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RESEARCH ARTICLE

DIGITAL BACK PROPAGATION IN OPTICAL SOLITONS FOR PBR REDUCTION

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ABSTRACT

We investigate the use of Digital Back Propagation technique to optical solitons for long distance transmission. An optical solitons pulse has been transmitted over distance of 18,000 km. Results indicate a finite pulse spreading with pulse Broadening Ratio (PBR) of 13. But using Digital back propagation over virtual fiber of 800km before receiver detection helped reduce the PBR to nearly zero

INTRODUCTION

Optical solitons are short pulses of light traveling in natural mode of an optical fiber. Solitons are distinguished from other optical waves because of its characteristic to maintain its shape during propagation through fiber. This makes them suitable for long distance transmission in optical fiber, because. Optical Soliton are expected to bring revolution in photonics making long distance transmission of the order of tens of thousands of km. (Russell, 1844). Russell observed the phenomenon of pulse propagation over long distances using short duration pulses without any temporal and spectral distortions in water waves. This was then extended to Optical fiber being the transparent transmission media and hence discovery of solitons. Voronin and Zheltikov, (Voronin, 2003) demonstrated self frequency shift effect due to Raman scattering resulting in frequency shift towards longer wavelengths in optical solitons. The effect is particularly significant for ultra short duration pulses of order of femto seconds. Resulting spreading of pulse and decrease in pulse energy makes long distance propagation difficult for sequence of pulses. (Huttner,1999). Huttner *et al* calculated the maximum pulse spread in the presence of Polarization Dependent Losses (PDL) even for zero Differential group Delay (DGD). This confirmed distortions due to occurrence of Pulse Mode Dispersion (PMD) and (PDL) which affected the transmission dynamics of pulse. Moreover, second-order effects, i.e., effects created by the frequency dependence of the PDL are significant in pulse spreading (Huttner, 2000).

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Huttner *et al* show that the concatenation of birefringent fibers may have zero differential group delay over a whole range of wavelengths but that a pulse propagating down the concatenation may still experience significant pulse spreading (Gravemann, 2004). Gravemann *et al* proved that Pulse Mode dispersion (PMD) up to second order dispersion is responsible for pulse broadening in long haul communication and derived analytical expressions both for the effective pulse broadening and the eye opening penalty due to PMD up to second order (Ping Lu, 2003). Ping Lu and Liang Chen demonstrated pulse broadening/narrowing strongly dependence on frequency chirp induced spectrum broadening and higher order PMD induced effective chromatic dispersion. So, research indicated pulse broadening in optical solitons over long distance transmission of few thousands of kilometers resulting in overlapping pulses at the receiver.

Digital back propagation was introduced as a solution to compensate dispersion as well as non-linear distortions in optical signal by virtue of virtual fiber with its characteristics opposite to that of transmitting fiber before or after receiver. The idea was to negate the effects caused by uncontrollable fiber parameters by signal processing. Net result was improved result as if in a lossless fiber transmission. DBP before receiver detection is known as pre-compensation as proposed by (Roberts, 2006) Roberts *et al* in a single-channel fiber-optic system. The desired signal waveform at the receiver is used as the input to DBP. Post compensation DBP was proposed to offer better flexibility and (Li *et al*., 2008) demonstrated its real time implementation for nonlinearity compensation. Ip and Kahn (Ip and Kahn, 2008) investigated a non-iterative asymmetric Split Fourier Method (SFM) for implementing

DBP. Results showed that three samples per symbol are required for DBP to achieve good numerical accuracy (Mateo, 2008). Mateo *et al*. investigated the impact of Cross Phase Modulation (XPM) and Four Wave Mixing (FWM) on electronic impairment compensation using DBP in coherent WDM systems. Coupled NLSE and total- field NLSE are used to study the impacts of XPM and FWM, respectively. The inverse NLSEs are solved using symmetric iterative SSFS (Shao, 2013) Liang *et al* investigated a digital back propagation (DBP) scheme for dispersion and non-linearity compensation.

