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HYBRID TECHNIQUE BASED PAPR REDUCTION IN CO-OFDM SYSTEM

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ABSTRACT

Orthogonal frequency division multiplexing (OFDM) is a principle multiple carrier modulation formats; and at present it is widely used in various types of applications such as wireless and optical communication. It is regarded as a perfect method which is used for high speed optical communication. Furthermore, it has high spectral efficiency and robustness to path losses. Likewise, it suffers from high peak to average power ratio (PAPR) which is considered as one of the main problems that is experienced by the optical OFDM systems. It has a crucial effect on the characteristics of the system. Notably when PAPR increases, the nonlinear and linear impairments in optical fiber will be high including chromatic dispersion (CD) and polarization mode dispersion (PMD) as linear impairments; and nonlinear characteristics due to self-phase modulation, cross-phase modulation and four-wave mixing. This paper proposes an efficient cascaded hybrid technique to reduce the PAPR by combining the nonlinear technique of modified sliding norm transformer (MSNT) and the clipping linear technique in the 4QAM coherent optical OFDM (CO-OFDM) system. In effect, the proposed technique does not need to send side information to the receiver; in addition it doesn't cause degradation in the bit error rate and bandwidth. The simulation results reveal that the system performance is significantly improved in comparison with individual techniques of clipping and modified sliding norm transformer. As a result, it is clearly found that PAPR reduction can achieve 5.1dB from the original signal when a 10Gb/s OFDM signal is rated at a laser power 5dBm for bit error rate of 1x10-3. Moreover, the measured quality factor (QF) is enhanced by about 1.1dB and error vector magnitude (EMV) by nearly 1 dB withallowable distance 660 km over single mode fiber (SMF).

Keywords: Orthogonal frequency division multiplexing, peak-to-average power ratio, complementary cumulative distribution function, coherent optical OFDM, modified sliding norm transformer, 4QAM, clipping, bit error rate.

1. INTRODUCTION

As known, the expansion in Internet networks and multimedia services in the world had led to using multi carrier modulation (MCM) techniques. One of them is orthogonal frequency division multiplexing (OFDM) which is widely used in long haul and high bit rate optical transmission system due to its good spectral efficiency and data rate [1].A major defect of OFDM systems is their high peak-to-average power ratio (PAPR) because when signal change from frequency domain to time domain using inverse fast fourier transformer (IFFT),the obtained signal is that by adding all the sub carriers; and once all the subcarriers are added in phase, the result exhibits a peak N times beyond average power [2].

In order to reduce PAPR, researchers are investigating many techniques to minimize the peak power. The techniques used to reduce PAPR could be classified into linear and nonlinear categories. Likewise linear techniques are classified into distortion and distortion less. The distortions techniques include clipping and filtering [3], windowing [4] and compounding [5].The distortion less techniques like, selective mapping technique (SLM)[6], partial transmit sequence (PTS)[7], interleave [8] tone injection & tone reversion (TI &TR)[9], active constellation extension (ACE)[10], Coding [11], and pre-coding[12]. Techniques previously mentioned which are used to minimize PAPR can not only lead to a loss in bandwidth and data rate, but also can grow in BER, power of the signal and computational difficulty because they need to send side information to the receiver. On the other hand, nonlinear technique includes, reduced complexity max norm algorithm (RCMN), modified sliding norm transform (MSNT) and L_2-by-3 that mention in [13]. For nonlinear technique, there is no need to send side information to the receiver. So, the complexity of the system will be reduced and there is no loss in data rate and bandwidth.

In this paper a combination of the MSNT and clipping scheme is employed in CO-OFDM systems to reduce the PAPR for the first time as based of our knowledge. This paper is divided into five sections as follows: The introduction is presented in Section one, in addition Section two focuses the light on PAPR problem in OFDM. In section three, hybrid technique is proposed on PAPR based on combining the nonlinear technique of modified sliding norm transformer (MSNT) and the clipping linear technique in the coherent optical OFDM (CO-OFDM) system. The forth section presents system setup, while section five reveals the simulation results and discussion. Finally, conclusion is also presented.

