Rajshahi University Journal of Science & Engineering **ISSN 2309-0952**
Vol. 43: 63-72, 2015

Optimization of Q-Values for Coherent Optical Transmission Network

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Abstract

In this paper we have analyzed the Gaussian Non-linear Interference (G_{NLI}) spectrum considering non identical channels, non-identical links and Amplified Spontaneous Emission (ASE) noise power spectrum for Coherent Optical Transmission Network (COTN) to calculate the Optical Signal to Noise Ratio (OSNR) and Quality (Q) values. In this study, three different Baud rate values (13.875Gbaud, 27.75Gbaud, and 55.5Gbaud) are considered to compute the Q values and OSNR in the COTN. Consequently, the COTN produces 111 Gb/s, 222 Gb/s and 444 Gb/s line rates for three different Baud rate values (13.875Gbaud, 27.75Gbaud, and 55.5Gbaud) respectively in PM-16QAM modulation format. It is confirmed that the OSNR is always greater than Q values. It is also found that the differences between OSNR and Q are 0.23dB, 1.73dB, and 3.24dB for 111Gb/s, 222Gb/s and 444Gb/s line rates respectively. Here transmission of launch power per span, number of channels, number of spans and the fiber dispersion in the optical link are considered.

Keywords: Quality values (Q);Optical SNR (OSNR); Erbium Doped Fibre Amplifier (EDFA); Gaussian Non-linear Interference (G_{NLI})

INTRODUCTION (HEADING 1)

At present higher Baud rate and smaller channel spacing for the super channel are the key factors to optimize and develop the COTN [1-2].Therefore, Q factor is an important parameter to design the high bit rate of optical system network. In this regard, there are reasons to measure the Q factor for optimizing and developing the existing long haul communication systems which are associated with the six criteria given below [3]. Firstly, Q factor is derived from OSNR; as a result, it is the function of OSNR which measure the performance of receiver section qualitatively for a required SNR. Secondly, we can compute the Q factor scales dynamically because it is related with OSNR. Thirdly, bit error rate calculation is relatively difficult because it takes long time to collect the bit error values for a. fixed target in which system designer follows the worksheet. On the other hand, the fourth reason is that to measure the scale of Q values is reasonably simple because it is performed in dB format. The fifth criterion is that normally we measure the noise in receiver section using Optical Spectrum Analyzers (OSA). In this case, around 0.0125THz is the optical bandwidth which is the optical signal measurement scale. In practice, the sixth reason is that the OSNR is greater than the Q scale which varies from 0.2dB to 3dB where the margin around 2dB is at the end of the light detector device.

Consequently, we consider the non-linear propagation effects to measure the Q factor. Schroedinger equation is the solution to solve the nonlinear model but it takes long time for computation of the system. Nowadays, optical simulator tool is also more expensive and simulation process is time consuming [6]. In this respect, GN is the accurate and appropriate model [5], [7], [8], [10] to solve these limitations. In this regard, GN model is used to calculate the PSD of Non Linear Interference (NLI) and also the model reduces the computational complexity for non identical channels and links of the COTN [4], [8].

On the other hand, EDFA is used as a span of the link. Therefore, there is an ASE noise spectrum after each span and amplification is done periodically in the network. Then, we accumulate the ASE noise power and NLI noise power to measure the OSNR after total number of spans. In this way, we follow the optical bandwidth and required electrical bandwidth to measure the Q values of the optical network.

In this paper, an analytical study is done to generate the PSD of NLI and ASE noises for COTN to determine the OSNR and Q values. It is also shown that the relationship between OSNR and Q for different line rates. Where line rates effect on the COTN are considered to measure the electrical bandwidth. Simulation is performed using MATLAB software to measure the variation between OSNR and Q factor for receiver section in the system. The difference penalty between OSNR and Q factor is simulated considering number of channels, number of spans and input transmitting launch power per span respectively. It is found that the difference between OSNR and Q is 0.2dB to 3.2dB for 111 Gb/s to 444 Gb/s data rates considering different system parameters in the COTN.

