



NONLINEARITY MITIGATION IN IM/DD OPTICAL OFDM USING NEW SLM SCHEME

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ABSTRACT

Optical orthogonal frequency-division multiplexing (O-OFDM) systems have received a great deal of attention as a transmission technology for high-capacity long-haul optical transport networks. However, it is also very sensitive to nonlinear effects due to high peak to average power ratio (PAPR) problem as conventional OFDM system. This paper proposes Fast Hartley based selective mapping with Riemann Sequence for PAPR reduction in IM/DD Optical OFDM system. Results show that the proposed method performs better in terms of PAPR and bit error rate performance and it is less complex than other conventional methods.

Keywords: O-OFDM, PAPR, SLM.

INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has recently been introduced in optical communications because of its robustness against channel dispersion and its high spectral efficiency [1]. It is a promising technique for long haul and high speed optical transmission systems. It is also becoming popular because it can effectively reduce inter symbol interference caused by dispersive channel also it is immune to chromatic dispersion (CD) and polarization dispersion (PMD) [2]. The use of OFDM in optical communications mitigates transmission impairments and at the same time, provides high-data rate transmission across dispersive optical media. It is also used in wireless and wireline applications and in almost every major communication standards. Among the proposed OFDM systems, Intensity Modulation and Direct-Detection (IM/DD) technique inherently is a low cost and attractive for future cost-sensitive, short-range & high-speed transmission such as passive optical network (PON), indoor optical wireless communication and interconnections in data centre [3]. The two most popular IM/DD OFDM systems are DC-offset OFDM (DCO-OFDM) and asymmetrically clipped optical OFDM (ACO-OFDM) [4]. Fast Hartley transform (FHT) has been proposed as an alternative modulation/demodulation processing in IM/DD optical OFDM systems [16]. The complexity of FHT with real input constellation is half of that of FFT with complex input constellation [5]. Thus, FHT is perfect for IM/DD systems due to its low complexity.

However high peak to average power ratio (PAPR) and sensitivity to carrier frequency offset are two major drawback of optical OFDM (OOFDM) like conventional OFDM. Various techniques have been proposed to reduce the PAPR comprising clipping and filtering [7], coding schemes [8], companding transform [10], Tone Reservation and Tone Injection [6], Active constellation extension (ACE) [11], multiple signal representation techniques such as SLM and PTS [13-14] and interleaving [12] etc. All these techniques are selected

according to various criteria such as bandwidth expansion, loss in data rate, system complexity, BER increase, power increase. Among all these basic techniques for PAPR reduction, SLM is an attractive technique as it can obtain better PAPR by modifying the OFDM signal without distortion. Generation and selection of phase sequence is one of the important aspects of the SLM technique for good PAPR reduction. In [15] rows of Riemann matrix are used as phase factors for SLM and it is shown that this scheme performs better than other previously proposed phase sequences such as Hadamard and Chaotic sequences but it has only discussed the PAPR performance without applying into optical OFDM transmission.

This paper proposes a low complexity SLM technique for PAPR reduction in optical OFDM system. In this research work, FHT based SLM technique with Riemann sequence as phase factor sequence is proposed for PAPR reduction in OOFDM- IM/DD system. Here for comparison purpose, the signal is mapped into M-QAM format if FFT is used, whereas with the FHT scheme aM-PAM or BPSK format is considered as in [4]. We adapt the FHT-based SLM for optical OFDM (OOFDM) using Riemann sequence as phase factor sequence. To the best of our knowledge, no demonstration of FHT-based SLM for IM/DD optical OFDM systems based on Riemann Sequence exists in the literature.

The paper is organized as follows. Initially the transmitter and receiver models of conventional SLM, FHT based SLM, generation of Riemann matrix and its use as phase sequence is discussed then experimental set up for FHT based SLM-OOFDM with Riemann matrix as phase sequence and simulation results are presented and finally conclusion of the proposed work given.

