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An Effective Combining Transformer to Relieve Fiber Nonlinearity in CO-OFDM System

Liqaa A. AL-Hashemi
Dept. of Electrical Engineering
University of Basrah,
Basrah, Iraq
Email: leqaa.abdulsattar@gmail.com

Sinan M. Abdul Satar
Dept. of Electrical & Electronic Eng.
University of Technology
Baghdad, Iraq
Email: sinansma@yahoo.com

Ghaida A. Al-Suhail
Dept. of Electrical Engineering
University of Basrah,
Basrah, Iraq
Email: ghaida_alsuhail@yahoo.com

Abstract— In this paper, the aim is to combat a considerable Chromatic Dispersion and non-linearity that are introduced in the optical channel. Therefore, we propose a new combination for the first time in Coherent-Optical Orthogonal Frequency Division Multiplexing (CO-OFDM) system to suppress effectively these drawbacks for the purpose of configuring long haul Optical transmission. The system basically depends on mitigating the Peak to Average Power Ratio (PAPR) of the 4QAM sent signal. A new combination occurs between clipping which is linear technique and nonlinear L2-by-3 technique. The simulation results reveal that the system performance has been significantly improved in terms of BER, Optical Signal-to-Noise Ratio (OSNR)via launch power

Keywords— CO-OFDM, Chromatic Dispersion, Non-linearity, Clipping, L2by3 Transform, PAPR

I. Introduction

In the last few years, there has been a growing interest in the information technology infrastructure due to its phenomenally high usage in out day to day life ranging from smart devices to the internet and many other fields. In most cases, optical fiber technology works as an effective solution to sustain growth and satisfy the requirements of the state of the art techniques like OFDM.

Furthermore, OFDM is considered as one of the most important multiple carrier modulation format which has many applications in wireless communication and in optical communication.

However, CO-OFDM is considered as a good technique for high speed optical communication and in long haul because of its good spectral efficiency, high data rate in addition to its strong capability of anti-dispersion[1].

It is worth mentioning that CO-OFDM system provides the possibility to use Digital Signal Processing (DSP) techniques in the transmitter and the receiver to compensate the effect of optical fiber losses like CD and NL. The main problem of OFDM system is the high PAPR for the signal after Invers Fast Fourier Transformer(IFFT) that would be transmitted through the optical channel. To illustrate, high PAPR means increasing the optical channel losses, also it means increasing the distortion of the signal due to the nonlinear devices in the system. Thus, a reduction of the PAPR to a minimum value is needed in order to enhance the system performance. Even though several researches have been made to show the different methods that are used to minimize PAPR.

Furthermore, examples of the previously mentioned methods are Distortion techniques as Clipping and Filtering[2, 3],Windowing and Companding[4, 5] while the distortion less techniques like Selective Mapping Technique(SLM)[6, 7],Partial transmit sequence(PTS) [8, 9], Interleave [10], Tone Injection & Tone Reversion (TI & TR)[11], Active Constellation Extension(ACE)[12],block coding and pre-coding[6].

It has been noticed that all these methods have the ability to reduce PAPR in a perfect manner but some of them degraded Bit Error Rate (BER). In other words , they lessen data rate and band width because they need to send side information to the receiver . Moreover, they also have the ability to increase the computational complexity. Table (1)summarizes the main properties of some PAPR reduction method[13].

TABLE 1: COMPARISON BETWEEN DIFFERENT PAPR REDUCTION METHOD [13]

No	Technique	Computational Complexity	BW Consu mption	degrade BER	degrade Data rate	Comments
1	Clipping &Filtering	no	no	yes	no	Add noise distortion
2	Windowing	no	no	yes	no	Distortion
3	Companding	yes	yes	no	yes	Need Side information
4	SLM	yes	yes	yes	yes	Need Side information
5	PTS	yes	yes	yes	yes	Need Side Information
6	Interleaving	yes	call ed yes	no	yes	Need Side Information
7	TI	yes	yes	no	yes	Need Side information
8	TR	yes	no	yes	yes	No Need Side information
9	ACE	yes	no	yes	no	
10	Coding	yes	yes	no	yes	
11	DSNT	no	no	no	no	No Need Side information

In this work, it is noteworthy that a combination between nonlinear PAPR reduction technique namely L2by3, has been used for the first time. Then again, this combination is derived from Discreet Sliding Norm Transformer (DSNT) and clipping technique. On the other hand, the new technique has gained benefit from the characteristics of the two original technologies in terms of the lack of necessity to send side information to the receiver and reduce computing, in addition to having no affect on the data rate of information.

