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PERFORMANCE ANALYSIS OF WSXC AND WIXC SSM OXC IN WDM OPTICAL NETWORKS

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Abstract - The impact of inband crosstalk on an optical signal passing through optical cross-connect nodes (OXC's) in wavelength division multiplexing (WDM) optical network, is studied from the equation of electric field with crosstalk and the corresponding current. The analysis has been done for two SSM (space switching matrix) OXC architecture namely WSXC & WIXC where later one has full wavelength conversion capability. Although WIXC attenuates more crosstalk though it is found that depending on the values of optical propagation delay differences, coherent time of lasers and time duration of one bit of the signal, the required power penalty in WIXC may be greater than that of WSXC in some cases. The analysis has been performed on the measures of Bit Error Rate (BER) and Power Penalty.

Keywords*- Inband crosstalk, optical cross-connect, wavelength division multiplexing (WDM), wavelength selective cross-connect (WSXC), wavelength interchanging cross-connect (WIXC).*

I. INTRODUCTION

In a wavelength division multiplexing (WDM) optical network, the optical cross-connect (OXC) at each node carries out wavelength sensitive switching in optical form without restoring to electro optical conversion. A number of OXC architectures have been proposed in [1] and [2], each of which has its own unique features, strengths and limitations. While cross-connecting wavelengths from input to output fibers OXC introduces inband and intraband crosstalk. The inband crosstalk which is also known as homodyne crosstalk has the same wavelength as the signal and degrades the transmission performance seriously. When an optical signal passes through an OXC, many crosstalk contributions are combined with the signal[3]-[5].

In this paper, the performance of wavelength selective cross-connect (WSXC), wavelength interchanging cross-connect (WIXC) is investigated and compared in the presence of inband (Homodyne) crosstalk which is caused by non-ideal performance of an optical node.

II. INBAND CROSSTALK IN WSXC AND WIXC

Inband crosstalk is a major problem in optical network.

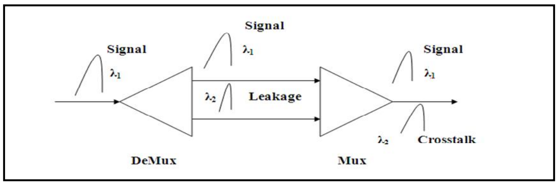

Figure. 1 A cascaded wavelength demultiplexer and multiplexer as a source of in-band crosstalk

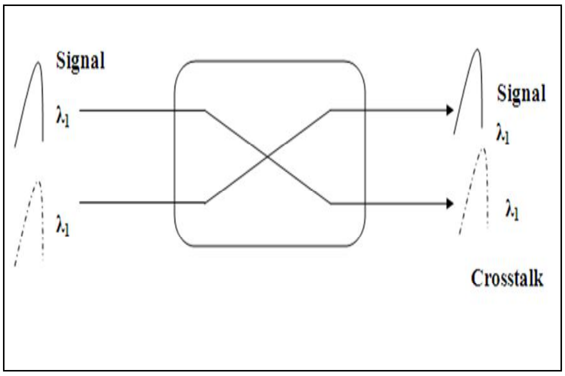

Figure. 2 An optical switch as a source of in-band crosstalk

One source of this arises from cascading a wavelength demultiplexer with a wavelength multiplexer as shown in Figure 1. The demux ideally separates the incoming wavelengths to different output fibers. In reality however a portion of the signal at one wavelength, say λ_i, leaks into the adjacent channel λ_{i+1} because of non ideal suppression within the demux. When the wavelengths are combined again into a single fiber by the mux, a small portion of the λ_i,that leaked into the λ_{i+1} channel, will also leak 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 inband crosstalk. [6]

Another source of this type of crosstalk arises from optical switches as shown in Figure 2, due to the non ideal isolation of one switch port from the other. In this case, the signal contains different data. The crosstalk penalty is highest when the crosstalk signal is exactly out of phase with the desired signal.