2. PAPR IN OFDM

OFDM system consists of a large number of modulated sub channels. To put it in another way, coherent addition of (N) subcarriers that have a same phase will produce peak power (N) multiplied by the average power. A large PAPR intensify the intricacy of the analog to digital converter (ADC) and digital to analog converter (DAC) which decreases the efficiency correspondently. Another key point is that the existence a large number of severally modulated subcarriers in the OFDM system, so the peak power value of the system can be verified as high in comparison with the average power of the whole system. Furthermore, logical addition of (N) signals have a similar phase generate a peak which is (N) times the average signal. Let's the Baseband time-domain OFDM signal u(t) comprising from claiming N_{sc} subcarriers which represented as a vector B_k= {b1, b2, b3, to b_{N-1}} might a chance to be composed as:

$$u(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} B_k e^{j2\pi k \Delta_f t} \qquad 0 \le t \le NT \qquad (1)$$

Where Δ_f is the space between subcarrier, B_k is the modulation symbol and NT is the data block period. The PAPR of the sent signal is:

$$PAPR = \frac{P_{peak}}{P_{avg}} = 10 \log_{10} \frac{\max_{0 \le t < NT} |u(t)|^2}{1/_{NT} \int_0^{NT} |u(t)|^2 dt} \qquad (2)$$

Where P_{peak} presents the peak output power and $P_{avg:}$ the average output power.

Minimizing $max|u(t)|$ is the goal of all PAPR method. Complementary cumulative distribution function (CCDF) is a parameter used to discover the effectiveness of any PAPR technique. Still yet the purpose behind such a use is helping to determine the probability that PAPR of a definite data block transcend the given threshold. The cumulative distribution function (CDF) for the signal sample having amplitude is given by the equation below[2]:

$$F(z) = 1 - exp(z) \qquad (3)$$

The CCDF of the PAPR is given by the equation below:

$$P(PAPR > z) = 1 - P(PAPR \le z) = 1 - F(z)^N = 1 - \left(1 - exp(-z)\right)^N \qquad (4)$$

3. BASIC PRINCIPLE OF THE HYBRID TECHNIQUE

Hybrid technique includes clipping which is linear algorithm and modified sliding norm transformer which is nonlinear algorithm. This technique utilizes good properties of linear techniques and nonlinear techniques in terms of having no necessity to transfer side information to the receiver as well as not effect on the bandwidth, bit error rate and data rate. This technique is used to reduce PAPR in direct detection optical OFDM (DD-OOFDM) system in [14]. To the best of our knowledge, this technique is used for the first time in CO-OFDM system to minimize PAPR. Thus the hybrid technique is explained as follows.

3.1 Modified sliding norm transformer (MSNT)

MSNT algorithm was first mentioned in [15] which is modified form Dursun's algorithm. Dursun or L_2-by-3 algorithm which is nonlinear was proposed and reviewed in [16,17].

L_2-by-3 uses three samples in each sliding window with a parameter α that has a major controlling in order to compute the output sample as in the equation (5).

$$y_n = \frac{u_n\#}{\sqrt{\alpha + u^2_{n-1} + u^2_n + u^2_{n+1}}} \qquad (5)$$

The inverse of L_2-by-3 is used in the receiver:

$$u_n = \left(+\sqrt{u_n^2}\right) \operatorname{sign}(y_n) \qquad (6)$$

For MSNT it is different from L2-by-3the algorithm because it uses two samples with two controlling parameters α and β in each sliding window in order to calculate the output sample as in equation (7).

$$y_n = \begin{cases} u_o & n = 0 \\ \frac{u_n}{\sqrt{\alpha + \beta . |u_n|^2 + |u_{n-1}|^2}} & n = 1,2,3,..N-1 \end{cases} \qquad (7)$$

The invers of MSNT is used in the receiver as in equation:

$$u_n = \begin{cases} y_o, y_n \neq 0, n = 0 \\ y_n . \sqrt{\frac{\alpha + |u_{n-1}|^2}{1 - \beta \cdot |y_n|^2}} \\ 0 \quad y_n = 0 \end{cases} \qquad (8)$$

PAPR value will be changed depending on α and β values. PAPR is directly proportional to α where it changes from (0 to 1) and inversely proportional to β where it changes from (1 to 10). This technique is a smaller amount sensitive to the mapping order and number of sub-carriers [15].

3.2 Clipping

The clipping method is the uncomplicated PAPR reduction technique, which bound the maximum of transmit signal to a pre-defined level. Similarly if the signal exceeds this level it will be clipped, where as if it will not pass without change [18]. Figure-1 shows OFDM transmitter with clipping.

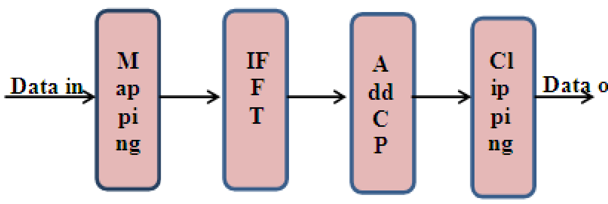

Figure-1. OFDM transmitter using clipping.

