New Compensation Technique for Fiber Impairments in Ultra High Capacity Super channel Based on (QDPASK) Dense wavelength division multiplex (DWDM) systems

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Abstract

In this paper we want to increase the data rate and to get larger transmission distance, therefore we use the Advanced modulation technique QDPASK in DWDM system with low channels space. In case of long transmission distance and multi channels system both giving rise to inter channel crosstalk induced by fiber nonlinearities as a result the use of advanced modulation technique becomes difficult. In this paper Quaternary differential phase amplitude shift keying (QDPASK) is designed for 32 dense wavelength division multiplexing (DWDM) channels, therefore we proposed a new cascade compensation system consist of optical and digital back propagation techniques (ODBP) for compensate the linear and nonlinear effects . A performance of the system was reported using QDPASK DWDM fiber-optic system for various system parameters. The research is tested in VPI maker environment.

Keywords: Quaternary differential phase amplitude shift keying QDPASK, dense wavelength ,division multiplexing DWDM, digital back propagation DBP optical back propagation OBP.

الخلاصه

في هذا البحث نحن نرغب بزيادة انتقال البيانات وللحصول على اطول مسافة نقل ولذلك تم اقتراح جديد لمنظومة تعويض الخسائر ان استخدام طرق تضمين متقدمة (QDPASK) مع منظومة تجميع الاطوال الموجية الكثيفة (DWDM) مع تباعد قنوات قليل . في حالة مسافات النقل الطويلة والانظمة متعددة القنوات في هذه الحالة المنظومة سوف تعاني من خسائر نتيجة التأثيرات الخطية و اللاخطيه للألياف الضوئية كنتيجة لذلك استخدام طرق التضمين المتقدمة يصبح صعبا جدا. في هذه البحث طريقة التضمين (QDPASK) صممت ل منظومة تجميع الاطوال الموجية الكثيفة بسعة 32 قناة. لذلك تم اقتراح جديد لمنظومة تعويض خسائر متتاليه تتألف من تقنية الانتشار الراجع البصري ثم بعدها تقنية الانتشار الراجع الرقمي وسمية هذه التقنية الجديده ب(ODBP) للتعويض عن جميع التأثيرات الخطية واللاخطيه لقنوات الاتصال الضوئية . ادائية المنظومة تم اختبارها لمختلف المعلمات باستخدام حزمة البرمجة VPI.

الكلمات المفتاحيه : رباعي الطور التفاضلي لمفتاح تحول السعة ، تجميع الكثيف للأطوال الموجية ، الانتشار العكسي الرقمي، الانتشار العكسي البصري .

1. Introduction

The DWDM optical fiber communication systems can be optimized for better performance and simplicity of implementation by maximizing the spectral efficiency using different digital modulators, detectors and multiplexing techniques (Matsumoto and Sanuki 2007). In currently deployed transmission links, different modulation formats with high spectral efficiency are attractive choice for upgrading the capacity. Most of the available systems are used on off key modulation formats, phase shift keying etc(Kaur1 *et.al.*, 2016).The increase spectral efficiency and reduce symbol rate produce from using multilevel modulation. In addition, it's given the flexibility of using lower bandwidth electronics (Hansryd ,2004).one of the important modulation method its phase modulation where in which the information encoded in phase of the signal and its widely used in optical communication systems. The using of phase modulation because include higher receiver sensitivity and its compatible with multi-level signal like QPSK and DQPSK formats .

The maximum transmission range of PSK limited by the noise of the signal

(Jochen, 2008). In the long distance systems, nonlinear noise phase produce from the operation of translation the amplitude noise to phase noise result from fiber nonlinearity. Impairment produce from the nonlinear effect will become. severer for higher-speed systems that require higher signal peak power .Quadrature differential phase amplitude-shift-keying (QDPASK) modulation. It is widely used and compatible for high for high speed and long distance. Both linear and nonlinear performance analyses. of RZ-DPSK in WDM and DWDM systems are necessary . All the nonlinear effect such as CPM, FWM increase in multichannel system (increase the number of channels). In this paper, we numerically investigate. the performance of QDPASK DWDM systems due to nonlinear effects like XPM and FWM(Khan *et.al.*,2014).