The remainder of this paper is organized as follows. Part I outlines the introduction, part II presents the optical fiber impairments while part III reviews the CO-OFDM system, PAPR concept and the Complementary Combined Distribution Function (CCDF). The proposed technique is discussed in part IV while part V is devoted to the system architecture and part VI represent the Simulation and results. Finally, the conclusion of this work is presented in the last part.

II. OPTICAL FIBER IMPAIRMENTS

It has been noticed that there are two types of optical fiber impairments. The first one represents linear impairments like , attenuation and CD. Where as the second one is nonlinear impairments like Cross Phase Modulation (XPM), Self Phase Modulation (SPM), Four Wave Mixing(FWM), Brillouin Scattering (BS) and Raman Scattering(RS). There is no doubt that all the previously mentioned impairments can cause degradation of system performance. Moreover, the linear impairments could be eliminated by the way of using optical amplifier in order to reduce the affect of attenuation on the signal. Additionally, the dispersion compensating fiber (DCF) or equalizer can be used to reduce the effect of CD on the received signal[14]. In contrast, in the case of the nonlinearity impairments which causes phase rotation in the received signal, Inter Carrier Interference between Sub-Carriers, Interference between the main carrier and Sub-Carriers and Inter Symbol Interference especially ; when the power for the signal is high the effect of non-linearity impairments should be compensate on the signal.

III. CO-OFDM SYSTEM

Figure(1)illustrates the block Diagram of OFDM technique which has been utilized in optical communication due to its fascinating properties that are shown when they are used in long haul system. Furthermore, OOFDM can be separated into two classes that are Direct Detection Optical OFDM (DDOOFDM) and CO-OFDM. Generally, DD-OOFDM has a straightforward receiver in that it requires a guard band embedded between optical carrier and OFDM subcarriers to alleviate interference[14]. This will decrease the spectral efficiency. Moreover, OFDM require more power since some power is utilized for transmitting subcarrier[15].

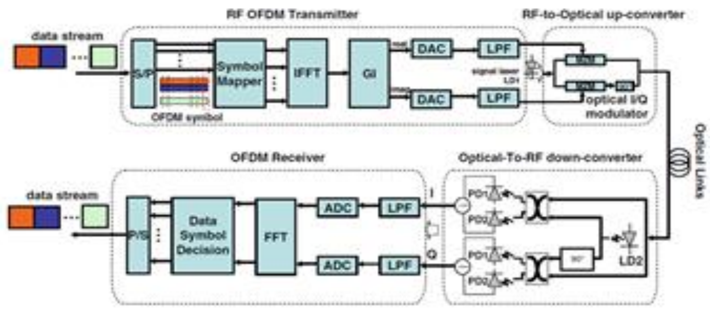

Fig. 1.Block Diagram for Optical OFDM [16]

To that end, CO-OFDM requires Continues Wave laser (CW) at the recipient in order to create the carrier locally. It has been illustrated that CO-OFDM have better spectral efficiency, robustness against polarization dispersion and sensitivity to phase noise[17], to give an explanation , OFDM framework is comprised a substantial quantities of balanced sub carriers. Moreover, coherent addition of (N) sub carriers that have the same phase will create a peak power which (N) can be duplicated by the normal power.

Significantly, a huge PAPR increases the multifaceted nature of the (ADC) and (DAC) which in turn diminish the productivity. It has been noticed that the presence of a large number of multi-modulated sub-carriers in the OFDM signal will result in the signal being high if it is different and normal for the entire signal. Furthermore, logical addition of (N) signals have the same phase generation of a peak which is (N) times the average signal. Let's the Baseband time-domain OFDM signal x(t) comprising from claiming Nsc subcarriers which are represented as a vector $X_N=\{X_k, k=0,1,\ldots,N-1\}$ might a chance to be composed as:

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{\frac{j2\pi}{NL}kn} \qquad 0 \leq n \leq NL-1 \qquad (1)$$

