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Research Paper

Reduction of peak to average power ratio (PAPR) in orthogonal frequency division multiplexing (OFDM) system

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ABSTRACT: *In advance communication field there should be high data rate in addition to power efficiency and low bit error rate. This demand of high data rate can be fulfilled by single carrier modulation but compromising the trade-off between power efficiency and bit error rate. Again in the presence of selective fading environment it is difficult in case of single carrier modulation to achieve high data rate with low bit error rate performance. To overcome these problems advance step towards multicarrier modulation scheme is possible to get high data rate in this selective fading channel with low bit error rate performance. To achieve better performance using multi carrier modulation we make the subcarriers to be orthogonal to each other and the technique is called as the Orthogonal Frequency Division Multiplexing (OFDM). But the greatest disadvantage of the OFDM technique is its high Peak to Average Power Ratio (PAPR). Here in this paper we will describe how PAPR is increased and its reduction by SLM technique.*

Keywords: *OFDM, PAPR, Multicarrier modulation.*

I. INTRODUCTION

In multi-carrier modulation, the most commonly used technique is Orthogonal Frequency Division Multiplexing (OFDM). It has recently become very popular in wireless communication. As we know in single carrier system, a single fade causes the whole data stream to undergo into the distortion i.e frequency selective fading and also, single carrier is more sensitive to multipath. To overcome the frequency selectivity of the wideband channel experienced by single-carrier transmission, multiple carriers can be used for high rate data transmission. In multicarrier transmission, a single data stream is transmitted over a number of lower rate subcarriers. Ease of implementation, high spectral efficiency, resilience to impulse noise and multipath are few advantages of OFDM systems. It is a multicarrier system that utilizes a parallel processing technique allowing the simultaneous transmission of data on many closely spaced, orthogonal subcarriers. Inverse fast Fourier transforms (IFFT) and fast Fourier transform (FFT) in a conventional OFDM system are used to multiplex the signals together and decode the signal at the receiver, respectively.

II. OFDM(ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING)

In an OFDM system, a high-rate data stream is split into N low-rate streams that are transmitted simultaneously by the subcarriers. Each of them may be modulated using quadrature amplitude modulation (QAM) or quadrature phase-shift keying (QPSK) [4]. The input data symbol X(k) for $0 \leq k \leq N-1$ is modulated by a set of N orthogonal frequencies of IFFT, then the OFDM output sequence x(n) for $0 \leq n \leq N-1$ is represented by

The output of OFDM transmitter is given by

$$x(n) = \frac{1}{N}\sum_{k=0}^{N-1} X_k\, e^{j2\pi\Delta f k t}, 0 \leq k \leq N-1 \qquad (1)$$

Where X_k is the input to k_{th} carrier
Δf is the bandwidth of each subcarrier
NΔf is the bandwidth of total OFDM subcarrier

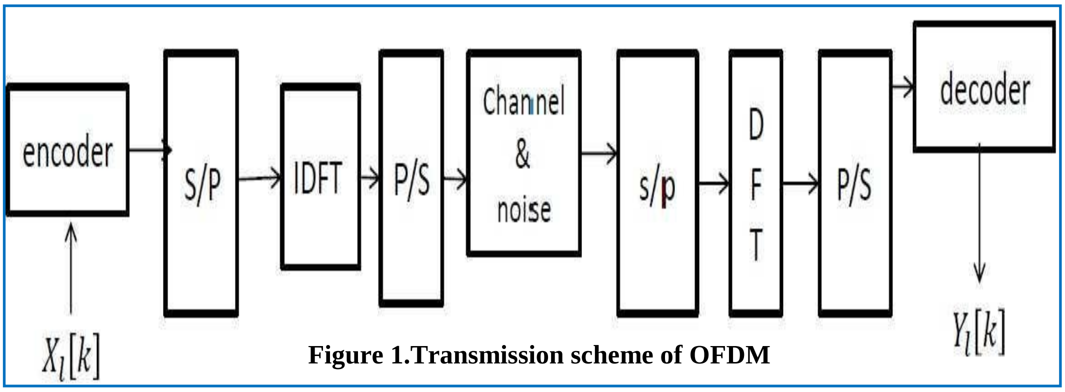

Figure 1.Transmission scheme of OFDM

The OFDM symbol $x[n]$ is a complex number and its real and imaginary parts are denoted by $x_{\Re}[n]$ and $x_{\Im}[n]$. According to the central limit theorem as N gets large, the distributions of $x_{\Re}[n]$ and $x_{\Im}[n]$ become normal (Gaussian). This means that $|x[n]|$ has Rayleigh distribution.
In OFDM the subcarriers are chosen to be orthogonal (i.e.,$\Delta f = 1/NT$).
Mathematically, signals are orthogonal if

$$\int_a^b \Psi_p(t)\Psi_q(t)dt = \begin{cases} K & for\, p = q \\ 0 & for\, p \neq q \end{cases} \quad (2)$$

