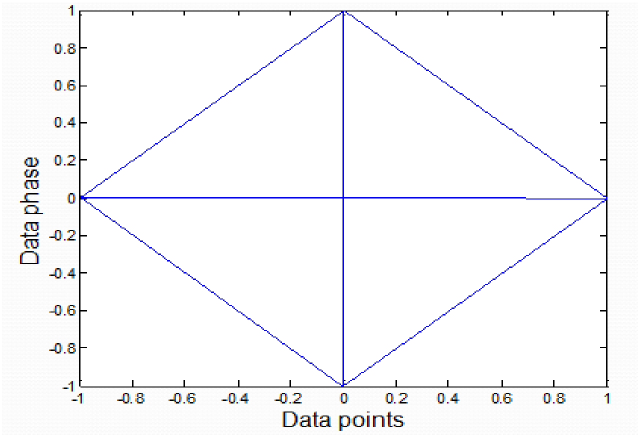

Figure: 5 Modulated data

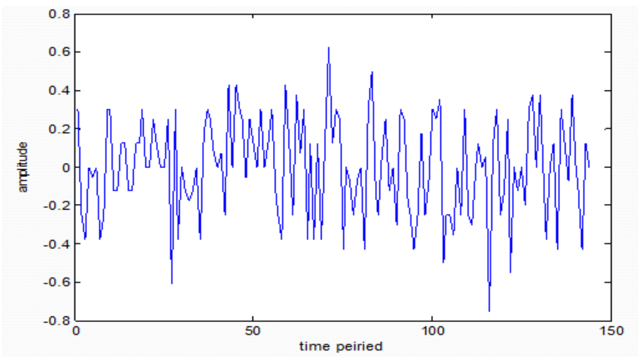

Figure: 6 OFDM signal generated

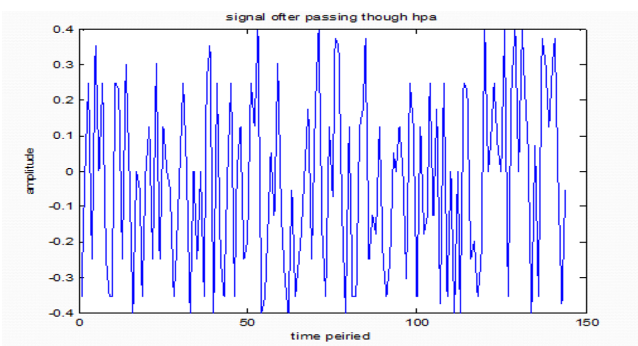

Figure: 7 signal after PAPR reduction (Clipped signal)

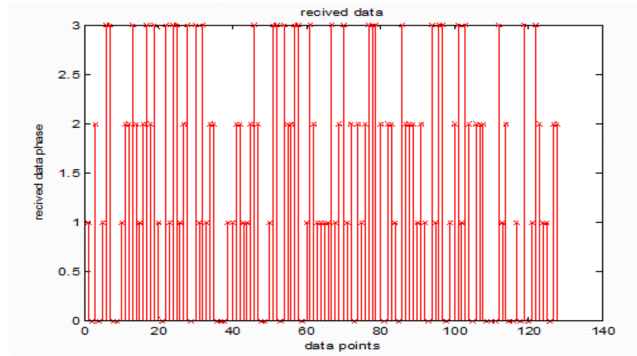

Figure: 8 Received data

5. SELECTIVE MAPPING

Selective mapping (SLM) is a relatively simple approach to reduce PAPR. The basic idea is to generate a set of sufficient different OFDM symbols x(m),$0 \leq m \leq M-1$, each of length N, all representing the same information as the original OFDM symbol x, then transmit the one with the least PAPR [2], [3]. Mathematically, the transmitted OFDM symbol ˜x is represented as

$$\tilde{x} = \arg\min_{0 \leq m \leq M-1} \left[PAPR\left(x_{(m)}\right) \right]$$