Inband crosstalk can be divided into coherent crosstalk and incoherent crosstalk. When the phase of the crosstalk signal is correlated with that of the main signal, it is called coherent crosstalk. When the phase of the crosstalk signal is not correlated with that of the main signal, it is called incoherent crosstalk. Crosstalk signals generated from the same source are coherent crosstalk and crosstalk signals generated from different sources are incoherent crosstalk. Coherent crosstalk is believed not to cause noise but causes fluctuations of signal power.

The lightpath, representing the optical layer connection between the source-destination node pairs, can be set up through the intermediate OXCs in either a wavelength- continuous (WC or VWP, virtual wavelength path) or non-wavelength-continuous (NWC or WP, wavelength path) fashion. In the WC case, the same wavelength is used over the entire lightpath whereas, in the NWC case, different wavelengths may be used in different optical links along the given path. Setting up the lightpath would not only involve selecting the route to be followed but also the wavelengths to be used along the selected route[6].

Wavelength conversions at the intermediate nodes is necessary if NWC (WP) lightpaths are to be supported. This, however, would require the OXCs to do wavelength conversion in addition to their switching functions. The OXCs may, in turn, be classified based on their wavelength conversion capability [6].

Among a number of proposed SSM OXC structures WSXC and WIXC are focused. An OXC without any conversion capability is called a wavelength selective cross-connect (WSXC) whereas an OXC with full conversion capability is referred to as a wavelength interchanging cross-connect (WIXC). Examples of these have been shown in the figure3 and 4.

Here, SSM refers to the space switching matrix, used to switch the optical signals without doing any wavelength conversion. The wavelength converters required have been shown separately .

A typical structure of OXC is shown in figure 5, which consists a total of *N* optical demultiplexers, *M* optical switches and *N* multiplexers. Each of the input fibers to an optical demultiplexer contains *M* different wavelengths. Each of these passes through an optical switch before they are combined with the outputs from the other *M-1* optical switches.

Assuming the OXC is fully loaded the OXC will be interfered by *M+N-2* homodyne crosstalk contributions, *N-1* of which are leaked by the optical switch leaked by the (OXC) demultiplexer / multiplexer pair. [7]

If we consider the signal with wavelength 1 in input fiber 1, noted as λ_{11} or the main signal. λ_{11} will be interfered by *N-1* crosstalk contributions leaked from the *N-1* signals with wavelength 1 in the other *N-1* input fibers. Similarly, when each signal with wavelength 1 is demultiplexed to one path, there will be a fraction of it in each of the other M-1 outputs of the corresponding demultiplexer because of the non-ideal

