

SLM Using Riemann Sequence Combined with DCT Transform for PAPR Reduction in OFDM Communication Systems

Pepin Magnangana Zoko Goyoro, Ibrahim James Moumouni, Sroy Abouty

Abstract—Orthogonal Frequency Division Multiplexing (OFDM) is an efficient method of data transmission for high speed communication systems. However, the main drawback of OFDM systems is that, it suffers from the problem of high Peak-to-Average Power Ratio (PAPR) which causes inefficient use of the High Power Amplifier and could limit transmission efficiency. OFDM consist of large number of independent subcarriers, as a result of which the amplitude of such a signal can have high peak values. In this paper, we propose an effective reduction scheme that combines DCT and SLM techniques. The scheme is composed of the DCT followed by the SLM using the Riemann matrix to obtain phase sequences for the SLM technique. The simulation results show PAPR can be greatly reduced by applying the proposed scheme. In comparison with OFDM, while OFDM had high values of PAPR –about 10.4dB our proposed method achieved about 4.7dB reduction of the PAPR with low complexities computation. This approach also avoids randomness in phase sequence selection, which makes it simpler to decode at the receiver. As an added benefit, the matrices can be generated at the receiver end to obtain the data signal and hence it is not required to transmit side information (SI).

Keywords—DCT transform, OFDM, PAPR, Riemann matrix, SLM.

I. INTRODUCTION

OFDM is the technology for future broadband systems. It has risen in popularity in wireless and wire line applications. The recent interest advances in this technique is mainly due to the recent advances in digital signal processing technology. International standards making use of Orthogonal Frequency Division Multiplexing (OFDM) for high-speed wireless communication are already established or being established by IEEE 802.11, IEEE 802.16, IEEE 802.20, and European Telecommunications Standards Institute (ETSI) Broadcast Radio Access Network (BRAN) committees.

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For wireless applications, an OFDM-based system can be of interest because it provides greater immunity to multipath fading and impulse noise, and eliminates the need for equalizers, while efficient hardware implementation can be realized using Fast Fourier transform (FFT) techniques.

OFDM is a multi-carrier modulation technique that is unlike other modulation techniques. In OFDM the carriers have substantial overlap. For better transmission, even single carrier waves is being replaced by multicarriers, OFDM transmits multiple high data rates signals by using sub carriers. The sub-carriers are orthogonal with each other and hence do not interfere with each other. OFDM is currently the next choice for next generation mobile communications, primarily because it offers high bandwidth efficiency due to overlapping of spectra, its robustness to frequency selective fading channels and its efficient and easy implementation [6].

However, though OFDM has many advantages, there also disadvantages. One of the major disadvantages of OFDM is the high Peak-to-Average Power Ratio of OFDM signal. These multi-carrier systems have a problem that Peak-to-Average Power Ratio (PAPR) increases with the increase of the number of subcarrier, which causes poor power efficiency or serious performance degradation to transmit power amplifier.

Many PAPR reduction techniques have been proposed in the literature [7]-[13]. It should be noted that most of the methods are based on the same idea of selecting the time domain signal to be transmitted from a set of different representations with the constraint of minimization of PAPR which would degrade the performance of system. These techniques can mainly be categorized into Signal scrambling techniques and Signal distortion techniques [14].

Signal scrambling techniques are all variations on how to scramble the codes to decrease the PAPR. Coding techniques can be used for signal scrambling. Golay complementary sequences, Shapiro-Rudin sequences, M-sequences, Barker codes can be used to efficiently reduce the PAPR. However, with the increase in the number of carriers, the overhead associated with exhaustive search of the best code would increase exponentially. More practical solutions of the signal scrambling techniques are block coding, selective mapping and partial transmit sequences.

The signal scrambling techniques can further be classified into:

- Schemes with explicit side information
 - Block codes: e.g. linear block code scheme, cyclic code scheme
 - Probabilistic schemes: e.g. SLM, PTS, Interleaving schemes
- Schemes without side information

Examples: Block coding scheme, Hadamard transform method, Dummy sequence insertion method etc. Signal

Scrambling techniques, with side information reduces the effective throughput since they introduce the redundancy.

