Homodyne Crosstalk Optimization in Cascaded OADMs by Polarization Control

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Abstract

Homodyne crosstalk causes severe system performance degradation in optical networks by beating with the desired signal. This is more critical in ring and bus networks when consecutive nodes lead to a cumulative homodyne crosstalk. In this paper we present a polarization control technique to reduce the beating and therefore improve the network performance.

I. INTRODUCTION

Multiwavelenght optical networks will be an essential technology for the future information infrastructure. Wavelength division multiplexing (WDM) is used in optical networks to fully utilize the bandwidth of a single-mode optical fiber. In some topologies as ring and bus networks, there can exist several Optical Add-Drop Multiplexers (OADMs) in cascade. These topologies, in opposition to optoelectronically-regenerated networks, have the advantage of an improved reliability and simplified network management.

If in some topologies, each node has one associated wavelength, in others, the same wavelength can be inserted and removed in consecutive nodes. In some of them the channel is reused without reinsertion of new data or regeneration as in Node 3 of figure 1.

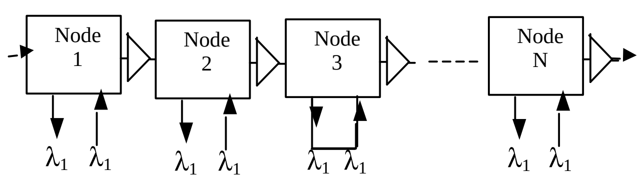

Fig. 1 – Generic WDM network

Has a result of non-ideal removal in each node, the channel will be degraded by homodyne crosstalk. Previous analyses have shown that even small amounts of homodyne crosstalk from a number of sources can significantly degrade network performance, [1,2,3,4].

Since the homodyne crosstalk is cumulative and cannot be eliminated at the receiver, it will have an impact in the maximum number of consecutive nodes without electrooptic regeneration.

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II. HOMODYNE CROSSTALK

A. *Theory*

The homodyne crosstalk is due to coherent interference in the receiver between the inserted channel and the residuals of the removed channel. Assuming a perfect NRZ waveshape and linear signal polarization, the optical signal at the photoreceiver, with a nominal optical frequency of w_0 can be described as [5]

$$\begin{aligned}&A \cdot d_s(t)\cos\left[w_0 t + f_s(t)\right] + \sum_{i=1}^{N} \sqrt{d_i} \cdot A \cdot d_{xi}(t) \\ &\cdot \cos\left[w_0 t + f_{xi}(t)\right] \cdot \cos\left(q_i\right) + \\ &+ \sum_{i=1}^{N} \sqrt{d_i} \cdot A \cdot d_{xi}(t)\cos\left[w_0 t + f_{xi}(t)\right] \cdot \sin\left(q_i\right) \qquad (1)\end{aligned}$$

The first two additive terms are for the signal polarization and the third is for the signal perpendicular polarization. A is the signal field amplitude; d_s(t) and d_{xi}(t), represent the field's random data modulation of the signal and the i_{th} crosstalk and can take the values of "0" or "1"; f_s(t) and f_{xi}(t) are the random phase of the signal and the i_{th} crosstalk field; δ_i is the power ratio between the i_{th} crosstalk field and the signal; q_i represents the polarization angle mismatch between the i_{th} crosstalk element and the signal. q_i can be regarded as time independent, considering any polarization variation in the network transmission would be slow with reference to the bitrate.

The optical power at the photodetector for the "zero" state will be

$$P(t)\big|_{d_s(t)=0} = \frac{1}{2}A^2 \cdot \Bigg\{ 2 \cdot \sum_{i=1}^{N-1} \cdot \sum_{j=i+1}^{N-1} \sqrt{d_i \cdot d_{ji}} \cdot d_{xi}(t) \cdot d_{xj}(t) \cos\left[f_{xi}(t) - f_{xj}(t)\right] \cdot \cos\left(q_i - q_j\right) + \sum_{i=1}^{N} d_i \cdot d_{xi}(t) \Bigg\} \tag{2}$$

and for the "one" state, the optical power at the photodetector is

$$P(t)\big|_{d_s(t)=1} = \frac{1}{2}A^2 \cdot \Bigg\{ 1 + 2 \cdot \sum_{i=1}^{N} \sqrt{d_i} \cdot A \cdot d_{xi}(t) \cdot \cos\left[f_s(t) - f_{xi}(t)\right] \cdot \cos\left(q_i\right) + 2 \cdot \sum_{i=1}^{N-1} \cdot \sum_{j=i+1}^{N-1} \sqrt{d_i \cdot d_j} \cdot d_{xi}(t) d_{xj}(t) \cdot \cos\left[f_{xi}(t) - f_{xj}(t)\right] \cdot \cos\left(q_i - q_j\right) + \sum_{i=1}^{N} d_i \cdot d_{xi}(t) \Bigg\} \tag{3}$$

B. *Optimization*

By looking at (2) and (3), it's easy to see that the beat noise between the signal and the crosstalk elements is dependent of the phase and polarization mismatch between them. By judicious control of the polarization, such as $\cos(q_i - q_j)$ could be zero or, at least, minimized, the effects of the beat noise should also be minimized.

