Impact of Component Crosstalk on the Performance of a WDM Cross-connect based on Mechano-optical Space Switch

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Abstract

In this paper we investigate the crosstalk characteristics of an optical wavelength division multiplexed (WDM) cross-connect (OXC) based on mechano-optical space switch using a numerical model. Two effects, the switch crosstalk factor (Xsw) and multiplexer (MUX)/demultiplexer (DEMUX) crosstalk factor (Xmux/Xdemux) that degrade the bit error rate (BER) performance of the OXC are investigated. Numerical simulation results show that for a BER of 10^{-9}, the OXC faces a power penalty of 3.15 dB for the increment of switch crosstalk factor from -40 dB to -25 dB at a multiplexer crosstalk factor of -30 dB.

Keywords: WDM cross-connect (OXC), mechano-optical space switch, bit error rate (BER), component crosstalk.

1. Introduction

With the advent of wavelength division multiplexing (WDM) systems that carry large numbers of wavelength channels on the same fiber, a new level of cross-connects seem to be highly desirable. WDM OXCs [1-5] allow us to cross-connect a large number of wavelength channels at the wavelength granularity. The OXC topology studied in this paper is based on a mechano-optical space switch. These OXCs consist of three stages-multiplexing, space switching and finally, a demultiplexing stage. A SOA amplifier is applied between the MUX and space switch and between the space switch and DEMUX to compensate the fiber loss. A problem directly related to this type of OXC is crosstalk originating from the optical add/drop multiplexers and space switches. Crosstalk and in particular coherent crosstalk can degrade the whole system performance.

In this paper the impact of component crosstalk on the BER performance of a space switch based OXC is studied and afterwards the amount of power penalty as a function of component parameters for a specific BER of 10^{-9} is evaluated.

2. Architecture of the OXC:

The structure of the OXC is shown in Fig. 1. The OXC consists of N optical demultiplexers, space switch and N multiplexers. Each of the input fibers connected to input fibers contain M different wavelength, $\lambda 1$, $\lambda 2$,…., λ_M. The optical demultiplexer separates the incoming wavelength into M paths. So there are N×M number of paths in total that pass through the mechano-optical space switch before they are multiplexed by the optical multiplexers.

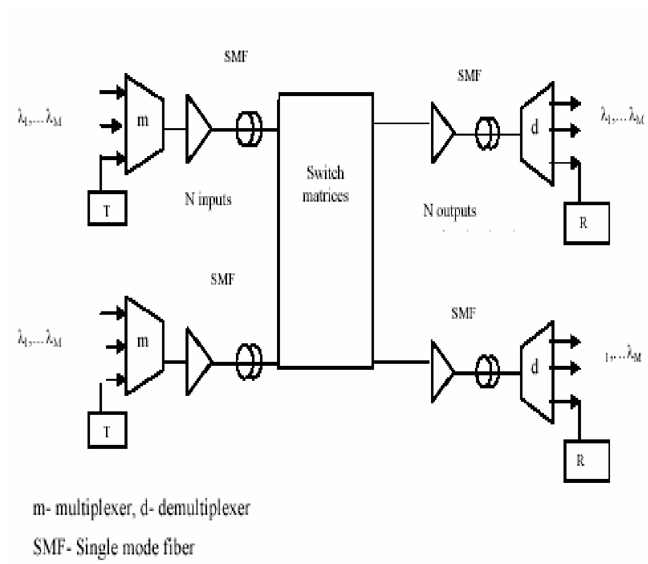

Fig. 1: Basic architecture of the OXC.