The signal distortion techniques introduce both in-band and out-of-band interference and complexity to the system. The signal distortion techniques reduce high peaks directly by distorting the signal prior to amplification. Clipping the OFDM signal before amplification is a simple method to limit PAPR. However, clipping may cause large out-of-band (OOB) and in-band interference, which results in the system performance degradation. More practical solutions are peak windowing, peak cancellation, peak power suppression, weighted multi-carrier transmission, companding etc.

Reference [1] Proposed an approach which uses the default index of the phase vectors of Hadamard sequence for the reduction of complexity.

Reference [2] also proposed the scheme with Selected Mapping (SLM) using randomness in phase sequence selection. This scheme obtained significant PAPR reduction performance with that of ordinary SLM techniques.

A. Zolghadrashi and M.H. Ghamat proposed many extension schemes for reducing complexity of SLM. The authors present two new techniques based on selective mapping and selective scrambling combined with Hadamard matrix to reduce Peak-to-Average Power Ratio (PAPR) in OFDM systems.

M. Palanivelan et al, utilized Circulant, Hadamard and Hilbert matrices to obtain phase sequences for the SLM techniques. The experimental results clearly prove that Hilbert matrices approach offers the best PAPR reduction, while [5] proposed a blind algorithm for Peak-to-Average Power ratio (PAPR) reduction in OFDM systems based on Selected Mapping (SLM) algorithm as a distortionless method. In the proposed method some special number of carriers in the OFDM frame is reserved to be rotated with one of the possible phases according to the number of phase sequence blocks in SLM algorithm. The simulation results show using matlab have the same system performance as the conventional SLM algorithm, while there is no need to send any side information to the receiver.

The main objective of this research is to design an algorithm for OFDM systems that will reduce PAPR of the overall system, with an improvement over other algorithms and a very reasonable complexity. In this paper, we propose an efficient reduction of PAPR technique based on joint SLM using

Riemann sequence and Discrete Cosine Transform (DCT) matrix transform. So far as we know the closest work to our algorithm was by Zhong peng Wang [2] which SLM model did not use Riemann sequence.

In this work, the data stream is transformed by DCT matrix $N \times N$, then the transformed data is processed by the SLM unit where each data block is multiplied by B different number of phase sequence vectors, and each row of a Riemann matrix is taken as the phase sequence for multiplication. If the data passed by DCT matrix before IFFT, the autocorrelation coefficient of IFFT input sequence is reduced, then the PAPR of OFDM signal could be reduced with low complexity and no side information is required because the matrices can be generated at the receiver to recover the original data which is transmitted with lowest PAPR. However, compared with other SLM techniques, an extra scaling of $1/M$ (M is the size of the Riemann matrix) for the whole matrix is required for getting the normalized matrix. Simulation results are presented which demonstrate that our proposed scheme achieves significantly better PAPR reduction compared to [4].

The organization of this paper is as follow. Section 2 presents OFDM signal model and the PAPR problem. Section 3, the reduction PAPR schemes based on combined DCT transform matrix and SLM technique are proposed, the proposed schemes in section 4, Numerical results are presented in Section 5. Section 6 draws conclusions.

II. THE OFDM SYSTEM MODEL AND THE PAPR PROBLEM

A. OFDM System Model

Let $A = [A_0 A_1 \dots A_{N-1}]^T$ denote an input symbol vector in the frequency domain, where A_k represents the complex data of the k th subcarrier and N is the number of subcarriers. The input symbol vector is also called the input symbol sequence. The OFDM signal is generated by summing all the N modulated subcarriers each of which is separated by $1/NT_s$ in the frequency domain, where T_s is the sampling period. Then, a (t) continuous time baseband OFDM signal is defined as:

$$a(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} A_k e^{j2\pi \frac{k}{NT_s} t} \quad (1)$$

$$, 0 \leq t \leq NT_s$$

Where

$$f_k = k\Delta f, \quad \Delta f = \frac{1}{NT_s}$$

Let $a = [a_0, a_1 \dots a_{N-1}]^T$ denote a discrete time OFDM signal vector. Then, a corresponds to the inverse fast Fourier transform (IFFT) of A , that is, $a = QA$, where Q is the IFFT matrix.