But no research has been advocated in application of DBP to solitons. More recently, Yushko *et al.* (2015) demonstrated soliton transmission coherent optical detection optimizing and comparing digital backward propagation and in-line optical filtering as a means to suppress soliton timing and phase jitter. Results indicate efficient jitter suppression for transmission links using different types of fiber. Efficiency of jitter suppression decreases with increasing launch power. But using DBP nonlinear propagation can lead to enhanced performance of the fiber network systems. We have implemented pre-compensation DBP in optical soliton transmission over distance of 18,000 km without any amplifiers and achieved significant reduction in PBR of propagated pulse.

MATERIALS AND METHODS

We propose a simulation set up in MATLAB with source as optical pulse generator. The transmission fiber which is Single Mode fiber with attenuation (α) =0.2 dB/km, non-linearity coefficient 'γ'= 3 W km^{-1}, Fiber Length 'L' = 18,000 km, second order dispersion coefficient 'β_2' = -0.2 X 10^{-4} ps^2/km. second order dispersion coefficient is considered negative so that dispersion 'D' > 0 in normal region of dispersion characteristics. To implement SMF in MATLAB we make use of Symmetric Split Fourier Method (SSFM) of Non-Linear Schrodinger Equation (NLSE) given by:

$$\frac{\partial A}{\partial z} = \left(-i\,\frac{\beta_2}{2}\frac{\partial^2 A}{\partial t^2} + \frac{\beta_3}{6}\frac{\partial^3 A}{\partial t^3} - \frac{\alpha}{2}A\right) + \quad \text{Term I}$$

$$\underbrace{i\gamma|A|^2\;A - \frac{\gamma}{\omega_0}\frac{1}{A}\frac{\partial}{\partial t}\left(|A|^2\;A - i\gamma\,T_r\,\frac{\partial|A|^2}{\partial t}\right)}_{\text{Term II}} \qquad \text{.........1}$$

NLSE is invertible equation which can be effectively used for forward transmission as well as for modeling virtual fiber with negative transmission characteristics. Term I indicates dispersion effect which is linear in nature while term II originates from fiber non-linearities.

Ignoring the higher order dispersion and ignoring Raman effect for picoseconds pulse under consideration equation (1) reduces to:

$$\frac{\partial A}{\partial z} = \underbrace{\left(-i\,\frac{\beta_2}{2}\frac{\partial^2 A}{\partial t^2} - \frac{\alpha}{2}A\right) +}_{} \quad \text{Dispersion = D}$$

$$\underbrace{i\gamma|A|^2\;A - \frac{\gamma}{\omega_0}\frac{1}{A}\frac{\partial}{\partial t}\left(|A|^2\;A\right)}_{\text{Non-linearity= N}} \qquad \text{........2}$$

Therefore $\frac{\partial A}{\partial z}$= $(D + N).E(z,t,$ 3

Assuming propagation distance z= nh where n is integer and h is the step size, SSFM can be used to implement SMF transmission as:

$E(nh,t) = e^{[h.\,(D + N)]\,E(\,(n-1)h,t)}$ 4

where $E(\,(n-1)h,t)$ is result of previous step.

For virtual fiber used for DBP, with transmission characteristics opposite to that of transmitting fiber, that is (-γ,-β_2,-α)

$E(nh,t) = exp[h.\,-(D + N)]\;E(\,(n-1)h,t)$ 5

that is, D $\longrightarrow$ -D, N $\longrightarrow$ N.

RESULTS AND DISCUSSIONS

Unchirped hyperbolic secant pulse is used for long distance transmission over distance of 18,000 km. Hyperbolic secant pulse is given by:

$x(t) = N\,sech^2\left(\frac{t}{\tau}\right)$ 6

Where N is order of soliton . In our case N= '1'.

For implementing the NLSE using SSFM first Full width Half Maximum (FWHM) points of input pulse are computed. FWHM is used to estimate the highest frequency point and hence number of sample points across the input pulse. This follows Nyquist theorem for calculating sampling points.