2. Analysis of Crosstalk

The analytical equations for this type of OXC topology are depicted in this section. To facilitate the description we now consider the signal power with wavelength channel i and input fiber j, noted as P_i^j, in the rest of this paper. Hence the main signal power under study with wavelength channel i_o and contained in the input fiber j_o is defined as P_{io}^{jo} .The main signal power P_{io}^{jo} will be interfered by (N-1) crosstalk contributions leaked from the N-1 signals with wavelength i_0 in the other N-1 input fibers. We consider the power of the crosstalk contributing signal with the same wavelength channel i_o but contained in another input fiber j as P_{io}^{i} .Then the output power of the considered signal with added crosstalk contributions can be given as (assuming that all wavelength channel carry bit '1')[1]:

$$P_{io1}^{out} = P_{io}^{jo} + P_{io}^{j}\left[X_{sw}(N-1)\right] - 2P_{io}^{j}\left[X_{sw}\sum_{t=1}^{N-2} t\right]$$

$$-2\sqrt{P_{io}^{jo}}\sqrt{P_{io}^{j}}\left[\begin{array}{l}\sqrt{X_{sw}X_{demux}}N(M-1) \\ +\sqrt{X_{mux}X_{sw}}(M-1)N \\ +\sqrt{X_{mux}X_{demux}X_{sw}} \\ (M-1)(NM-N-1) \\ +\sqrt{X_{sw}}(N-1) \\ +\sqrt{X_{mux}X_{demux}}(M-1)\end{array}\right]$$

$$-2P_{io}^{i}\left[\begin{array}{l}X_{sw}\sqrt{X_{demux}}N(N-1)(M-1) \\ +X_{sw}\sqrt{X_{mux}}N(N-1)(M-1) \\ +\sqrt{X_{demux}X_{mux}X_{sw}}(N-1)(M-1)\end{array}\right] \quad (1)$$

In this equation X_{sw} is the crosstalk factor of the switch matrix and is defined as the fraction of the input power routed to other outputs. X_{demux} and X_{mux} are the crosstalk factor of the demultiplexer and multiplexer. The first term of this equation expresses the signal power, the second term expresses the crosstalk power, the third term is the beat term between N-1 crosstalk contributions, the fourth term is the beating between signal to crosstalk and the last term is the beating between different crosstalk contributions. Let $P_{io}^{out(ref)}$ is the output power of the wavelength channel i_o when the OXC is carrying only wavelength channel i_o .Then the crosstalk can be defined as:

$$Crosstalk = \frac{P_{io}^{out(ref)} - P_{io1}^{out}}{P_{io}^{out(ref)}} \quad (2)$$

As wavelength channel i_o may carry bit '1' or bit '0' at any instant of time, equation (1) has to be modified. If wavelength channel i_o carries bit '0', then (1) turns to:

$$P_{io0}^{out} = P_{io}^{j}\left[X_{sw}(N-1)\right] - 2P_{io}^{j}\left[X_{sw}\sum_{t=1}^{N-2} t\right]$$

$$-2P_{io}^{i}\left[\begin{array}{l}X_{sw}\sqrt{X_{demux}}N(N-1)(M-1) \\ +X_{sw}\sqrt{X_{mux}}N(N-1)(M-1) \\ +\sqrt{X_{demux}X_{mux}X_{sw}}(N-1)(M-1)\end{array}\right] \quad (3)$$

$$P_{io}^{out(ref)} = 0 \quad (4)$$

Considering the detector shot noise and receiver noise, the bit-error-rate (BER) of a WDM system for the optimized decision-threshold setting consisting of a mechano-optical space switch based OXC can be written as[6],

$$BER_{worstcase} = \frac{1}{8}\left[\begin{array}{l} erfc\left(\frac{1}{\sqrt{2}}\frac{i_1 + i_{CT0} - i_D}{\sigma_{1\_0}}\right) \\ + erfc\left(\frac{1}{\sqrt{2}}\frac{i_D - i_{CT0} - i_0}{\sigma_{0\_0}}\right) \\ + erfc\left(\frac{1}{\sqrt{2}}\frac{i_1 + i_{CT1} - i_D}{\sigma_{1\_1}}\right) \\ + erfc\left(\frac{1}{\sqrt{2}}\frac{i_D - i_{CT1} - i_0}{\sigma_{0\_1}}\right)\end{array}\right] \quad (5)$$

In this equation i_D is the decision threshold current. A variable decision-threshold can provide a lower penalty if it is adjusted so as to minimize the bit error rate. The photo detector is assumed to be AC coupled to the decision circuit. The optimum value of decision-threshold i_D can be expressed as,

$$i_D = \frac{\sigma_{0\_1}i_1 + \sigma_{1\_1}i_0}{\sigma_{0\_1} + \sigma_{1\_1}} \quad (6)$$