2. Effect of Linear and Nonlinear impairments in QDPASK DWDM system

In the linear and nonlinear regimes of optical fiber the spectral efficiency varies for various detection and modulation methods. Main challenges an optical signal propagating through the fiber face is linear and non-linear effects (Mussolin *et.al.*,2013).

Linear effects include pulse broadening of the signal due to dependence of refractive index on wavelength. This effect of pulse broadening is explained by group velocity dispersion (GVD) parameter β2 in Eq.(1).

$$\beta_2 = \frac{1}{C}\left(2\frac{dn}{d\omega} + \omega\frac{d^2n}{d\omega^2}\right) \text{--(1)}$$

Where: ω : angula frequency , C : speed of light . Most main effects of fiber nonlinearity such as self-phase modulation (SPM) and cross phase modulation (XPM) arise from the instantaneous power fluctuation . The nonlinear phase angle variation of a signal at ω_1 due to its own power and power of signal at another frequency ω_2 is given by Eq.(2) (Kaur1 *et.al.*,2016).

$$\emptyset_{NL} = n_2k_0L(|E_1|^2 + 2|E_2|^2) \text{-- (2)}$$

Dispersion compensation system in SMF used the negative dispersion of dispersion compensation DCF. where the fiber nonlinearites results from Kerr effect. The self phase modulation exist in the single channel where SPM results from Kerr effect by phase modulation of the transport signal by the signal itself . As a result of phase variation the transmission impairment exist in optical communication channel and gives disturbance , We can see that the spectral properties if the phase modulation will effect by phase noise in the channel. In the receiver the performance of the transmission system don’t depend on direct detection disturbing phase modulation because phase information is lost. In case of presence the dispersion the phase. modulation is converted into intensity. modulation this will effect on both phase modulated ,intensity modulated.

Nonlinear in DWDM System

The nonlinear Schrodinger equation is the main object in study the nonlinear effect such as CPM and FWM in multi channels systems DWDM. If we consider the two pulses pump and probe pulses A1 (t, z), A2 (t, z) respectively propagated in the optical fiber. The wave propagation equation is described by (Khayer and Islam 2009).

$$\frac{\partial A_2(t,z)}{\partial z} = -\frac{\alpha}{2}A_2(t,z\alpha) - \beta_{12}\frac{\partial A_2}{\partial t} - \frac{i\beta_{22}}{2}\frac{\partial^2 A_2}{\partial t^2} + i\gamma_2P_2(t,z)A_2(t,z) + 2i\gamma_2P_1\left(t - {}^{z}/_{V_1}, z\right)A_2(t,z) \text{ ------(3)}$$

Where : α is the attenuation coefficient of the fiber, $\beta_{2(1,2)}$ is the fiber chromatic dispersion parameter, $\gamma_{1,2} = {}^{2\pi n_2}/_{\lambda_{1,2} A_{eff}}$ is the nonlinear coefficient, n2 :nonlinear refractive index, λ_2 and λ_1 are the two pulses probe and pump signal wavelengths, A_{eff} is the effective fiber core area, $P_1 = |A_1|^2$ and $P_2 = |A_2|^2$ are optical powers of the pump and probe, respectively.

Here the work the important term in equation (3) is the fifth term it's the XPM. In the probe signal induced by the pump signal the probe operate in continues wave (CW) while the pump signal is modulated by electrical data (NRZ) format at data rate 40Gb/s , 0 dBm power level. The cross phase modulation produce crosstalk result from phase fluctuation fromr Kerr effect and followed by the noise phase related to intensity noise conversion from dispersion of fiber. Therefore, the output power of signal (probe) results crosstalk in the time domain showed as (Shariful *et.al.*, 2009).

