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Analyses on the Effects of Crosstalk in a Dense Wavelength Division Multiplexing (DWDM) System Considering a WDM Based Optical Cross Connect (OXC)

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Abstract- Dense wavelength division multiplexing (DWDM) is usually used on fiber optic backbones and long distance data transmission. The crosstalk contribution due to inter-band crosstalk is significant for ultra dense WDM system, causes much higher noise, and degrades the network performance severely. This paper presents the results of a crosstalk analysis of dense wavelength division multiplexed (DWDM) cross-connect (OXC) topology. A set of parameters have been studied along with the simulation and results to observe the effect of crosstalk.

Index Terms— Crosstalk, Power Penalty, Bit error rate (BER), Dense Wavelength division multiplexing (DWDM), Optical cross connect (OXC).

1 INTRODUCTION

WAVELENGTH Division Multiplexing (WDM) is a system in which the available bandwidth is divided into separate channels with each channel carrying one signal [1]. The data rate of each channel can be limited, frequently to 10 Gb/s, but with many channels the total data rate is high. WDM has not always been a popular choice. The invention of erbium-doped fiber amplifiers (EDFA) is largely responsible for enabling this technique [2]. There are three variations of WDM that are commonly used: Broad WDM, Coarse WDM and Dense WDM (DWDM). However, Dense WDM allows information at various channels to be transmitted in different wavelength with its huge channel capacity and link distance [3] and utilizes many wavelengths spaced narrowly, and is most commonly located in C-Band, the wavelength range from 1539nm to 1565nm. One key advantage of DWDM is that gain region of Erbium-Doped Fiber Amplifiers (EDFA) is also in C-band, which enables all the wavelengths to be amplified to overcome loss over long spans of fiber and high passive losses (e.g. from splitting, multiplexing, etc.). Optical cross-connect (OXC) is an essential network element in a WDM optical network [4]. A number of OXC architectures have been proposed in [4] and [5], each of which have its own unique features, strengths, and limitations. Imperfections of the optical components used in these architectures give rise to optical crosstalk [6-7]. The effect of inter-band crosstalk has been neglected in [8-11] and in our work, it is found that, the crosstalk contribution due to inter-band crosstalk is significant for ultra dense WDM (DWDM) system, causes much higher noise, and degrades the network performance severely.

2 CROSSTALK

When signals from one channel arrive in another they become noise in the other channel, crosstalk occurs. This can have serious effects on the signal-to-noise ratio and hence on the error rate of the system. Crosstalk is usually quoted as the "worst case" condition. It will be one of the major limitations for the introduction of OXC in all optical networks. Crosstalk is classified as in-band (homodyne or intra-band) and inter-band (heterodyne) crosstalk. In-band crosstalk has the same wavelength as the signal and degrades the transmission performance seriously [12-16]. The crosstalk within the same wavelength slot is called intra-band crosstalk. Moreover, In-band crosstalk can be divided into coherent crosstalk and incoherent crosstalk. Coherent crosstalk is that whose phase is correlated with the signal considered and incoherent crosstalk, whose phase is not correlated with the signal. On the other hand, Inter-band crosstalk is crosstalk situated in wavelengths outside the channel slot (wavelengths outside the optical bandwidth) and considered as a less severe phenomenon. However, in DWDM technique this can be very predominant and degrades the network performance severely. The different classes of crosstalk are clarified in fig. 1.

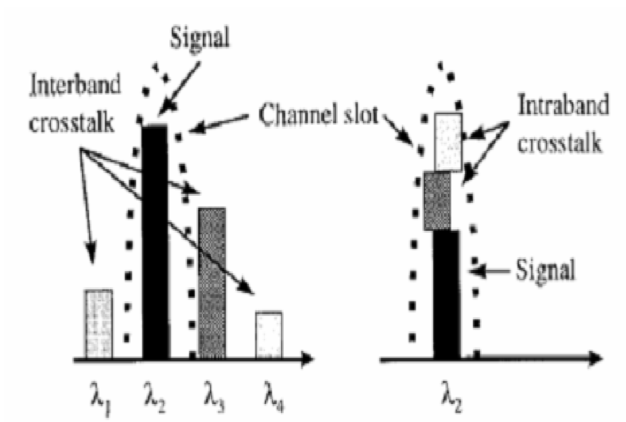

Fig 1. Inter-band and intra-band crosstalk

3 SYSTEM MODEL AND OXC TOPOLOGY

Fig. 2 shows the system model of a DWDM network using an N×N unidirectional OXC. Each input multiplexer of Fig. 2