OFDM WITH FHT BASED SLM

Conventional SLM and FHT based SLM

SLM is a PAPR reduction technique suitable for a wide range of applications. In this method, the data symbols are copied into U sections, each multiplied by U



deferent rotation vector. Then IFFT is applied to the different signal representations in order to select the one with minimum PAPR in conventional SLM. Figure-1 shows the conventional scheme for PAPR reduction. In conventional SLM scheme, U statistically independent sequences X^u ($0 \leq u \leq U-1$) are generated from the original sequence X with U individual phase sequences that can be written as in [6]

$$X^u = X \square H^u \quad X^u = [X^u(0), \dots, X^u(N-1)]$$

$$= [X(0)H^u(0), \dots, X(N-1)H^u(N-1)], (0 \leq u \leq U-1) \quad (1)$$

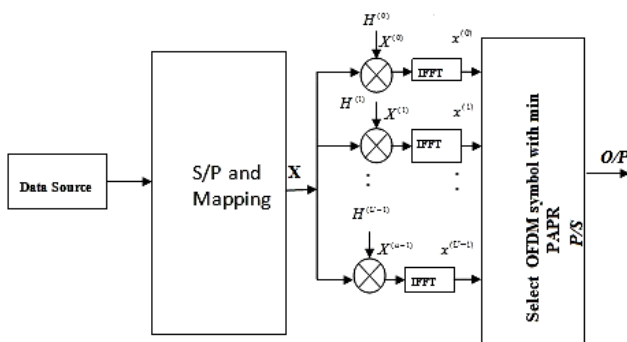


Figure-1. Block diagram of conventional SLM technique.

Where \square is denoted as the component-wise multiplication of the two vectors. In general, each symbol of the phase sequences H^u should have unit magnitude to preserve the power, and the first phase sequence $H^{(0)}$ is usually the all one sequence. Then a set of candidates X^u can be generated as

$$X^u = \text{IFFT}(X^u) = \text{IFFT}(X \square H^u), (0 \leq u \leq U-1) \quad (2)$$

Among the data blocks X^u , only one with the lowest PAPR is selected for transmission and the corresponding selected phase factors should be transmitted to receiver as side information. As U increases, PAPR reduction becomes large while the computational complexity becomes too high, mainly due to U IFFTs.

Here, the analyzed optical system is IM/DD, which requires real-valued OFDM signals. Therefore to implement FFT based SLM for IM/DD OOFDM, it is required to maintain Hermitian Symmetry (HS) to get real signal. Fast Hartley transform (FHT) has been proposed as an alternative modulation/demodulation processing in IM/DD optical OFDM systems [5]. It is a real trigonometric transform. If the input constellations are real, the generated OFDM symbols are real. Therefore, FHT for IM/DD systems does not need Hermitian symmetry, which is required in conventional fast Fourier transform (FFT) and the direct and inverse Hartley

transforms are identical, so that the same algorithm can be applied for the OFDM modulation and demodulation. Moreover, the complexity of FHT with real input constellation is half of that of FFT with complex input constellation [5]. Thus, FHT is perfect for IM/DD systems due to its low complexity. Figure-2 shows the transmitter and receiver structure of FHT based SLM. Here P^u ($0 \leq u \leq U-1$) are U independent sequences generated from Riemann matrix. All the elements of $P^{(1)}$ are always set to one, in order to consider also the original OFDM frame. Here all the rows of Riemann matrix B except the first row are used as phase vectors, which are multiplied by the OFDM frames. It results not only in phase change but also in amplitude change of the modulated data symbols and the average energy of the OFDM signal after multiplication with phase sequence increases [15].

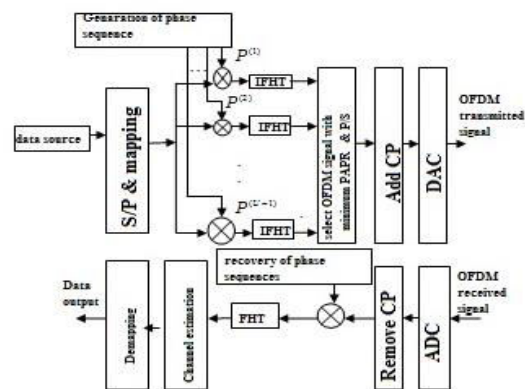


Figure-2. Transmitter and receiver diagram of FHT based SLM-OFDM.

Then the Peak to average power ratio (PAPR) of the proposed method is calculated. If x^u is the FHT based SLM signal then, the Peak to average power ratio (PAPR) of x^u , is represented as

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

Where $\max |x^u|^2$ the peak is signal power, and $E[|x^u|^2]$ is the average signal power of new SLM signal. According to Central Limit Theorem, x is approximately independently and identically distributed (i.i.d).

EXPERIMENTAL SET-UP FOR FHT based SLM-OOFDM

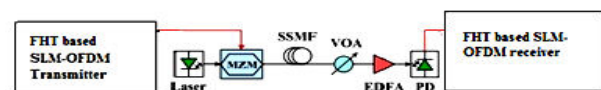


Figure-3. Experimental setup for proposed FHT based SLM - OOFDM System.