Model structure for the COTN is in section II. Mathematical expression for quality factor measurement is available in section III. Section V is the simulation results and comments. Finally we put the conclusion in VI.

MODEL STRUCTURE

The objective of the model of COTN is to measure the OSNR to calculate the Q values considering the ASE and NLI noises in the optical link of the network. In the transmitter section, 11 numbers of channels are used to make a super-channel where 6^{th} channel is the center number of the channels. f_{c+n}, f_{c-n} and f_c are the function to make the Even, Odd and Center channel to produce the polarization multiplexing in the transmitter of the COTN. Then modulated optical signal is passed through the optical filter [11]. The optical combiner is used to combine the filtered signal. The Pure Silica Core Fiber [13-14] which is a commercial fiber is used in the link of the optical network to propagate the optical carrier frequency taking the input transmitting power in every span. The specification of the PSCF commercial fiber is presented in Table I. EDFA acts as a span and is repeated after 90 km optical link in the network. 60 numbers of EDFA are used in this work as a number of spans. The p_{NLI} is the NLI noise power which is measured in the input of the EDFA and the P_{ASE} is the ASE noise power calculated after each EDFA in network [12] and is presented in the following Fig.1. [8-9]. After 60 numbers of spans, the ASE and NLI noises are accumulated to The objective of the model of COTN is to measure the OSNR to calculate the Q values considering the ASE and NLI noises in the optical link of the network. In the transmitter section, 11 numbers of channels are used to make a super-channel where 6^{th} channel is the center number of the channels. f_{c+n}, f_{c-n} and f_c are the function to make the Even, Odd and Center channel to produce the polarization multiplexing in the transmitter of the COTN. Then modulated optical signal is passed through the optical filter [11].The optical combiner is used to combine the filtered signal.

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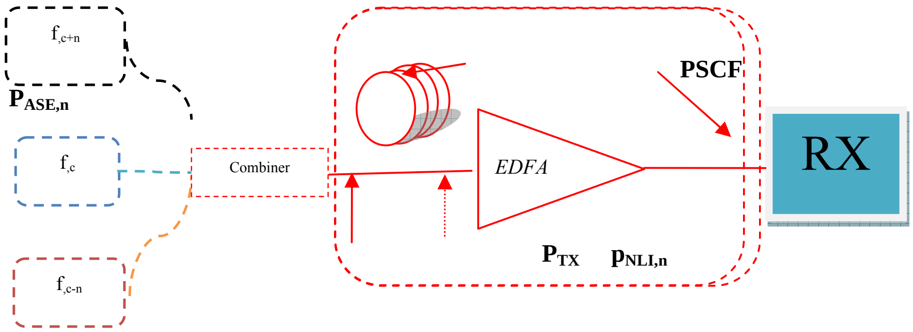

Fig.1. Coherent Optical Transmission Network

THEORETICAL ANALYSIS

To calculate the Power of NLI noise, the Equ. (127)- (129) of [10] is followed and presented below. The factor is that the Gaussian Noise (GN) model is chosen for its non identical channel and non identical link specification of the COTN.

$$p_{NLI} = \frac{16}{27} . B_n \sum_{n_s=1}^{N_s} \gamma_{n_s}^2 L_{eff,n_s}^2 . \prod_{n_s'=1}^{n_s-1} g_{n_s'}^3 e^{-6\alpha_{n_s'} L_{s,n_s'}} . \prod_{n_s'=n_s}^{N_s} g_{n_s'} e^{-2\alpha_{n_s'} L_{s,n_s'}} . \sum_{n=1}^{N_{ch}} G_{ch,n} G_{ch,n} G_{ch,i} . (2-\delta_{n,i}) \Psi_{n,i,n_s} \quad (1)$$