B. The PAPR Problem

In general, the PAPR of OFDM signals $a(t)$ is defined as the ratio period between the maximum instantaneous power and its average power during an OFDM symbol

PAPR is defined as:

$$PAPR = 10 \log_{10} \frac{P_{peak}}{P_{av}} \quad (2)$$

P_{peak} and P_{av} are computed as :

$$P_{peak} = \max |a(t)|^2 = N |A|^2 \quad (3)$$

$$P_{av} = \frac{1}{T} \int_0^T |a(t)|^2 dt = A^2 \quad (4)$$

So, PAPR is expressed as:

$$PAPR[dB] = 10 \log_{10} N \quad (5)$$

High Peak-to-Average Power Ratio has been recognized as one of the major practical problem involving OFDM modulation. High PAPR results from the nature of the modulation itself where multiple subcarriers or sinusoids are added together to form the signal to be transmitted. When N sinusoids add, the peak magnitude would have a value of N , where the average might be quite low due to the destructive interference between the sinusoids. High PAPR signals are usually undesirable for it usually strains the analog circuitry. For e.g. power amplifier has High PAPR, signals would require a large range of dynamic linearity from the analog circuits which usually results in expensive devices and high power consumption with lower efficiency (operate with larger back-off to maintain linearity).

In OFDM system, some input sequences would result in higher PAPR than others. For example, an input sequence that requires all such carriers to transmit their maximum amplitudes would certainly result in a high output PAPR. Thus by limiting the possible input sequences to a smallest sub set, it should be possible to obtain output signals with a guaranteed low output PAPR.

For an OFDM signal, that has 126 carriers each with normalized power of 1W, then the maximum PAPR can be as large as $10 \log_{10} 126$ or 21 db. This is at the instant when all 126 carriers combine at their maximum point unlikely but possible.

High PAPR could cause problems when the signal is applied to a transmitter which contains non-linear components such as High Power amplifier (HPA) in the Transmitter chain. The PAPR has the worst case value PAPRWC which depends on the no. of subscribers N . The non-linear effects on the transmitted OFDM symbols are spectral spreading, inter-

modulation and changing the signal constellation. In other words, the nonlinear distortion causes both in-band and out-of-band interference to signals.

III. PROPOSED PAPR REDUCTION METHODS

A. Proposed Approach Riemann Sequence

In the proposed approach, rows of normalized Riemann matrix (B) are used as phase rotation vectors [15]. The Riemann matrix [17] is obtained by removing the first row and first column of the matrix R, where:

$$R(i, j) = \begin{cases} i-1 & \text{if } i \text{ divides } j \\ -1 & \text{otherwise} \end{cases} \quad (6)$$

Using Equation (6), Riemann Matrix (A) of order 4 can be written as:

$$A = \begin{bmatrix} 1 & -1 & -1 & -1 \\ -1 & 2 & -1 & -1 \\ 3 & -1 & 3 & -1 \\ -1 & -1 & -1 & 4 \end{bmatrix} \quad (7)$$

B. Selected Mapping (SLM)

The SLM technique was first described by Bauml et al. [16]. In the SLM, the input data sequences are multiplied by each of the phase sequences to generate alternative input symbol sequences. Each of these alternative input data sequences is made the IFFT operation, and then the one with the lowest PAPR is selected for transmission. Figure 1 shows the block of the SLM technique. A_k is the OFDM data block, B_u is the phase vectors and A_u is the modified data vectors in the frequency domain. So the time domain signal

$$a_u(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} A_k B_{u,k} e^{j2\pi k \Delta f t} \quad 0 \leq t \leq NT \quad (8)$$

Where $u=1, 2, \dots, U$ and N is length of A , also the number of sub-carriers.

Among the modified data blocks, the one with the lowest PAPR is selected for transmission. The amount of PAPR reduction for SLM depends on the number of phase sequences U and the design of the phase sequences.