$$P_{21}(t, L) = P_2(L) + \Delta S_{21}(t, L) ----------------------(4)$$

Where : $\Delta S_{21}(t, L)$ is the cross phase modulation (CPM) produce crosstalk power in time domain, $P_2(L)$ is the output of the probe fiber end .frequency domain describe of the intensity fluctuation in the probe channel caused by the intensity modulation of the pump channel can be given (Khayer and Islam 2009).

$$\Delta\tilde{S}_{21}(f_2, L) = 4\gamma_2 P_2(L) P_1(f_2, 0) \sin\frac{(\beta_{22} f_2^2 L/2)}{\alpha - i f_2 d_{21}} \exp\left(\frac{f_2}{v_2 l}\right) --------------5)$$

Where : L fiber length , $P_1(f_2, 0)$is the power spectral density of the pump. wave at the input , d_{21} is the relative. walk–off between the two channels.Linear approximation the walk-off can be expressed as $d_{21} = D\Delta\lambda_{21}$, where $D = -(\frac{2\pi C}{\lambda^2})\beta_2$ is the fiber dispersion coefficient. $\Delta\lambda_{21}$ and λ are the wavelength spacing and average wavelength between probe and pump signals respectively.

Equation (5) can be explain long haul transmission multi channel optically system, where the intensity. variation at the receiver is the added the cross phase modulation created by the fiber link .In optical communication channel at a specific bit rate the term $P_1(f_2, 0)$ represent the power spectral density of high power bit pattern. At RZ bit pattern in this work the XPM cross talk power was obtained by integrating $\Delta\tilde{S}_{21}(f_2, L)$ from 0 to bitrate .as a result the optical power due to XPM induced crosstalk is seen in eq.(6)(Torger Tokle 2007).

$$P_{XPM} \approx 2\int_0^{Bit\ Rate} \Delta\tilde{S}_{21}(f_2, L) ----------------------(6)$$

4.Nonlinear Compensation Techniques

Optical fiber impairment can be classified into two parts the first one called linear loss such as dispersion where the dispersion consist of chromatic, polarization, and material. The other type called nonlinear impairment it consist of noise phase such as cross phase modulation and four wave mixing al the fiber loss can be compensated using the following categories.

4.1 Digital back-propagation

The signals that received is input into a fiber with fiber parameters has opposite-sign values of transmitted fiber link. In this work, this the method can be performed by determine the (NLSE) that control the signal propagation through the fiber link in the receiver as shown in figure (1). The NLSE control the propagation (for single-polarization) in two directions at opposite sign as shown eq.(3) (Rafique *et.al.*, 2011). Where the electrical field envelop can be defined by E parameter. The propagation constant called βj and the loss coefficient called α. The nonlinear index γ. The back-propagation, algorithms can be solved numerically using SSFT where all parameters are set to be the opposite values to those in the fiber, link and all amplifiers replaced by attenuator . The fiber is divided into parts consist of D and N parts referred to linear and nonlinear parts respectively . In the absence of single noise, the back-propagation. method can fully compensate the linear and nonlinear fiber impairments. However, a compromise must be found between accuracy and complexity (Ezra *et.al.*, 2008).

$$\frac{\partial E}{\partial Z}+\frac{\alpha}{2}E+\frac{i\beta_2}{2}\frac{\partial^2 E}{\partial t^2}-\frac{\beta_3}{6}\frac{\partial^3 E}{\partial t^3}-i\gamma|E|^2E=0 \text{-----------------} (7)$$

launch electric field are supposed to propagate in the z direction Eq. 1 shown as [Rameez Asif et al 2012]; where is :$\frac{\partial E(z,t)}{\partial Z}=-\frac{\alpha}{2}E(z,t)$ Linear attenuation ,$\frac{i\beta_2}{2}\frac{\partial^2 E(z,t)}{\partial t^2}$ Second order dispersion ,$\frac{\beta_3}{6}\frac{\partial^3 E}{\partial t^3}$ third order dispersion ,$-i\gamma|E|^2E(z,t)=0$ Kerr effect, λ_0 :is the center wavelength (Liang *et.al.*,2014).

$$D=-\frac{\alpha}{2}-\frac{i\beta_2}{2}\frac{\partial^2}{\partial t^2} \text{------} (8)$$

$$N=i\gamma|E|^2 \text{------} (9)$$

If the backward operates on the envelope of E(z, t), this algorithm can perform with any modulation format of the optical communication system. we can note that the performance of back propagation is limited by amplified spontaneous emission (ASE) noise . BP can only take into account the measured impairments(Rameez *et.al.*, 2012).