In Equ. (1), p_{NLI} is the power of non linear signal inference of i^{th} number of the center channel and Ns is the total number of optical link in the network. γ is the non-linearity coefficient of the PSCF commercial optical fiber and L_{eff} is the effective length [12] and presented as follows:

$$L_{eff} = (1 - \exp(-\alpha L_s)) / \alpha \quad (2)$$

Where L_s is the span length and α is the fiber loss coefficient per kilometer. g is the gain product. N_{ch} is the total number of channels. $G_{ch,n}$ and $G_{ch,i}$ are the spectral density for the n^{th} and i^{th} channel in the transmitter part [16] like below:

$$G_{ch,n} = \frac{P_{ch,n}}{R_s} \quad (3)$$

$$G_{ch,i} = \frac{P_{ch,i}}{R_s} \quad (4)$$

In Equ. (3) and Equ.(4) $P_{ch,n}$ and $P_{ch,i}$ are the channel power for n^{th} and i^{th} channels. R_s is the line rate of the channel. In this work three different types of line rates [19] are presented to measure the Q factor.

$\delta_{n,i}$ and Ψ_{n,i,n_s} are the operators to choose the n^{th} and i^{th} channel to generate the PSD using GN model. When $n=i$ and $n \neq i$, the Ψ_{n,i,n_s} and Ψ_{i,i,n_s} work respectively in the following way [10]:

$$\Psi_{n,i,n_s} = \frac{\text{asinh}(\pi^2(2\alpha_{n_s})^{-1}|\beta_{2,n_s}|[f_{ch,n} - f_{ch,i} + B_{ch,n}/2]B_{ch,i})}{4\pi(2\alpha_{n_s})^{-1}|\beta_{2,n_s}|} - \frac{\text{asinh}(\pi^2(2\alpha_{n_s})^{-1}|\beta_{2,n_s}|[f_{ch,n} - f_{ch,i} - B_{ch,n}/2]B_{ch,i})}{4\pi(2\alpha_{n_s})^{-1}|\beta_{2,n_s}|} \quad (5)$$

$$\Psi_{i,i,n_s} = \frac{\text{asinh}(\frac{\pi^2}{2}|\beta_{2,n_s}|[2\alpha_{n_s}]^{-1}B^2{}_{ch,i})}{2\pi|\beta_{2,n_s}|[2\alpha_{n_s}]^{-1}} \quad (6)$$

B_{ch} and β_2 are the bandwidth of the channel and disperion[15] of the fiber is used in equ.(5) and (6). *asinh* controls the array of complex number [17]. ASE noise spectral density is used [18] as below:

$$G_{ASE} = F\,h\,f_o\,A_S \quad (7)$$

In Equ.(7), *F, h,* f_o and A_s are the noise figures, plank constant, center frequency and loss of the link. Loss of the link depends on fiber loss per kilometer and length of the link. To measure the Q factor, the OSNR [18] is required.

$$\text{OSNR} = \frac{P_{TX}}{N_s\,(G_{ASE} + G_{NLI})B_n} = \frac{P_{TX}}{N_s\,(P_{ASE} + p_{NLI})} \quad (8)$$

Where B_n is optical bandwidth which is multiplied with G_{ASE} and G_{NLI} to obtain the P_{ASE} and p_{NLI} respectively. Then, scaling the transmitting input power per link is used to measure the optimum OSNR and Q factor of the network [5].

$$\text{OSNR} = \frac{P_{TX}}{(P_{ASE} + P_{TX}^3\,p_{NLI}\,B_{ch}^{-3})} \quad (9)$$

The Q factor is derived from OSNR and is used as an Equ.(10) in [10] and Equ.(4-11) in [3] as given below:

$$Q = 20\log\sqrt{OSNR}\,\sqrt{\frac{B_n}{R_s}} \quad (10)$$

SIMULATION AND RESULTS

In this section Matlab programming is run to measure the Q values of the COTN. As a result, theoretical model used in section III for NLI and ASE are simulated according to the given data in Table I and Table II. Consequently, Table III represents the output of the simulation. In this case, modulation format PM-16QAM is used to calculate bit rate (R_B) of the system. This format transfers eight bit per symbol. In this simulation, three different types of Baud rate [19] are used to observe the quality of the network. The line rate of the channel 13.875Gbaud, 27.75Gbaud and 55.5 Gbaud produces the 111Gbit/s, 222Gbit/s and 444Gbit/s bit rate respectively for PM-16QAM. This work confirms the required quality of the system for these three different types of Baud rate with assumed parameters.