Here $\sigma_{1\_0}^2$ is the variance of receiver noise which exists when signal bit '1' is interfered by crosstalk due to bit '0', $\sigma_{0\_0}^2$ is the variance of receiver noise which exists when signal bit '0' is interfered by crosstalk due to bit '0', $\sigma_{1\_1}^2$ is the variance of receiver noise which exists when signal bit '1' is interfered by crosstalk due to bit '1' and $\sigma_{0\_1}^2$ is the variance of receiver noise which exists when signal bit '0' is interfered by crosstalk due to bit '1'. The interference variances are expressed as,

$$\sigma_{1\_0}^2 = \sigma_{th}^2 + 2eR_d(P_s + P_{CT0} + P_{sp})B \quad (7)$$

$$\sigma_{0\_0}^2 = \sigma_{th}^2 + 2eR_d(P_{sp} + P_{CT0})B \quad (8)$$

$$\sigma_{1\_1}^2 = \sigma_{th}^2 + 2eR_d(P_s + P_{sp} + P_{CT1})B \quad (9)$$

$$\sigma_{0\_1}^2 = \sigma_{th}^2 + 2eR_d(P_{sp} + P_{CT1})B \quad (10)$$

where e is the electronic charge, R_d denotes the responsivity of the photodiode and σ_{th}^2 denotes the receiver thermal noise and it can be expressed as,

$$\sigma_{th}^2 = \frac{4KTB}{R_L} \tag{11}$$

where K is Boltzman constant, T is the temperature(300 degree Kelvin in this paper), B is the electrical bandwidth of the receiver equal to the bit rate and R_L is the receiver front end load(50Ω for this paper).

The spontaneous emission factor P_{sp} can be expressed as,

$$P_{sp} = hf\eta_{sp}(G-1)B \tag{12}$$

Here h is the Palnk's constant, f is the carrier frequency at wavelength $\lambda = 1.55\mu m$, η_{sp} is the spontaneous emission factor and G is the optical amplifier gain which is taken 250 for this study. In relation (5), i_1 is the photocurrent when the signal bit is "mark" and i_0 is the photocurrent when the signal bit is "space" assuming received signal power, P_S to be zero. Then i_1 can be expressed as,

$$i_1 = 2R_D P_S \tag{13}$$

If P_{CT1} represents the crosstalk power due to "mark" signal bit and P_{CT0} is the crosstalk power due to "space" signal bit, then they are expressed as,

$$P_{CT0} = -P_{io0}^{out} \tag{14}$$

$$P_{CT1} = P_{io}^{out(ref)} - P_{io1}^{out} \tag{15}$$

The corresponding crosstalk currents are given by,

$$i_{CT1} = R_d P_{CT1} \tag{16}$$

$$i_{CT0} = R_d P_{CT0} \tag{17}$$

3. Results and Discussion

Following the analysis presented in section 2, the bit error rate (BER) results are evaluated at a bit rate of 10 Gb/s for number of input fibers, N=4 and for the number of channels, M=8 with several values of the input power. Fig. 2 shows the BER performance against the signal power for different value of switch crosstalk factor, Xsw and for a MUX/DEMUX crosstalk factor of -25 dB. The power penalty also evaluated from the BER plots at a BER of 10^{-9}. For calculating the penalty the plot without crosstalk is taken as the reference. It can be seen from the plots that the BER and power penalty both increases with the increment of switch crosstalk factor. For example the system faces a power penalty of 0.25 dB for the increment of Xsw from -40 dB to -35 dB and a power penalty of 0.7 dB for the increment of Xsw from -40 dB to -30 dB. It is also noticed that if the switch crosstalk factor is increased beyond the value of -30 dB then the power penalty becomes more than 3 dB where a power penalty below 1 dB is suitable for a communication system.