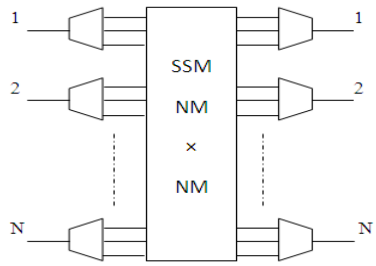

Figure. 3 WSXC OXC architecture

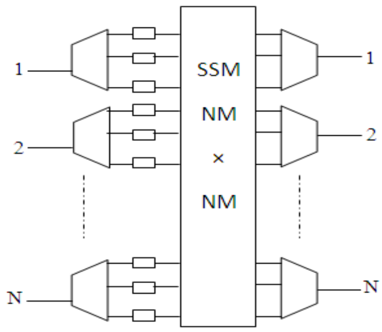

Figure. 4 WIXC OXC architecture

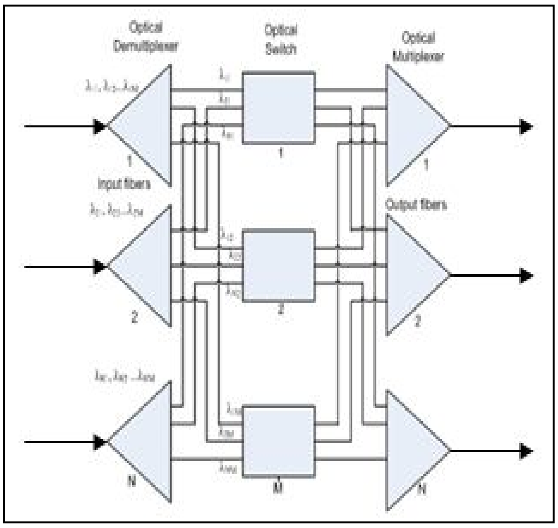

Figure. 5 Typical structure of an Optical Cross Connect

crosstalk specification of optical demultiplexers. These M-1 crosstalk contributions can be leaked from any signal with wavelength 1 in all the N input fibers. The number of contributions leaked from each signal is random, from 0 to *M-1*, depending on the cross connecting state of the OXC. Defining X_1 as the number of contributions leaked from λ_{11} in a given state of the OXC,

$$X_1 \in [0, M\text{-}1]$$

Defining, X_j(j=[2,N]) as the number of contributions leaked from λ_{j1} fin the same state of the OXC, taking into account the N-1 contributions leaked by the optical switch 1, we have

$$X_j \in [1, M] \quad \text{and}$$

$$X_1 + \sum_{j=2}^{N} X_j = M + N - 2$$

The field of the main signal and all the M+N-2 crosstalk contributions can be expressed as

$$\vec{E}(t) = Eb_s(t)\cos[\omega_s t + \Phi_s(t)]\,\overrightarrow{P_s}$$
$$+\sum_{i=1}^{X_1} \sqrt{\varepsilon}E\, b_s(t-\tau_i)\cos[\omega_s(t-\tau_i) + \Phi_s(t-\tau_i)]\,\overrightarrow{P_i}$$
$$+ \sum_{j=2}^{N}\sum_{k=1}^{X_j} \sqrt{\varepsilon}Eb_j\left(t-\tau_{jk}\right)\cos\left[\omega_j\left(t-\tau_{jk}\right) + \Phi_j\left(t-\tau_{jk}\right)\right]\overrightarrow{P_{jk}} \qquad (1)$$

Where E is the signal field amplitude which is assumed to be unchanged as the leaked power is rather low; bs(t) and bj(t) (j=[2,N]) are the binary data sequences with values of 0 or 1 in a bit period T of $\lambda_{11}$and λ_{j1}, respectively, $\omega_s(t), \Phi_s(t)$, and $\omega_j(t), \Phi_j(t)$ are the center frequencies and phase noises of the lasers, respectively, $\overrightarrow{P_s}$ is the unit magnitude polarization vector of the signal; τ_i, τ_{jk} and $\overrightarrow{P_i}$, $\overrightarrow{P_{jk}}$ are the propagation delay differences and unit magnitude polarization vectors of the contributions, respectively; ε is the optical power ratio of each crosstalk contribution to the signal and for simplicity we assume all the crosstalk contribution have the same power. , $\overrightarrow{P_s}$, $\overrightarrow{P_i}$ and $\overrightarrow{P_{jk}}$ are treated as time invariant here as they change rather slowly compared to the bit period. Now depending on relation between $\tau_i, \tau_{jk}, \tau_{coherent}$ and T three cases may be considered for which the laser relative intensity noise (RIN) will get different values [7].

Case 1: If $\tau\left(\tau_i and \tau_{jk}\right) > \tau_{coherent}$:

As $\Phi_s(t)$ is uncorrelated with $\Phi_s(t-\tau_i)$ *and* $\Phi_j\left(t-\tau_{jk}\right)$ are also uncorrelated with each other for different k. In that case the noise power can be expressed as

$$\sigma_{RIN,1}^2 = \varepsilon \textstyle\sum_{l=1}^{M+N-2} \cos^2\theta_l \qquad (2)$$

$$\cos\theta_l = \overrightarrow{P_s}\,.\,\overrightarrow{P_i}$$

where, θ_l is the polarization angle difference between the *l*th crosstalk contribution and the signal.