That is to say that this method can maximize average power and reduce peak power with low accomplishment complexity and does not need to send additional information to the receiver. Clipping method is considered a non-linear process that causes (in & out) band distortion. In other words, the out-band causes spectral extension and can be taken away by filtering out signal after clipping. For in-band distortion causes to limit

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BER and disposed by performed clipping with the adequately oversampled OFDM signals (e.g., L ≥4) the BER performance will be less degraded [19]. The clipped signal as in:

$$c(u_n) = \begin{cases} u_n & \text{if}|u_n| \leq A \\ A\frac{u_n}{|u_n|} & \text{if}|u_n| \geq A \end{cases} \quad (9)$$

Where u_n is OFDM signal and A is the threshold amplitude of the signal. We can define the clipping ratio as in:

$$CR = \frac{A^2}{P_{in}} \quad (10)$$

The proposed technique is a combination between clipping and MSNT. The equation that described the technique is obtained by substituting equation (7) in equation (9):

$$c(y_n) = \begin{cases} y_n & \text{if } |y_n| \leq A \\ A\frac{y_n}{|y_n|} & \text{if } |y_n| \geq A \end{cases} \quad (11)$$

$$c(y_n) = \begin{cases} \frac{u_n}{\sqrt{\alpha+\beta.|u_n|^2+|u_{n-1}|^2}} & if\ |y_n| \leq A \\ A\frac{\frac{u_n}{\sqrt{\alpha+\beta.|u_n|^2+|u_{n-1}|^2}}}{\left|\frac{u_n}{\sqrt{\alpha+\beta.|u_n|^2+|u_{n-1}|^2}}\right|} & if\ |y_n| \geq \end{cases} \quad (12)$$

The proposed combination techniques are obtained when we use equation (12) in the transmitter. In the receiver side, equation (8) is used in order to obtain the original signal u_n.

4. SYSTEM SETUP

The difference between the original CO-OFDM and the proposed system is that in using clipping with MSNT in the transmitter and IMSNT in the receiver. This is clarified in Figure 2(a, b). The system contains OFDM transmitter, Optical section (IQ modulator, optical channel and coherent detection) and OFDM receiver.

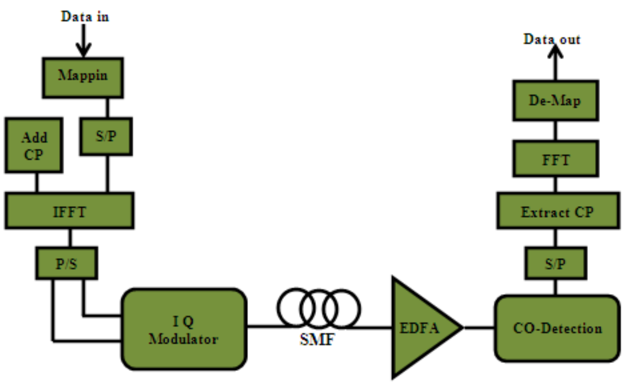

Figure-2a. Original CO-OFDM.

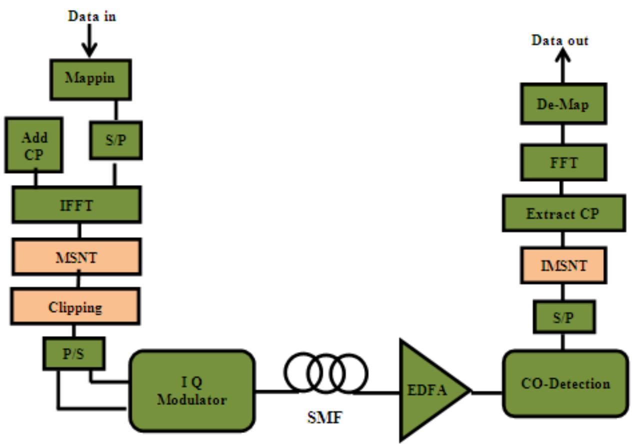

Figure-2b. CO-OFDM system with proposed PAPR hybrid.

4.1 OFDM transmitter

The input data is mapping by using QAM modulator which may be (4, 16, 32 or 64), then the modulated signal pass through S/P converter which convert it to complex vector with size M. Then this vector passes through IFFT to generate OFDM signal (u_n) and the signal is consequently converted from frequency domain to time domain as defined in the equation below.

$$u_n = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} U_k \exp\left(\frac{j2\pi kn}{N}\right) \cdots 0 \leq n \leq N-1 \quad (13)$$

Furthermore, cyclic prefix is added to signal in order to ensure that ISI and ICI do not occur. Then OFDM signal which is equal to u_n= [u_0, u1, u2…] ^{T} enters MSNT in order to obtain y_n. Later the signal is clipped by using clipping algorithm using equation (9). The clipped signal can be written as C(y_n)= C(y_n) + d_n where d_n denote as the clipping noise. The signal then converted to the optical signal by using IQ modulator in order to send it through the optical channel.

