Strictly Non-Blocking Optical Cross – Connect for WDM Wavelength Path Networks

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Abstract

We describe the design and performances of a strictly non-blocking optical cross-connect node for WDM wavelength path networks. The optical cross-connect (OXC) prototype was experimentally tested as an 2 x 2 WDM system with two input / output ports with two wavelengths per port. The OXC was inserted in a network with a transmission length of 95 km with a STM-16 bit stream per channel. The performance of a single and a cascade of OXC's was simulated and the results verified against the experimental ones.

I. INTRODUCTION

Wavelength Division Multiplexing (WDM) is one of the election techniques for further upgrading the capacity of the existing transmission links in a cost effective way, opening the door to new and potentially efficient all-optical routing schemes, replacing what is nowadays performed by complex electronics in a quick and efficient way [1, 2]. All optical WDM functionality could provide, in terms of performance and cost an effective answer, to the requirements of the transport network at the transmission path layers level and may also pave the way to less hierarchical network structure [3].

Optical networking is growing towards providing solutions to the real world issues of constructing large scale networks that are robust, regardless of failure and traffic expansion and will evolve smoothly with time and size. The advances in optical technology have been allowing the realisation of wavelength routing elements, such as highly flexible optical cross-connects (OXC) [4].

Current OXC are based on electronic switch fabrics that cross-connect the incoming data on the electrical domain. However, with the emergence of WDM networks that carry large number of wavelengths channels, a new level of cross-connect in the optical domain are highly desirable [5].

In optical networks using WDM technology, an optical cross-connect is an essential equipment, transparent to signal format the OXC allows the optical network to be re-configurable on a wavelength-to-wavelength basis, to interchange and optimise traffic patterns providing the routing functions, simplifying the network growth and enhancing network survivability.

Various OXC architectures have been proposed, based in two elementary switching schemes: space switching and wavelength switching. For each of these switching schemes several architectures can be used [6, 7]. It is not viable to determine the best solution for every case, because this depends on the applications in case. However, it is possible to conclude that an OXC based on space switching provides better transmission performance at the expense of complete modularity [6].

In its most general architecture form, a space switching strictly non-blocking (meaning that any set of demands can be routed through the cross-connect but any additional demands that need to be routed will never require the re-routing of the previously routed channels) optical cross connects with k input fibres and N wavelength channels per fibre consist of 5 stages [5]: demultiplexing, wavelength conversion, space switching, multiplexing and amplification. Several OXC based on these stages have been proposed, using non-blocking architectures for the space-switching matrix like: *Crossbar*, *Benes*, *Spanke-Benes* and *Spank* [7].

In this paper, we propose an enhanced version of an OXC architecture using 1 X 2 optical switches and based on the half *Spanke*, where the multiplexing stage of the OXC was replaced by a power coupling stage. In this way a completely non-blocking, re-configurable and link modular OXC was achieved. In section II the OXC architecture is described and the relevant characteristics are analysed. In Section III laboratorial results are presents and compared with simulation in section IV.

II. IMPLEMENTED OXC ARCHITECTURE

Figure 1 shows the schematic diagram of the proposed OXC, this OXC has 2 input ports each one handles 2 WDM channels separated by 200 GHz and the input signals can be routed to any of the 2 output ports. The OXC also has a tributary port, which allows a local add-drop functionality. For sake of simplicity the EDFA´s placed at the output ports to compensate the OXC attenuation are not shown. The

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multiwavelength signal from each incoming fibre is demultiplexed and commuted by the space switching matrix to each of the output optical power coupler.

The DEMUX is designed to be compliant with the ITU 200 GHz frequency grid, has a -3 dB bandwidth of 135 GHz and a channels isolation higher than 46 dB. The electro-mechanical optical switch's used have an isolation higher than 50 dB.

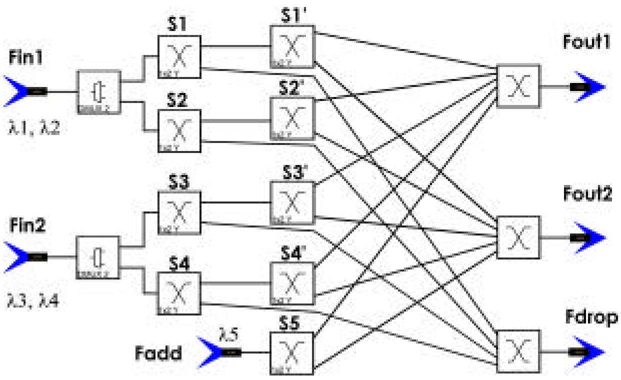


Figure 1 - Implemented OXC scheme

By definition, this OXC architecture is strictly non-blocking and transparent to bitrate and data format, due to its all-optical implementation. This OXC is link modular since the addition of new input/output fibres just requires the addition of new elements without changing the OXC structure. On the other hand the OXC is not wavelength modular, since the adding of a new channel changes all the used DEMUX's.