The OFDM symbols set can be generated by multiplying the original data block X = [X1 X2 . . . XN], element by element, by M different phase sequences pm, each of length N, prior to performing IDFT. These phase sequences are represented as

$$p_m = \left[e^{j\varphi_{m,1}}\ e^{j\varphi_{m,2}}\ \ldots\ e^{j\varphi_{m,N}} \right],\ 0 \leq m \leq M-1,$$

Where ϕm,k takes values between 0 and 2π, excluding 2π,i.e., ϕm,k ∈ [0, 2π) for k = 1, 2, . . . ,N. Then the modified OFDM symbol x(m), $0 \leq m \leq M-1$, is the IDFT of the element-by-element multiplication of X and Pm.

$$x_{(m)} = IDFT\left[X_1 e^{j\varphi_{m,1}}\ X_2 e^{j\varphi_{m,2}}\ \ldots\ X_N e^{j\varphi_{m,N}} \right].$$

If QAM symbols are used as input to the OFDM system, this multiplication has the effect of rotating data symbols within the QAM constellation. A block diagram of the SLM technique is depicted in Fig. 15. For implementation simplicity, the phase sequences pm can be set to {±1,±j} as these values can be implemented without multiplication. The extent of PAPR reduction achieved depends on the number of generated phase sequences M and the design of these sequences [9]. Information about the selected phase sequence should be transmitted to the receiver as side information to allow the recovery of original symbol sequence at the receiver, which

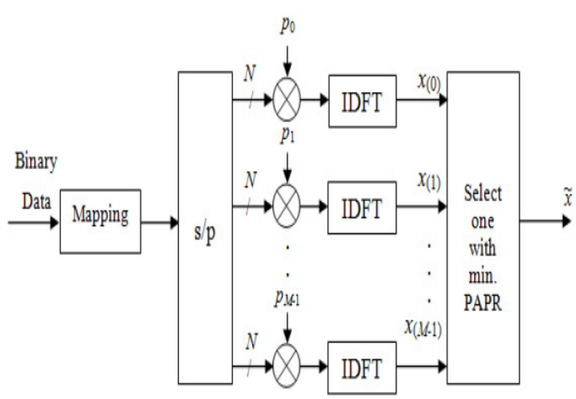

Figure: 9 Block diagram of OFDM transmitter with SLM

Form above Figure 9 reduces the data transmission rate. SLM needs to transmit [log2M] bits as side information, where [y] denotes the smallest integer that does not exceed y, and M IDFT operations for each data block. Moreover, the phase sequences pm, 0 ≤ m ≤ M−1, need to be stored at both the transmitter and receiver. An erroneous detection of the side information causes the whole OFDM symbol to be recovered incorrectly.

Therefore, strong protection of the side information is required resulting in more loss of data transmission rate. To avoid the need for transmitting side information, several blind SLM schemes have been studied [84]–[88]. Among these, the maximum likelihood decoder is derived for the scheme in [7], which shows the same BER performance as the conventional SLM scheme assuming perfect side information recovery but causes large decoding complexity at the receiver. In [9], a blind SLM scheme with low decoding complexity was proposed in which the side information is embedded into each phase sequence by giving the phase offset to the elements of the phase sequence, which are determined by the bi orthogonal vectors for the partitioned sub blocks. A maximum likelihood decoder with low decoding complexity was derived for the proposed scheme, which reduces the decoding complexity by (M − 2)/M compared with the conventional blind SLM scheme in [7]. Also, it was shown that for QPSK and 16-QAM that the BER of the scheme is almost the same as that of the conventional blind PTS in [8].The optimization process of selecting the best out of M OFDM signals may not be computationally feasible if the size of the OFDM blocks is large, and more importantly, if the number of phase sequences M is increased, which is required to achieve a substantial PAPR reduction [9]. Many attempts have been made to address the problem of increased computational complexity incurred by the conventional SLM when a substantial PAPR reduction is required. Reference [9] proposed two reduced complexity SLM schemes.

