

PAPR Reduction in OFDM System using Phase Sequence of Riemann Matrix

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Abstract: Orthogonal Frequency-division multiplexing is an attractive technique for high-bit-rate communication systems. It has been widely used in modern wireless communication because of its high data rate, immunity to delay spread and frequency spectral efficiency and other advantages. Besides these advantages, one of the major drawback of OFDM is the high Peak-to-average-power ratio (PAPR) of the Transmitter's output signal, as it restricts the system performance. Clipping method is the simplest method to reduce the PAPR of the OFDM system but it has some limitations. Here we are using Selective Mapping (SLM) method which provides good performance for reduction of PAPR, where the actual transmit signal is selected from a set of signals to construct the transmitted signal. In this paper SLM method provide better PAPR reduction compared to normal OFDM signal.

Keywords: Orthogonal Frequency-division multiplexing (OFDM), Peak-to-average-power ratio (PAPR), Selective Mapping (SLM), Inverse Fast Fourier Transform (IFFT).

I. INTRODUCTION

The technology of Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier digital communication modulation technique which makes use of multiple sub-carriers and the frequency of overlapping technology. OFDM is mainly used in digital audio broadcasting (DAB), digital video broadcasting-terrestrial (DVB-T), mobile multimedia access communication (MMAC), IEEE802.11a, IEEE802.16 and IEEE 802.20. However, as the OFDM symbol is modulated by the sum of a number of independent sub-carrier signal, and the subcarriers are statistically independent, when the number of subcarriers comes to a certain extent, the peak to average power is much larger than the single-carrier system, which requires the system power amplifier, A/D and D/A converter with a larger linear dynamic range.[10][12] So that the OFDM system can easily lead to interference between adjacent channels, and the orthogonal is destroyed. It is therefore important to minimize the PAPR. The high PAPR feature will cause poor efficiency of power consumption, in band distortion, and spectral spreading when an OFDM signal is passed through a nonlinear power amplifier [9].

A. Reduction Methods

There are number of techniques are present to reduce PAPR in OFDM. The first is distortion technique, in this method clipping and companding techniques are used [2]. These are rather simple techniques and provides good PAPR reduction. The second method is coding technique [6] in this different types of coding are used like block coding etc. The third method is probabilistic method which include selective mapping (SLM), partial transmit sequence (PTS) [8]. Among all these existing techniques, the clipping procedure is easy to implement and it has less

complexity, the simplest to approach a specified PAPR threshold in the processed OFDM symbols. However, clipping time domain signals causes out-of band spectral regrowth and in band distortion. However the in band distortion can also degrade bit error performance of the OFDM system. The second is coding technique. It is an efficient method to reduce the PAPR for a small number of subcarriers, but it is inefficient transmission rate significantly for a large number of subcarriers. The third kind is probabilistic technique or the redundancy technique which is including selective mapping (SLM) and the Partial transmit sequence (PTS) etc. In this paper we proposed SLM technique. The basic idea of SLM is to produce U alternative transmit sequences seeded from the same data source and then to select the transmit signal exhibiting the lowest PAPR. The idea stems from the fact that as the PAPR is determined by the sequence of the transmit data vectors; X_m multiplying the data vectors by some random phase will change the PAPR properties after the IFFT. There are different phase sequences are used to reduce PAPR like $(1, -1)$, $(1, -1, +j, -j)$. Here the phase sequences are used from Riemann matrix. Rows of Riemann matrix are used as phase factor.

In this paper we reduce the PAPR using SLM technique with Riemann matrix as phase factor and compare with the PAPR of the original signal.

II. SYSTEM MODEL

A. OFDM Signal

For OFDM system implementation, Inverse Fast Fourier Transform (IFFT) is usually being utilized to modulate multiple sub-band signals in an OFDM. In OFDM system, the information data symbol are passed through serial to

parallel convertor and modulated using different modulation scheme like quadrature amplitude modulation (QAM), binary phase shift keying (BPSK) and quadrature phase shift keying (QPSK) to form a complex vector of size N. Here single signal bit is divided into N different parallel routes An N point FFT or IFFT operation is used to modulate and demodulate the data. The Complex vector is written as:

$$X = [X_0, X_1, X_2, \dots, X_{N-1}] \quad (1)$$

Mathematically the OFDM symbol is represented as,

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi k \frac{n}{N}} ; 0 \leq n \leq N - 1$$

