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Effect of Joint PAPR Reduction Scheme for Optical OFDM Systems

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***Abstract*— The demand for large data traffic and high data rates has led to the incorporation of Orthogonal Frequency Division Multiplexing (OFDM) in optical systems for long haul transmission. Using OFDM, high data rates can be achieved by sending data simultaneously over multiple lower data rate subcarrier frequencies. However, the high value of Peak to average Power ratio (PAPR) has emerged as a major drawback of OFDM signal. Various PAPR reduction techniques exist in literature. This paper presents a Joint Modified Sliding Norm Transform (SNT) and clipping based PAPR reduction technique for Optical OFDM systems. Also the effect of PAPR reduction on the fiber span is studied.**

Index terms - Orthogonal Frequency Division Multiplexing (OFDM), Peak to Average Power Ratio (PAPR), Clipping, Modified Sliding Norm Transform (SNT).

I. INTRODUCTION

OFDM is multi carrier modulation (MCM) technique in which high speed data is carried over multiple subcarriers. The main OFDM is high spectral efficiency because of orthogonal subcarriers which eliminate the need of guard band between the subcarriers. Some of the applications of OFDM include digital subscriber lines; high-definition television broadcasting, 4G long-term evolution based cellular networks and optical communication [1]. OFDM is considered as a suitable technique for high speed communication due its inherent advantages of reduced intersymbol interference and high spectral efficiency [2].However, OFDM signal has an inherent drawback of high PAPR value which occurs due to large number of subcarriers which increases the non linear effects of the optical fiber and also puts a constraint on range of nonlinear network devices such as analog-to-digital converters, amplifiers and modulators. Hence there is a need to reduce the PAPR of OFDM signal in optical transmission systems.

II. OFDM SYSTEM

OFDM is modulation technique in which the data stream to be transmitted is split into a number of parallel low data rate bit carriers. At the transmitter, high rate digital data stream to be sent is split into N parallel streams. Each of the data stream is then mapped using some modulation scheme which in this work is QAM-4 mapping after which IFFT is performed to obtain OFDM signal. After that, a cyclic prefix is added to the OFDM symbol by adding samples from end of the sequence to the start of the sequence. The OFDM sequence is then used to modulate the optical carrier for which Mac Zehnder modulator (MZM) is generally used. The modulated signal is transmitted over Optical fiber channel. Figure 1 depicts the basic block diagram of an Optical OFDM communication system.

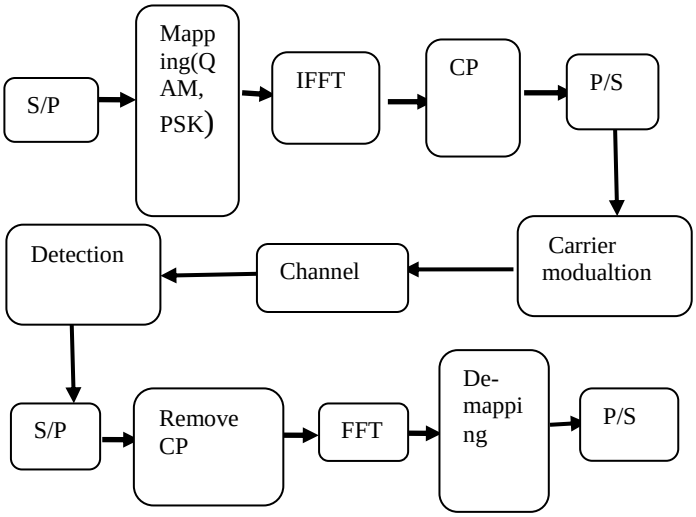

Fig. 1. Block diagram of optical OFDM system

At the receiver, Photodetectors(PD) are used to detect the RF signal and convert it into electrical OFDM signal which is then converted form serial to parallel form. The electric domain data is then converted from analog to digital using an analog-to- digital converter (ADC). After the removal of cyclic prefix, the Fast Fourier transform (FFT) is performed to demodulate the data which is transformed from time domain to frequency domain. Finally, data is detected by demapping and parallel to serial conversion.