Figure-3 shows the experimental setup for proposed FHT based SLM - OOFDM system. The SLM-OFDM signal is encoded and decoded using MATLAB. The generated SLM signal was then uploaded into an arbitrary waveform generator (Tektronix AWG710) operating at 2.5GSa/s to generate 3.28Gb/s OFDM signal. The laser with 5 kHz line-width was used to generate the optical carrier. A MachZehnder modulator (MZM) was adopted to modulate the optical carrier with the generated SLM-OFDM signal. At the receiver, a variable optical attenuator (VOA) was used to vary the received optical power. The optical signal is amplified by an EDFA which is used to maintain a constant input power of photo detector (PD). The received O-OFDM signal can be converted into electrical signal using PD. The electrical signal is filtered by the low pass filter (LPF) with a 3dB bandwidth of 10GHz. The filtered electrical OFDM signal was captured using a 10GS/s real-time digital phosphor

oscilloscope (Tektronix AWG710) and the received digital SLM-OFDM signal was decoded by offline processing using MATLAB.

SIMULATION RESULTS AND DISCUSSIONS

This section presents the simulation results of the performance of the proposed scheme and conventional schemes to verify this technique. Figures 4 & 5 shows the CCDF performance for the evaluation of PAPR of conventional SLM with $U=2$ & 4 for $N=256$ & 1024 respectively. Here over sampling factor L is taken as 4. From the results, it is clear that with the increased value of U , the PAPR of SLM decreases. The performance of the proposed method is evaluated in an OFDM system with QPSK modulation the carrier frequency is $f_c = 5\text{GHz}$ and the bandwidth is $B = 20\text{MHz}$. All these simulation results are performed using MATLAB software.

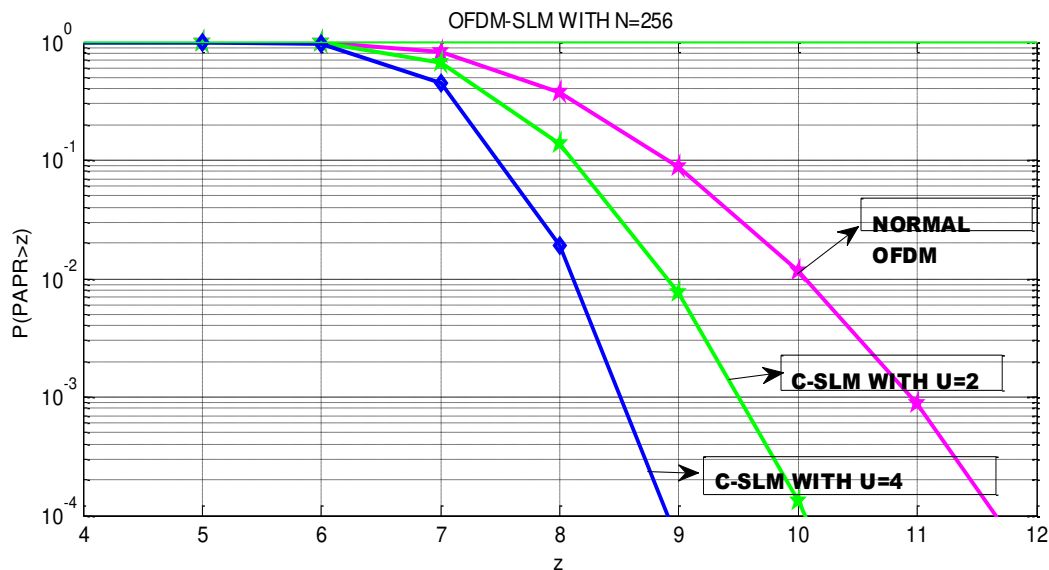


Figure-4. PAPR performance of OFDM system and conventional SLM for $U=2$ & 4 with QPSK modulation for $N=256$.