The first scheme substitutes the M-IFFT blocks with one IFFT block and a conversion matrix, to produce the M − 1 permutations of the OFDM signal from the output of the single IFFT block. The second uses two IFFT blocks with a conversion matrix. Considering an OFDM system with LN-point IFFT block, where L is the oversampling factor, the first scheme reduces the computational complexity required for the original M − 1LN-IFFT blocks to (M − 1) × 3LN complex additions. The second scheme reduces the computational complexity required for the original M −2LN-IFFT blocks to (M − 2) × 3LN complex additions. This gain in complexity is achieved at the cost of a slight degradation in PAPR reduction for the first scheme, and almost a negligible degradation for the second scheme. One further refinement was presented in [1] to ensure that the elements of the phase rotation vectors, composing the conversion matrix in [9], have an equal magnitude by giving them the form of a perfect sequence. If the elements of the phase rotation vectors all have the same magnitude, the periodic autocorrelation function

(PACF) of the corresponding conversion vectors has the form

$$\sum_{m=0}^{N-1} g[m].g^*[(m-n)_N] = E.\delta[n], \quad 0 \le n \le N-1.$$

Where g[m] is the M element of the conversion vector, is the complex conjugate operation, (.)N denotes the modulo N operation, E is a constant and δ[n] is the delta function. Sequences which satisfy the above condition, are defined as perfect sequences.

The perfect sequences adopted are compositions of certain base vectors and their cyclically shifted equivalents. To reduce the computational complexity of the conversion process, two constraints are imposed: First, the maximum number of non-zero elements in the base vectors is limited to 4; Second, the non zero elements in the base vectors must belong to the set {±1,±j,±1 ± j}. Performing an exhaustive search, three classes of perfect sequence of length LN were identified. However, more perfect sequences can be obtained, if the above constraints are removed. Using these three perfect sequences, three reduced complexity SLM schemes are proposed and proved to achieve a substantial gain in complexity reduction with PAPR reduction performance loss no more than 0.2dB. In [2], a pilot phase sequence enabling data recovery without side information and a low complexity decoding scheme are proposed. The BER performance of the proposed scheme is approximately the same as that of the conventional SLM scheme with side information and considerably better than that of the Maximum Likelihood decoding scheme. In addition, the computational complexity of the proposed decoding scheme is much lower, as compared to the maximum likelihood decoding scheme. In [3], the authors proposed a low-complexity SLM scheme.

Which generates alternative OFDM signals by adding mapping sequences to the OFDM signal in time domain? The proposed scheme considerably reduces the computational complexity without sacrificing BER and PAPR reduction performance. In [94], the authors developed a set of conversion matrices for the SLM scheme based on some periodic properties of the IFFT matrix. Candidate signals are obtained via multiplying the time-domain OFDM signal by the conversion matrices. To reduce the complexity, both real and imaginary parts of the conversion matrices were restricted to the values {0,±1}. Therefore, the generation of candidate signals involves no complex multiplications. For an OFDM system with N subcarriers and L oversampling factor, the scheme uses one LN-point IFFT and 3LN complex additions to generate other candidate signals. Unfortunately, the number of valid candidate signals is restricted to 12, leading to a strictly limited PAPR reduction performance. This scheme is modified in [5] by dividing the frequency-domain signals into multiple sub-blocks to increase the number of the valid conversion matrices, and thus more candidate signals are available for PAPR reduction.