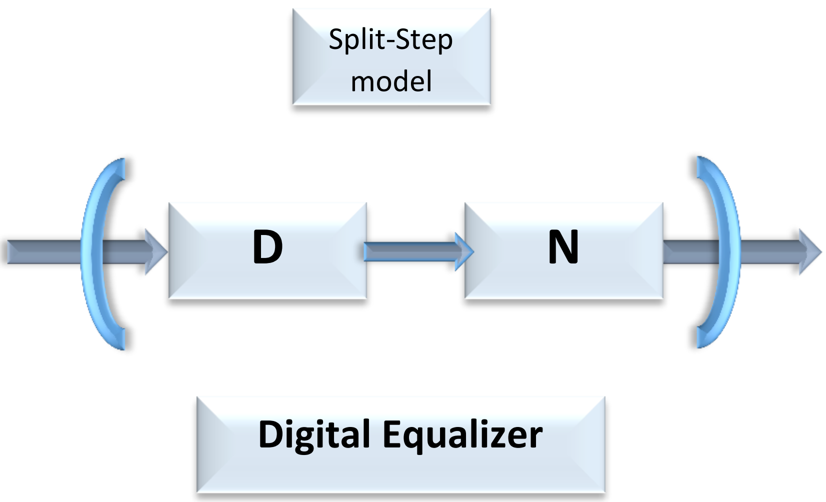

Figure (1) illustrate Schrodinger nonlinear equation (SNLE) linear and nonlinear parts

4.2 Optical Back Propagation

An optical back propagation its more easer and efficient method and consist of two main parts the first one DCF or may be used fiber Bragg grating (FBG) to minimize the linear effect like dispersion the second part highly nonlinear fiber (HNLF) is to minimize the nonlinearities of the fiber with parameters as shown in in table (1)

TABLE (1) OBP PARAMETERS

parameters	DCF	HNLF
α	0.52 dB/Km	0.28 dB/Km
γ	0.011 W-1km-1	1823 W-1km-1
D	-230ps2/Km	0.004ps2/Km

OBP the minimize the nonlinearities of the fiber. OBP can be classifies into three types the first one called receiver based optical back propagation the second called in line optical back propagation. The last one called inline nonlinear compensator.NLC techniques.(Ranju and Sameksha,2009).The nonlinear Schrodinger equation is invertible equation the propagated signal is completely recovery back if we suppose no noise the received signal through invers NLSE

$\frac{\partial E}{\partial Z} = (-D - N)E(z,t)$-- (10)

The input field and the propagation in optical fiber is stated in equations (11,12) respectively

$E_0(t,0) = \frac{\sqrt{E_0}}{\sqrt{\pi}T_0} Exp[\frac{-t^2}{2T_0^2}]$--(11)

After propagate in optical fiber the output transmission link

$E_{s(t)} = \frac{E(t,L_{final})}{\sqrt{2}}$ --(12)

Where : $E(t, L_{final})$ represent received field distorted with linear and .nonlinear effect and id given by :

$E(t, L_{final}) = ME(t,0)$ ---(13)

Where [Ranju and Sameksha 2009]

$M = \exp[i \int_0^{L_{final}} [D(t) + N(t,s)ds$---(14)

The D factor solved numerically by opposite sign if we use dispersion compensated fiber can eliminate the accumulated dispersion of optical fiber link. The N factor ,called nonlinear compensator are used to compensate the nonlinear effects. We use the inverse of the amplifier with gain (1/G) is used between fiber compensator and nonlinear fiber section to compensate the loss produced by these two parts. the coherent detection. Output of nonlinear compensator at constant. (K), is given by (Shariful *et.al.*, 2009)

$E_{out} = KE_s(t)\exp[-i2\gamma L|E_s(t)|^2$ ---(15)

In this paper as a results we use a simulation of the proposed model (ODBP) where it consist of from DBP and OBP algorithms in cascaded manner in the receiver side to compensate linear and nonlinear impairments.

