Effect Of In-Band Crosstalk For Datapath Routing In WDM/DWDM Networks

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ABSTRACT: *Physical layer impairments are the major limitation for the high speed optical WDM/DWDM networks. They significantly affect the signal quality resulting poor quality of transmission which is normally expressed in terms of bit-error rate. To cope up with the future demand, increase in the no. of channels and data speed further enhances these impairments. Hence new techniques are needed, which mitigate these impairments and ensure a better quality of transmission. Among the physical layer impairments we have studied the impact of in-band crosstalk on transmission performance of a transparent WDM/DWDM network. In this paper, the effects of component crosstalk with finite interferers on the performance of a WDM receiver are studied. Bit error rate (BER) and power penalty in the receiver are calculated using a simplified analysis which can represent the performance of the WDM receiver in case of small number of interferers. Some optimum detection thresholds are suggested for minimum bit error rate. Optimum detection thresholds for minimum bit error rates in the WDM receiver in presence of component crosstalk are investigated.*

KEYWORDS: *Bit error rate, crosstalk, detection threshold, optical network, wavelength division multiplexing (WDM)*

I. INTRODUCTION:

Fiber-Optic communication system has an important advantage of exploiting the large bandwidth (nearly equal to THz) of an optical fiber [1, 2]. However, it is extremely difficult to exploit all of the huge bandwidth of a fiber using a single high capacity wavelength channel due to optical-electronic bandwidth mismatch [3]. A major breakthrough occurred with the advent of wavelength division multiplexing (WDM), which is a method of sending many light beams of different wavelengths simultaneously down the core of an optical fiber [4]. In WDM networks, prisms and diffraction gratings can be used to multiplex or de-multiplex different wavelength signals. However, as a result of their imperfect filtering characteristics, the separation of the wavelengths at the receiver may not be ideal, leading to performance degradation due to crosstalk [5, 6]. Incoherent or in-band crosstalk occurs in optical networks when a desired signal and unwanted optical fields with the same nominal wavelength arrive simultaneously at a receiver. If the desired and interfering fields are not phase co-related, they beat at the receiver, causing power fluctuations that increase the bit-error rate (BER). This phenomenon has long been recognized as a serious problem in optical networks [7, 8]. One of the major crosstalk in optical networks with WDM transmission is component crosstalk. Component crosstalk occurs in optical networks when a desired signal and an unwanted signal from neighboring input ports, with the same wavelength arrive simultaneously at a channel [9, 10]. The desired and the unwanted signal are not correlated in phase due to power fluctuation of laser. Therefore, they interact with each other, causing power fluctuations and increasing bit error probability of the system. Bit error rate of the receiver can be evaluated by calculating the noise in the photo-detector output due to crosstalk in addition to the noise of the detector itself [11]. In many cases, the probability density function (pdf) of overall noise is assumed Gaussian to calculate bit error rate. However, the Gaussian model, despite its simplicity, cannot accurately describe the signal-crosstalk noise, especially when the number of interfering channels is not very large. The maximum number of channels that can be used in a WDM system is limited by the total noise (including crosstalk) in the receiver system [12]. Therefore, several non-Gaussian models are developed to get a better estimate of the system performance. The pdf of such non-Gaussian models developed for finite interferers uses different techniques, such as saddle point approximation, numerical integration, Gram-Charlier series, and modified Chernoff bound [15,16]. However, these are often computationally complex and in many cases give little physical insight. In this paper, the effects of component crosstalk with finite interferers on the performance of a WDM receiver are studied [17]. Bit error rate (BER) and power penalty in the receiver are calculated using a simplified analysis which can represent the performance of the WDM receiver in case of small number of interferers[18]. Based on this study, optimum detection thresholds for minimum BER in the presence of component crosstalk are suggested, which is important for the best possible design to minimize this crosstalk.In Section 2, crosstalk and its mathematical model are discussed. The bit error rate & power penalty at the receiver output is calculated in Section 3 while the results of the analysis are given in Section 4. Finally, in Section 5, a conclusion is given.