III.PAPR

One of the major shortcomings of the OFDM modulation is a high peak to average power ratio (PAPR) is which occurs due to presence of a large number of subcarriers which when added coherently produces a large PAPR [2]. PAPR of a signal x(t) can be defined as given by (1).

$$\text{PAPR} = \frac{\max[(|x(t)|)^2}{\text{E}(|x(n)|^2)} \quad (1)$$

Generally, complementary cumulative distribution function (CCDF) is used to illustrate the reduction in PAPR of OFDM system and is defined as the probability that the PAPR of an

OFDM frame exceeds a threshold value and is expressed as given below [4].

$$(PAPR > \mathrm{PAPR_O}) = 1 - P(PAPR \leq \mathrm{PAPR_O}) = 1 - (1 - \exp(-\mathrm{PAPR_O}))^N \quad (2)$$

The value of PAPR of OFDM signal increases with increase in number of subcarriers and high PAPR value enhances the non linear effects in an optical channel [3]. Hence, by reducing the value of the PAPR of an OFDM signal, the power level of the output signal after modulation can be kept low. High PAPR also requires a high dynamic range of linear power amplifier, Digital to Analog/ Analog to Digital converters for operation in linear region. Hence there is need of reduction in PAPR of OFDM signal.

IV. PAPR Reduction Techniques

In order to reduce the high PAPR value in optical OFDM systems, various techniques have been proposed in literature .Some of the important techniques are signal clipping, companding, SLM, PTS, non linear sliding norm transforms etc.

Amplitude clipping is a simple PAPR reduction technique for OFDM signal. In this method, a predefined value of the amplitude is used to limit the peak value (P) of the input signal. Signal having values higher than this threshold value are clipped to the peak value as follows:

$$f(x) = \{P \text{ when } x > \mathrm{P}, \; x \text{ when } 0 \leq x < P\} \quad (3)$$

The main problem in this case is that the amplitude clipping introduces undesired clipping noise [4]. Then companding technique is another pre-distortion technique for PAPR reduction in which the amplitude of the small signal is enlarged while the large signal remains almost the same. Hence, the signal amplitude is re-distributed which results in reduced PAPR. μ- Law is used for companding. Using this transform, the gain of PAPR reduction and noise enhancement both are increased as the parameter μ is increased. Hence there is increase in noise due to companding for a constant value of signal-to-noise ratio [5] [6].

Then there are signal scrambling based PAPR reduction techniques like selected mapping (SLM) and Partial transmit sequence (PTS) techniques. But these techniques add additional computations and require side the information of vectors used for transformation for correct reception . This can degrade the spectral efficiency of the system.

Then Non linear transformation using L2-by-3 based Sliding Norm Transform (SNT) is a PAPR reduction technique which does not require additional information at the receiver. At the transmitter, it uses three samples, x_{n-1}, x_n, x_{n+1}, and a controlling parameter, α, in each sliding window to calculate the output samples [3][7].

$$y_n = \frac{x_n}{\sqrt{\alpha + x_{n-1}^2 + x_n^2 + x_{n+1}^2}} \quad (4)$$

At the receiver, Inverse Sliding norm transform is applied according to (5).

$$x_n = \left(\sqrt[3]{x_n^3}\right).sign(y_n) \quad (5)$$

A modified sliding norm transform has been presented in [8] which SNT uses two parameters α and b. SNT uses three samples to calculate an output sample but modified SNT uses only two complex value samples and so the computational complexity is less than that of the *L*2-by-3 method The vales of a and b can be adjusted to obtain desired PAPR reduction and power spectral density. The modified sliding norm transform is defined in (6).

$$y_n = \begin{cases} x_o, & n = 0 \\ \dfrac{x_n}{\sqrt{a + b.|x_n|^2 + |x_{n-1}|^2}} & n = 1,2,3 \ldots . N-1 \end{cases} \quad (6)$$

For reception, the inverse of the transform is applied as given in (7).

$$x_n = \begin{cases} y_o \, , y_n \neq 0, n = 0 \\ y_n . \sqrt{\dfrac{a + |x_{n-1}|^2}{1 - b.|y_n|^2}} \\ 0 \qquad\qquad y_n = 0 \end{cases} \quad (7)$$

The value of PAPR increases with increase in a. For a >1, the PAPR starts increasing than original OFDM signal, so a is kept between 0 to 1. Also, PAPR reduces considerably with increase in b as evident in figure 4. Hence the values of a and b need to be optimized for desired results.