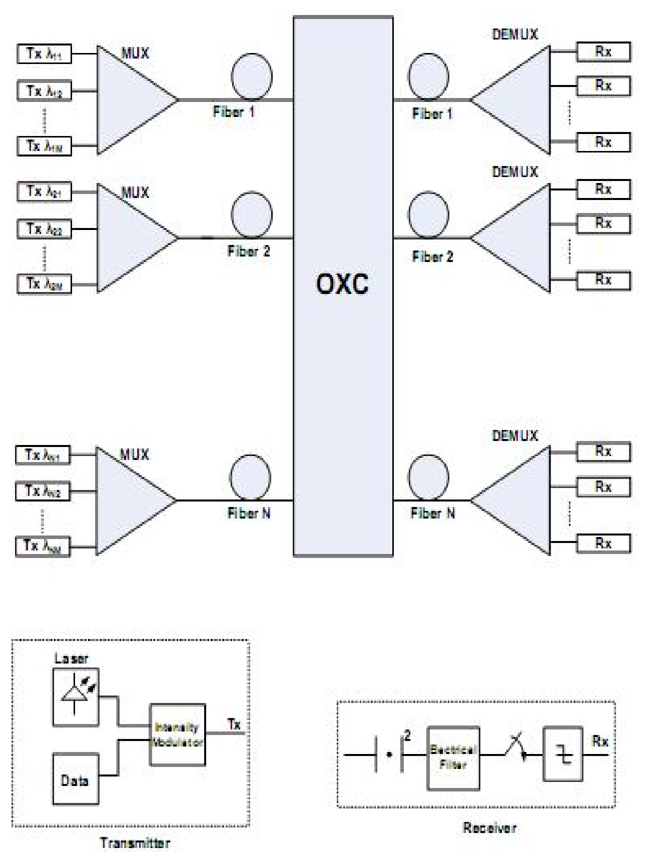

Fig. 2: Model of a DWDM system with N×N unidirectional OXC

combines M wavelengths coming from the M transmitters, and is connected through the optical fiber to the input port of the OXC, the detail view of which is given in Fig. 3.

The OXC uses N number of (M×1) multiplexers and (1×M) demultiplexers and M number of (N×N) optical switches. The demultiplexer of OXC separates M wavelengths. The optical switch takes N number of same wavelength signals coming from all the N input fibers and routes each wavelength to any of the N output fibers according to the destination address. The multiplexer of OXC again combines M number of wavelengths and sends them to a single fiber. The output demultiplexer of Fig. 2 separates the M wavelengths and sends them to the individual user terminal.

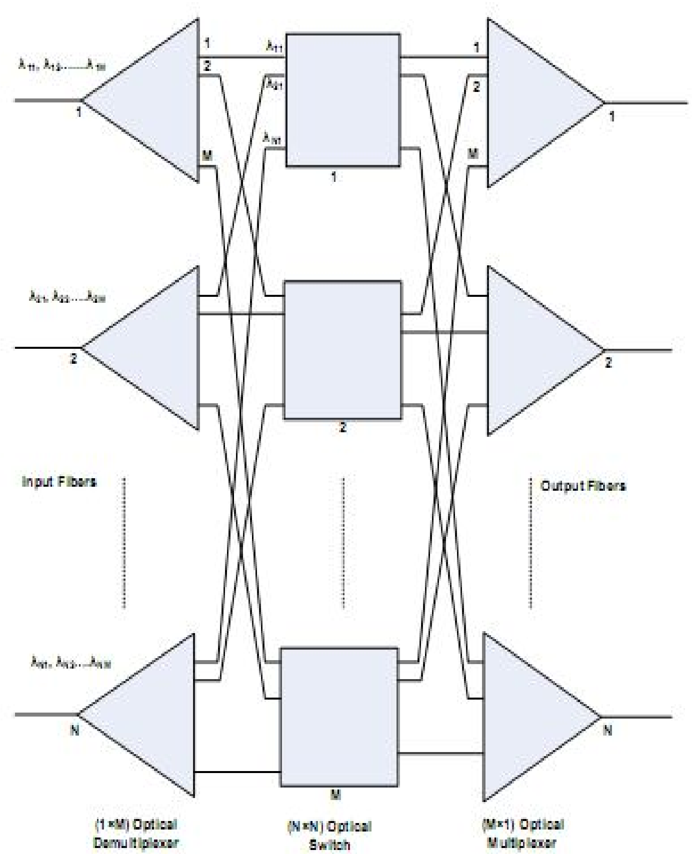

Fig. 3: Conventional OXC using multiplexer, demultiplexer and optical switch. This OXC has N input and output fibers and each fiber carries M number of wavelengths.