B. Orthogonality in OFDM

One of the key advantages of OFDM is its efficient use of the frequency band as the subcarriers are allowed to overlap each other in the frequency domain. The N equally spaced subcarriers will be orthogonal if the frequency separation between subcarriers is $\Delta f = 1/NT_s = 1/T_s$. where $N.T_s$ is symbol duration, and rectangular windowing of the IFFT is performed. Under these conditions the subcarriers will have a sinc waveform frequency response. Figure 1 shows the frequency response of a 5 carrier system where it is seen that because of the orthogonal relationship the maximum of a particular sample corresponds to a null in all other carriers, therefore eliminating the effects of interference. Smoother window functions (e.g. Raised Cosine Filter) reduce the out of band emissions and Inter Carrier Interference (ICI) susceptibility to system imperfections (e.g. frequency offset) but they increase the symbol period. Mathematically, orthogonality of two signals, $\psi_k(t)$ and $\psi_l(t)$ over time period $N.T_s$ is described in below equation.

$$\int_0^{NT_s} \psi_k(t) \psi_l^*(t) dt = \begin{cases} 0, & k \neq l \\ C, & k = l \end{cases}$$

Where C is constant.

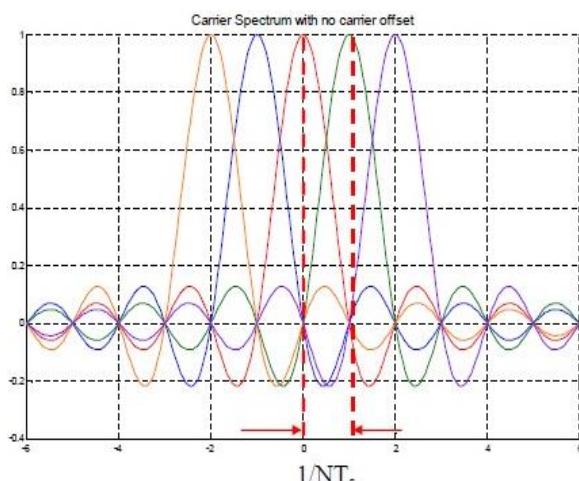


Fig. 1. Frequency spectrum of 5 orthogonal subcarriers of an OFDM transmitted signal

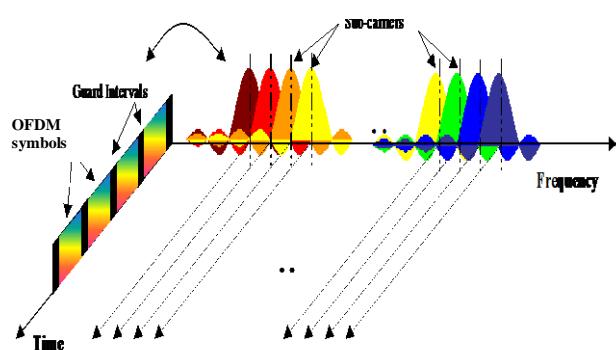


Fig 2 Frequency and time domain representation of the OFDM symbol

C. Block diagram of OFDM system

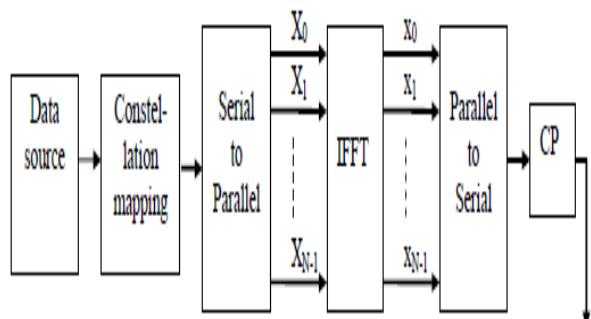


Fig.3 Basic OFDM transmitter

Figure 3 shows a baseband transmitter structure for OFDM utilising the Fourier transform for modulation. Here the serial data stream is mapped to complex data symbols (using PSK, QAM, etc) with a symbol rate of $1/T_s$. The data is then demultiplexed by a serial to parallel converter resulting in a block of N complex symbols, X_0 to X_{N-1} . The parallel samples are then passed through an N point IFFT, resulting in complex samples x_0 to x_{N-1} . Assuming the incoming complex data is random it follows that the IFFT is a set of N independent random complex sinusoids summed together. The samples, x_0 to x_{N-1} are then converted back into a serial data stream producing a baseband OFDM transmit symbol of length $T=N.T_s$. A Cyclic Prefix (CP), which is a copy of the last part of the samples is appended to the front of the serial data stream before Radio Frequency (RF) up conversion and transmission [5]. The CP combats the disrupting effects of the channel which introduce Inter Symbol Interference (ISI). The PAPR for above system is plot using CCDF function.

D. PAPR Definition

PAPR is nothing but the ratio maximum power to average power in OFDM symbol.

$$\text{PAPR} = \text{P}_{\text{PEAK}} / \text{P}_{\text{AVERAGE}} = 10 \log_{10} \max [|x_n|^2] / E [|x_n|^2]$$

Where P_{PEAK} represents the peak power of OFDM signal and P_{AVERAGE} represents the average power of OFDM signal.