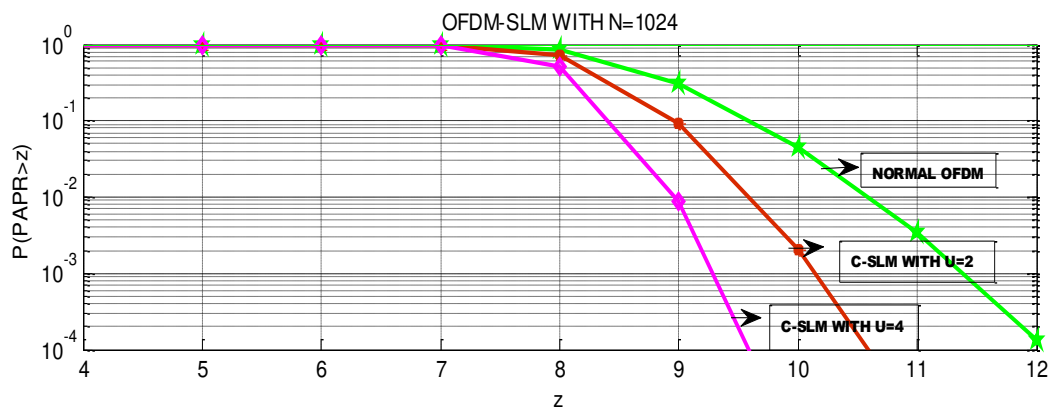


Figure-5. PAPR performance of OFDM system and conventional SLM for $U=2$ & 4 with QPSK modulation for $N=1024$



In Figures 6 & 7 PAPR performance of conventional SLM, Riemann based SLM and SLM with normalized Riemann with QPSK for $N=128$ & 256 is

analyzed. It is verified from the results that with the use of Riemann & normalized Riemann sequence, PAPR of SLM-OFDM system is reduced by 2.3dB at $\text{CCDF}10^{-2}$.

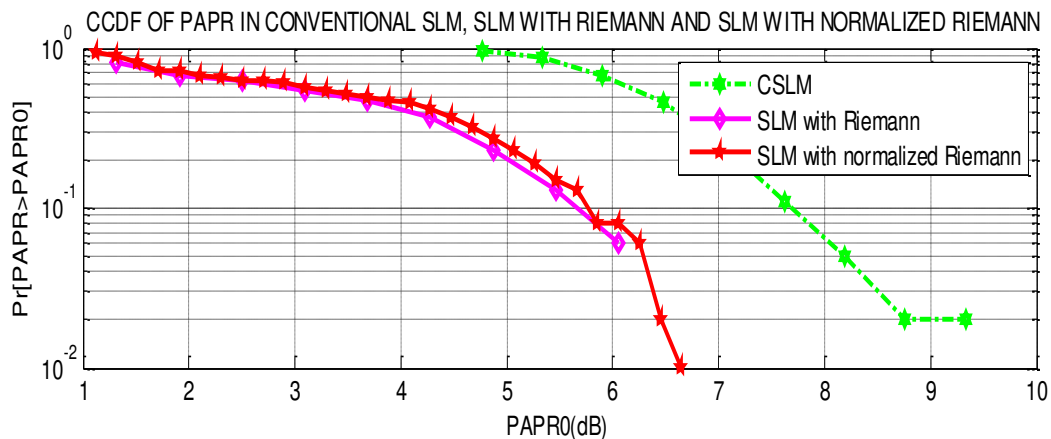


Figure-6. PAPR performance of conventional SLM, Riemann based SLM and SLM with normalized Riemann with QPSK for $N=128$

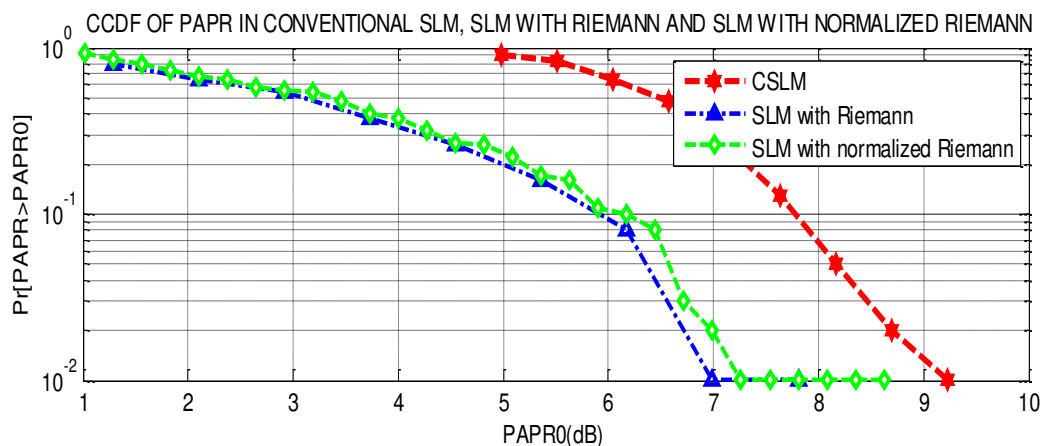


Figure-7. PAPR performance of conventional SLM, Riemann based SLM and SLM with normalized Riemann with QPSK for $N=256$.