TABLE I. SPECIFICATION OF PSCF [13] -[14]

Fiber Types	α [dB/km]	γ [1/W/km]	D [ps/nm/km]
PSCF	0.162	0.60	21

TABLE II. SIMULATION PARAMETERS

Parameters	***Data***
Channels(N_{ch})	11
Operating wavelength (λ)	1550[nm]
Channel Spacing(Δf)	0.05[THz]
Span Length (Ls)	90[km]
Number of span(Ns)	60
Noise Figure(F)	6[dB]
Center frequency (f_c)	193.41[THz]
Channel Bandwidth(B_{ch})	0.032 [THz]
Optical Noise Bandwidth(B_n)	0.0125[THz]

TABLE III. SIMULATION DATA FOR REQUIRED Q VALUES

R_s[Gbaud]	***B_n[THz]***	***R_B[Gbit/s]***	***OSNR[dB]-Q[dB]***
13.875	0.0125	111	0.23
27.75	0.0125	222	1.73
55.5	0.0125	444	3.24

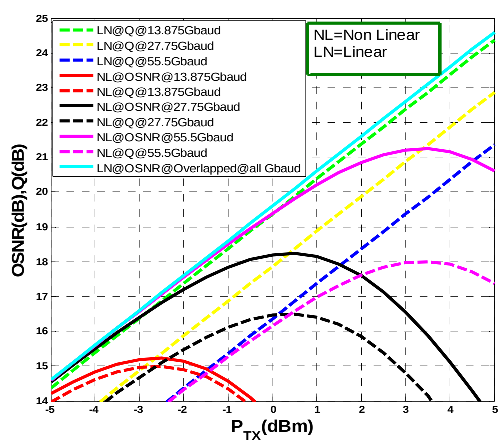

Fig.2. Q (dB), OSNR (dB) vs input launch power per span P_{TX} (dBm) for three different Baud rates.

Fig.2 presents the OSNR (dB)and Q (dB) versus input transmitting power per span (P_{TX}) [dBm].In the results, the OSNR and Q values for linear and non linear propagations are measured. The solid line is for OSNR performance of the system where dotted lines convey the information for Q values. The red, black and magenta color lines are for 13.875 Gbaud rate, 27.75Gbaud and 55.5 Gbaud symbol rates for non linear propagation respectively. The dotted blue, yellow and green color lines show the linear propagation. For linear propagation, we consider only ASE noise power where non linear interference (p_{NLI}) power is off during linear propagation. In the case of OSNR, the results get overlapped because of linear propagation which is denoted by Cyan color line. It is also found that in optimum point values, the linear and non linear difference is 1.76dB. It is also found that, for linear confirmation, the P_{TX} is changed along with OSNR by 1dB linearly. Here, considering 13.875 Gbaud rate, the optimum P_{TX} is -2.5dBm when the optimum OSNR and Q are 15.23dB and 14.99dB respectively. In this rate,the difference between OSNR and Q values is 0.23dB.For 27.75 Gbaud rates, the optimum P_{TX} is 0.5dBm when the optimum OSNR and Q are 18.23dB and 16.49dB respectively. Consequently, the difference between the OSNR and Q values is 1.73dB.For 55.5 Gbaud rates, the optimum P_{TX} is 3.5dBm when the optimum OSNR and Q are 21.24dB and 18.00dB respectively. As a result,the difference between the OSNR and Q values is 3.24dB.