We will study the case, when the channel in each node is reused without insertion of new data (node 3 in figure 1). If this happens in consecutive nodes, the effects of homodyne crosstalk would be more notorious in opposition to the usual case when another data channel is inserted in the node. Figure 2 illustrates one possible configuration where the optical channel on the node can be removed or reused by changing the state of the 2X2 switch.

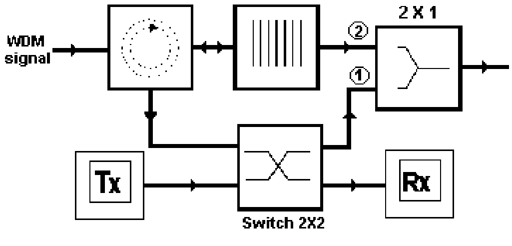

Fig. 2 Typical configuration of an OADM

If an optical polarizer is inserted between the optical switch and the passive coupler, it should be possible to control the polarization mismatch between the signal and the crosstalk (paths (1) and (2) respectively).

C. *Simulation*

To evaluate the improvements of controlling the polarization before reusing a channel, an optical network with cascaded OADMs was simulated. The system was simulated with the optical network simulation program PTDS from Virtual Photonetics (figure 3).

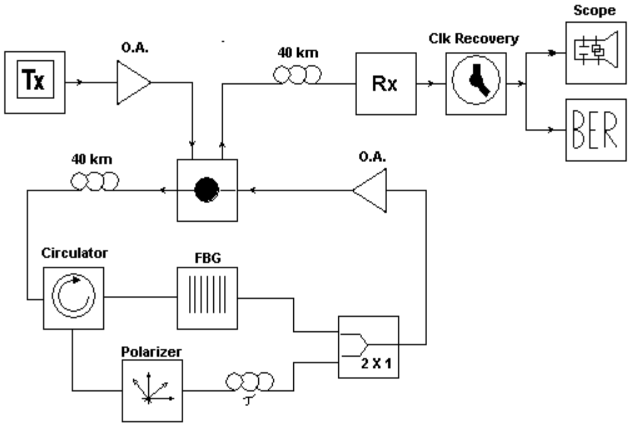

Fig. 3 – Simulated optical network, with an ideal optical loop to implement the cascaded OADMs based on fibre Bragg gratings.

All the effects responsible for degradation of the signal, such as dispersion, PMD, non-linear effects in the fiber, amplifiers noise figure or even thermal and shot noise in the receiver, were neglected. Only the non-ideal removal in the OADM (responsible for the homodyne crosstalk) was not neglected.

An optical loop was used to implement the cascaded OADMs, i.e. by changing the number of laps inside the loop, it's possible to change the number of nodes of the network. The transmitter is based on a laser externally modulated by a Mach-Zhender, driven by a PRBS signal at 10 Gbit/s in NRZ format. Only one channel was used to prevent other effects such as heterodyne crosstalk.

Inside the loop, or in each node, there is an OADM with the same configuration as explained in figure 2. The fiber Bragg grating has an extinction ratio of 27 dB (common value in these devices) leading to the same value of homodyne crosstalk.

The reflected channel is reinserted using an ideal MUX. Before reinsertion, the removed channel passes trough a path of fiber to misalign temporally the bit pattern. Actually, for faster than Gb/s optical signals, the bit patterns of different paths in practical OADMs are generally misaligned due to factors such as fiber jumper length differences and demultiplexer-multiplexer port-dependent delays [6].

After the delay line, to eliminate the beat between the crosstalk and the signal, a polarization controller rotates the angle of polarization by 90 degrees since this should be the angle were the homodyne crosstalk is minimized. In a practical way, a polarization controller and two state of polarization analyzers (one in each path) for monitoring in real time, would enable the rotation of 90 degrees.

Finally, the receiver is based on an ideal PIN without shotnoise and thermal noise and an ideal clock recovery unit. The results are presented in section III.