4.2 Optical section

The RF signal is converted to the optical signal using IQ modulator. The real component (I) and imaginary component (Q) of the output signal from the OFDM stage are sent to I/Q optical modulator that contains two lithium Niobate (LiNb) Mach-Zehnder modulators (MZM). The electrical signal from the OFDM stage will be modulated by MZM to the optical carrier with a laser diode of 193.01 THz.

The optical signal is then sent through the SMF with a dispersion compensated fiber (DCF) and an Erbium Doped Fiber Amplifier (EDFA) which is used to amplify the signal and to compensate the losses during transmission. The last part of the optical channel is the coherent optical detection. The coherent optical OFDM receiver converted optical signal to the electrical signal using four photo detectors with phase difference between them (90^o).

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4.3 OFDM receiver

At the receiver the received signal enters the inverse of nonlinear MSNT in order to compute u_n from y_n by using equation (8). Cyclic prefix is removed in order to do (FFT) which convert the signal from time domain to frequency domain. After that the signal is converted to the serial form in order to do de-mapping and retrieval of the original signal.

5. RESULT AND DISCUSSIONS

There is no doubt that the simulation of the CO-OFDM system with PAPR reduction which is mentioned in this paper use VPI photonic simulation program with MATLAB co-simulation so as to simulate the system. The OFDM coder and OFDM decoder were built with hybrid PAPR reduction method (MSNT with clipping) all in MATLAB (R2014a).For the optical channel, optical modulator and optical detectors which were dealt with by using VPI.Figure-3 shows the simulation scheme.Table-1 summarizes the system parameters.

Table-1. System parameters.

Symbol	Description	Value
BR	BitRate	10Gbps
TW	TimeWindow	8*1024/BitRate
Nsc	Number OF subcarrier	64
CP	Cyclic Prefix	1/8
M	Order of Mapping	4QAM
L	Over Sampling	4
BpS	Bit per symbol	2
fc	Optical Frequency	193.1 THz
	Laser linewidth	100KHz
α_{optic}	Attenuation for Fiber	0.2dB/Km
α_{DCF}	Attenuation for DCF	0.5 dB/Km
SMF	Length of SMF	50Km
DCF	SMF(Dispersion Compensating fiber)	5Km
Loop	L	10
α		0.2
β		10
Laser Power		5 dBm

At first we examine the effect of changing the values of α and β on PAPR reduction.Figure-3 shows the CCDF compression between the OFDM original signals and the signal after reducing PAPR with MSNT using equation (7) for different values of α (0.1 to 1)and set β to 10. Moreover, it demonstrates that the relation is direct between α and PAPR whenever α increase PAPR increases too. From the figure we obtain a minimum PAPR at α equals 0.2.

Figure-4 demonstrates the PAPR for original OFDM signal and after reduction of PAPR using MSNT for different values of β (1 to 10) and set α to 0.2.It is noticed that PAPR has minimum value whenever β increases and we obtain the minimums at β equals to 10. So, in our simulation we set α to 0.2 and β to 10.

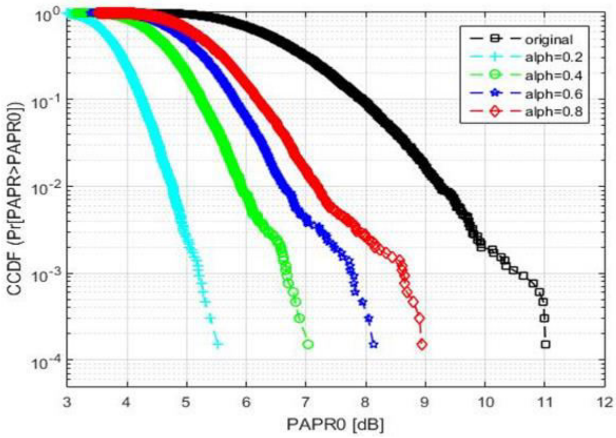

Figure-3.CCDFvs.PAPR in MSNT for different values of α and β=10.