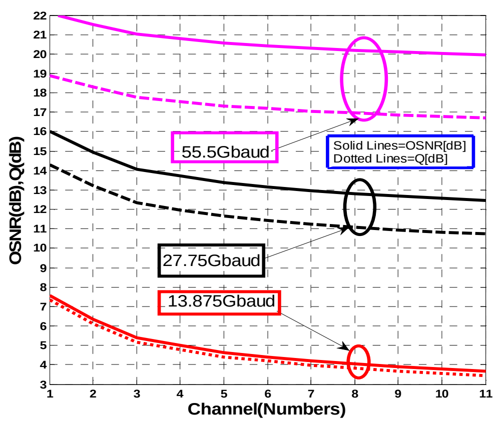

Fig.3. Q (dB), OSNR (dB) vs Channel Numbers with different values of symbol rates

Fig.3. presents the channel numbers versus Q (dB)and OSNR (dB) in the COTN. The solid and dotted lines represent the OSNR and Q values respectively. The red, black and Magenta colour lines are for 13.875Gbaud, 27.75Gbaud and 55.5Gbaud respectively. The OSNR is going down with the addition of channels in the network. The result shows that, for 13.875 Gbaud symbol rate, the end of Q value and OSNR is 3.44dB and 3.66 dB respectively. Where the difference between OSNR and Q is 0.23dB. The OSNR(end) and Q (end) for 11^{th} number of channel are 12.46dB and 10.73dB using 27.75Gbaud symbol rate. As a result, 1.73dB is the difference between OSNR and Q values. At 11^{th} number of channel position, the OSNR and Q are 19.95dB and 16.71dB respectively considering 55.5Gbaud symbol rate .Thus the difference between OSNR and Q is 3.24dB.

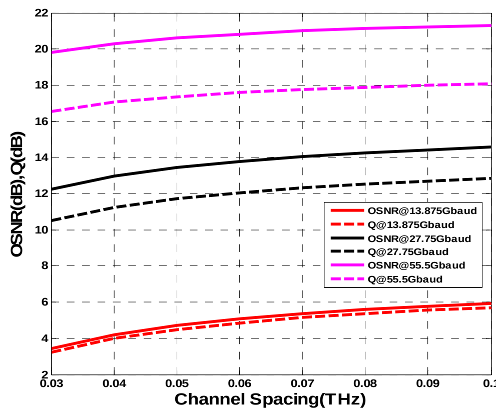

Fig4. Q (dB), OSNR (dB) vs Channel Spacing (THz) with different values of symbol rates considering PSCF

Fig.4. shows the channel spacing effects with respect to the Q (dB) and OSNR (dB) in the network. The dotted and solid lines present the Q values and OSNR respectively. Red, black and magenta colour lines bear the 13.875Gbaud, 27.75Gbaud and 55.5Gbaud symbol rates respectively. The OSNR and Q values are going up with the increment values of channel spacing in network. The ASE and NLI noise effects are considered to simulate the OSNR and Q factor. For the value of 0.1THz channel spacing, it is found that the Q factor is around 5.69dB, 12.82dB and 18.06dB where OSNR is approximately 5.92 dB, 14.55dB and 21.30dB for 13.875Gbaud, 27.75Gbaud and 55.5Gbaud symbol rates respectively. It is observed that Q values are less than OSNR by 0.23dB, 1.73dB and3.24dB for 13.875Gaud, 27.75Gbaud and 55.5Gbaud symbol rates respectively.

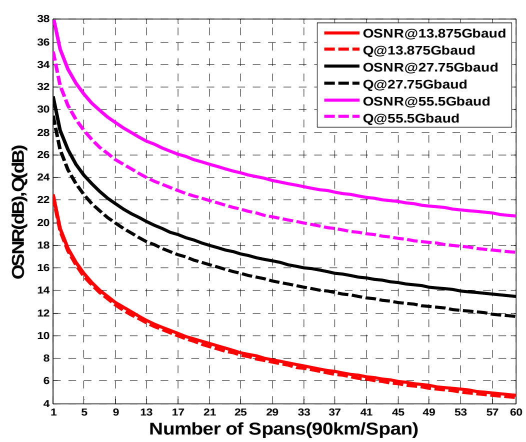

Fig 5. Q (dB), OSNR (dB) vs number of span (90km/span) with different values of symbol rates considering PSCF.