II. IN-BAND CROSSTALK:

In WDM/DWDM network, a message is sent from one node to another node using a wavelength continuous route called light paths (LPs) without requiring any O-E-O conversion and buffering at the routing node. Multiplexing, de-multiplexing and switching are done in the optical domain using prisms and diffraction gratings.Non-ideal nature of these component results in-band crosstalk, which has the same wavelength as the signal and degrades the transmission performance of the network. In-band crosstalk can be divided into coherent crosstalk, whose phase is correlated with the desired signal considered, and incoherent crosstalk whose phase is not correlated with the signal considered [19, 20].Coherent crosstalk is believed not to cause noise but causes small fluctuation of signal power. In this paper, we considered in-coherent crosstalk which has the more adverse effect than coherent crosstalk. Incoherent crosstalk is often analyzed using the pdf of the noise in the received photocurrent. The pdf can be derived from the fields of the wanted signal and of each interfering signal.
Desired optical signal and each interfering signal are assumed to be

$$E_S(t) = \overrightarrow{r_s}\, b_s(t)\sqrt{p_s}\exp[(j\omega_s t + j\phi_s(t)] \qquad (1)$$

$$E_{\varepsilon k}(t) = \overrightarrow{r_k}\, b_k(t)\sqrt{\varepsilon_k p_s}\exp\,[(j\omega_s t + j\phi_k(t)] \qquad (2)$$

Where all the fields have same nominal optical frequency, ω, Φ(t) represents the independent phase fluctuation of each optical source, p_s is the optical power in the desire signal, and $E_{\varepsilon k}$ is the optical power of the k^{th} interference relative to the signal. $b_{s,k(t)}$ =0,1 depending on whether zero or one is transmitted by the desired and interference signal at time t. The total incident optical field on the photo detector can be written as for N crosstalk term

$$E_{ph}(t) = E_S(t) + \textstyle\sum_{k=1}^{N} E_{\varepsilon k}(t) \qquad (3)$$

$$E_{ph}(t) = \overrightarrow{r_s} b_s(t)\sqrt{p_s}\, exp\,[(j\omega_s t + j\phi_s(t)] \sum_{k=1}^{N} \overrightarrow{r_k}\, b_k(t)\sqrt{\varepsilon_k p_s} exp\,[(j\omega_s t +\ j\phi_k(t)] \qquad (4)$$

For unit detector responsivity and for worst-case assumption of identical polarization of signal and crosstalk, the photocurrent i(t) is given by

$$i_{ph}(t) = \left|E_{ph}(t)\right|^2 \qquad (5)$$

$$i_{ph}(t) = b_s^2(t)p_s + 2p_s \textstyle\sum_{k=1}^{N}\ b_s(t)b_k(t)\sqrt{\varepsilon_k} cos\theta_k(t) +\ \ p_s \sum_{k=1}^{N} b_k^2(t)\varepsilon_k \qquad (6)$$

Where $\theta_k(t) = \Phi_k(t) - \Phi_s(t)$, k=1,…..N, are random phase. Ignoring the small terms in the order of ε_k, the overall receiver noise in the photo-detector is

$$n(t) = 2p_s \textstyle\sum_{k=1}^{N} b_s(t)b_k(t)\sqrt{\varepsilon_k} cos\theta_k(t) + n_g(t) \qquad (7)$$

When ZERO is transmitted by the signal channel, there is no crosstalk and noise $n_0(t)$ = ng(t), where ng(t) is the usual Gaussian noise in the receiver. When ONE is transmitted by the signal,
Channel Crosstalk generates a total noise of

$$n_1(t) = 2p_s \textstyle\sum_{k=1}^{N} b_k(t)\sqrt{\varepsilon_k} cos\theta_k(t) + n_g(t) \qquad (8)$$

