PERFORMANCE ANALYSIS OF FIBER OPTIC LINK USING DIFFERENT OBP TECHNIQUES

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ABSTRACT

*Optical fiber has emerged as significant medium for transmission, in wireless and landline communications, Due to broad bandwidth and quality of transmission. But, it cannot be considered as an idea medium; the capacity of fiber- optic system is affected by various linear and nonlinear impairments. Nonlinear impairments results due to the dependence of refractive index on launched power in optical fiber. Back propagation is an effective method for compensating nonlinearity. In this paper, optical back propagation techniques for mitigating nonlinear effects has been analyzed.. A performance comparison of different compensating techniques has been carried out using Quadrature Amplitude Modulation (QAM) in fiber-optic system for various system parameters. It is concluded that inline-NLC provide improved performance over the inline-OBP and receiver based-OBP. The research is conducted in MATLAB environment.***

KEYWORDS: *Optical fiber communications, nonlinear effects, optical back propagation techniques, m-ary Quadrature amplitude modulation, Bit error rate.*

I. INTRODUCTION

In order to support dramatically increasing data traffic demand, High-capacity optical backbone networks are needed. But, optical fiber also possesses some unwanted properties. Dispersion and nonlinearity are the major limiting factors in light wave communication. Various signal processing techniques are necessary to reduce the nonlinear impairments and fully exploit the system capacity. Back propagation technique can be classified as Digital Back Propagation and Optical Back Propagation (OBP). In Digital Back propagation, the sign of distance is reversed and the nonlinear Schrodinger equation is solved in digital domain. Due to large amount of computation resources required for reducing nonlinearity in WDM based fiber optic system; digital back propagation is replaced by OBP.

Various methods for compensating nonlinearity have been proposed. Digital back propagation (DBP) algorithm jointly compensate for dispersion and nonlinearities [1-2] along with the coherent receiver. For DBP, Split-step Fourier methods (SSFM) is used to solve the inverse of nonlinear Schrodinger equation (NLSE). The performance of DBP can be improved [3] by using modified split-step Fourier method, known as M-DBP. Due to high bandwidth requirements and computational complexities of DBP, an alternative technique is derived. This technique was known as optical back propagation (OBP) [4]. An optical phase conjugator with high dispersion and nonlinear fibers for OBP based fiber-optic system design was investigated. The proposed technique outperforms the midpoint optical phase conjugation [5] and digital backpropagation with the same step size. An analytic formulas for the improvement in optical signal-to-noise ratio (OSNR) was derived by digital nonlinear compensator [6] for dispersion uncompensated links. The dependency of the upper boundary on different fiber types and OSNR improvement practical system conditions is discussed.

A numerical model for receiver side all-optical signal processing[7] method, i.e. optical backward propagation (OBP) using dispersion compensating fiber (DCF) and non-linear compensator (NLC) was discussed and observed a 66% increase in the transmission distance by implementing inline-OBP as compared to conventional OBP with 256 QAM.

In this paper, we compare the nonlinearity compensating schemes using different optical back propagation techniques. We extend our previous report [7] by comparing the receiver-based OBP, Inline-OBP and Inline- NLC. In section 2, theoretical evaluation of optical back propagation along with receiver-based OBP is discussed. Section 3 provides results and discussions for numerical simulations. In section 4, conclusion and future work are discussed.

II. Optical Back Propagation (OBP)

The technique used to remove fiber dispersion and nonlinear effects using optical domain, is called optical back propagation (OBP) and it is applicable to signals of any modulation format. An OBP include the Dispersion compensating fiber (DCF) for compensating Dispersion occurring in fiber and nonlinear compensator (NLC) section to reduce nonlinear effects of the preceding transmission fiber, respectively. Depending upon the use of OBP module in fiber optic system, OBP techniques [8] can be classified as: Receiver-based OBP, Inline OBP and Inline NLC techniques. In receiver- based OBP, the OBP module is placed at the end of fiber-optic link but prior to receiver section. In inline based OBP, the OBP module is placed in transmission link, preferably at each amplifier site. In case of inline NLC, the NLC module is placed at each amplifier site. Whereas, dispersion is compensated at receiver end.