Where X_k is the symbol carried by the k_{th} sub-carrier, L is the oversampling factor. The OFDM signal contain an N number of modulated sub-carrier, which when added up coherently can give a very large PAPR[18]. The PAPR of the transmit signal is:

$$PAPR = \frac{P_{max}}{P_{avg}} = \left[\frac{max|x(n)|^2}{E\{|x(n)|^2\}}\right] \qquad (2)$$

Where P_{max} is the max power, P_{avg} is the average power. Importantly, minimizing the $max|x(n)|$ is the goal of all PAPR techniques. Moreover, Cumulative Distribution Function (CDF) is a parameter that is used in order to know the effectiveness of any PAPR technique. The aim of PAPR diminishment plans is to move the CDF curve as much to the left as could be allowed. Scientifically CDF can be clarified with a set of data having the Probability Density Function (PDF). With that in mind, in order to obtain the CDF, the integral of the PDF is computed. Thus complementary (CCDF) is the complement of the CDF. Basically, CCDF is defined as the probability of transmitted OFDM symbols that are exceeding the threshold value, PAPR(0).

$$\mathrm{CCDF} = \mathrm{Prob}(\mathrm{PAPR} > \mathrm{PAPR0}) = 1 - (1 - exp(PAPR_0))^N \quad (3)$$

IV. PROPOSED TECHNIQUE

The proposed technique, which is the main concern of this paper, is a combination of two techniques . That is to say, the first technique is a clipping technique which is a distortion technique. Where as the second one is L2by3 which is nonlinear technique and derived from Discrete Sliding Norm Transformer. It has been argued that L2by3 was first discussed by Dursun's and used in wireless system[19]. Moreover, 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 low computational complexity. To put it another way, let OFDM signal in equation (1) with N samples. After using L2by3 transformer in the transmitter, the signal becomes y_n.

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

Where α is a constant control which varies between 0 and 1 and control the value of PAPR. When α increases the PAPR value increases too and vice versa as shown in Figure 2.

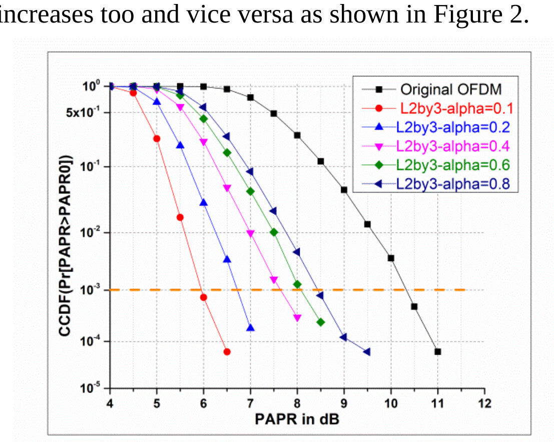

Fig.2. PAPR Reduction controls by parameter α [0:0.1:1]

Additionally, in equation (4) three samples are used for each norm window. Then the clipping technique is used in order to clip the signal to the specified threshold. The previously mentioned signal will be as as in the following equation.

$$c(y_n) = \begin{cases} y_n & \text{if } |y_n| \le A \\ A\frac{y_n}{|y_n|} & \text{if } |y_n| \ge A \end{cases} \quad (5)$$

Where A is the threshold amplitude of the signal and $c(y_n)$ is the clipping signal. Furthermore, it has been noticed that the original data in the receiver would be obtained by the way of using the revers of the L2by3 transformer :

$$x_n = \left(\sqrt[2]{u_n^2}\right) sign(y_n) \quad (6)$$

V. SYSTEM ARCITECTURE

Basically , the system architecture of CO-OFDM contains five blocks . The first one is OFDM transmitter which consists of QAM-Mapping, IFFT, parallel to serial .Moreover, the PAPR proposed technique is implemented after IFFT block as shown in figure (3). To that end, matlab (2014a) has been used in order to implement the whole OFDM transmitter and receiver.