If $\tau\left(\tau_i and \tau_{jk}\right) < \tau_{coherent}$:Depending on the relation between τ and T two cases may arise.

Case 2(a): If $\tau\left(\tau_i and \tau_{jk}\right) \ll T$:

As $b_s(t-\tau_i)$ equal to $b_s(t)$ approximately in this case, so coherent crosstalk do not cause noise but causes fluctuation. So, noise power will be

$$\sigma_{RIN,2a}^2 \varepsilon \textstyle\sum_{j=2}^{N}\left(\sum_{k=1}^{X_j} cos\phi_{jk}\, cos\theta_{jk}\right)^2 \qquad (3)$$

Case 2(b): If $\tau\left(\tau_i and \tau_{jk}\right) > T$:

As $b_s(t-\tau_i)$ becomes completely incorrelated with $b_s(t)$ due to unsynchronus nature of $b_s(t)$ the noise power will be

$$\sigma_{RIN,2b}^2 = \frac{1}{3}\varepsilon\sum_{i=1}^{X_1}(cos\phi_i cos\theta_{jk})^2$$
$$+ \varepsilon \textstyle\sum_{j=2}^{N}\left(\sum_{k=1}^{X_j} cos\phi_{jk}\, cos\theta_{jk}\right)^2 \qquad (4)$$

For worst case scenario with fully loaded OXC for the above cases crosstalk may be expressed as

$$\sigma_{RIN,1}^2 = \varepsilon(M+N-2) \qquad (5)$$
$$\sigma_{RIN,2a=}^2 \varepsilon M(N-1) \qquad (6)$$
$$\sigma_{RIN,2b}^2 = \tfrac{1}{3}\varepsilon M + \varepsilon M(N-1) \qquad (7)$$

III. EXPERIMENTS AND DISCUSSIONS

The detail analysis of Homodyne crosstalk is described in section 2. Figure 3 and Figure 4 shows WSXC and WIXC architectures. Inband crosstalk induced RIN due to these OXCs is given by equations 1-4 for both coherent and incoherent case. Case 1 represents the incoherent inband crosstalk while there are 2 cases for coherent inband crosstalk.

Case 2a occurs when optical propagation delay differences are much less than the time duration of one bit (τ<<T) which means $b_s(t-\tau_i)$==$b_s(t)$. Again case 2b represent the case when τ>T and $b_s(t-\tau_i)$ become uncorrelated completely with $b_s(t)$ as $b_s(t)$ is a random sequence and they are not synchronized. The To observe the BER performance we assumed the worst case scenario and simulated equation 5-7 incorporating the Homodyne crosstalk induced RIN into these equations. To evaluate the expression of σ_{th} as given by equation

$$\sigma_{th}^2 = (4kTB_e/L) \qquad (8)$$

we assumed, T=300K, k=1.38x10^{-23}, B_e=10^9 Hz and R_L=50 Hz.

Figure 6 gives the comparative plots of BER against the signal power for WSXC OXC having number of wavelengths per channel, M = 4 and separately for case1, case 2a and case2b . In plots of figure 4.1[(a)-(c)], the number of channels, N is varied as N= [4 8 16 32 64] and it is found that the BER increases significantly with increase.