If $p \neq q$,then two carriers are said to be orthogonal i.e 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. The orthogonality of the carriers means that each carrier has an integer number of cycles over a symbol period.

III. PAPR(PEAK TO AVERAGE POWER RATIO)

A major hurdle to the widespread use of OFDM is the high Peak to Average Power Ratio(PAPR) of OFDM signals.OFDM symbols are summation of several orthogonal waveforms ,so they have varying and large fluctuation of signal envelop which is measured by PAPR. An OFDM signal consists of a number of independently modulated subcarriers, which can give rise to a large Peak to Average Power Ratio(PAPR),when added up coherently. When N equi-amplitude signals are added with the same phase, they produce a peak power that is N times the average power. The peak power is defined as the power of a sine wave with amplitude equal to the maximum envelope value.
The PAPR of the transmit signal is defined as

$$\text{PAPR}=\frac{\max_{0\le t<NT}|x(t)|^2}{\frac{1}{NT}\int_0^{NT}|x(t)|^2dt} \quad (3)$$

PAPR occurs when the carriers having same phases are added coherently. This can be shown by a simple example, taking 4 point IFFT. Here the serial data is divided into 4 parallel blocks, then it is multiplied with 4 no. of carriers generated by IFFT block. Then the output of IFFT is shown as below:

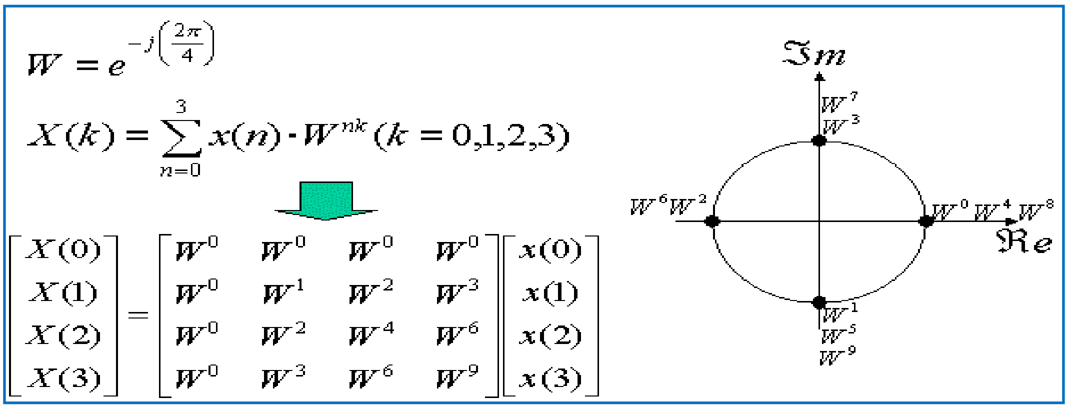

Figure 2. Output of 4*4 IFFT

Where, X (k) is the output of IFFT block, x (n) is the input data, W^{nk} is the twiddle factor which represent the unit circle in a complex plane. The output of IFFT block is

X (0) = x (0) + x (1) + x (2) + x (3)
X (1) = x (0) – jx (1) – x (2) + jx(3)
X(2) = x (0) – x (1) + x (2) – x (3)
X(3)=x(0)+jx(1) – x(3) – jx(3)

Here the output X(0) has equal phase and hence get added coherently. The value is squared to get power, its peak power also increases causing maximum envelop fluctuation.

Now the Signal to Noise Ratio (SNR) is given by the ratio of signal power by noise power.

$$\text{SNR} = \frac{signalpower}{noisepower} = \frac{\sigma_x^2}{N_0\,\Delta f} \tag{4}$$

For N no. of carriers $\text{SNR} = N\left[\frac{\sigma_x^2}{N_0\,\Delta f}\right]$

$$\text{Peak Power} = N\sigma_x^2 \tag{5}$$

As N increases peak power also increases, this shows that this peak power depends on the no. of carriers. Figure 4.shows that as the no. of carriers increases PAPR also increases.