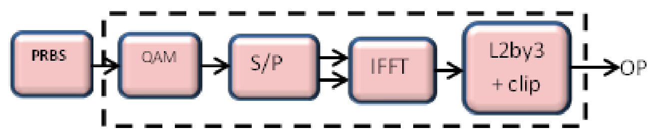

Fig.3. OFDM Transmitter

Notably, the optical transmitter uses I/Q modulator which encompass two Mach-Zehnder modulator (MZM) in order to modulate the real and imaginary part of the signal on optical carrier frequency 193.1THz which is generated by Continuous-Wave laser. Furthermore, VPI transmission maker 9.5 has been used in order to implement optical transmitter and receiver. While in the optical receiver there are two pairs of photodetector ,an optical 90^o hybrid to detecte the In-phase and Quadruter component. With this in mind, OFDM receiver of the original data returend to use L2by3 invers before the Fast Fourier Transformer (FFT) as shown in figure (4).

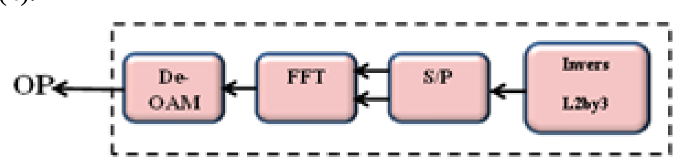

Fig.4.OFDM Receiver

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والصور في الاشكال ايضا غير واضحة

VI. SIMULATION AND RESULTS

From the research that has been carried out , it is possible to notice that the system is simulated by the way of using Matlab (2014a) and VPI transmission Maker9.5. To give more explanation, the system parameters are summarized in Table 2.

TABLE .2: SIMULATION PARAMETERS USED IN VPI COHERENT OPTICAL OFDM

Global parameters	
BitRate	10 Gbps
Symbol rate	40 Gbps
Sequence length	8192
Samples per bit	2
QAM-4 sequence generator	
Bits per symbol	2
Constellation type	square
OFDM modulator	
Max possible subcarriers	128
Cyclic Prefix	1/8
CW laser	
Carrier Frequncy	193.1THz
Power	5dBm
LineWidth	0.1MHz
SMF+DCF	
SMF length	50km
DCF length	5km
Number of loop	10
Attenuation for SMF	0.2dB/km
Attenuation for DCF	0.5 dB/km
Dispersion coefficient SMF	16 ps /nm/km
Dispersion coefficient DCF	-160 ps /nm/km
α	0.1
Clip Ratio	0.7

The efficiency of PAPR reduction techniques could be checked using two ways. First way is the distribution of PAPR which is given by CCDF. The second way is evaluating system performance In terms of improved BER, EVM, and quality factor. In the current paper the two ways has been used.

Figure 5 demonstrates the CCDF of the original signal, clipping signal, L2-by-3 and combined technique for optical OFDM signals.

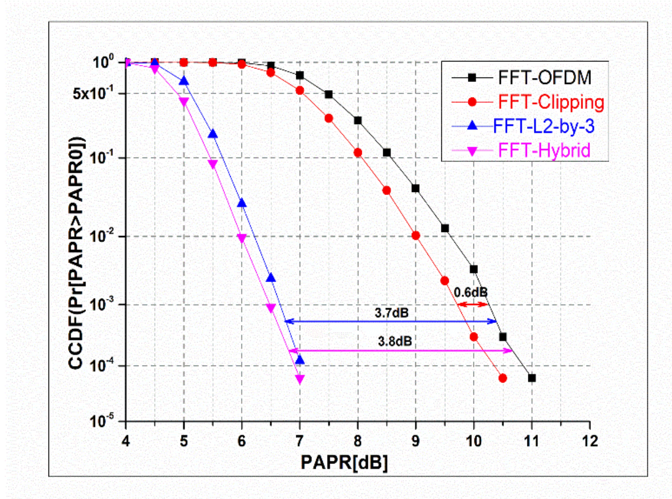

Fig.5. CCDF of PAPR for clipping, L2by3 and proposed Combined PAPR techniques

From the diagram, it has been illustrated that the PAPR of OFDM signal with combined technique lessened fundamentally in contrast to the original OFDM. The PAPR lessened about 0.6dB with a clipping technique and 3.7dB with L2by3 technique while PAPR is lessened by 3.8dB with proposed technique at the probability threshold 10^{-3}. Table 3 represents the comparison of the proposed method with traditional methods such as SLM and PTS.