III. PROPOSED METHODOLOGY

A. SLM Technique

SLM PAPR reduction technique has been first proposed by Bamul et.al. Selective mapping is a simple PAPR suppression method for OFDM signals. The SLM technique is basically implemented from the idea of symbol scrambling. In this scheme, a set of candidate signals are generated to represent the same information, then the signal with lowest PAPR is selected for transmission. The information about the selection of these candidate signals need to be explicitly transmitted along with the selected signal as side information. Selected mapping technique needs to transmit the information to receiver, with the selected signal, as side information. If there is any error in the received information, then it is difficult for the receiver to recover the information from the transmitted selected signal. Due to this problem a strong protection is needed regarding side information. If the receiver has these side information then the process of decoding become very simple. SLM PAPR reduction technique can be employed for larger number of subcarriers with moderate complexity.

The actual transmit signal having lowest PAPR is selected from a set of sufficiently different signals which all represents the same information shown in figure 4. SLM technique is very flexible as they do not impose any restriction on modulation applied in the subcarriers or on their number. Here the rows of Riemann matrix are used as set of candidates.

B. Block diagram of SLM

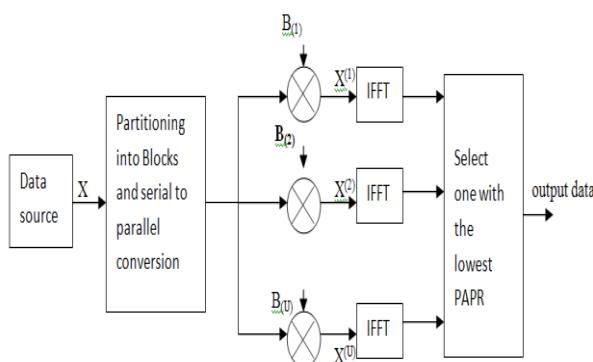


Fig. 4. Block diagram of SLM technique

In selected mapping (SLM) method a whole set of candidate signals is generated representing the same information, and then the most favourable 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. [7] The OFDM data block represent in equation 1 is multiplied by element with phase sequences present in equation 2.

$$B_U(t) = [b_{u,0}, b_{u,1}, \dots, b_{u,N-1}]^T \quad (1)$$

$$\text{Where } u = 1, 2, \dots, U \quad (2)$$

To make the U phase rotated OFDM data blocks.

$$X_u(t) = [X_{u,0}, X_{u,1}, \dots, X_{u,N-1}]^T$$

Where $X_{u,m} = X_m a_{u,m}$, $m = 0, 1, \dots, N-1$,

All U phase rotated OFDM data blocks represent the same information as the unmodified OFDM data block provided that the phase sequence is known. After applying the SLM technique to X.

$$x_u(t) = \frac{1}{N} \sum_{m=0}^{N-1} X_m a_{u,m} e^{j2\pi f_m t}, \quad 0 \leq t \leq NT$$

The PAPR is calculated for U phase rotated OFDM data blocks by

$$\text{PAPR}[x_u(t)] = \frac{\max_{0 \leq t \leq NT} |x_u(t)|^2}{\frac{1}{NT} \int_0^{NT} |x_u(t)|^2 dt}$$

Among the phase rotated OFDM data blocks, the one with the lowest PAPR is selected and transmitted. 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. Output data of the lowest PAPR is selected to transmit. PAPR reduction effect will be better as the copy block number U is increased. SLM method effectively reduces PAPR without any signal distortion. But it has higher system complexity and computational burden. This complexity can less by reducing the number of IFFT block.

C. Riemann Matrix as phase sequence

The element of v^{th} row in Riemann matrix R are either v or -1, here the diagonal elements in matrix are 1 to N, where N is nothing but the size of Riemann matrix. Therefore when v^{th} row, ($2 \leq v \leq U$) of matrix R is used as phase sequence B^U , it results not only in phase change but also amplitude change of the modulated data symbols. Therefore, the average transmitted power of alternative frequency domain OFDM signals, X^u , $1 \leq u \leq U$ will not be the same as original OFDM signal X. Here, X^u is the u^{th} alternative frequency domain OFDM signal. Consider an SLM-OFDM system with 8 subcarriers, which uses rows of Riemann matrix (R) as phase sequence. An 8*8 Riemann matrix is given by,

$$R = \begin{bmatrix} 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ -1 & 2 & -1 & -1 & 2 & -1 & -1 & 2 \\ -1 & -1 & 3 & -1 & -1 & -1 & 3 & -1 \\ -1 & -1 & -1 & 4 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & 5 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & 6 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & 7 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 & 8 \end{bmatrix}$$