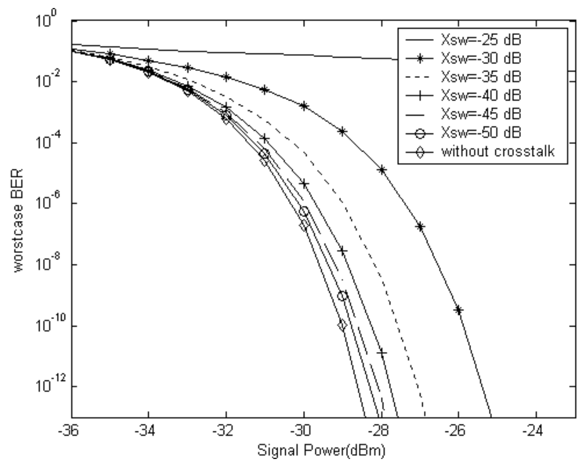

Fig. 2: BER versus signal power as a function of switch crosstalk factor for N=4, M=8 and Xmux=-25 dB.

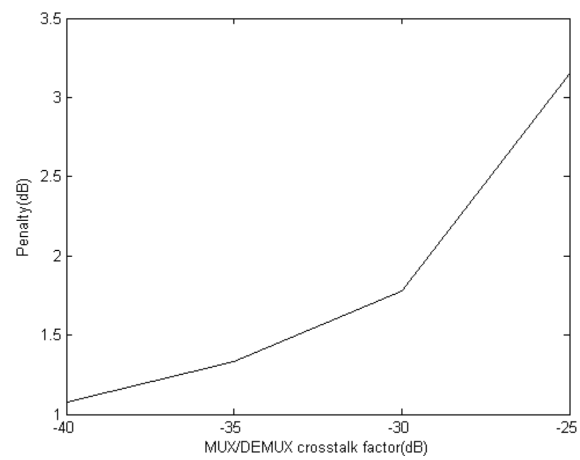

Fig. 3: Power penalty versus MUX/DEMUX crosstalk factor for N=4, M=8 and X_{sw}=-30 dB.

Fig. 3 shows the power penalty due to the increment of MUX/DEMUX crosstalk factor, Xmux/Xdemux and for a fixed value of switch crosstalk factor which is -30 dB. From this figure it is also evident that the power penalty increases with the increment of MUX/DEMUX crosstalk factor. For example, when the value of MUX/DEMUX crosstalk factor is increased from -40 dB to -30 dB at a switch crosstalk factor of -30 dB then the system faces a power penalty of 0.7 dB.

4. Conclusion

Performance degradation due to component crosstalk of a WDM cross-connect (OXC) based on mechano-optical space switch has investigated. Component crosstalk limits the BER performance of the OXC and also causes power penalty.

References

[1] T. Gyselings, G. Morthier and R. Baets, "*Crosstalk analysis in multiwavelength optical cross-connects*", J. Lightwave Technology, vol- 17,no 8,pp 1273-1283,Aug 1999.

[2] Y. K. Chen and C .C. Lee, "*Fiber Bragg grating based large nonblocking multi wavelength cross-connects*" ,J. Lightwave Technology, vol 16, no-10, pp 1746-1756, Oct 1998.

[3] M. Tabani, M. Kavehrad, M. I. Irshid, "*A Novel Integrated-optic WDM Cross-connect for Wide Area All Optical Networks",* Journal of Lightwave Technology, Vol.11, no 3, pp.955-960, March 1993.

[4] T. Y. Chai, T. H. Chen, S. K. Bose, C. Lu, G. Shen, "*Crosstalk Analysis for Limited-Wavelength-Interchanging Cross-connects*", IEEE Photonics Technology Letters, Vol.14, No 5, pp. 1237-1249, May 2002

[5] G. R. Hill et al., "*A Transport Network Layer Based on Optical Network Elements*", Journal of Lightwave Technology. Vol. 11, pp. 667-679, 1993.

[6] S.P.Majumder, S.F.Mahmud, Md.Hossam-E-Haider," *Crosstalk Limitation of a WDM System due to Optical Cross-connect (OXC)*",pp 159-162 ,3rd International Conference on Electrical and Computer Engineering,Dhaka,Bangladesh.Dec.28-30,2004.