Signal propagation through optical fiber is governed by nonlinear Schrodinger equation (NLSE). This NLSE governing the forward propagation in transmission channel [8] can be written as

$$\frac{-\partial u}{\partial z} - \frac{\alpha}{2}u - \frac{i\beta_2}{2}\frac{\partial^2 u}{\partial t^2} + \frac{\beta_3}{6}\frac{\partial^3 u}{\partial t^3} + i\gamma|u|^2 u = 0 \qquad (1)$$

Here u represents envelope of optical field, α is fiber loss coefficient, β_j is jth order dispersion, γ is nonlinear coefficient, t is retarded time. Eq.(1) can be written as

$$\frac{\partial u}{\partial z} = (\check{D} + \check{N})u \qquad (2)$$

where $\check{D}$ is a linear operator and given by

$$\check{D} = -\frac{\alpha}{2} - \frac{\beta_2}{2}\frac{\partial^2}{\partial t^2} + \frac{\beta_2}{3}\frac{\partial^3}{\partial t^3} \qquad (3)$$

and $\tilde{N}$ is a nonlinear operator, given by

$$\check{N} = i\gamma|u|^2 \qquad (4)$$

Various solution methods can be used to solve NLSE numerically such as finite-difference method and split-step method (SSM).

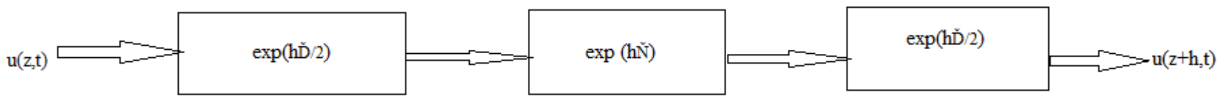

Figure 1. Split-step Method

In split-step method, as shown in fig. 1.. the fiber is divided into two sections, where for each section, we perform the integration i.e.

$$u(z+h,t) = \exp\left(h\left(\check{D} + \check{N}\right)\right)u(z,t) \qquad (5)$$

The NLSE is invertible equation. The transmitted signal can be exactly recovered back, in the absence of noise, by backpropagating the received signal through inverse NLSE i.e.

$$\frac{\partial u}{\partial z} = (-\check{D} - \check{N})u \tag{6}$$

Back propagation is applicable directly on complex field envelope u (z,t). This technique can be used for any type of modulation format with required step size selection. Consider the input field envelope is given by:

$$u_0(t,0) = \sqrt{\frac{E_0}{\sqrt{\pi}T_0}}\, exp\left[\frac{-t^2}{2T_0^2}\right] \tag{7}$$

After propagating through optical fiber, let the output of transmission link is

$$u_s(t) = \frac{u(t,L_{tot})}{\sqrt{2}} \tag{8}$$

Where $u(t, L_{tot})$ represents the received field envelope, distorted with dispersion and nonlinear effects and is given by

$$u(t,L_{tot}) = Mu(t,0) \tag{9}$$

where

$$M = exp\left[i\int_0^{L_{tot}}[\check{D}(t) + \check{N}(t,s)]ds\right] \tag{10}$$

Since, exp(ŷ)exp(-ŷ) =1 and u (t, L_{tot}) = u_b(t,0)Thus, using back propagating technique , Eq. (9) will be

$$u_b(t,L_{tot})=M^{-1}u_b(t,0) \tag{11}$$

$$M^{-1} = A(t,x,y)B(t,x) \tag{12}$$

In order to solve, M^{-1}, Symmetric split-step Fourier technique is used, having (h) as step size. Operator (A) denotes fiber dispersive effects and operator (B) denotes nonlinear phase shift.
Fig. 2. shows the schematic diagram of receiver-based optical back propagation i.e. the OBP module is placed at receiver section.

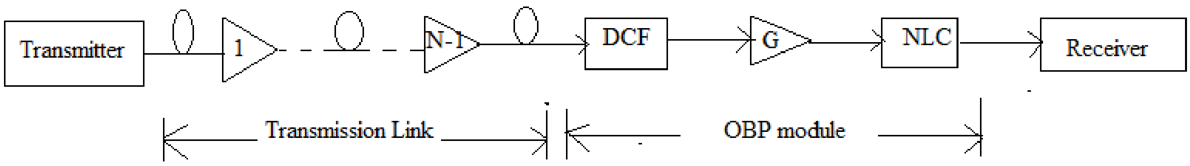

Figure 2. Schematic diagram of receiver-based OBP technique

From Fig. 2. Operator (A) can be solved using DCF which compensate for the accumulated dispersion of the last span of optical fiber link. For solving operator (B), NLC is used. An amplifier with gain (G) is used between DCF and NLC section to compensate the loss produced by these two sections. In case of coherent detection, Output of NLC[8] with complex constant(K), is given by

$$u_{out} = Ku_s(t)\exp[-i2\gamma_1 L_{eff,1}|u_s(t)|^2] \tag{13}$$

III. RESULTS AND DISCUSSIONS

In fiber-optic system, the amplifier spacing (L_a) and step size (h) plays a significant role in evaluating the nonlinear effects. The results are predicted for various nonlinear compensating techniques such as receiver based OBP, inline-OBP and inline-NLC. Different parameters such as BER, transmission distance, Q-factor, Launched power, m-ary QAM are considered. For ideal BP, generally the step size is kept smaller as compared to amplifier spacing.
The results are calculated using Gaussian pulse for m-ary QAM format. The various system parameters includes operating wavelength =1.55 μm, total transmission distance = 2500 km, dispersion coefficient (ß) =-21 W^{-1} km^{-1}, attenuation coefficient (α)= 0.2 dB/km, amplifier spacing L_a= 100 km.