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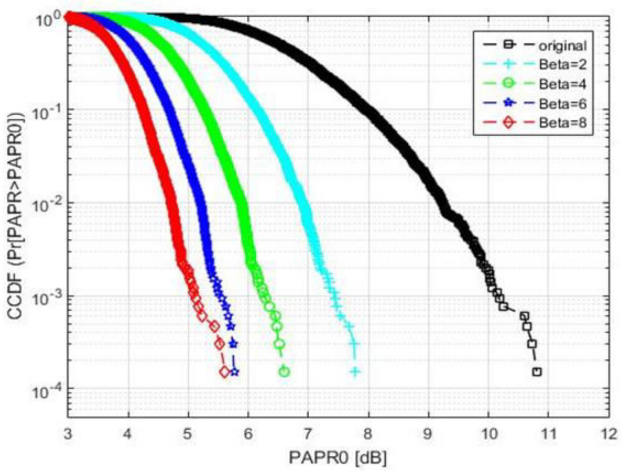

Figure-4. CCDF vs. PAPR for original system and CO-OFDM system using MSNT for different values of β and α=0.2.

As mentioned before the MSNT algorithm is classified as a smaller amount sensitive scheme to the mapping order and number of sub-carriers. Table-2 demonstrates the value of PAPR that we obtained after change the number of subcarriers and QAM order. We deduce that the value of PAPR is not affected by the change of the QAM order when utilizing the same number of subcarriers.

Figure-5 illustrates the CCDF for PAPR comparison between the original OFDM signal and the signal when using MSNT, clipping and combination between clipping and MSNT. Still yet, from the Figure below it could be noticed that the reduction for the PAPR when using clipping is about 0.6 dB at probability 10^{-3}, but when using MSNT the reduction is about 4.7dB at probability $1x10^{-3}$; while for the hybrid technique reduction of PAPR is being around 5.1dB.

Table-2.PAPR Reduction using MSNT algorithm

PAPR in dB					
Nsc	QAM	β =10			
		α=0.2	α=0.4	α=0.6	α=0.8
32	4	5.5	7.2	8.3	9.1
	16	5.5	7.2	8.3	9.1
	64	5.5	7.2	8.3	9.1
64	4	6.2	7.5	8.2	8.8
	16	6.2	7.5	8.2	8.8
	64	6.2	7.5	8.2	8.8
128	4	7.3	8.5	9	9.4
	16	7.3	8.5	9	9.4
	64	7.3	8.5	9	9.4

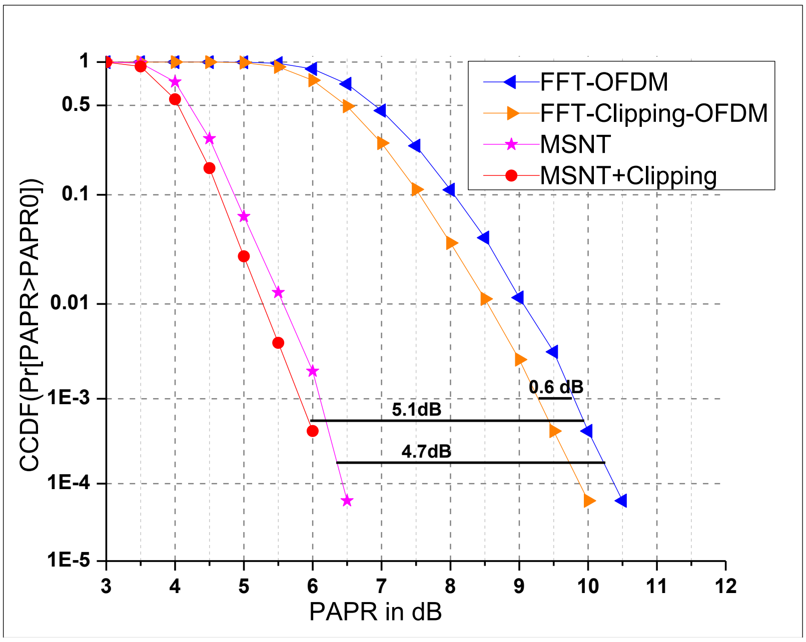

Figure-5. CCDF vs. PAPR for MSNT, clipping and proposed hybrid PAPR reduction techniques.

To find out the system performance, it is essential to examine the BER, Quality Factor (QF), error vector magnitude (EVM) and the constellation Diagram for two systems with and without using the proposed Hybrid PAPR reduction technique. Within these two systems, the laser launch power is set at 5dBm and the system parameters are also considered as mentioned in Table-1.The signal sent in the optical channel is affected by

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several factors such as phase noise, nonlinearity and dispersion that lead to digression in BER, Quality Factor and error vector Magnitude (EVM) when the distance increase. In order to extend the transmission distance we need to increase the power of the transmitted signal to ensure that the information arrives without loss. When the transmission distance is long, the optical signal power becomes weak because of the insertion loss of the nonlinear optical device, so we need to increase the power. But, the nonlinear optical devices are affected by the larger optical power that may lead to a significant degradation in the system performance.