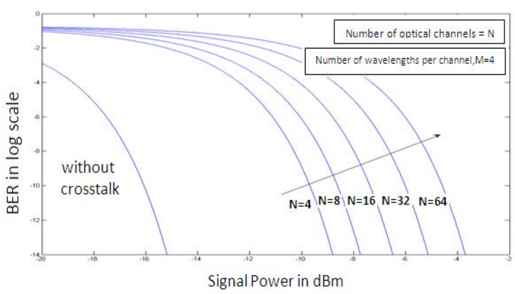

Figure. 6(a) BER performance in presence of incoherent homodyne crosstalk (case 1) for WSXC OXC with varying number of channels and with no. of wavelengths per channel=4

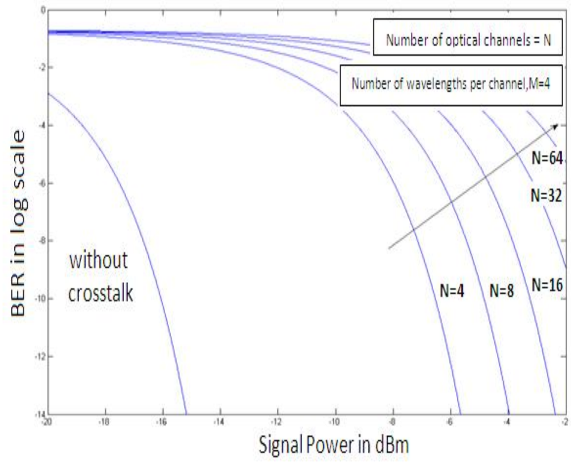

Figure. 6(b) BER performance in presence of coherent homodyne crosstalk for τ<<T (case 2a) for WSXC OXC with varying number of channels and with no. of wavelengths per channel=4

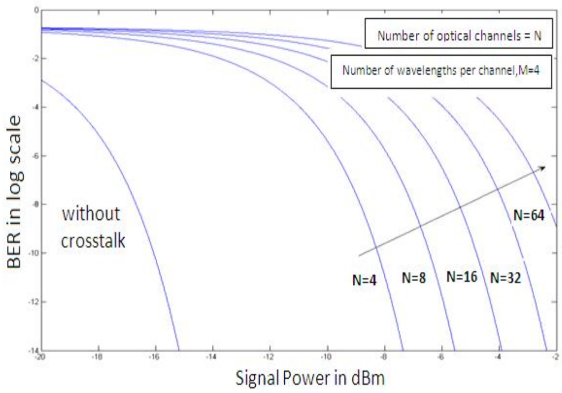

Figure. 6(c) BER performance in presence of coherent homodyne crosstalk for τ<<T (case 2a) for WSXC OXC with varying number of channels and with no. of wavelengths per channel=4

of N. It is also evident from the curves that incoherent crosstalk results in lower BER than that of coherent crosstalk. Similar results have been found for WIXC OXC in Figure 7 keeping all the parameters same. Here we can notice the BER curves are shifted which means power requirements are different for a specific BER in between these architectures.

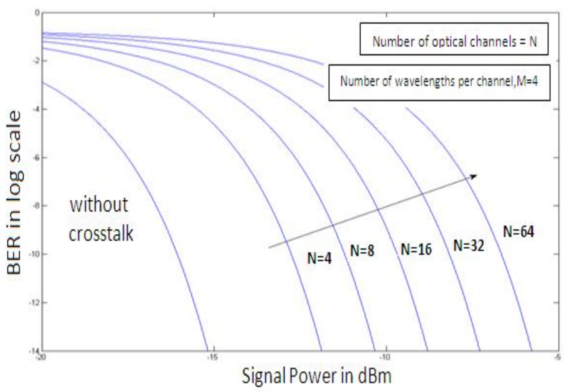

Figure. 7(a) BER performance in presence of incoherent homodyne crosstalk (case 1) for WIXC OXC with varying number of channels and with no. of wavelengths per channel=4

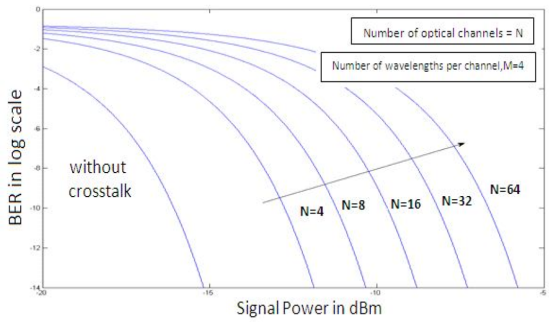

Figure. 7(b) BER performance in presence of coherent homodyne crosstalk for τ<<T (case 2a) for WIXC OXC with varying number of channels and with no. of wavelengths per channel=4