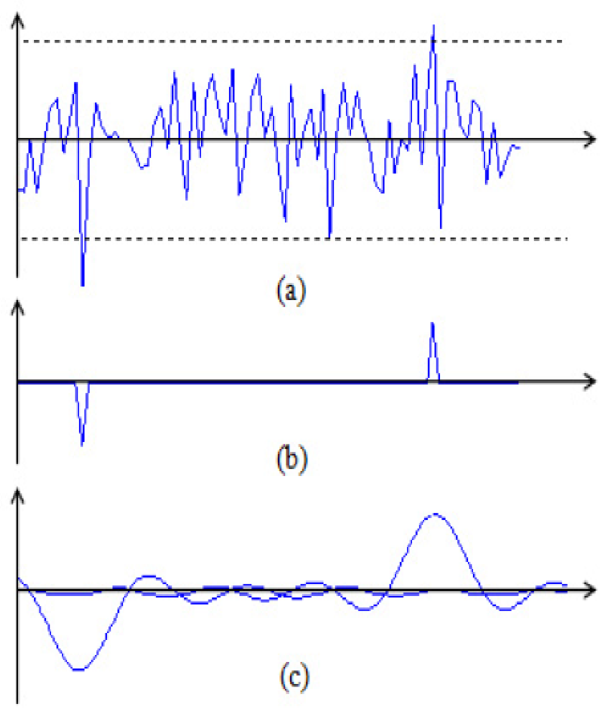

Figure: 10 Peak Cancellation (a) OFDM signal (b) Identified peak (c) scaled and shifted peak cancellation waveform

By applying this scheme, the number of candidate signals can be increased from 12 to 28 and 128 for the two sub-blocks and four-sub block cases, respectively. Another possible solution is the IFFT manipulation technique based on Radix-2 decimation in time IFFT [6], [7]. This method divides the decimation in time based IFFT into a common part and a remaining part, where the sum of the number of stages in both part is log2 N. In [8], a similar decimation in frequency IFFT scheme is proposed to reduce the computational complexity.

However, the problem with these methods is the trade-off between the computational complexity and the PAPR reduction capability. Reference [9] also suggested decimation in frequency IFFT scheme together with an interleave and butterfly ensemble to generate multiple candidates. Orthogonality in the frequency domain is kept and better PAPR reduction performance is achieved without additional complex multiplications. In [10], additional alternative OFDM symbols are generated through linear combinations of other alternative OFDM symbols. The Figure 11 shown the OFDM is multicarrier system for each carrier we can applying the different phase shift at the 11 point it shows low PAPR.

Therefore, the additional computational complexity due to the IFFT operations can be reduced while keeping the PAPR reduction performance similar to that of the conventional SLM scheme. The authors in [10] proposed a scheme which produces OFDM sequences by rotating the symbol phase using multiple all pass filters instead of the multiple complex multiplication modules and IFFT modules employed in the conventional SLM scheme.

This scheme avoids using the multiple IFFT modules that incur a heavy computational burden at the transmitter, thereby reducing the computational complexity. The reduction in complexity is however achieved at the cost of a slight degradation in PAPR reduction performance. For example, the proposed scheme with 8 first order all-pass filters for 2048 subcarriers OFDM system reduces the number of required multiplications by 69.2% and additions by 63.1% at a sacrifice of only 0.25 dB PAPR increase compared to the conventional SLM scheme with 8 IFFT modules.