For N interferers and Gaussian noise, the pdf of the noise in the received photocurrent can be obtained by integrating the Gaussian noise over all possible values of phase offset between signal and each interferences [13, 14]. Assuming the phase difference between signal and interferers are independent and uniformly distributed between (0, π), the noise photocurrent pdf is given by

$$p_{nk}(y) = \frac{1}{\sqrt{2\pi\sigma}\pi^N} \times \left[\int_0^\pi .. \int_0^\pi exp\left\{-\frac{\left(y-\sum_{k=1}^N A_K cos\theta_k\right)^2}{2\sigma^2}\right\}\right] d(\theta_1) \ldots d(\theta_N) \qquad (9)$$

Where and σ is the variance of thermal noise. The effect of Crosstalk is maximum $A_k=2\sqrt{\varepsilon_k}p_s$ when phase difference is close to 0 and the pdf can be approximated by expanding the cosine term by first order Taylor Series [13] up to the term Θ_k^2

$$p_{nk}(y) = \frac{1}{\sqrt{2\pi\sigma}\pi^N} \times \left[\int_0^\pi .. \int_0^\pi exp\left[-\frac{\left\{y-\sum_{k=1}^N A_K\left(1-\frac{\theta_k^2}{2}\right)\right\}^2}{2\sigma^2}\right]\right] d(\theta_1) .. d(\theta_N) \qquad (10)$$

Expanding the square term and keeping term up to Θ_k^2, the pdf for noise when signal is transmitting 1 is given by

$$p_{nk}(y) = \frac{1}{\sqrt{2\pi\sigma}}\left\{\prod_{k=1}^N f(y)\right\} exp\left[-\frac{(y-\sum_{k=1}^N A_K)^2}{2\sigma^2}\right] \qquad (11)$$

Where

$$f(y) = \sqrt{\frac{\sigma^2}{2\pi A_k(y-\sum_{k=1}^N A_k)}}\, erf\left[\pi\sqrt{\frac{A_k(y-\sum_{k=1}^N A_k)}{2\sigma^2}}\right]$$

III. CALCULATION OF BER & POWER PENALTY:

BER in the presence of in-band crosstalk is given by fraction of the received photocurrent pdf's that fall on the wrong side of some decision variable d, for each combination of data "1"s and "0" of the signal and crosstalk[14]. Here we followed a simplified approach as given by Santu Sarkar et. al for extreme case when all interferers are transmitting "1", so that we have an upper bound for BER during our routing and wavelength assignment algorithm[21,22].

$$p_e = \frac{1}{2}p_{e0} + \frac{1}{2}\left[\frac{1}{2}p_{e1(b_k=0)} + \frac{1}{2}p_{e1(b_k=1)}\right] \qquad (12)$$

Where

$$p_{e0} = \frac{1}{2}erfc\left(\frac{d}{\sqrt{2\sigma_{th}^2}}\right)$$

$$p_{e1}(b_k=0) = \frac{1}{2}erfc\left(\frac{I_s-d}{\sqrt{2\sigma_{th}^2}}\right)$$

$$p_{e1}(b_k=1) = \frac{1}{2^{N+1}}\left\{\prod_{k=1}^N f(I_s-d)\right\}\sum_{k=1}^N erfc\left\{\frac{(I_s-\sum_{k=1}^N A_k)}{\sqrt{2\sigma^2}}\right\}$$

Here the weighting function f(y) is approximated as f $(I_s$-d) to make the integral possible. σ^2 is the variance of the receiver of the receiver noise when "1" is transmitted by the signal channel and σ_{th}^2 is the variance of the receiver thermal noise when "0" is transmitted. Expansion for BER at the WDM receiver is given by [14]:

$$p_e = \frac{1}{4}erfc\left(\frac{d}{\sqrt{2\sigma_{th}^2}}\right) + \frac{1}{8}erfc\left(\frac{I_s-d}{\sqrt{2\sigma_{th}^2}}\right) + \frac{1}{2^{N+3}}\left\{\prod_{k=1}^N f(I_s-d)\right\}\sum_{k=1}^N erfc\left\{\frac{(I_s-\sum_{k=1}^N A_k)}{\sqrt{2\sigma^2}}\right\} \qquad (13)$$