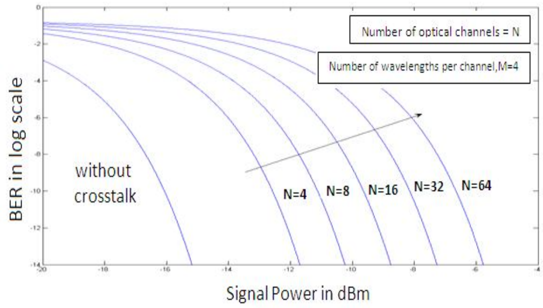

Figure. 7(c) BER performance in presence of coherent homodyne crosstalk for τ<<T (case 2a) for WIXC OXC with varying number of channels and with no. of wavelengths per channel=4

Figure 8 shows the plot of power penalty against number of channels due to the incoherent homodyne crosstalk induced RIN in a WSXC architecture shown in figure. The data for the calculation of power penalty is taken for a standard BER of 10^{-9}.The plot shows that with increase of number of channels power penalty increases. The effect of number of wavelength per channel on power penalty and the

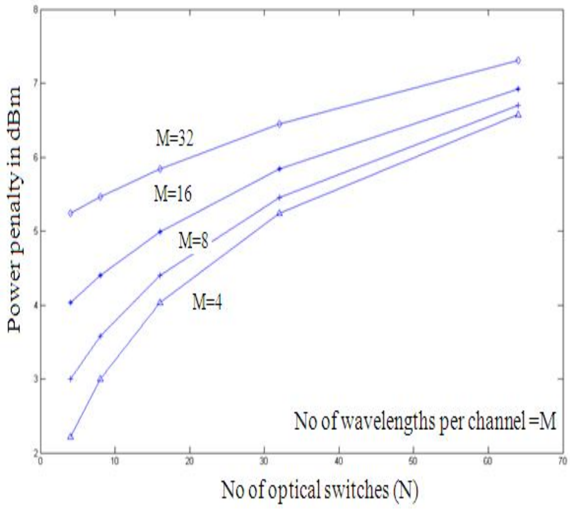

Figure. 8 Power penalty as a function of number of channels for different number of wavelengths per channel for incoherent homodyne crosstalk in WSXC OXC. Power penalty is plotted to get an overall BER of 10^{-9}. The data is obtained from figure 6

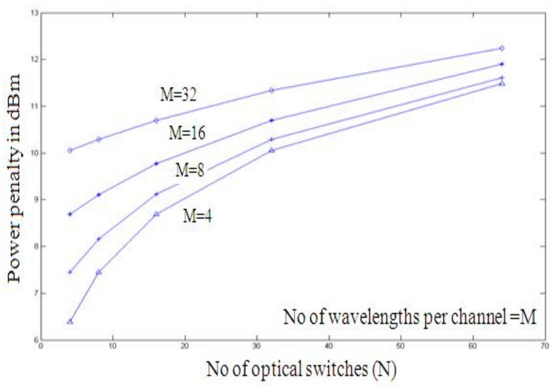

Figure. 9 Power penalty as a function of number of channels for different number of wavelengths per channel for incoherent homodyne crosstalk in WIXC OXC. Power penalty is plotted to get an overall BER of 10^{-9}. The data is obtained from figure 7.

Results are also shown in figure 8.We have got an upward shift of power penalty against number of channels for an increase in number wavelength per channel. Figure 9 gives similar plot for WIXC architecture.

CONCLUSIONS

We have calculated all the power penalties considering the worst case scenario, but this requirement may be relaxed if the probability distribution function (PDF) is known for the phase noise of the laser and the polarization angle differences.

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