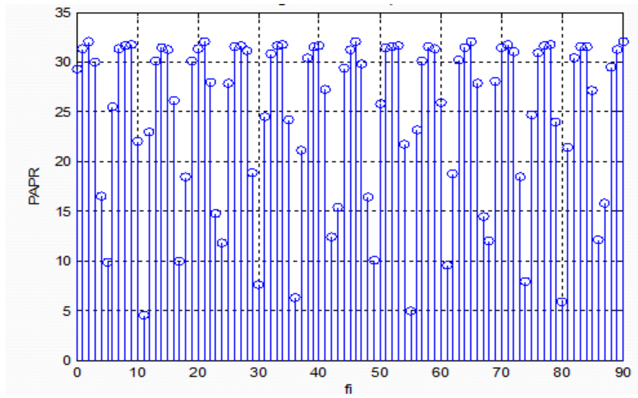

Figure: 11 PAPR with different phase shift

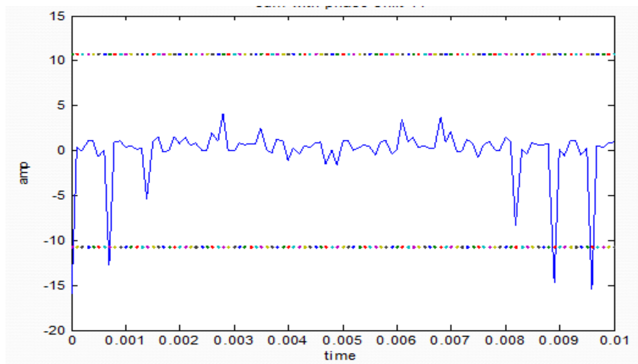

Figure: 12 Sum with phase shift

6. PARTIAL TRANSMIT SEQUENCE

In partial transmit sequence (PTS), an input data block of length N is partitioned into a number of disjoint sub-blocks. The IDFT for each one of these sub-blocks is computed separately and then weighted by a phase factor. The phase factors are selected in such a way as to minimize the PAPR of the combined signal of all the sub-blocks. Figure 13 shows a block diagram of the OFDM transmitter with PTS technique. Let an input data block, X = [X1 X2 . . . XN] be partitioned into M disjoint sub-blocks, Xm = [Xm,1 Xm,2 . . . Xm,N], 1 ≤ m ≤ M, such that any two of these sub-blocks are orthogonal and X is the combination of all the M sub-blocks

$$X = \sum_{m=1}^{M} X_m.$$

Then the IDFT for each sub-block, xm, 1 ≤ m ≤ M, is computed and weighted by a phase factor bm = ejϕm, where ϕm = [0, 2π), 1 ≤ m ≤ M. The objective now is to select the set of phase factors, bm's that minimizes the PAPR of the combined time domain signal x, where x is defined as

$$x = \sum_{m=1}^{M} b_m \, x_m.$$

In the process of selecting the optimum phase factors, search is usually limited to a finite number of elements to reduce search complexity [9]. Assume that the set of allowed phase factors is defined as bm = ej2πkW , where k = 0, 1, . . .,W − 1, and W is the number of allowed phase factors. The first phase factor b1 can be set to 1 without any loss of performance,therefore,M−1 phase factors are to be found by an exhaustive search [9]. Hence, WM−1 sets of phase factors are searched to find the optimum one. The reduction in PAPR attainable depends on M and W. On one hand, the larger is the number of sub-blocks M, the greater is the reduction in PAPR. On the other hand, the search complexity is increasing exponentially with M. In addition, M IDFT blocks are needed to implement the PTS scheme, requiring _log2W(M−1) bits of side information to be transmitted [9]. Another factor that affects PAPR is the type of partitioning employed.

Three kinds of partitioning schemes are prevalent: adjacent, interleaved, and pseudo-random partitioning [10]. Of these, pseudo random partitioning has been found to be the best choice. In the literature, various techniques are suggested to reduce the computational complexity of the PTS scheme and yet maintain a substantial reduction in PAPR. Reference [16] proposes a scheme that updates the set of phase factors iteratively till PAPR drops below a specified threshold. In [10], a simple iterative flipping algorithm is proposed to reduce the complexity of the PTS method by converging to a sub-optimal choice of the phase factors.