The Power Penalty is found by comparing the photocurrents at receiver that produce the same BER with and without crosstalk

$$PP = 10\log_{10}\left(\frac{I_s}{I_{s|NC}}\right) \qquad (14)$$

$I_{s/NC}$ being the photocurrent when there is no crosstalk (NC). Now the BER in case of no crosstalk is

$$P_{e|NC} = \frac{1}{2}erfc\left(\frac{B_{NC}}{\sqrt{2}}\right) \qquad (15)$$

Where

$B_{NC} = I_{s/NC}/2\sigma$ is the SNR of receiver. The BER with crosstalk is

$$P_e = \frac{1}{4}erfc\left(\frac{\frac{d}{\sigma_{th}}}{\sqrt{2}}\right) + \frac{1}{8}erfc\left(\frac{2B-\frac{d}{\sigma_{th}}}{\sqrt{2}}\right) + \frac{1}{2^{N+3}}\sum_{k=1}^{N} erfc\left[\sqrt{2}B - 2\sqrt{2}\varepsilon_k NB - \frac{d}{\sqrt{2\sigma^2}}\right]$$
$$\times \prod_{k=1}^{N}\left[\frac{1}{4B}\sqrt{\frac{1}{\pi\sqrt{\varepsilon_k}\left(1-2N\sqrt{\varepsilon_k}-\frac{d}{2\sigma B}\right)}}\,erf\left(2\pi B\sqrt{\sqrt{\varepsilon_k}\left(1-2N\sqrt{\varepsilon_k}-\frac{d}{2\sigma B}\right)}\right)\right] \qquad (16)$$

Where $B = I_s/2\sigma$ is the SNR with crosstalk, Therefore,

$$PP = 10\log_{10}\left(\frac{B}{B_{NC}}\right) \qquad (17)$$

Without component crosstalk, the required SNR to achieve a BER of 10^{-9} is $B_{NC} = 6$. So, for a BER of 10^{-9} in the presence component crosstalk, the Power Penalty is given by $PP = 10\log_{10}(B/6)$.

IV. SIMULATION AND RESULTS:

In this paper, we discuss the simulation result for an optimal lightpath selection mechanism based on a guaranteed QoT. We use MATLAB for our simulation work. In Figure 1 dotted lines shows different channels from one node to another in an optical network and dark lines shows the optimum path with minimum bit error rate . There are multiple paths from one node to another but if we consider two nodes, there is only one optimal path from source to destination.