The OXC shown in Fig. 3 consists of a total of N optical demultiplexers, M optical switches, and N multiplexers. Each of the input fibers to optical demultiplexers contains M different wavelengths. The optical demultiplexers spatially separate the incoming wavelengths into M paths. Each of these paths passes through an optical switch before they are combined with the outputs from the other M–1 optical switches.

4. CROSSTALK IN OPTICAL CROSS CONNECT (OXC)

Crosstalk is the general term given to the effect of other channels on the desired signal. In OXC, crosstalk arises due to the imperfect operation of the multiplexers, demultiplexers and switches. The dumultiplexer ideally separates the incoming wavelengths to different output paths. In reality, however, a portion of the signal at wavelength, say λ_i leaks into the adjacent channel λ_{i+1} because of the non ideal separation within the demultiplexer. When the wavelengths are again combined into a single fiber by the multiplexer, a small portion of the λ_i that leaked into the λ_{i+1} channel, will also back into the common fiber at the output. Although both signals contain the same data, they are not in phase with each other, due to different delays encountered by them. This causes in-band crosstalk. The crosstalk penalty is highest when the crosstalk signal is exactly out of phase with the desired signal. Crosstalk arises in switches due to the non ideal isolation of one switch port from the other. In this case, the signal contains different data causing the inter-band crosstalk when combined in the multiplexer into the same output fiber. Inter-band crosstalk also arises due to the demultiplexer that selects one channel and imperfectly rejects the others.

5 MATHEMATICAL EXPRESSION

For different number of channels and hops the crosstalk can be calculated using the equation:

$$\sigma^2 = M \cdot b^2 \cdot R_d^{\ 2} \cdot P_s^{\ 2} \left\{ 2\varepsilon_{adj} + (N-3)\varepsilon_{nonadj} + X_{Switch} \right\} \quad (1)$$

Where, M is number of hops, b is ratio of signal peak power, N is number of channels, R_d is detector responsivity, P_{in} is input power, ε_{adj} is effective adjacent channel crosstalk, ε_{nonadj} is effective non adjacent channel crosstalk, X_{switch} is crosstalk value (in linear units) of the optical switch fabric.
For most practical DWDM networks, this requirement of BER is 10^{-12} (~ 10^{-9} to 10^{-12}), which means that a maximum one out of every 10^{12} bits can be corrupted during transmission. Therefore, BER is considered an important figure of merit for DWDM networks; all designs are based to adhere to that quality. BER in DWDM system is calculated by the equation:

$$BER = 0.5\, erfc\left(Q / \sqrt{2}\right) \quad (2)$$

Here Q is a function proportional to the receiver signal-to-noise ratio (SNR) and expressed as:

$$Q = \frac{(R_b \times P_s)^2}{\sqrt{(\sigma_{ase}^{\ 2} + \sigma_c^{\ 2})}} \quad (3)$$

R_b is the bit rate or data rate, P_{in} is Signal power (dbm), σ_c is the Crosstalk, σ_{ase} is ASE (amplified spontaneous emission) noise induced by parametric gain and spontaneous Raman scattering in optical fiber Ramen amplifier. It is an unwanted noise which is as follows:

$$\sigma_{ase} = \sqrt{\{(G-1) \cdot N_{sp} \cdot h \cdot \upsilon \cdot BW\}} \quad (4)$$

Where, G is gain, N_{sp} is spontaneous emission factor or population-inversion factor, h is Planck's constant (6.634×10^{-34}JKg^{-1}K^{-1}), $\nu = c/\lambda$ is the frequency of the signal, c is the speed of light (3×10^{8}), λ is the wavelength, BW is the band width (hertz).
In order to calculate Power Penalty from crosstalk, we first calculate the power for without crosstalk then for with crosstalk. The difference between the two gives the Power Penalty which can be given as:
Power penalty (PP) = Power without crosstalk - Power with crosstalk (5)

6 SIMULATION & RESULTS

Following the analytical expression presented in section 4 BER performance against different input power has evaluated without considering the effect of crosstalk for different bandwidths (B) in figure 4. In our study we have used Matlab 2007b in order to simulate the results and curves.