In the transmitter, the linear power amplifiers are being used, so the Q-point must be in the linear region. Due to the high PAPR the Q-point moves to the saturation region hence the clipping of signal peaks takes place which generates in-band and out-of-band distortion. In-band distortion increases the BER at the receiver and Out-off-band distortion causes spectral re-growth**.** So to keep the Q-point in the linear region the dynamic range of the power amplifier should be increased, but this reduces its efficiency and also enhances the cost. So, our objective should be to reduce this PAPR.

IV. ANALYSIS OF PAPR USING CCDF

The cumulative distribution function (CDF) of the PAPR is one of the most frequently used performance measures for PAPR reduction techniques. In the literature, the complementary CDF (CCDF) is commonly used instead of the CDF itself. The CCDF of the PAPR denotes the probability that the PAPR of a data block exceeds a given threshold. From the central limit theorem, the real and imaginary parts of the time domain signal samples follow Gaussian distributions, each with a mean of zero and a variance of 0.5 for a multicarrier signal with a large number of subcarriers. Hence, the amplitude of a multicarrier signal has a Rayleigh distribution, while the power distribution becomes a central chi-square distribution with two degrees of freedom. The CDF of the amplitude of a signal sample is given as below.

$$F(z) = 1 - \exp(z) \tag{6}$$

CCDF is a monotonously decreasing curve**.** The CCDF of the PAPR of a data block with Nyquist rate sampling is derived as

$$\begin{aligned} P(\text{PAPR} > z) &= 1 - P(\text{PAPR} \le z) \\ &= 1 - F(z)^N \\ &= 1 - \left(1 - exp(-z)\right)^N \end{aligned} \tag{7}$$

This expression assumes that the *N* time domain signal samples are mutually independent and uncorrelated. The CCDFs are usually compared in a graph. The horizontal and vertical axes represent the threshold for the PAPR and the probability that the PAPR of a data block exceeds the threshold, respectively. Speaking roughly, the closer the CCDF curve is to the vertical axis, the better its PAPR characteristic.

V. SELECTED MAPPING TECHNIQUE

This is an effective and distortion less technique used for the PAPR reduction in OFDM. The name of this technique indicates that one sequence has to be selected out of a number of sequences. The first SLM scheme was introduced by Bauml, Fischer and Huber in 1996 [8].The basic idea of this technique is based on the phase rotation. The lowest PAPR signal will be selected for transmission from a number of different data blocks (independent phase sequences) that have the same information at the transmitter. Figure 4 shows a block diagram of SLM scheme [9].

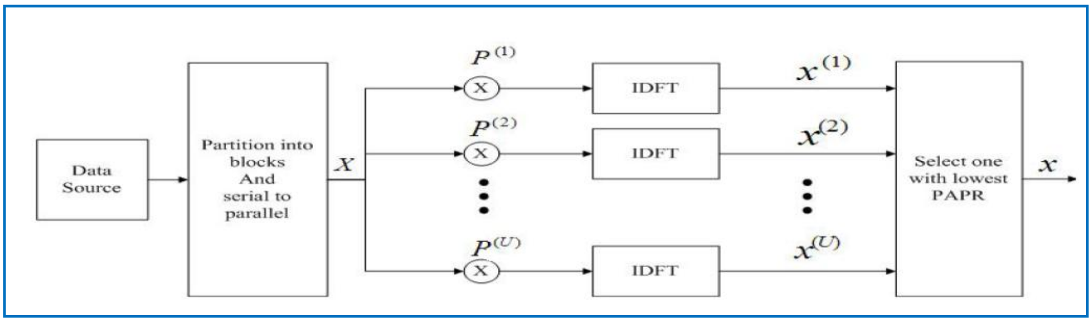

Figure 3. Block diagram of SLM

Let us consider X is the data block with X (k) as the mapped sub symbol(i.e. the symbol from the constellation). Where k = {0, 1, 2, ...N − 1}. Let the u^{th} phase vector is denoted as $P^{(u)}$,where u={1, 2, ...U}.The u^{th} candidate vector that is generated by the multiplication of data block with the phase vector is denoted as $x^{(u)}$. So we can write the equation to get the k^{th}element of u^{th} candidate vector as