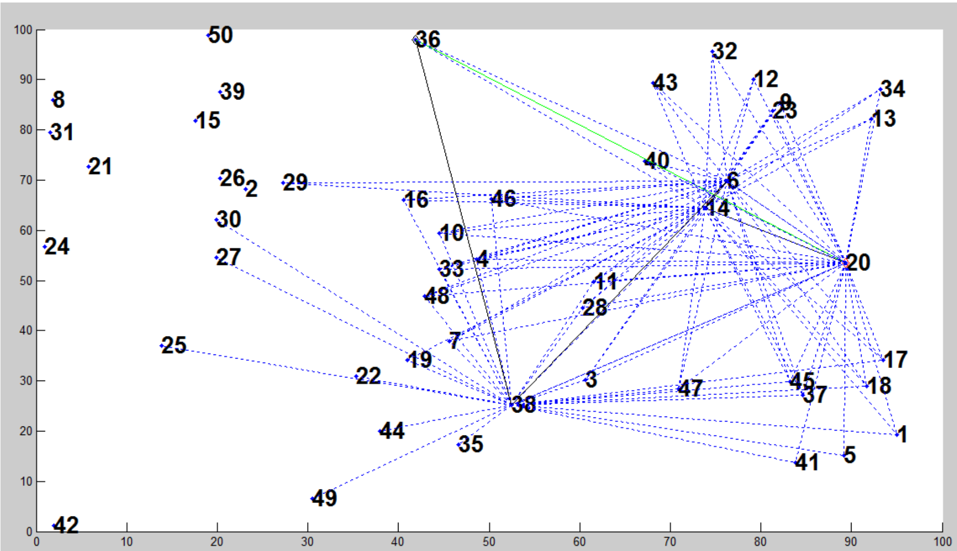

Fig.1 different paths between various nodes in optical network

The performance degradation due to In-band crosstalk depends very much on the no. of crosstalk interferences. In the following figures, the BER is plotted as a function of input power for different number of interfering channels (N).

These figures show that BER increases significantly as the no. of crosstalk component increases. Here we have neglected the effect of shot noise and assumed that all interferers have same amount of crosstalk level. Fig. 2(a), 2(b), 2(c), 2(d), 2(e), 2(f) shows the graph between BER and Input Power for different number of Interfering Channels (N) at a fixed crosstalk level of -25 dB,