TABLE .3: COMPARISON PAPR REDUCTION TECHNIQUES

Method	PAPR original [dB]	After PAPR [dB]	Reduction in [dB]
PTS [20]	11.1	9.8	1.3
SLM [20]	11.1	9.9	1.2
Companding [4]	13.9	10.7	3.2
Proposed	10.3	6.5	3.8

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Moreover, Figure 6 shows the variation of Optical Signal to Noise Ratio (OSNR) with Distance for the original signal and when using the PAPR proposed technique. To put it another way , when PAPR is high the nonlinearity of the optical fiber is high too , so this will limit the transmission distance. From the previously mentioned figure, a better OSNR has been obtained for the signal with proposed PAPR reduction than the signal without any PAPR reduction technique. Thus this means that the proposed technique has the ability to enhance OSNR for the system and maximize the transmission distance.

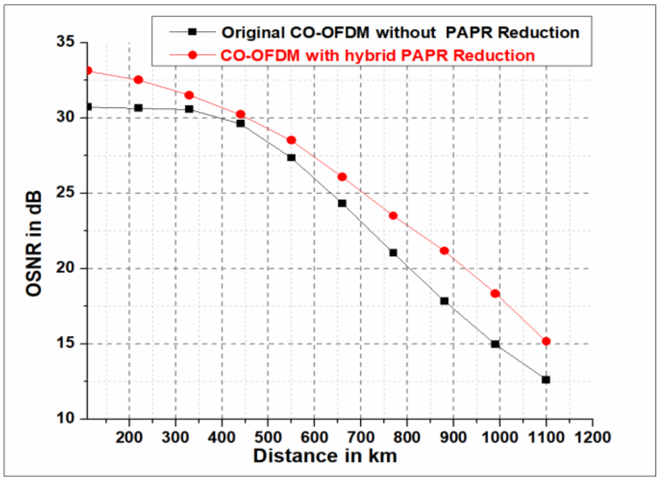

Fig.6.OSNR vs. Distance

The relation between OSNR vs. input launch power of the laser source is depicted in Figure (7). As previously mentioned in CO-OFDM system, higher PAPR will increase nonlinearity impairment which means that low OSNR is obtained.

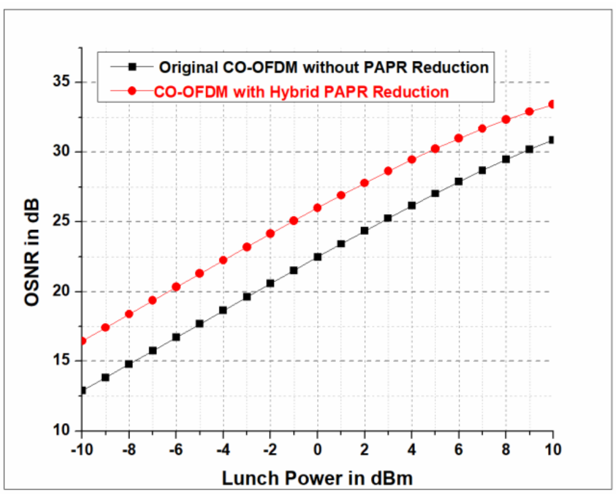

Fig.7.OSNR vs. Launch Power of Laser

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In Figure 7, the signal with hybrid proposed technique it has been displayed. It needs lower launch power in order to achieve the same value of OSNR compared with the original signal. It means that lower launch power, more low PAPR and eventually minimum nonlinearity and good OSNR.

Basically, the effect of reducing PAPR can be investigated by using the proposed technique on the Bit Error Rate (BER), Quality Factor (QF) and Error Vector Magnitude (EVM) correspondingly. Thus Figure 8 represents the relation between EVM Vs. distance in km. The figure illustrates that EVM for a system with proposed PAPR reduction can introduce better performance than the system without any PAPR reduction. All this happens due to the nonlinearity for the system is lessened when PAPR is reduced. As an example at a distance of 550 km, an improvement of 1dB is obtained for the system with proposed PAPR reduction compared with system without PAPR reduction.