3. Proposed System design

To enhancement the bit rate up to 50% we use the advanced modulation technique this technique consist of combining amplitude shift key and differential quadrate phase shift key (Torger ,2007).The combined modulated system is shown in figure (2). And the combination can be achieved by little modification for the transmitter and the receiver design . the modification of the transmitter included add extra modulator while in the receiver side we add more photo detectors to detect and extraction the information in ASK and QDPSK. The optical pulse width is the same for DQPSK and DQPSK-ASK, but since more information is stored in .each pulse for DQPSK-ASK technique. One of the factors that limit the performance of QDPASK method it's the dependence on phase noise result from fiber nonlinearity such as self phase. Modulation, cross phase. modulation and four wave mixing Where the amplitude modulation causes symbol power variation. And the nonlinear phase shift for different symbols not equal. causes the distortion. Therefore, we use in this paper the modified back propagation algorithms to compensate the linear and nonlinear effect in DQPSK-ASK DWDM. The transmitter side consist of two parts the first one DPSK is illustrated as shown in figure (1). Where a sequence of bits is generated , the symbols are generated using DPSK encoder using 4bits per symbol. When transmitting information, the signal phase fluctuate according to source.symbols.In a linear optical transmission system with optical amplifiers, the field of N return-to-zero (RZ) pulses at the end of the transmission can be expressed as(Sen ,2010)

$F(t) = [\sum_{n=0}^{N-1} a_n \, u(t-nT) + z(t)]e^{-j\omega_c t} + C.C.$---------------------------------(16)

where ω_c is the angular frequency of the optical carrier, T is the bit period, u(t-nT) is the envelope function of the RZ pulse in the n-th time slot,the amplitude of n pulses called a_n.

the additive noise z(t). For DPSK, the information is encoded in a relative phase change of the signal amplitude an with respect to the previous symbol an-1. In this Letter, we choose an= ±1, a digital "0" will be represented by a phase change of p or $a_n = -a_{n-1}$, and a digital "1" will represented by no phase change or $a_n = a_{n-1}$.