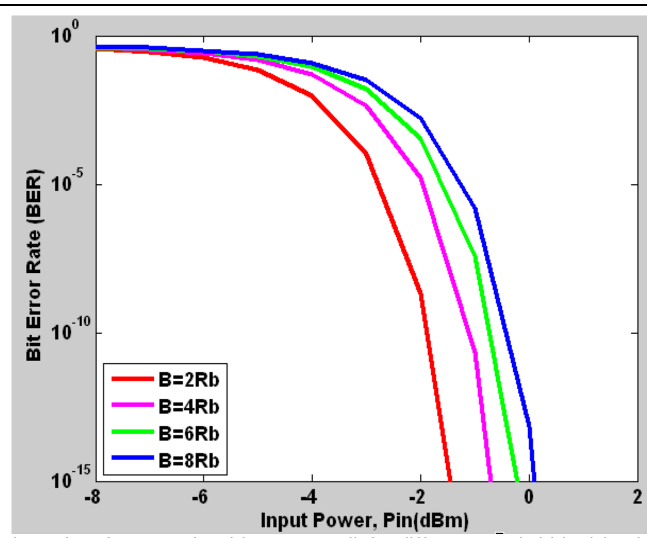

Fig 4: Plot of BER vs. Pin without crosstalk for different Bandwidths (B), with optimized parameters (Bit rate, R_b=10Gb, N_{sp}=1.8, Gain, G=20dB)

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The input power is taken from the range of -8 dbm to 1dbm. It is seen that the BER increases with increase in input power (Pin). It is also shown that to have more bandwidth we need for more input power. The figure 5 shows BER against input power (dbm) for different values of crosstalk where bandwidth has kept fixed at 2Rb. The input power is taken from -5dbm to 20dbm. Here we can see that crosstalk increases when BER increases.

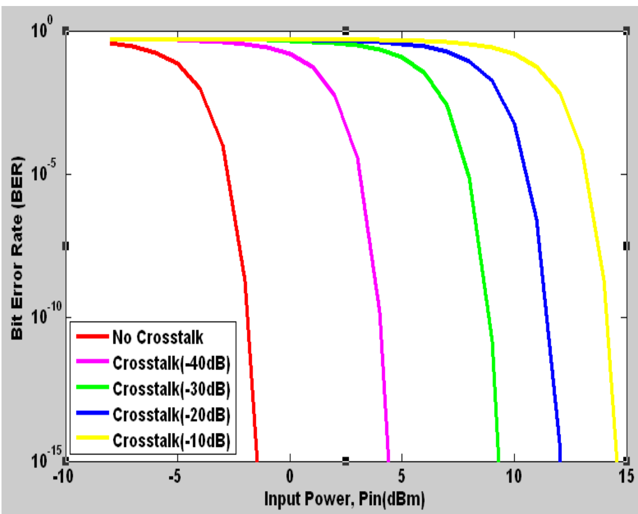

Fig 5: Plot of BER vs. Pin for different values of crosstalk in dB

The power penalties can be calculated using the eqn. 5 which is shown in fig.6. Here we have taken $10^{(-6)}$ as Bit error rate (BER) and calculated the power penalty corresponding of this value. We got input power -2.6 dbm when crosstalk is zero. For -40dB crosstalk the power penalty is 5.8 dbm whereas for -30 dB it is 10.8dBm. Moreover, power penalty is 13.4 dbm and 15.7 dbm for crosstalk of -20dB and -10 dB respectively which has been calculated using the figure below. It can easily be said that power penalty increases with the increase of crosstalk.