3.1 BER vs. Transmission Distance

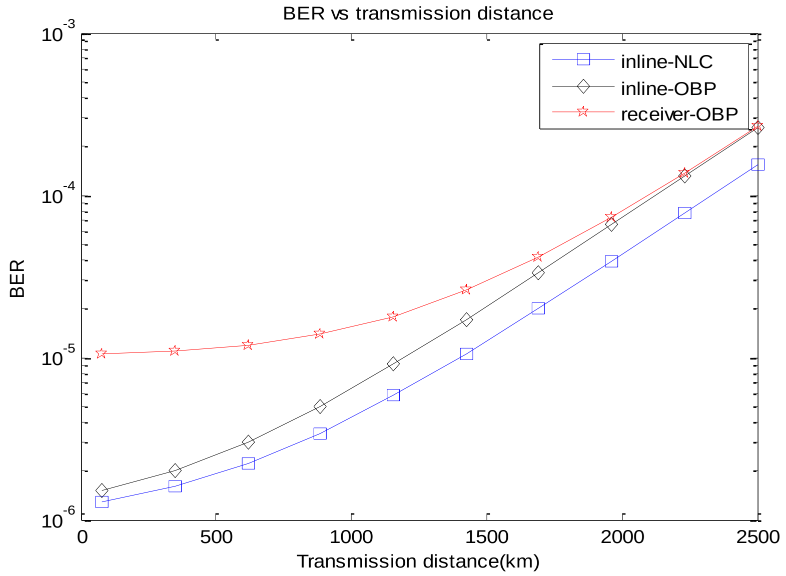

Figure 3. BER vs. Transmission Distance when L_a =100km, m=10.

Fig. 3. shows a BER for a transmission distance of 2500 km. The amplifier spacing L_a is taken as 100 km with m = 10. It is observed that the inline NLC exhibit the lowest BER at the initial point of the link, but it goes on increasing, as the length of transmission link is increased. The BER of of receiver based OBP is similar to inline-OBP when the transmission distance is increased.

3.2 BER vs. Q-factor

Q-factor stands for quality factor. It is a measurement of the signal quality and is proportional to the systems signal to noise ratio. Fig. 4. shows a BER with varying Q factor. Here, amplifier spacing (L_a) is taken as 100 km with m = 10. It is observed that in case of inline NLC, the BER decreases with increasing Q-factor. The performance of inline-OBP is almost similar to inline-NLC. But, the BER of receiver based OBP remains high for the same Q-factor.

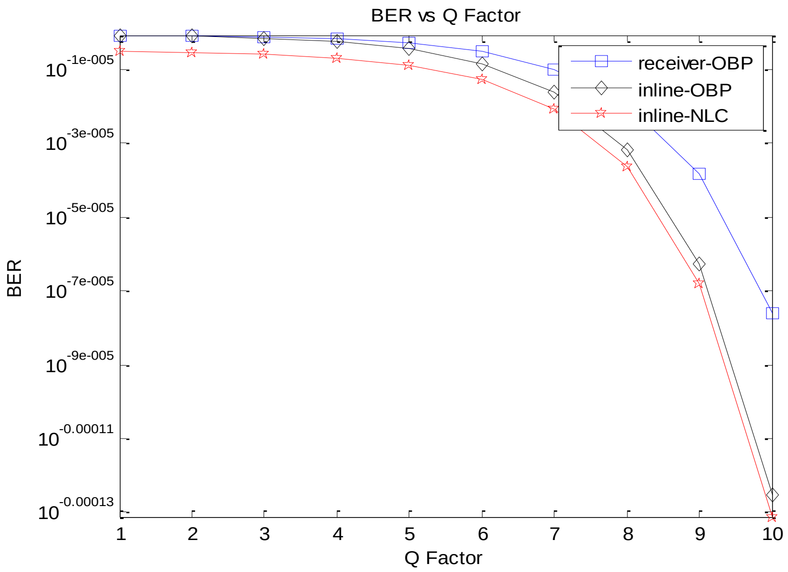

Figure 4. BER vs. Q Factor when L_a = 100 km, m=10.