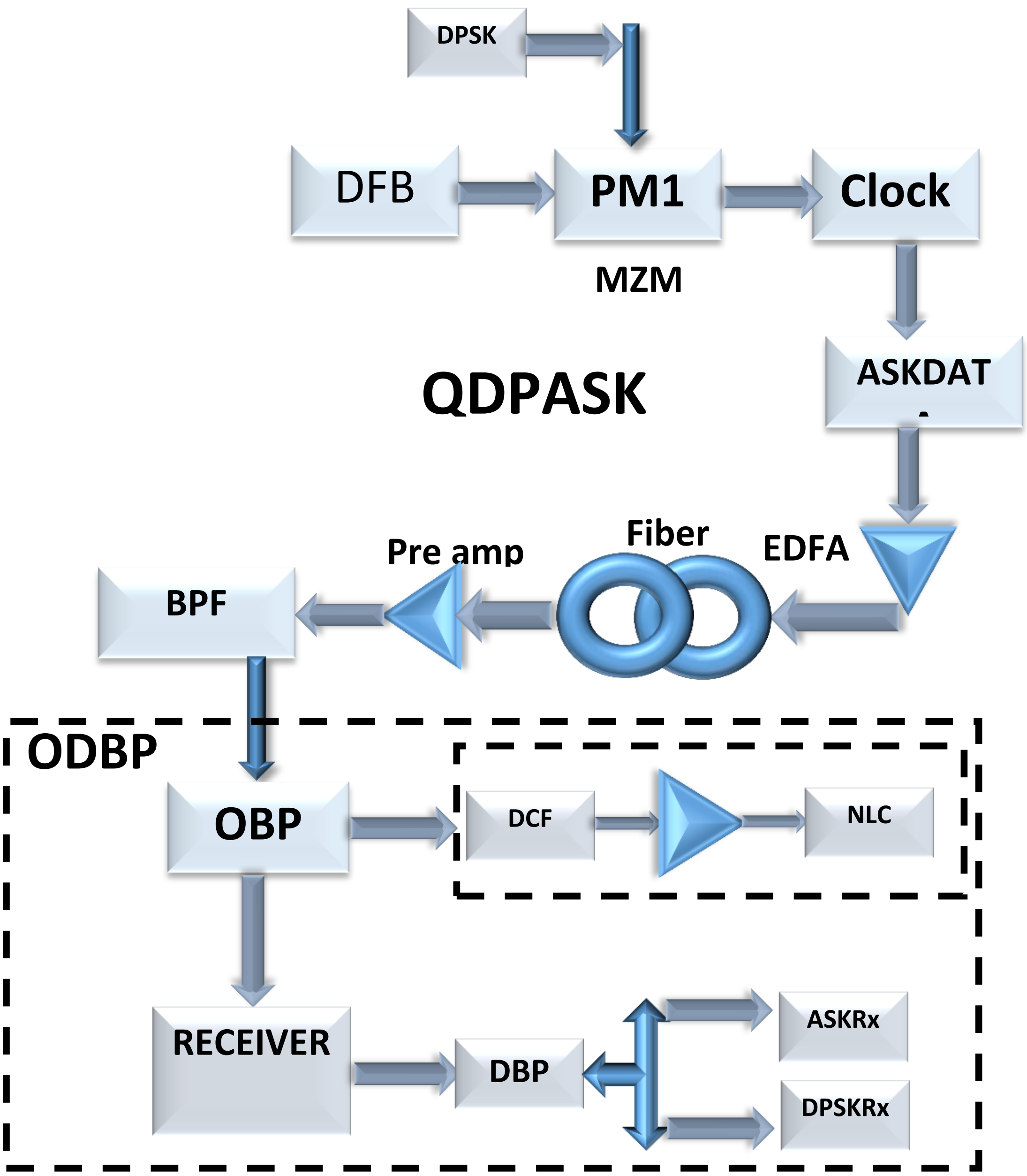

Figure (2) numerical experiment for single channel 10Gb/s QDPASK 32 ch.DWDM system ODBP.

4. Results and discussion

the VPI Transmission maker software package , this software provide exact physical approch of the simulated system.and accelerate the design for long haul transmission Link at high bit rate using different modeling techniques with large components in the transmitter and receiver side. This software provide. to the users many libraries of components such as laser source modulators, modulation technique, different fibers, filters , detectors and different measurements tool. Therefore the numerical experiment of figure (2) using VPI pakage was demonstrated. The simulated system of figure (2) consist of three. major parts the first one is the transmitter in this part we use PRBS bit sequence is used with NRZ modulation format at 10 Gb/s data rate. The laser array used as source in 32 ch. DWDM system with two output one of the output used for high power launched signal pump at frequency 191THz and the other low power probe data at frequency 191.05THz compared with pump power, the channel spacing 50GHz, the modulation performed with Mach-Zehnder Modulators . the modulated data sent by SMF we account Raman scattering ,and nonlinearity Kerr effect ,and also dispersion contribution ect ,nonlinear index, attenuation, at end of the fiber the probe data undergo to impairment due to fiber nonlinearities .