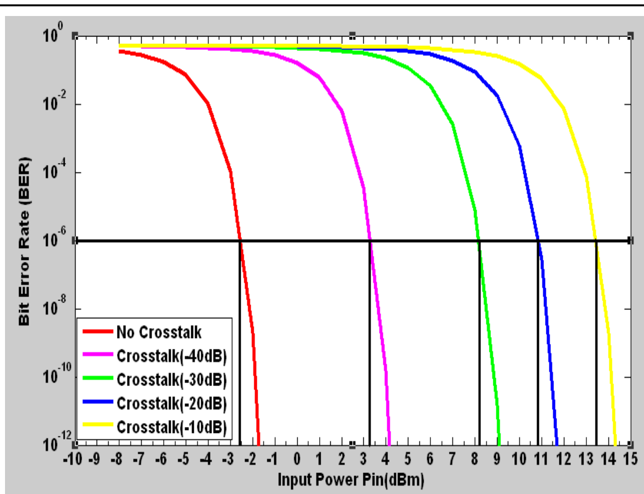

Fig 6: Plot of BER vs. Pin for different values of crosstalk in dB (Power

Figure 7 shows the effect of crosstalk with increasing the number of channels for different number of hops. It can be clearly said that if we increase the number of channels then crosstalk also increases. We can also implicate that lesser the number of hops lesser the crosstalk.

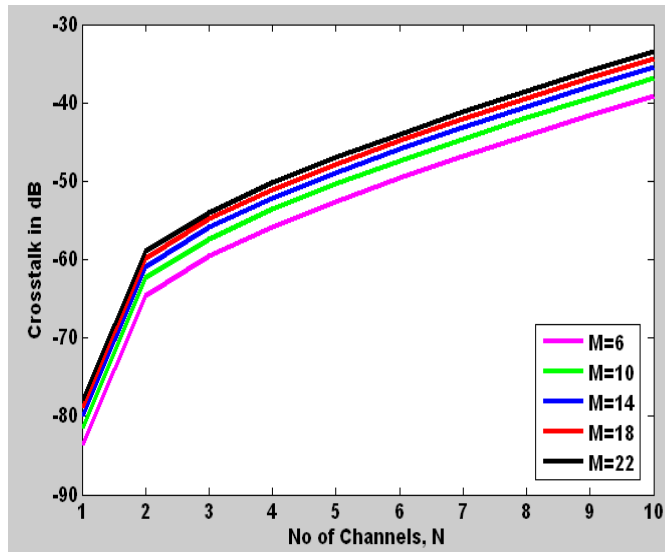

Fig 7: Crosstalk vs. Number of channels for different hops (M), with optimized parameters
(X_{switch}=0.01, R_d=0.85, b=1, ε_{adj}=0.5, ε_{nonadj}=0.5)

Finally in figure 8 the BER vs. Crosstalk for the variation of number of channels has been plotted. We can observe that crosstalk increases with the increase in the number of channels.

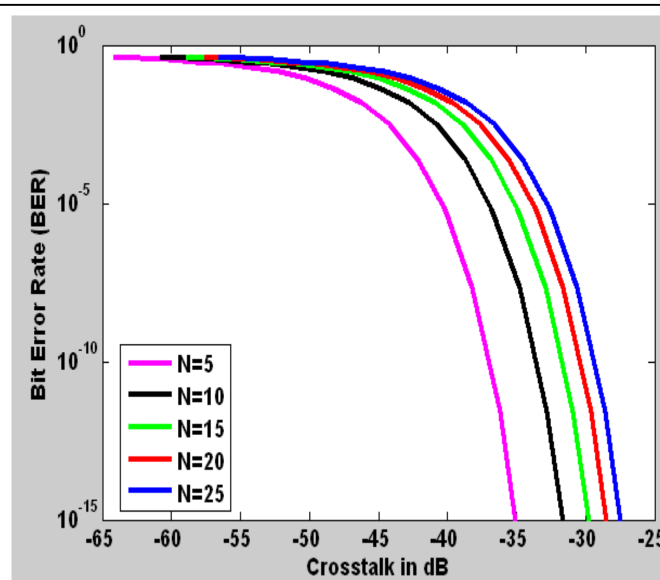

Fig 8: Crosstalk vs. BER for different channels (N), with optimized parameters (Bit rate R_b=10 GB, X_{switch}=0.01, R_d=0.85, b=1, ε_{adj}=0.5, ε_{nonadj}=0.5)

7 CONCLUSION

In this paper, crosstalk performance of a DWDM network with OXC has been analyzed and the effect of increasing channels and hops has been studied. Moreover, Power penalties for a particular bit error rate have also been calculated and it has been observed that for higher crosstalk the power penalty also increases. It has seen that BER increases with the increase of crosstalk. The introduction of more channels and hops also put adverse effect on the system by increasing the crosstalk. Further research can be carried out to evaluate the performance of a WDM network with OXC using different topologies of the OXC and to find a topology with optimum system performance.

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