Pulse broadening ratio is measure of pulse spreading and is expressed as ratio:

$PBR = \frac{FWHM_{output\ pulse}}{FWHM_{input\ pulse}}$ 7

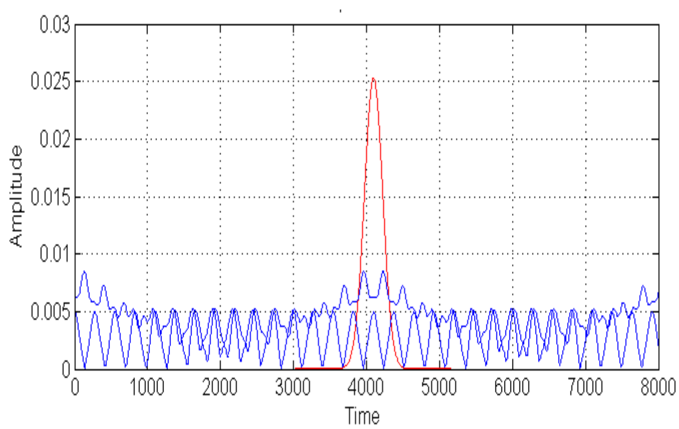

Fig. 1. Input pulse- red curve shows hyperbolic secant soliton pulse while blue curve shows output spectrum after 18,000km transmission which is given as input to DBP virtual fiber

So, higher the ratio more is spectral width of output pulse. Assuming ideal conditions where dispersion length is equal to non-linear length so that dispersion effect is cancelled by Self Phase Modulation (SPM) dominated non-linear effects, pulse broadens by factor of 13 as can be seen by blue curve variation in Figure 2. But after application of DBP the PBR is reduced to nearly '0' which confirms that DBP application nullifies the dispersion effects pulse undergoes during long distance transmission. Figure 3 shows the pulse evolution of DBP pulse which shows the pulses over entire length of transmission fiber. It clearly shows the shape of pulse is retained though amplitude has been reduced significantly due to fiber losses.