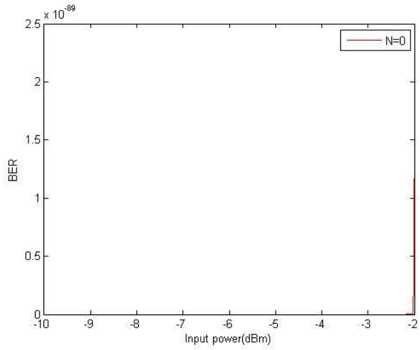

Fig. 2(a) Plot of BER with the Input Power for N=0

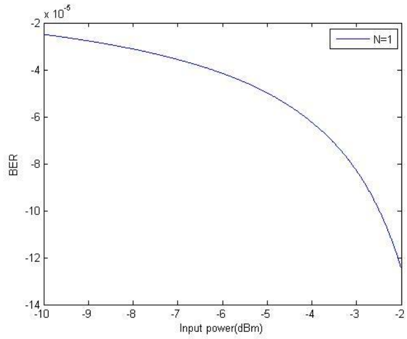

Fig. 2(b) Plot of BER with Input Power for N=1

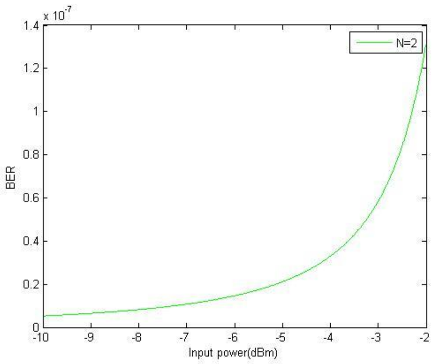

Fig. 2(c) Plot of BER with the Input Power for N=2

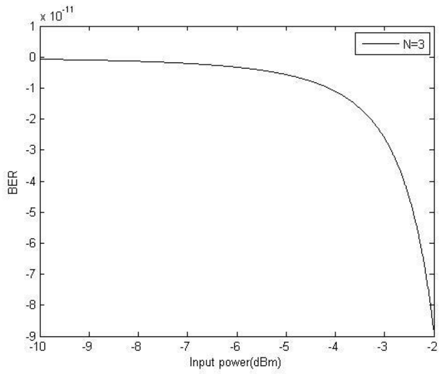

Fig. 2(d) Plot of BER with the Input Power for N=3

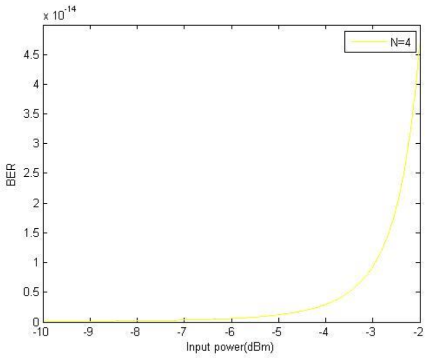

Fig. 2(e) Plot of BER with the Input Power for N=4

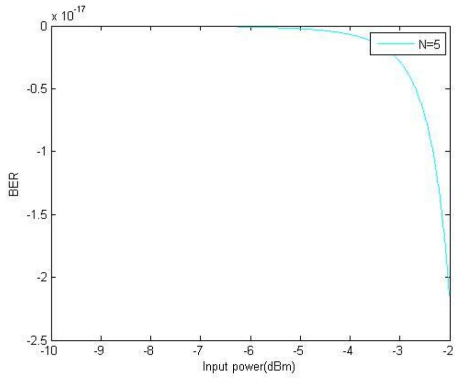

Fig. 2(f) Plot of BER with the Input Power for N=5

Fig. 3 shows variation of Power Penalty with Crosstalk level (total) for different number of interfering channels,

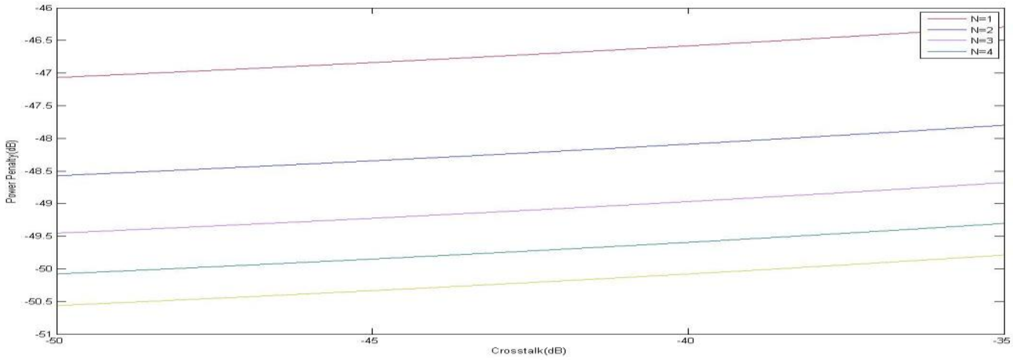

Fig. 3 Plot of Power Penalty with total crosstalk level for different number of interfering channels (N)

V. CONCLUSION:

In this paper, we have done a comprehensive survey on physical layer impairments and their impacts on transparent optical networks. Among the impairments we mainly focused on in-band crosstalk. Bit error rate and power penalties due to component crosstalk in a WDM Receiver has been calculated using a Taylor series and computed results are shown as a function of number of interfering channels, input power and crosstalk levels. Receiver Noise should be minimized to get the improvement through crosstalk minimization.

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REFERENCES:

[1] Chava Vijay Saradhi and Suresh Subramaniam,"Physical layer impairments Aware Routing (PLIAR) In WDM Optical Network Issues and Challenges,"IEEE Communication survey & Tutorials, vol. 11, no. 4, pp.109-129.fourth quarter.2009.

[2] Siamak Azodolmolky and et al, "A Survey on Physical layer impairments Aware Routing and Wavelength Assignment Algorithms in Optical Networks,"Computer Networks, vol.53, pp. 926-944, December 2008.

[3] Yurong Huang and et al, "Connection Provisioning with Transmission Impairment Consideration in Optical WDM Networks With High-Speed Channels," Journal of Lightwave Technology, vol. 23, no. 3,pp.982-993, march 2005.

[4] I. Tomkos, "Transport Performance of WDM metropolitan area transparent optical networks," in Proc., OFC, pp.350-352Mar.2002.