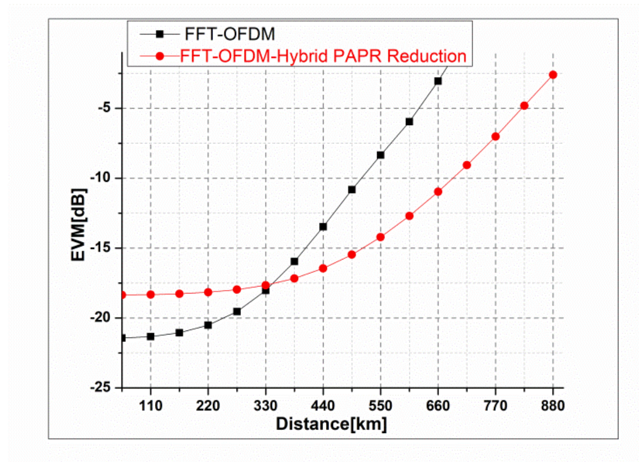

Fig.8.EVM vs. Distance

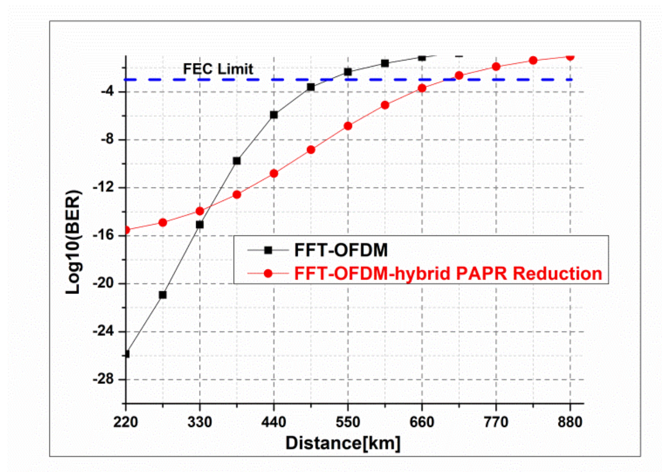

Fig.9.BER vs. Distance

Figure 9 outlines the relation between BER vs. Distances. As far as it is concerned , in order to send the signal to a long distance ,the power should be increased . In other words , this means increasing the nonlinearity in the system and thus increasing the BER. Moreover, figure 9 shows that BER for the system with proposed PAPR is less than BER for the system without PAPR, because reducing PAPR means improving OSNR and reducing non linearity of the system. A good example for the system with proposed PAPR reduction, BER equal to $1*10^{-3}$ at 715 km where the system without PAPR reduction the distance is 440km.

Finally, Figure 10 shows the relation between QF vs. distance. Quality Factor for the system with proposed PAPR reduction is better than for the system without PAPR reduction. Furthermore, the system shows an improvement in quality factor about 2.1 dB at a distance 440 km.

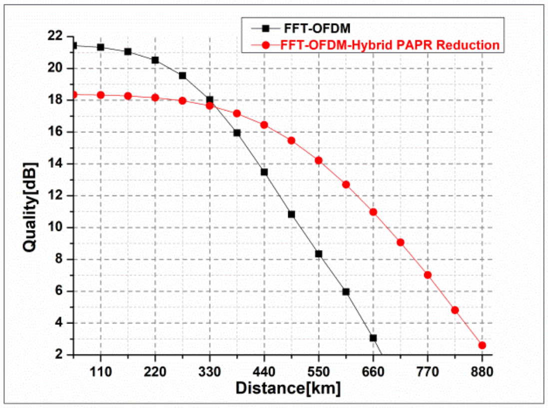

Fig.10. Quality Factor vs. Distance

VII. CONCLUSION

Based on the results, it can be concluded that CO-OFDM is considered as a promising candidate for future long-haul high capacity transmission systems but the main problem is PAPR. This paper has clearly shown that a new combination was proposed in order to reduce PAPR which in turn leads to the reduction fiber nonlinearity .Clearly ,the proposed technique is considered one of the effective techniques used in reducing the PAPR. In other words , an active technique in reducing the PAPR . Notably, this scheme has a simple implementation because it is not necessary to send side information to the receiver. In current paper, the CO-OFDM with and without proposed transform has been presented. The simulation is modeled by the way of using the VPI transmission Maker 9.5 system and Matlab (2014a) software. From the results obtained , it has been noticed that the proposed technique can reduce the PAPR of the CO-OFDM by 3.8dB .Furthermore, The signal with proposed PAPR can also achieve better OSNR ,QF about 2.1dB ,BER which increasing the distance about 715km in comparison with the original signal.

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