Another simulation was made to prove the effectiveness of this method. This time, the other effects that degrade the optical signal were taken into account: PMD, birefringence of the fiber, shot and thermal noise of the receiver, non-linear effects in the fiber etc.; only the dispersion was compensated, since it's a requisite for long-haul transmission at high bit rates such as 10 Gbit/s. The transmitter used was a four-channel WDM transmitter, spaced by 200 Ghz with a line width of 10 Ghz. The fiber Bragg grating used has a bandwidth of 100 Ghz with a rejection ratio of 27 dB. The spacing between nodes was 40 km with dispersion compensation.

III. RESULTS AND DISCUSSION

The first test was made to evaluate the effects on the BER on the homodyne crosstalk without and with polarization control. With all the effects responsible for the degradation of signal deactivated, only the homodyne crosstalk will reduce the BER.

The next figure shows the logarithm of the BER as a function of the number of cascaded OADMs (or nodes) with and without polarization control.

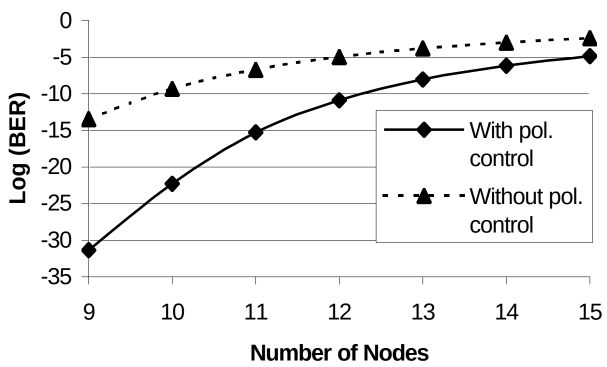

Fig. 4 – Log (BER) vs number of cascaded OADMs with and without polarization control (results obtained by simulation).

It's easy to see the dramatic improvement when we use polarization control. For a maximum BER of 10^{-10}, we can only have 9 nodes without any polarization control, while the number increases to 12 nodes with polarization control.

By looking at figures 5 and 6, it's possible to compare two eye diagrams after 12 nodes with and without polarization control.

Although with polarization control the crosstalk is still present, it is smaller in comparison with the case where no polarization control exists. This situation relies on the fact that only the beat noise is minimized; the optical power from the residuals of the channel is still there. These results, agree with the initial prevision of the theory.

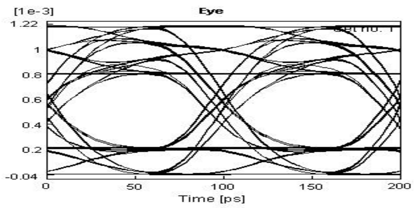

Fig. 5 – Simulated eye diagram after 12 nodes, without polarization control.

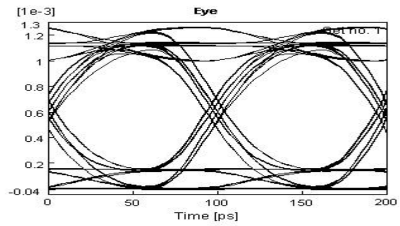

Fig. 6 – Simulated eye diagram after 12 nodes, with polarization control.

The second simulation (figures 7 and 8) used components with real figures of merit and 12 nodes with and without polarization control. An important factor such as the fiber birefringence and the PMD was taken into account.

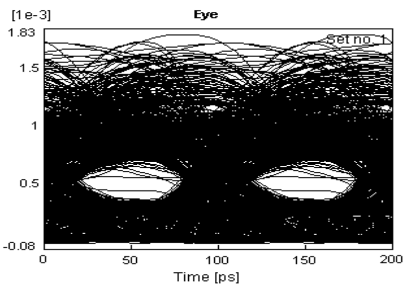

Fig. 7 – Simulated eye diagram after 12 nodes, without polarization control.

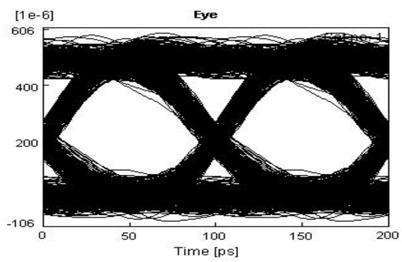

Fig. 8– Simulated eye diagram after 12 nodes, with polarization control.

Once again, the polarization control method was able to produce good results by reducing the beat noise between the crosstalk and the signal.

IV. CONLUSIONS

After the results presented, we can conclude that the homodyne crosstalk present in cascaded OADMs can be reduced by polarization control. The method is based in the rotation of the polarization of the reused channel before reinsertion. This improvement has consequences in the maximum number of nodes in an optical network without electrooptic regeneration and the consequent reduced cost of the network.

V. FUTURE WORK

These results encourage the laboratory testing, which will be made with the help of an optical test platform to simulate the optical nodes. [7]

VI. REFERENCES

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