At the receiver side we used different components to split the channels and recover the data, DWDM demultiplexer, PIN photo detector, low pass Bessel filter, with BER tester. 10 Gb/s bit rate QDPASK 32 ch. DWDM signal is transmitted over DWDM system with fully dispersion compensated system optical digital back propagation algorithms (ODBP) at fiber spans of 250 km SSMF. The gain-controlled EDFAs control on the power signal power back to the input signal power level and add ASE noise. After ODBP stage the QDPASK signal is decoded using a MZI and detected using a balanced direct detection receiver. The BER is measured using BER tester for different parameters. At the receiver,OBP,DBP algorithms (ODBP) was used to compensate the impairments of the physical channel as shown tables (2,3). In the simulation, the fiber is the standard single mode fiber (SMF) whose $\alpha, \beta_2\, \gamma$, 0.2 dB/km, -20 ps2/km and 2 *10-3 km^{-1} W^{-1} respectively. The span length is 250 km In each fiber span, attenuation is fully compensated by putting erbium doped fiber amplifier (EDFA), CD is fully undercompensated by the dispersion compensation fiber (DCF) and the remaining dispersion is compensated by OBP,DBP. At the receiver side OBP,DBP algorithms is applied to compensate the nonlinearity and the residual CD. The signals after compensation are demodulated by the coherent QDPASK detectors. The BER was determined by the eye pattern of the received signal. The BER performance of the OBP ,DBP algorithms versus the launched power and fiber length parameters is shown in tables (1,2). All the fiber losses (linear and nonlinear) are compensated using advanced compensation technique which is combination of optical and digital back propagation technique (ODBP) .

A- Input power on nonlinear effect .

The input launch high power (pump) is limited by-10 up to 10 dBm when fiber length 250 Km, at base data rate10 Gb/s with channel spacing 50GHz. In our work we varying pump signal power while remain a constant probe power at 0 dBm, the measuring BER shown in table (2) .The BER for low power signal probe channel increase with increasing the high power signal pump power while the BER decrease with it as shown in figure (3).

Table (2) :BER. of low power probe channel at different high power Pump signal

Channel (1) low Probe power= 0 dBm channel space =50GHz Bit rate = 10Gb/s fiber length= 250Km		
BER@ OBP	BER@ DBP	Pump Power (dBm)
10^{-4}	$2.3*10^{-4}$	-10
$0.1*10^{-4}$	$0.3*10^{-4}$	-6
$0.18*10^{-4}$	$0.2*10^{-4}$	0
$3.2*10^{-4}$	$4*10^{-4}$	2
$3.8*10^{-4}$	$6.2*10^{-4}$	4
$5.4*10^{-3}$	$8.4*10^{-3}$	6

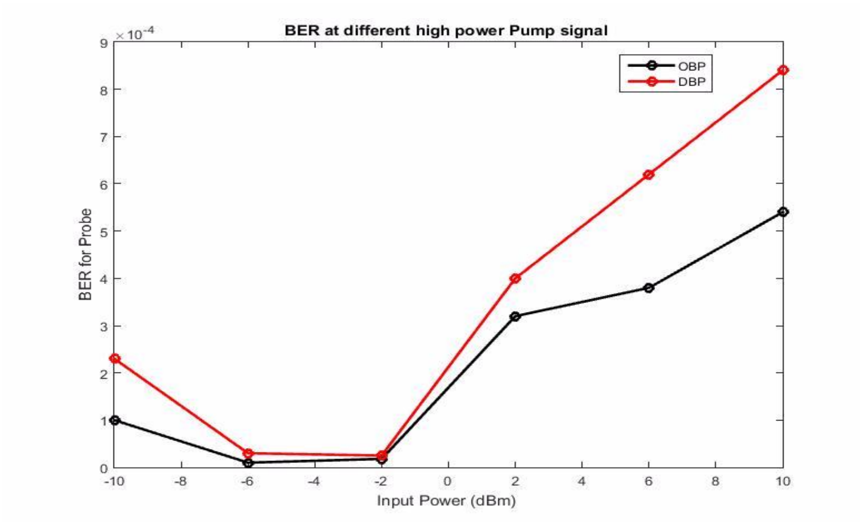

Figure (3) BER versus input power for optical back propagation and digital back propagation

B. influence of channel spacing

The cross phase modulation of varying power results from a number of channels can be written as (Yasin ,2008).

$$\left|P_{j,x,k}(\omega, L)\right| = \sum \frac{1}{W_c} 8\pi\gamma P_{j0} P_k(\omega) e^{-\alpha L} \frac{\mathrm{Sin}(\frac{D_c\omega^2}{2})}{D_c k \Delta\lambda\omega} - (17)$$

Where : W_c: different channels ,$D_c = {-2\pi c\beta_2}/{\lambda^2}$ CD, $\Delta\lambda = {\Delta\omega\lambda^2}/{c}$: separation wavelength,Δω: Channel spacing .We can observed from our results shown in table (3). that the low power probe BER data decreasing with increase channel spacing between channels neighbors according to equation (17).another observation can note that the BER decrease with increase the channel space when space become 200GHz we can get the optimum result as shown in table (3) and figure (4).