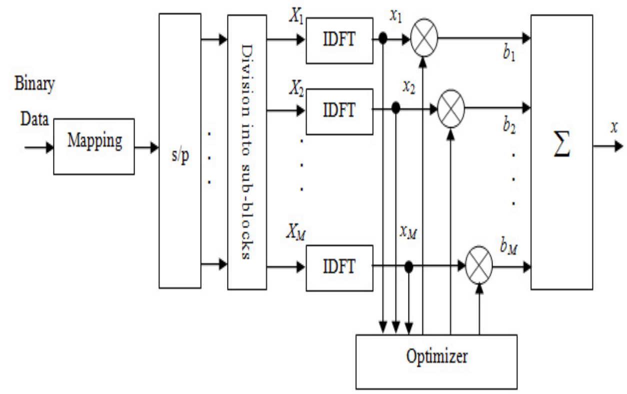

Figure: 13 Block diagram of OFDM transmitter with PTS

The phase factors are initially set to 1 and b1 remains 1 while the values of the other phase factors are chosen among all W possible values. In the first iteration, the second factor b2 is changed and the PAPR is computed. Then, the value of b2 which achieves the lowest PAPR is chosen as part of the final set of phase factors. The algorithm continues to work in the same manner till all phase factors are explored. In [10], algorithms are described for combining partial transmit sequences with reduced complexity and very little performance degradation. In [1] a gradient descent search for phase factors is proposed, which reduces search complexity at the expense of some performance degradation too. In [10], the authors proposed a PTS scheme based on listing the phase factors into multiple subsets table and utilizing the correlation among phase factors in each subset, in order to reduce the computational complexity. Reference [10] proposed a sign selection technique where a set of subcarrier signs is selected to significantly reduce the PAPR statistics for OFDM signals. To determine a good set of subcarrier signs with improved PAPR statistics while reducing the computational complexity of an exhaustive search over all combinations of sign patterns, the use of the quantum-inspired evolutionary algorithm (QEA) was proposed. QEA is an effective population based search algorithm that solves various combinatorial optimization problems. Other combinatorial optimization algorithms such as the artificial bee colony algorithm [11] and parallel tabu search algorithm [12] have been used to efficiently search a

ISSN No: 2309-4893
International Journal of Advanced Engineering and Global Technology
Vol-2, Issue-8, August 2014

good subset of phase rotating vectors for the PTS scheme to reduce the complexity.

An optimal search has been proposed in [13], where the computational complexity of the conventional PTS scheme is reduced by restricting the search among the alternative sequences inside a sphere by using sphere decoding algorithm. A PTS scheme with low computational complexity is proposed in [14], where two search steps are employed to find a subset of phase rotating vectors with good PAPR reduction performance. In the first step, sequences with low correlation such as Kasami sequences [15] or quaternary sequences of family A [16] are used as initial phase rotating vectors for PTS scheme. In the second step, local search is performed based on the initial phase vectors to find additional phase rotating vectors with good PAPR reduction performance. In [11], the authors propose a W-way tree based PTS scheme with low complexity, where the nodes in the tree correspond to phase factors and layers correspond to sub blocks. The calculation of candidate signals utilizes the structure of the tree by combining layers and weighting factors on the paths from the root to the leaves.

The scheme reduces complexity dramatically, whereas the PAPR reduction capability is kept as that achievable by the conventional PTS. Reference [12] proposed a PTS system based on selecting a phase sequence that maximizes the similarity between the input and output of the power amplifier model using the cross correlation as an optimized metric. A similar approach was proposed in [11] in which the distortion introduced by the nonlinearity of the power amplifier is predicted and then used to select the optimal phase sequences for the PTS or SLM methods. The adopted distortion metrics were the distortion to- signal power ratio (DSR) and the peak interference-to carrier ratio (PICR), which are predicted at the transmitter side after the IFFT. Figure 14 shows the output wave form of PTS.

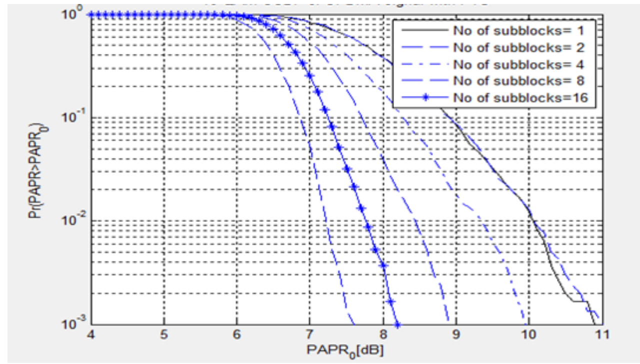

Figure: 14 QAM CCDF of OFDM signal with PTS

7. Tone Injection

Form the figure 15 in this technique the constellation size is increased so that each point in the original complex plane stellation is mapped onto several other points in the expanded constellation prior to IDFT processing. This extra degree of freedom facilitates a reduction in PAPR. Substituting a point in the original constellation for one in the expanded one is equivalent to injecting a tone with proper frequency and phase to the OFDM signal [9], and hence the name of this method. If a square QAM constellation is used with the original constellation size as M, and its points are spaced by d, then in order not to degrade the BER performance of the OFDM signal by using tone injection technique, the spacing between each original point in the original constellation and its equivalent points in the expanded constellation should be

$$D = \rho\, d \sqrt{M},$$

with $\rho \geq 1$. The kth QAM symbol on a single subcarrier with multiple constellation points is represented as

$$\tilde{X}_k = X_k + p_k\, D + q_k\, D,$$

where Xk is the kth original QAM symbol, pk and qk are integer numbers used to change the real and imaginary parts of Xk respectively, and they are chosen to reduce the PAPR [12]. Figure 16 graphically illustrates the tone injection procedure for 16-QAM constellation, where the original point labelled A maps to one of Ai's, i = 1, . . . , 8, from which possible values of p and q can be derived. Each one of these points is spaced by a distance D from A, where D is known to both transmitter and receiver.