Figures (6a, b, and c) show the relation for BER, Quality Factor and EVM versus distance when using proposed PAPR reduction technique and without using PAPR reduction. The signal constellation diagram of 4QAM is also compared along 660km SMF cable in original CO-OFDM system and when using the proposed hybrid PAPR reduction technique

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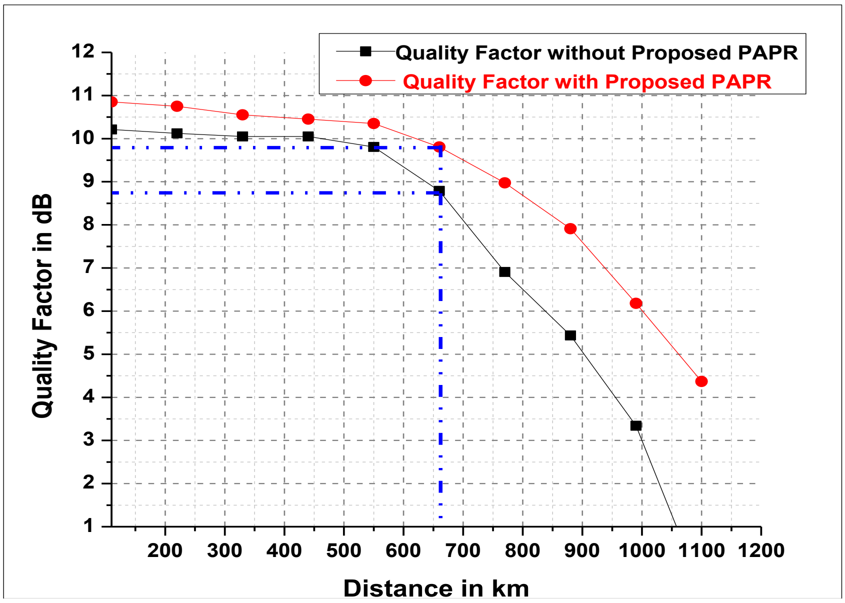

Figure-6a. Quality factor vs. distance.

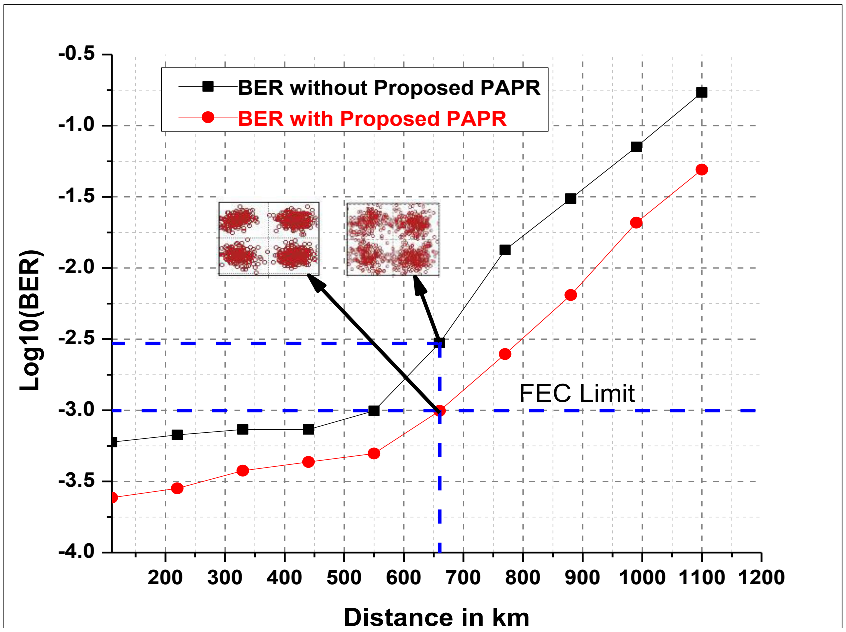

Figure-6b. BER vs. distance.