$$\boldsymbol{x^{(u)}(k) = X(k)P^{(u)}(k)} \quad \textbf{(8)}$$

The following equation expresses the optimal candidate that has the lowest PAPR and selected for transmission

$$\boldsymbol{x = argmin_{0\leq u\leq U}[PAPR(x^{(u)})]} \quad \textbf{(9)}$$

In SLM technique each data block will create U times phase sequences, if each mapping considered statistically independent, then CCDF of the Peak to Average Power Ratio (PAPR) in Selected Mapping (SLM) will be,

$$\textbf{P(PAPR}> z\textbf{)=}\boldsymbol{(1-(1-e^{-Z})^{N})^{U}} \quad \textbf{(10)}$$

Where U is the number of phase sequences, N is the number of subcarriers, and z is threshold. Figure.7 shows that by increasing the number of phase sequences U (SLM scheme) large PAPR reduction can be obtained.

VI. SIMULATION RESULTS

The parameters used for simulation are as follows. The first simulation shows the PAPR of two different number of carriers i.e N=256 and N=512.For N=256, the PAPR is about 9.2db and for N=512, the PAPR increases to about 10.4db.This shows that as the number of carrier increases the PAPR increases.
In second simulation using SLM along with IFFT, PAPR is reduced about 3.5db, for N=512.

Figure 6.shows the performance of peak to average power ratio (PAPR) reduction of OFDM symbol by using selected mapping (SLM) schemes. That was achieved by using equation (10), where number of subcarriers N is set to 256 , with different values of phase sequences U (1, 2, 4, 8, and16). It is clear from the figure that by increasing the number of phase sequences U (SLM scheme) large PAPR reduction can be obtained.