C. DCT Transform

The Discrete Cosine Transform (DCT) is a Fourier-like transform, which was first proposed by Ahmed et al. (1974)

[18]-[25]. The idea to use the DCT transform is to reduce the autocorrelation of the input sequence to reduce the peak to average power problem and it requires no side information to be transmitted to the receiver. In the section, we briefly review DCT transform.

The 1D discrete cosine transform (1D DCT) $A[k]$ of a sequence $a[n]$ of length N is defined as:

$$A[k] = a[k] \sum_{n=0}^{N-1} a[n] \cos\left[\frac{\pi(2n+1)k}{2N}\right] \quad (9)$$

For $k=0, 1, \dots, N-1$

The inverse DCT is defined as:

$$a[n] = \sum_{k=0}^{N-1} a[k] A[k] \cos\left[\frac{\pi(2n+1)k}{2N}\right] \quad (10)$$

$n=0, 1, \dots, N-1$ where $a[k]$ is defined as

$$a[k] = \begin{cases} \sqrt{\frac{1}{N}} & \text{for } k=0 \\ \sqrt{\frac{2}{N}} & \text{for } k=1, 2, \dots, N-1 \end{cases} \quad (11)$$

The basis sequences of the 1D DCT are real, discrete-time sinusoids defined by:

$$C_N[n, k] = \cos\left[\frac{\pi(2n+1)k}{2N}\right] \quad (12)$$

The DCT basis consists of the following N real sequences.

$$\{C_N[n, 0], C_N[n, 1], \dots, C_N[n, N-1]\} \quad (13)$$

The equation (9) is expressed in matrix below:

$$A = C_N a \quad (14)$$

Where A and a are both the vector with $N \times 1$ and C_N is a DCT transform matrix with $N \times N$. The row (or column) of the DCT matrix C_N are orthogonal matrix vectors. Then we can use this property of the DCT matrix and reduce the peak power of OFDM signals.

IV. PROPOSED SCHEME

The main idea of the proposed scheme is to use a combination of two appropriate methods. One is the DCT matrix transform technique and the other is the SLM technique. The technique is similar to the scheme proposed in the literature [26]. The transmitter block is shown in Fig. 1. We call this scheme 1. In the transmit end, the data stream is first transformed by DCT matrix, then the transformed data is processed by the SLM unit. If data block passed by DCT matrix before IFFT, the autocorrelation coefficients of IFFT input is reduced, so the PAPR of OFDM signal can also be reduced.

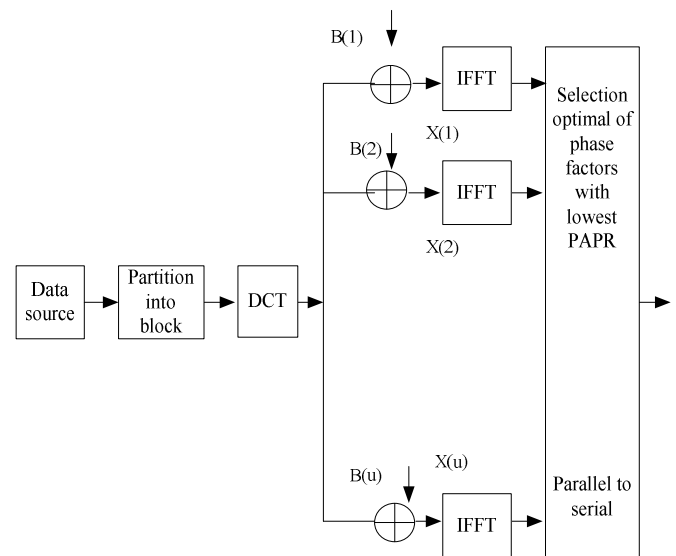


Fig. 1 Proposed scheme

V. SIMULATION RESULT

We carried out extensive simulation using MATLAB to evaluate the PAPR reduction performance of the proposed approach. OFDM systems with $N=256$ subcarriers was used for the simulation with BPSK modulation. In SLM unit, Riemann matrix for phase sequence is used. The parameters used for simulation are given in table 1 below.