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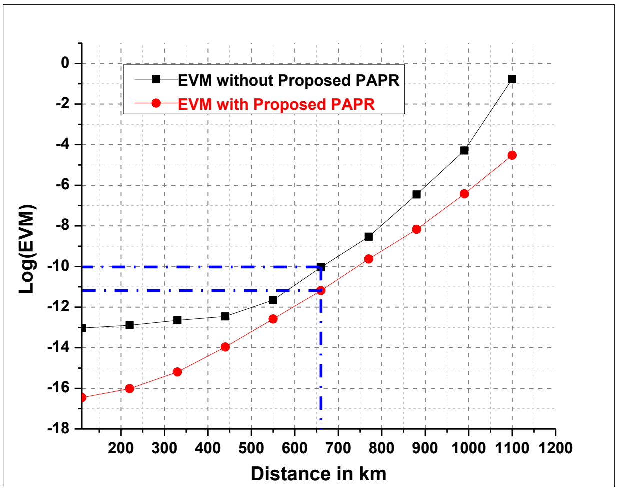


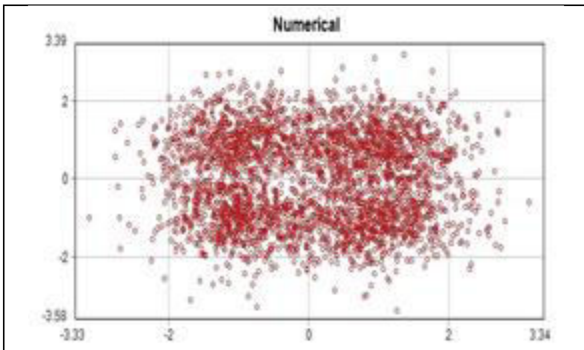
Figure-6c. EVM vs. distance.

Figure-6adepicts the change in quality factor with distance. It is noticed that the quality factor decreases with increasing distance because the transmitted power decreases over the long haul optical transmission; thereby to compensate this degradation in the received signal the power of the transmitted signal should be increased. The first curve (black) represents the quality factor of the system without adding the hybrid PAPR reduction technique; and in contrary the second curve (red) explains the quality factor of the system after adding the proposed technique to reduce PAPR. From the figure we observe an improvement in the quality factor of the system as the technique has evidently helped to reduce the impact of nonlinearity, phase noise and dispersion. For example at the distance 660km the quality factor for the system without PAPR reduction achieves8.721dB; meanwhile for the proposed PAPR reduction, the improvement in signal quality is around 1.1dB when QF achieves 9.8dB.

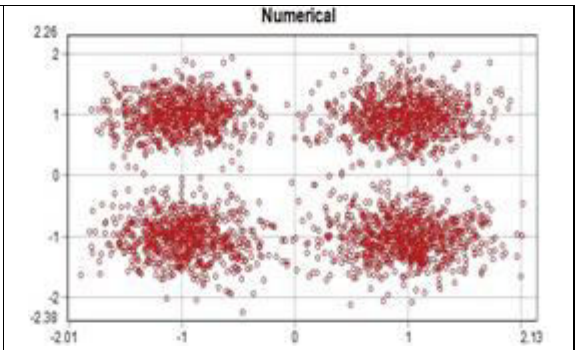
On the other hand, Figure-6b shows that BER metric of the original system without using PAPR reduction technique at 660km is higher compared with the system of proposed hybrid PAPR reduction technique. This means that the proposed technique can faithfully enhance the BER performance through reduction in the impact of nonlinearity, phase noise and dispersion. Similarly, Figure-6c displays the improvement in EVM about 1.1dB at the distance 660 km for the system with PAPR reduction in comparison with original OFDM system without PAPR reduction technique.

Figure-7a, b represents the comparison of signal constellation diagram for the system with and without PAPR reduction at a distance 660km. It is found that Figure-7b displays significant improvement in the received signal constellation when the hybrid PAPR reduction technique is employed. In other words, it can be concluded that the high PAPR due to the nonlinearity and phase noise produced by the system devices has been successfully reduced with high quality factor of 9.8dB.

Now, we investigate the effect of optical signal to noise ratio (OSNR) on the bit error rate (BER) and quality factor for the original system and the system based hybrid PAPR reduction. Thus Figure-8a shows the relation of BER vs. OSNR and Figure-8b depicts the received signal quality vs. OSNR, respectively. From Figure-8a, we can reach the target FEC BER limit when OSNR achieves 16dB for the system based on hybrid PAPR reduction. However, we notice that OSNR required becomes more than 22 dB in the original system without PAPR reduction. Thus the proposed system outperforms by 6dB the original OFDM system without any PAPR reduction scheme. Also, the figure draws a conclusion that the BER decreases once OSNR increases.



Constellation diagram without proposed PAPR



Constellation diagram with proposed PAPR

Figure-7. Constellation diagram.