One of these redundant points A1 to A8 is chosen for transmission in order to reduce PAPR of the transmitted signal. The PAPR reduction attainable using this method depends on the value of ρ in (3) and the number of modified symbols in the data blocks [9]. At the receiver, the symbol recovery process is carried out by applying a modulo-D operation to the received modulation symbol, which is then followed by the decoding process. Tone injection technique requires no side information at all and, consequently, there is no loss of bit rate. Also the complexity added at the receiver is negligible since only two modulo-D operations are required for the real and imaginary parts of the received symbol. Despite the advantages this method offers, it is weighed down by the increased complexity of the transmitter. Tone injection technique can reduce PAPR significantly at the expense of some increase in average signal power due to the use of enlarged signal constellation. It is possible to minimize this increase in power by appropriately remapping the signalling points or by carefully choosing the redundant constellation. References [13] and [11] proposes a tone injection technique with hexagonal constellation to achieve PAPR reduction with only a small power increase compared to the QAM constellation. It is possible to pack more regularly spaced signalling points using a hexagonal constellation than can be done with a QAM constellation of the same area.

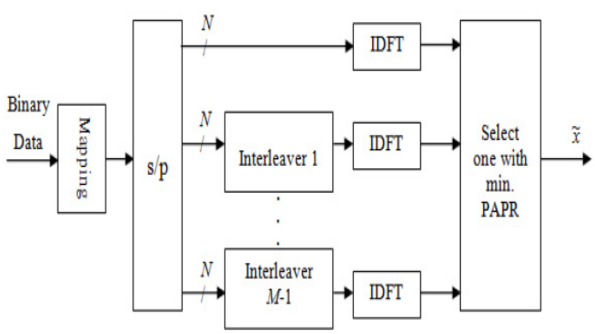

Figure: 15 Block diagram of Interleaved OFDM transmitter

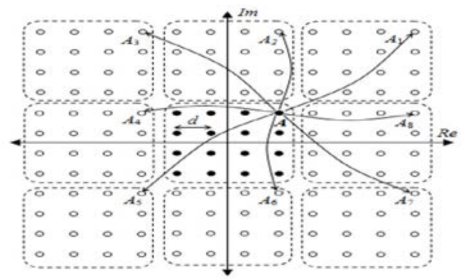

Figure: 16 Tone injection technique for 16-QAM constellation

7.1 CUMULATIVE DISTRIBUTION FUNCTION

The Cumulative Distribution Function (CDF) is one of the most regularly used parameters, which is used to measure the efficiency of any PAPR technique. Normally, the Complementary CDF (CCDF) is used instead of CDF, which helps us to measure the probability that the PAPR of a certain data block exceeds the given threshold. By implementing the Central Limit Theorem for a multi carrier 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 follow a Gaussian distribution. So Rayleigh distribution is followed for the amplitude of the multi carrier signal, where as a central chi square distribution with two degrees of freedom is followed for the power distribution of the system. The CDF of the amplitude of a signal sample is given by

$$F(z) = 1 - \exp(z)$$

The CCDF of the PAPR of the data block is desired is our case to compare outputs of various reduction techniques. This is given by

$$\begin{aligned} P(PAPR > z) &= 1 - P(PAPR \leq z) \\ &= 1 - F(z)^N \\ &= 1 - (1 - \exp(-z))^N \end{aligned}$$

ISSN No: 2309-4893
International Journal of Advanced Engineering and Global Technology
Vol-2, Issue-8, August 2014