Table (3) BER for ODBP algorithm

High power Pumpsignal = 0 dBm low powerprob = -10dBm bit rate= 10Gb/sec fiber length= 250Km ODBP Algorithms	
Channel spacing GHz	BER for probe
50	$0.213*10^{-4}$
100	$2.9*10^{-05}$
150	$7.3*10^{-08}$
200	$4.05*10^{-12}$

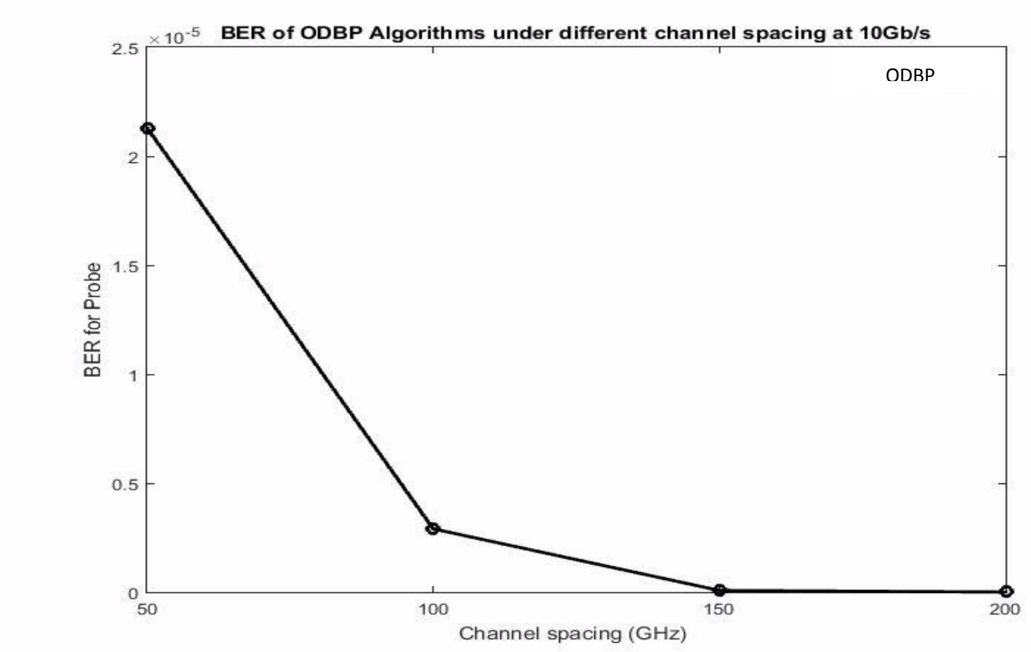

Figure (4) BER versus channel space for proposed optical digital back propagation (ODBP) algorithm

5. Conclusions

In this paper a numerical experiment of DWDM system was designed and demonstrated by using advanced QDPASK modulation technique and we introduce the effect of proposed method ODBP that consist of digital back propagation algorithm and optical back propagation algorithm to eliminate the linear and nonlinear effect in high bit rate super channel DWDM system. In our simulation, we report a significant reduction in BER using ODBP technique compared with each one of DBP,OBP alone according to our results showed that if we used the combination of OBP with DBP as a cascade we can get the best performance of the system as shown in results above. The relation between input power and phase noise in multi channels systems and the effect of channel space of DWDM system with BER value for ODBP algorithms showed in figures of results above. in order to increase spectral efficiency, it is preferred to use optimum launch power with low data rate per channel with channel spacing 50 GHz to increase the symbol rate.

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