TABLE I
SIMULATION PARAMETERS

Modulation	BPSK	
Number of data subcarriers(N)	256	
Total number of data symbols	10000	
Size of the phase sequence	256	

A total of 10000 data blocks were generated to obtain the CCDF plot of PAPR

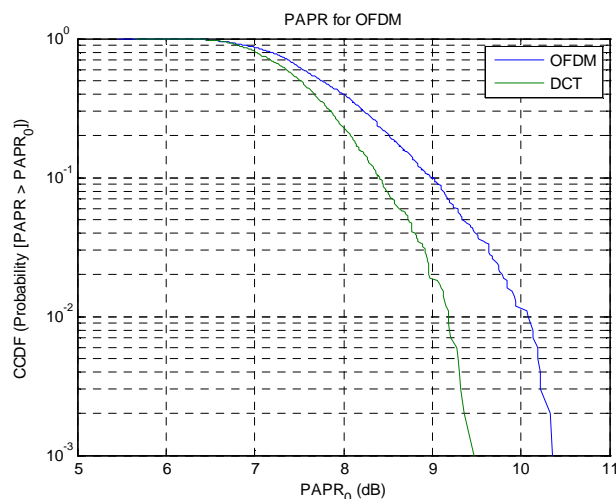


Fig. 2 CCDF plot of PAPR using DCT transform

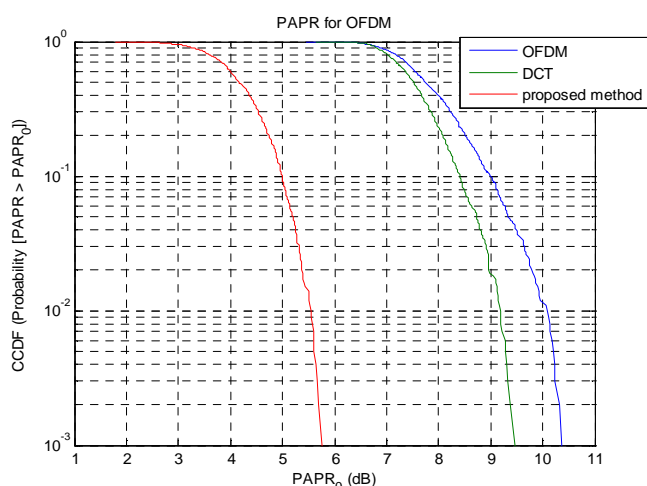


Fig. 3 CCDF plot of PAPR for proposed method

Following our proposed algorithm we carefully implemented the design in Matlab and the result is as shown above. We compared our result with recent works in the SLM domain and our proposed method performed better with lower complexity. When considering the works by [28] and [4] on SLM with no side information, they achieved max PAPR reduction of about 3 dB and 6.4 dB respectively with higher complexities. Our algorithm achieved about 5 dB in PAPR reduction and by adding the DCT in our algorithm we had a further reduction on the PAPR by about 1 dB less than the initial PAPR of the original OFDM signal with significant reduction on complexities compared.

VI. CONCLUSION

In this paper, techniques for PAPR reduction of OFDM signals have been proposed. These techniques combine the SLM technique using Riemann sequence and DCT matrix transform. The entire scheme consists of DCT matrix transform followed by the SLM using Riemann matrix for the phase sequence. The PAPR reduction performances were

evaluated using matlab simulation tool. Experimental result clearly proves that there is a significant reduction in PAPR. The proposed scheme reduced the PAPR by about 4.7 dB with very low complexities.

Our future work will be to extend this scheme by applying various normalization procedures on the matrices for further optimization of the PAPR.

ACKNOWLEDGMENT

We would like to thank to my supervisor who shepherded me through the bulk of the work, Prof. Ren-Yong Wu, Zeng Fanzi, whose encouragement, guidance and support from the initial to the final level enabled me to develop an understanding of the subject, their kindly but rigorous oversight of this work constantly giving us motivation to perform my maximum ability.

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