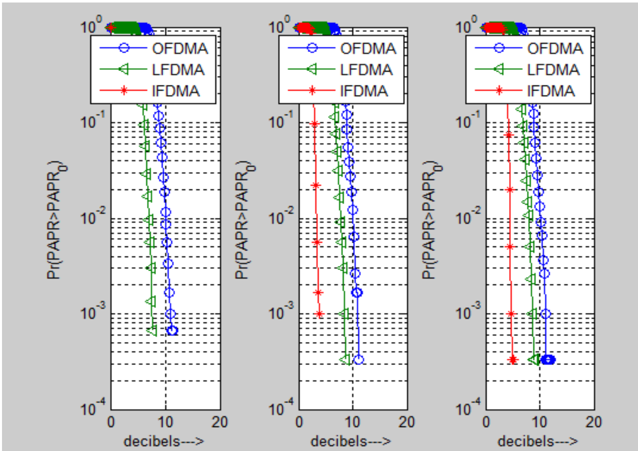

Figure: 17.CCDF of OFDMA, CCDF of LFDMA,CCDF of IFDMA

The above wave form shows the output of tone injection this extra degree of freedom can be exploited to reduce PAPR. At the same time, the power increase is less than that of the QAM constellation since signalling points in the hexagonal constellation will have average magnitude smaller than the corresponding average of the QAM constellation. Form the table 1 we comparing the four different PAPR Reduction techniques for that we calculating the different parameters shown below form that we can choose better PAPR reduction technique. A factor that influences the power increase is D. If D increases, the spacing between the redundant and original constellations increases, and hence the average transmits power increases. On the other hand, if D decreases, the original and redundant constellations move closer to each other, but not closer than a certain minimum distance separation between signalling points. Unfortunately, in this case the outermost points of the original constellation may have nearest neighbours that differ in more than one bit position. Consequently, the symbol error rate and hence the BER will increase.

Form the table we comparing the four different PAPR Reduction techniques for that we calculating the different parameters shown below form that we can choose better PAPR reduction technique. This undesirable effect can be alleviated by increasing D so that a sufficient separation between the original and redundant constellations is kept to ensure nearest neighbor points differ in just a single bit. This solution though increases the average transmit power.

Technique	Complexity	Distortion	Data Loss	Power Increase
Clipping and Filtering	No	Yes	No	No
Selective Mapping	Yes	No	Yes	No
Partial Transmit Sequence	Yes	No	Yes	Yes
Tone Injection	No	No	No	Yes

Table: 1 Comparison of PAPR reduction techniques

8. CONCLUSIONS

OFDM is an efficient multicarrier modulation technique for both wired and wireless applications due to its high data rates, robustness to multipath fading and spectral efficiency. Despite these advantages, it has the major drawback of generating high PAPR, which drives the transmitter's PA into saturation, causing nonlinear distortions and spectral spreading. The literature is rich with PAPR reduction techniques, which decrease PAPR substantially at the expense of increased BER, increased transmitted power, reduced bit rate, or increased complexity.

This survey has discussed many important aspects of PAPR reduction techniques and the impact of these techniques on a number of critical design factors. Some absolutely essential mathematical formulations were presented including the statistics of PAPR and the distribution of the OFDM signal. We demonstrated that no single technique is the best under all circumstances and the proper technique should be selected based on system requirements and available resources. For example, in OFDM systems with a large number of subcarriers ($N \geq 256$), signal distortion techniques and specifically clipping and filtering are the least demanding in terms of computational complexity, while achieving good PAPR reduction.

The subject of PAPR reduction assumes increased importance due to the fact that future wireless systems are likely to apply OFDM structures with higher number of subcarriers than present ones in order to achieve higher data rates and mobility. This implies that the problem of developing PAPR reduction schemes for OFDM systems that are capable of mitigating the problem with best performance tradeoffs, including minimum complexity and cost, is a rich subject with exciting possibilities for conducting further research.

Besides providing an extensive set of references to the subject of PAPR reduction techniques, this survey brings up to date previously available surveys with a treatment of most recent research as well as provides original contributions with simulations, complexity analyses, and a treatment of the topic under transmitted power constraint. The different available techniques and their trade-offs towards developing more efficient and practical solutions.

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