Here, Riemann matrix(R) serves as a phase sequence set with eight phase sequences because its rows are used as phase sequences to reduce the PAPR of the OFDM signal. Let, a QAM modulated frequency domain OFDM signal is applied to SLM-OFDM system and suppose that the 3rd row of Riemann matrix as a phase sequence provides the best PAPR reduction. In the 3rd row of Riemann matrix the value of all the elements is -1 except 3rd and 7th element, which has a value of 3. Hence it has exactly $c=2$ number of elements with value 3. When the elements with value -1 are used as phase factor, then they only produce the phase change whereas the two elements with value 3 produce the amplitude change. Therefore, the power level of two data subcarriers is increased by a factor of 9, which increases the average energy of the OFDM signal. Hence it has been verified by this example that when any row, except the 1st row is used for PAPR reduction in SLM-OFDM system then the average energy of the OFDM signal after multiplication with phase sequence increases.

D. Complementary Cumulative Distribution Function

In the communication world, CCDF measurement proves as one of the important tool [13]. This function provides comprehensive analysis of signal power peak. It is statistical technique that provides the amount of time, a signals spends above any given power level. However by using these plots a probability can be seen that a signal data blocks exceeds a given threshold. These CCDF plots can use to analyze the PAPR performance of the signals.

To calculate the CCDF for given data following steps should be followed.

1. Calculate Probability Density Function of the data
2. Take the integral of the PDF to get CDF (Cumulative Distributed Function)
3. Subtract the CDF from 1 to get CCDF as $CCDF = 1 - CDF$.

Mathematically it can be explained as follows Probability $P(PAPR > Z) = 1 - P(PAPR < Z)$

The CCDF plots can be easily simulated using in MATLAB.

IV. RESULTS AND SIMULATION

In this paper selective mapping PAPR reduction technique is analysed by using different number of phase sequences

TABLE I Parameters used for simulation

Sr. No.	Simulation Parameters	Value
1	Number of Subcarriers (N)	128
2	Modulation Type (M)	QAM-64
3	Number of phase sequence (U)	2, 4, 6, 8

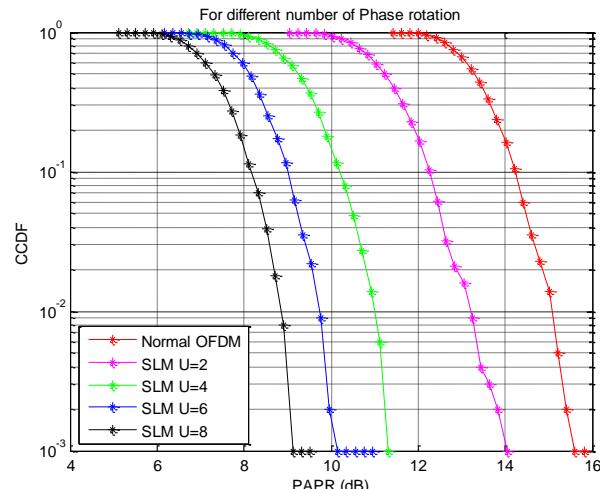


Fig. 5 CCDF Vs PAPR ratio for different no. of phase rotations

TABLE II Results of simulation

PAPR in dB	For Different phase rotations in SLM			
	U=2	U=4	U=6	U=8
15.5	14.04	11.3	10.15	9.1

V. CONCLUSION AND FUTURE WORK

The simulation is run for $N=128$ subcarriers, QAM-64 modulation for different no of phase rotations from table II it is clearly shown that the PAPR is reduced for SLM technique. The PAPR for OFDM without any reducing technique is 15.5 dB, while PAPR for different phase rotation is reduced as no of phase sequences are increased. But in Fig.5 it is observed that it will not be able to achieve a linear growth of PAPR reduction performance with further increase the value of U (like $U>=8$), the PAPR reduction performance of OFDM signal will not be considerably improved. PAPR reduction will be better as the block number U is increased. SLM method effectively reduces PAPR without any signal distortion. But it has higher system complexity and computational burden.

OFDM is a very attractive technique for multicarrier transmission and has become one of the standard choices for high speed data transmission over a communication channel. It has various advantages but also has one major drawback; it has a very high PAPR. In this paper, the different properties of an OFDM system are analyzed and the advantages and disadvantages of this system are understood. We have aimed to investigate SLM technique to reduce the high PAPR of the system.

However, no specific PAPR reduction technique is the best solution for the OFDM system. Various parameters like loss in data rate, transmit signal power increase, computational complexity increase should be taken into

consideration before choosing the appropriate PAPR technique. With the rising demand for efficient frequency spectrum utilization, OFDM proves invaluable to next-generation communication systems. The PAPR problem in OFDM is still an ongoing issue, especially for portable devices where the need to minimize the power amplifier linear range is paramount. So one can design or modify PAPR reduction technique such that it will take care of linear range of power amplifier as well as complexity reduction.

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