The PAPR performance result of proposed method i.e. FHT based SLM-OFDM using Riemann Sequence with BPSK modulation for $N=256$ is depicted in Figure-8. The PAPR Performance is compared with FHT based OFDM and FHT based conventional SLM. The

result clearly shows that PAPR is reduced by approximately 1dB at $\text{CCDF} 10^{-3}$ with the proposed method and this method will be helpful in reducing the nonlinearity problem of OFDM.

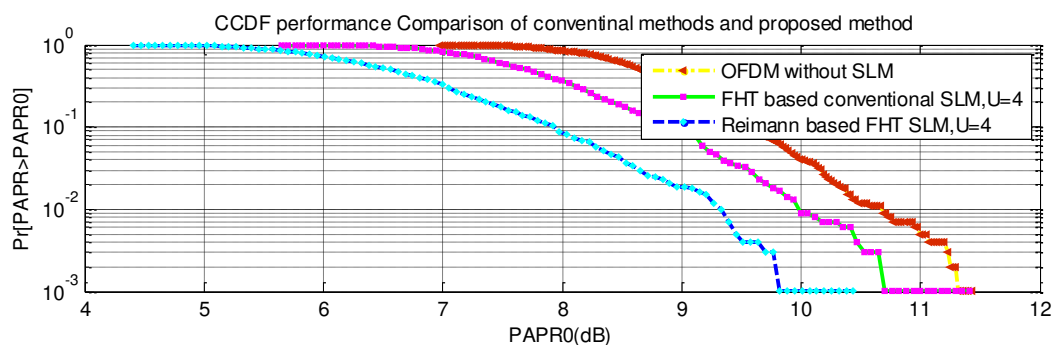


Figure-8. CCDF vs. PAPR for FHT based OFDM, FHT based SLM conventional SLM and Riemann based FHT SLM with BPSK for $N=256$.

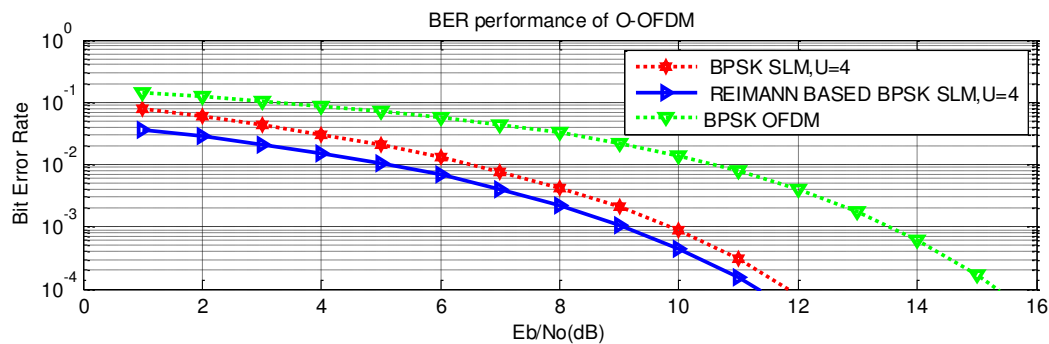


Figure-9. BER performance of FHT- based O-OFDM signal (BPSK ,N=64,U=4) without SLM, conventional SLM & Reimann based SLM

BER performance of FHTbased O-OFDM signal for BPSK without SLM, conventional SLM & Reimann based SLM is depicted in Figure-9. The simulation results are taken for no. of subcarriers $N=64, U=4$. For O-OFDM without applying any PAPR reduction technique, at a target BER of 10^{-3} , the required signal to noise power spectral density (E_b/N_0) is 13.8 dB and for Riemann based SLM, the E_b/N_0 required to achieve a target BER of 10^{-3} is reduced to 1.1dB compared to the conventional BPSK SLM. It can be observed from the results that for same E_b/N_0 , bit error rate is minimum for the proposed method.

CONCLUSIONS

This paper provides an effective and novel technique for nonlinearity mitigation of optical IM/DD system. The proposed scheme reduces the peak to average power ratio of OFDM signal as well as improves the BER performance of the system compared to the conventional method. The complexity of the proposed method is also less with the use of Riemann sequence and FHT based OOFDM. Riemann sequence reduces the no. of comparisons that need to achieve the desired result and by using FHT; no imaginary contribution has to be processed as it only processes the real part of the signal. This reduces the number of required electronic devices, achieving a lower cost system. In fact, the requirements of digital-to-analog and the analog-to-digital converters (DAC/ADCs) are halved.

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