Fig.5is the performance curve of OSNR (dB)and Q (dB) versus total number of spans where 90 km is per span length. Thus, 5600km is the total link distance. In the results, red, black and magenta color lines convey the information for 13.875Gbaud, 27.75Gbaud and 55.5Gbaud symbol rates respectively. The solid and dotted lines represent the OSNR and Q performance in the graph. The OSNR and Q performance curves go down when the number of span is added in the network. For 13.875Gbaud symbol rate, the OSNR (end) and Q (end) are 4.71dB and 4.49dB respectively. In the figure, when symbol rate is 27.75Gbaud, the OSNR (end) and Q (end) are 13.4416dB and 11.71dB. It is found that 55.5Gbaud makes 20.61dB OSNR (end) and 17.37dB Q(end) in the network. In this performance, it is observed that, 111Gb/s, 222Gb/s and 444Gb/s bit rates show the difference between OSNR and Q as 0.23dB, 1.73dB and 3.24dB respectively.

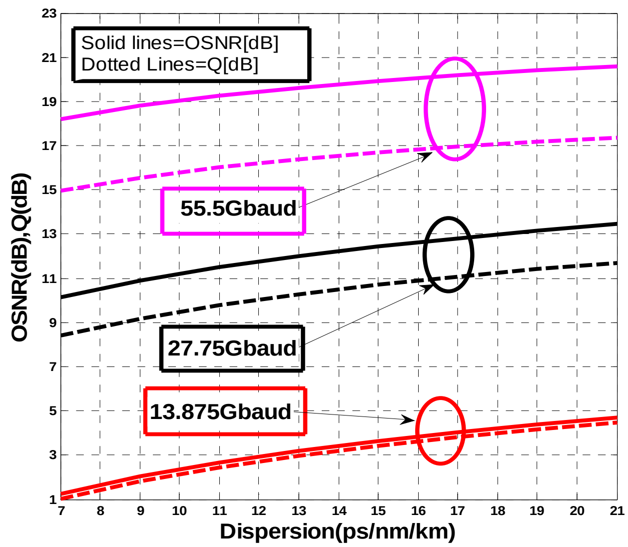

Fig. 6. Q (dB), OSNR (dB) vs fiber dispersion coefficient (ps/nm/km) with different values of symbol rates.

Fig.6 is the performance curve for fiber dispersion (ps/nm/km) versus OSNR (dB)and Q(dB) considering 111Gb/s, 222Gb/s and 444Gb/s bit rates. In this performance, it is observed that the OSNR is going up with the increment of dispersion values in the optical link. In this figure, magenta, black and red color lines are the 13.875Gbaud, 27.75Gbaud and 55.5Gbaud symbol rates. Solid and dotted lines are the OSNR and Q values in the curve. For dispersion 21(ps/nm/km), the OSNR and Q are 4.71dB and 4.48dB when symbol rate is 13.875Gbaud.For 27.75 Gbaud, the OSNR and Q are 13.44dB and 11.7dB. 20.6dB and 17.37dB are the OSNR and Q values considering the 55.5Gbaud symbol rate. It is observed that the differences between OSNR and Q are 0.23dB, 1.73dB and 3.24dB for 111Gb/s, 222Gb/s and 444Gb/s line rates respectively.

Conclusion

In this paper we have analyzed the Q values considering NLI and ASE noise effects on the COTN for three different symbol rates with commercially available PSCF optical fiber. It is observed that the difference between OSNR and Q varies from 0.23dB to 3dB for three different symbol rates. It is also stated that for low value of data rate, many channels are required where many transmitters and receivers are involved to get the target capacity which makes the system large and complex. Therefore, the system needs many channels and more input transmitting launch power per span. Thus, for a demanded Q value, an optimum baud rate is preferred to design the COTN.

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