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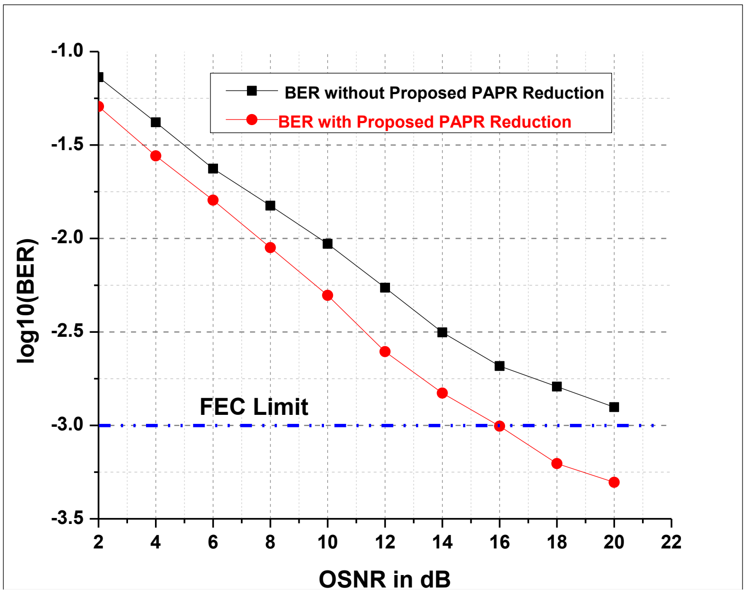

Figure-(8a). BER vs. OSNR.

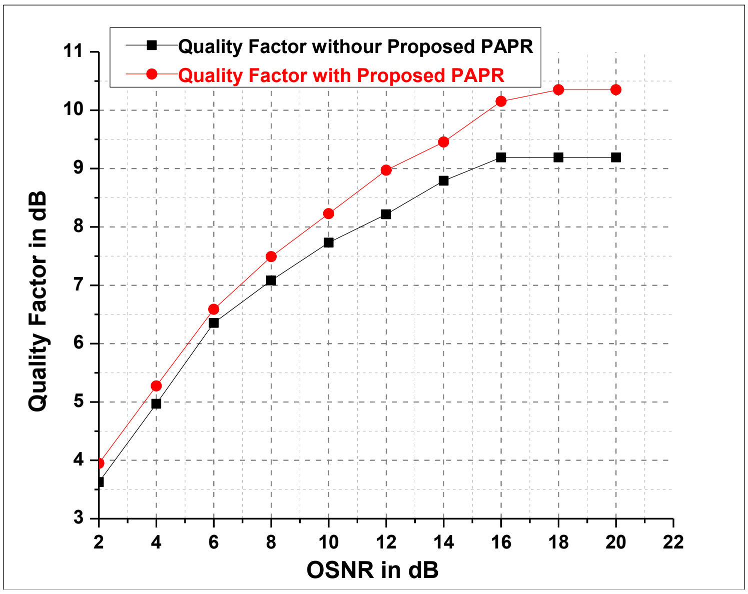

Figure-(8b). Quality factor vs. OSNR.

Now, Figure-8b shows that quality factor versus the corresponding OSNR when hybrid PAPR reduction is employed. The results describes that once the OSNR achieves (14- 20) dB the quality factor will steadily change between (9.4- 10.3) dB for a hybrid PAPR reduction and (8.9-9.1) dB for the original system without PAPR reduction, respectively. In consequence, this result indicates that the proposed technique has eventually enhanced the system quality performance by 0.5-1.2dB.

6. CONCLUSIONS

OFDM could be a promising technique for high data rate communication systems. Its advantages concern on high spectral efficiency and reduced ISI. However, high PAPR is associate degree inherent downside of OFDM that arises due to an oversized range of subcarriers. Once the subcarriers are added coherently, the outcome signal will turn out a high peak power that affects the performance of the system. Therefore, many techniques are used to reduce PAPR of OFDM signal. In this paper, a hybrid method of a combination between modified sliding norm transformer MSNT and clipping is used in CO-OFDM system for the first time to mitigate PAPR. The graph of CCDF illustrates that the proposed technique offers higher PAPR reduction than using either MSNT or clipping method. The reduction in PAPR achieves 5.1dB. Also, this technique has been investigated to examine the BER, Quality factor and constellation diagram when a fixed laser power is 5dBm rated at 1Gbps SMF over allowable distance up to 660km. The obtained results have shown that the hybrid PAPR reduction has led to a very significant improvement in system performance.

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