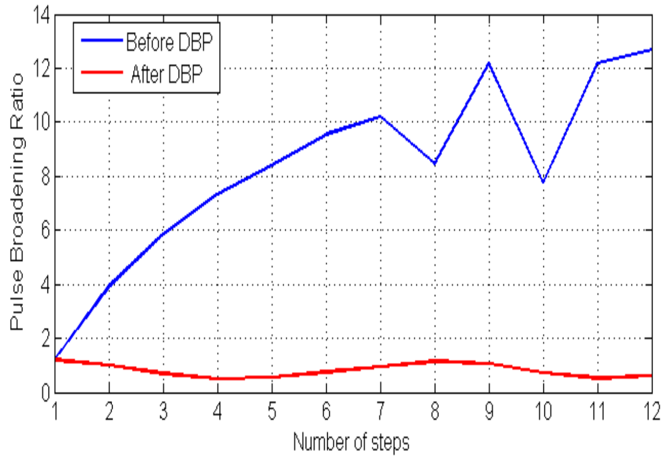

Fig. 2. PBR of optical pulse with and without DBP

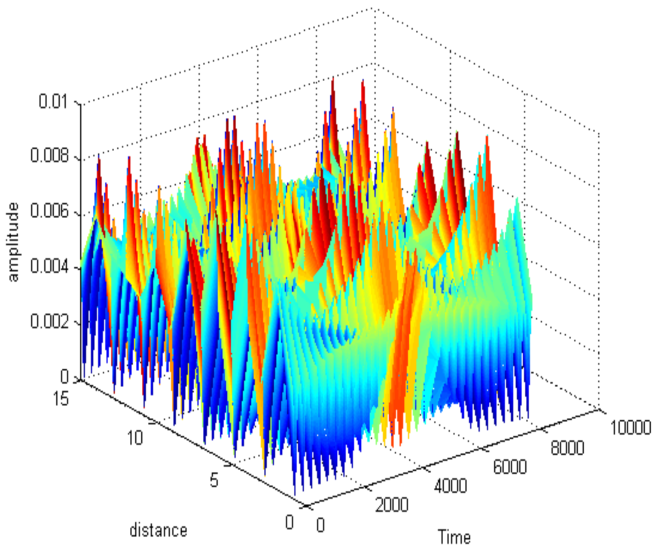

Fig. 3. Pulse evolution over all the steps using SSFM

Additionally, another important finding of this work is that, the virtual fiber used for counter propagation should not be necessarily of same length as transmission fiber. In our experiment we used transmission fiber of 18,000 km while virtual fiber length used for DBP is only 800 km.

Conclusion

We have demonstrated a novel application of DBP in pre-compensation configuration for reduction of PBR by factor of 13. This is significant result which can be extended for performance improvement in soliton transmission in terms of BER penalty and reduced jitter in soliton transmission. Further post-compensation DBP with coherent reception of signal may help in exploring the possibilities of repeater less soliton transmission of thousands of kilometers. Reduction in PBR has not been previously reported in Optical solitons using DBP.

REFERENCES

Gravemann, T. Kissing, J. and Voges, E. 2004. “Signal Degradation by Second Order PMD and Noise”, IEEE Photonics Technology Letters, Vol.16, No.3, pp. 795-797.

Huttner, B. Geiser, C. and Gisin, N. 2000. “Polarization-Induced Distortions in Optical Fiber Networks with Polarization-Mode Dispersion and Polarization-Dependent Losses,” *IEEE Journal of Selected Topics in Quantum Electronics,* Vol.6, No. 2, pp. 317-330.

Huttner, B. Gisin and Gisin, N. 1999. “Polarisation-Induced Pulse Spreading In Birefringent Optical Fibres With Zero Differential Group Delay,” ,” Optics Letters, Vol.24, No. 6, pp. 370-372.

Ip, E. and Kahn, J. M. 2008. “Compensation of dispersion and nonlinear impairments using digital backpropagation”, *Journal of Lightwave Technology*, Vol. 26, No. 20, pp 3416-3425.

Li, X., Chen, X., Goldfarb, G., Mateo, E., Kim, I., Yaman, F., and Li, G., 2008. “Electronic post-compensation of WDM transmission impairments using coherent detection and digital signal processing”, Optics Express, Vol. 16, No. 2, pp. 880-888.

Mateo, E. Zhu, L. and Li, G. 2008. “Impact of XPM and FWM on the digital implementation of impairment compensation for WDM transmission using backward propagation”, *Optics Express*, Vol. 16, No. 20, pp. 16 124-16 137.

Ping Lu and Liang Chen, 2003. “Statistical Distribution of Pulse broadening/ narrowing due to the Interaction of PMD and Frequency Chirp in Dispersion Shifted Fibers”, *Journals of Optics Communication,* pp 243-248.

Roberts, K. Chuandong, L. Strawczynski, L. O'Sullivan, M. and Hardcastle, I. 2006. “Electronic precompensation of optical nonlinearity," *IEEE Photonics Technology Letters*, Vol. 18, No. 1-4, pp. 403-405.

Russell, J. S. “Report on waves”, in Report of the 14th meeting of the British Association for the Advancement of Science, pp. 331, 1844

Shao, J. Kumar, S. and Liang, X. 2013. “Digital back propagation with optimal step size for polarization multiplexed transmission”, *IEEE Photonics Technology Letters,* Vol. 25, No. 23, pp. 2327-2330.

Voronin, A. A. and Zheltikov, A.M. 2003.“Soliton self-frequency shift decelerated by self steepening”, Optics Letters, Vol. 33, No.15, pp.1723.

Yushko, O. Redyuk, A. Fedoruk, M. Turitsyn., S. Blow, K. Doran, N. and Ellis, A. 2015. “ “Digital Back Propagation in Soliton Coherent Transmission”, OSA Tyrrhenian International Workshop on Digital Communications , 22nd September 2015, Italy, Florence

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