[5] Smita Rai, Ching-Fong Su and Biswanath Mukherjee, "On Provisioning in All- Optical Network: An Impairment-Aware Approach,"IEEE/ACM Transaction on Networking, vol. 17, no. 6, pp. 1989-2001, Dec.2009.

[6] Namik Sengezer and Ezhan Karasan, "Static Light path Establishment in Multilayer Traffic Engineering under Physical Layer Impairments," J.Opt.Communication & Networking, vol.2, no.9, Sept 2010.

[7] Konstantinos Christodoulopoulos and et al, " Offline Routing and Wavelength Assignment in Transparent WDM Networks,"IEEE/ACM Transaction on Networking, vol. 18, no. 5, pp. 1557-1570, Oct.2010.

[8] I, Tomkos et al., "Impairment Constrained Based Routing in Mesh Optical Networks," Proc. OFC 2007.

[9] C. Politi et al., "Physical Layer Impairments Aware Routing Algorithms based on Analytical calculated Q-Factor", Proc. OFC 2006.

[10] B. Ramamurty et al.,"Impact of Transmission Impairments on the Teletraffic Performance of Wavelength Routed Optical Networks,"Journal of Lightwave Technology, vol. 17, pp.1713-1723, Oct. 1999.

[11] T. Deng and S. Subramaniam, "Adaptive QoS Routing in Dynamic Wavelength Routed Optical Networks," Proc. Broadnets 2005.

[12] R. Ramaswami and K. Sivrajan, "Optical Networks: A Practical Perspective,

[13] Sarah D.Dods Trevoer B. Anderson "Calculation of bit-error rates and power penalties due to incoherent crosstalk in optical networks using taylor series expansions," j. Lightwave Technoloy., vol.23,No.4,pp.1828-1836,April.2005.

[14] Santu Sarakar and Nikhil R. Das, "Study of component crosstalk and obtaining optimum detection threshold for minimum bit-error-rate in a WDM receiver," j. Lightwave Technology., vol.27,No.19,pp.4366-4373,Oct.2009.

[15] Jun He, Maite, Brandt-Pearce and Suresh Subramaniam," QOS- Aware wavelength assignment with BER and latency Constraints for All-Optical networks," j. Lightwave Technology., Vol.27,No.5,pp.462-474,March 2009.

[16] Marcelo R. Jimenez, Rogerio Passy,Marco A. Grivet and Pierre Von Der, "Computation of power penalties due to intraband crosstalk [24] in optical system," IEEE Photonics Technology Letters, Vol.15, No.1, pp 156-158, Jan.2003.

[17] Keang-Po Ho, "Analysis of homodyne crosstalk in optical networks using Gram- Charlier Series", j. Lightwave Technology., Vol.17, No.2, pp.149-154, Feb- 1999.

[18] Yunfeng Shen, Kejie Lu and Wanyi Gu, "Coherent and Incoherent crosstalk in WDM networks ", j. Lightwave Technology.,Vol.17,No.5,pp.462-474,May 2003.

[19] I.T. Monroy and E.Tangliongga,"Perfomance evaluation of optical crossconnects by saddlepoint approximation," J. Lightwave Technol. vol. 16, pp. 317–323, Mar. 1998.

[20] T. Kamalakis and T. Sphicopoulos, " Asymptotic behavior of in-band crosstlalk noise in WDM networks," IEEE Photon. Technol. Lett vol. 15, pp. 476–478, Mar. 2003.

[21] Aneek Adhya, Debasish Datta,"Design Methodology for WDM backbone networks using FWM-aware heuristic algorithm,"Optical Switching and Networking, vol. 6, pp. 10-19, june 2008.

[22] Aneek Adhya and Debasish Datta,"Lightpath Topology Design for Wavelength-Routed Optical Networks in the Presence of Four- Wave Mixing,"J.Opt.Communication Network, vol. 4, No. 4, pp. 314-325, Apr. 2012.