The main advantages of SNT are improvement in terms out-of-band distortion in the system and the method does not require any side information to be transmitted and hence there is no loss in data rates .

Clipping offers high value of PAPR reduction but high clipping ratio leads to enhancement in noise.SLM and PTS have high computational complexity.

Hence, in this paper, a joint PAPR reduction technique using modified SNT and clipping with a low clipping ratio has been proposed.

V. Results

This paper presents a Joint Modified SNT and clipping based PAPR reduction technique. The Optical OFDM system is modeled using VPI software. OFDM signal generation and detection is done using MATLAB coding which is linked to VPI using CoSimulink block. The parameters used for PAPR reduction are 1, 2, 0.2 for a, b and clipping value respectively. The OFDM signal generated with the reduced PAPR is first unconverted to 7.5 GHz and then this electrical signal is used to externally modulate a LASER source operating at 193.1 TH using MZM modulator, This modulated optical signal is now launched into the optical fiber having span of 200 km which is then varied to study the Bit error Rate (BER) performance of the system. At the receiver, Direct Detection (DD) is employed by means of a photo diode.

The CCDF for OFDM signal shows 2.5 dB reduction in PAPR at a threshold probability of 1×10^{-3} using modified SNT which is further reduced by 1 dB after clipping is applied.

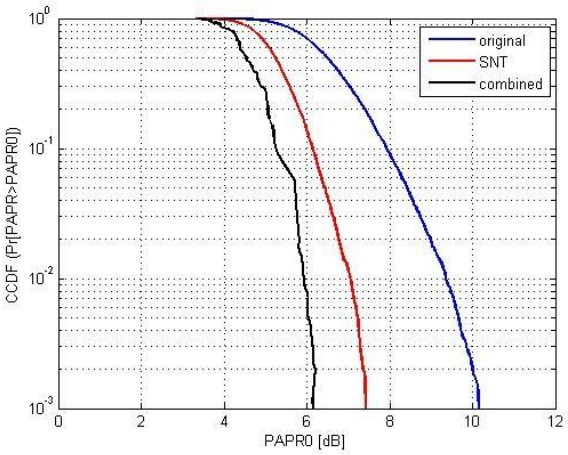

Fig 2. CCDF of OFDM original signal with and without PAPR reduction

The simulations are performed at 10 Gbps and effect of change in distance on BER of the received data is studied. Table 1 gives the comparison of BER values of the received signal with without PAPR reduction.

TABLE 1 BER of optical OFDM system at different length of optical fiber

S.No.	Distance (km)	BER (without PAPR reduction)	BER (with PAPR reduction)
1.	200	1.6×10^{-4}	4.9×10^{-5}
2.	400	1.2×10^{-3}	1.2×10^{-4}
3.	600	6.1×10^{-3}	1.2×10^{-3}
4.	800	1.5×10^{-2}	6×10^{-3}
5.	1000	1.9×10^{-2}	9.4×10^{-3}
6.	1200	2.2×10^{-2}	1.8×10^{-2}

From the table , it is evident that OFDM systems exhibit good BER performance for a distance up to 600 Km where for the same system with PAPR reduction technique, BER of $9.4*10^{-3}$ is obtained at a distance 1000km.Hence, it can be the distance of transmission can be improved using the proposed PAPR reduction technique.

VI. Conclusion

OFDM is a promising technique for long haul communication systems. Its advantages are high spectral efficiency and reduced intersymbol interference. But high PAPR is an inherent drawback of OFDM which arises due to a large number of subcarriers which when added coherently produce a large peak power which affects the performance of the system. Various methods have been proposed for reduction of PAPR of OFDM signal. This paper presents a novel joint PAPR reduction which is a combination of modified SNT and clipping. The graph for CCDF depicts that proposed technique offers better PAPR reduction than modified SNT. Also, the effect of proposed technique on the fiber length is studied. Hence it can be conclude that the distance of transmission can be improved using the proposed technique for Optical OFDM systems.

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