3.3 BER vs. Launched power

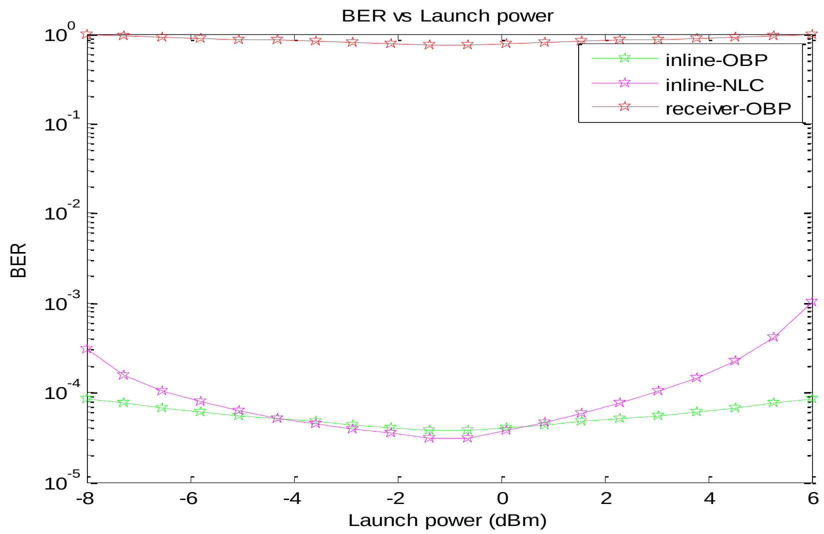

Figure 5. BER vs. Launch power when L_a =100 km; p=10 dBm; m-ary=16

In Fig. 5. Consider launch power of 10 dBm and 16-QAM. It shows that the BER of inline-OBP is lowest than other two techniques, when the launch power is kept low. But, when the launch power lies between (-2 to 0) dBm, the inline-NLC shows the lowest bit error rate. After this specific range, BER of inline-NLC again increases. The BER of receiver based OBP is highest and remains almost constant for a given power level.

3.4 m-ary QAM format vs. distance

The effect of m-ary QAM with 16, 32, 64, 128, 256 QAM on transmission distance is considered. From Fig. 6, increase in Transmission distance is observed with less number of symbols used in QAM. As the symbol rate increases, the transmission distance starts decreasing. However, inline-NLC is more efficient with increased symbol rate QAM, as compared to two other techniques and shows approximately same transmission distance for 32, 64,128 1nd 256 QAM

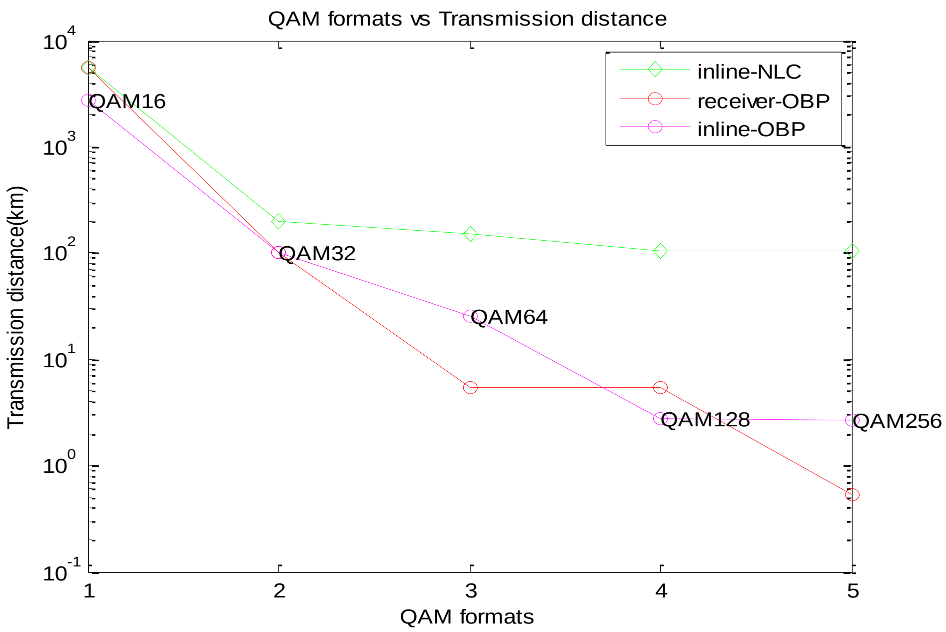

Figure 6. QAM formats vs. distance when L_a = 100 km; m=10.

IV. CONCLUSIONS & FUTURE WORK

Different optical back propagating techniques are studied to reduce the nonlinear effects. It is observed by taking a small step size; the bit error rate is reduced. IL-NLC outperforms as compared to receiver based OBP and IL-OBP.

This research is based on mathematically assumptions. So, in future more efforts can be done using experimental investigations, to get real time results. The research can be extended using other performance factors such as jitter, eye diagram.

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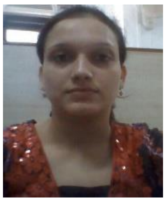

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