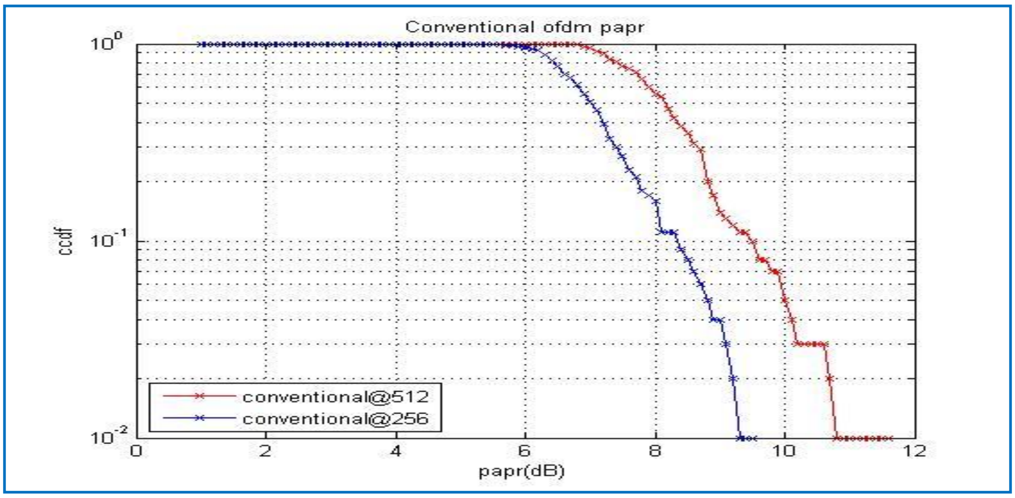

Figure 4.PAPR comparison considering different no. of carriers

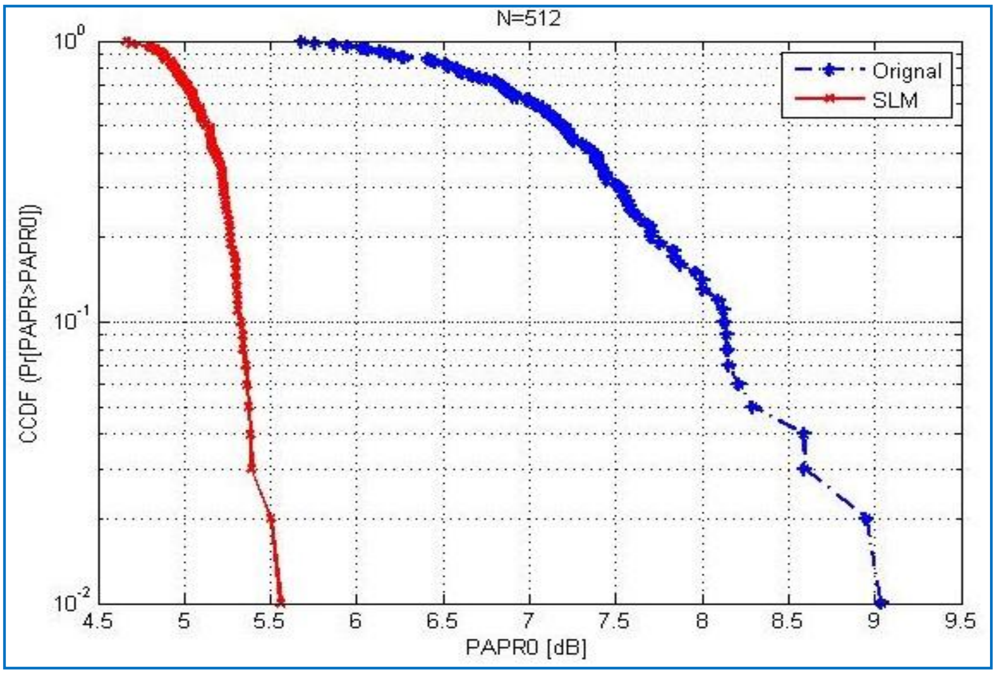

Figure 5.PAPR comparison for SLM

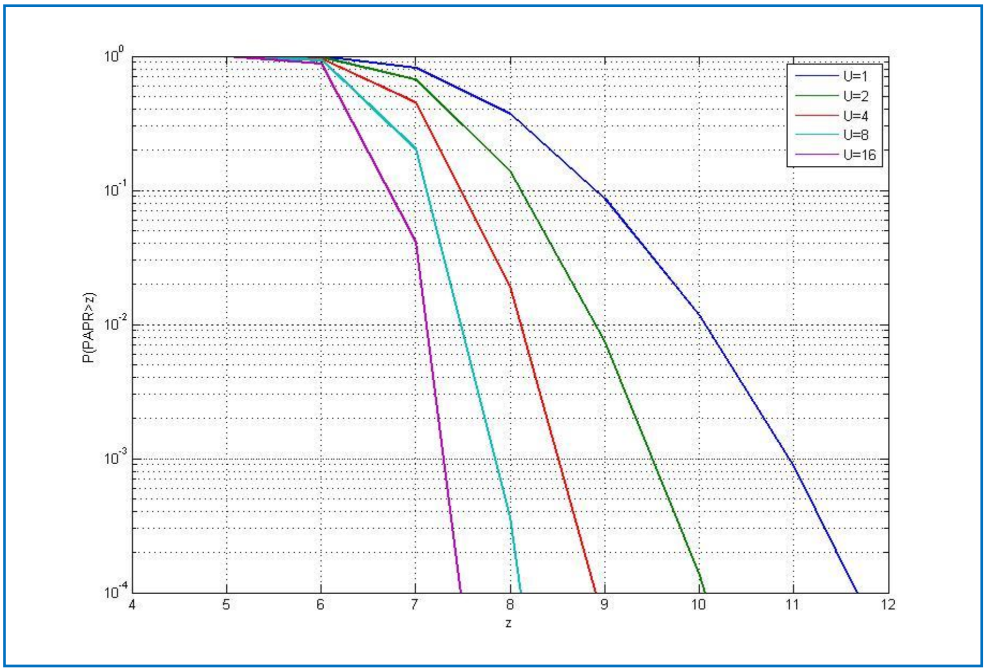

Figure 6. PAPR Reduction for SLM where N = 256 and U =1,2,4,8,16.

VII. CONCLUSION

In this paper we have studied how PAPR increases and its reduction using SLM technique.SLM is an attractive PAR reduction method for ODFM. From above simulation results several firm conclusions are drawn. For PAPR profile, it can be seen that PAPR depends upon the number of carriers. As number of carriers increases PAPR also increases.Using SLM technique, PAPR has been greatly reduced also in this technique it has been shown that, as the phases increases the PAPR decreases. Many researchers have proposed different reduction techniques, all of which have the potential to provide substantial reduction in PAPR at the cost of loss in data rate, transmit signal power increase, BER increase, computational complexity increase, and so on. Rather, the PAPR reduction technique should be carefully chosen according to various system requirement and transmit power amplifier must be taken into consideration to choose an appropriate PAPR reduction technique.

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