By using passive optical couplers at the output stage a constrain will be imposed on the increase on the number of optical channels due to optical attenuation, so for a large scale prototype the use of active optical coupler must be need.

The reconfiguration time of the OXC is related with the electrical characteristics of the mechanical-optical switch matrix, in our case. The reconfiguration time is less than 25 ms, which is acceptable for the operations of network configuration. This reconfiguration time is improved in relation to the commercial available ones, based on the same technology (discrete components) [8] and comparable with the configuration time of the commercial available based on MEM's [9].

In all-optical networks, the wavelength channels are considered as a transport resource allocated to a given data stream. An end–to–end connection can be either supported by one wavelength (Wavelength Path - WP) or can physically be transported over different wavelengths through the transmission links (Virtual Wavelength Path - VWP). In the latter case, the wavelength allocations are performed on a link-by-link basis and wavelength conversion must be, in principle, possible at all OXC nodes [3]. The WP technique suffers from a limitation of the network extension, flexibility, scalability and performance, imposed by the total number of wavelengths available. To cope with this limitation, the same set of available wavelengths must be reused but only on fully disjointed parts of the network. The proposed OXC architecture can provide cross-connect for both WP and VWP networks. The introduction of a wavelength conversion stage will allow the use of this OXC on a VWP network. The implemented OXC was specified for a WP network, therefore no wavelength conversion is used and is assumed that all wavelengths present at the OXC inputs are different [6].

III. OXC TEST

This section describes the experimental results obtained by the OXC implementation. The performance of the prototype was accessed by the measurements of relevant characteristics such as: configuration capacity, insertion loss and differential insertion losses, optical signal to noise ratio degradation and by the measurement of the channels BER degradation.

Figure 2 shows the results at the output port 1 of the configuration test, in each input fibre was insert the ASE noise of an EDFA, and the optical spectra on each output port was measured and show for all the configuration possibilities. It is possible to verify the complete OXC configuration capacity.

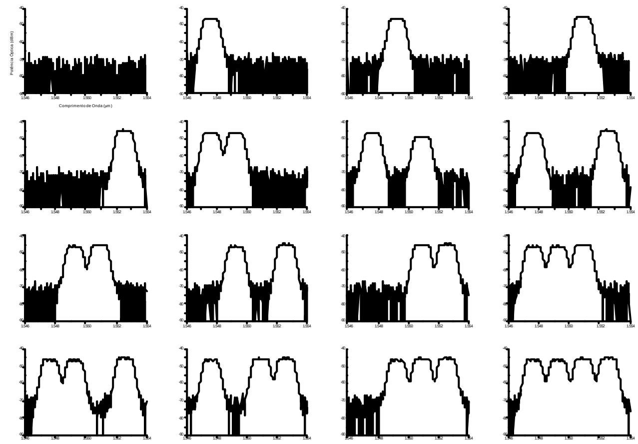


Figure 2 – Configuration possibilities. Tthe power scale is arbitrary and the wavelength scale is between 1546 and 1554 nm.

The total number of optical components that a given WDM signal passes through inside the OXC determines the attenuation or insertion loss. Two important parameters exist here: the worst case of insertion loss or total insertion loss, and the differential insertion losses (difference between the highest and the lowest loss path). A high worst-case insertion loss is less of a disadvantage than a high differential insertion loss. A high constant insertion loss can be compensated for with the addition of an optical amplifier. A high differential insertion loss adversely affects the optical receiver and can reduce the signal to noise ratio (SNR). In our prototype, the average insertion losses, measured before the output EDFA's, of all the input channels to the output 1 and 2 are respectively 14.96 dB and 13.13 dB (these differences are due to the use of diferent's types of passive optical couplers), with a differential insertion losses of 1.0 dB and 1.2 dB, respectively for output 1 and 2. The insertion loss for the local tributary port is 4.5 dB. These high attenuation values could be easily compensated by the output EDFA. Although as said before, the differential insertion loss can represent a system performance constrain, however in our case these values are small when compared with other commercial solutions [9].

To investigate the operation and system performance of this OXC, two point-to-point links with 50 (25+25) km and 45 (20+25) km of standard single mode fibre (G.652), were connected by the OXC routing node. Each link transports 2 WDM signals based at the ITU grid of 200 GHz (≈ 1.6 nm) spacing with wavelengths of 1547.72 nm + 1549.32 nm and 1550.92 nm + 1552.52 nm, designated as channels 4, 3, 2 and 1 respectively. The signals from four distributed feedback lasers (DFB) were externally modulated, through a Ti:LiNbO3 Mach-Zehnder intensity modulator, at 2.5 Gb/s with a non-return to zero (NRZ) 2^7–1 pseudo random bit sequence (PRBS). The OXC local add channel could have any wavelength with the 200 GHz ITU frequency grid and was designated as channel 5. Figure 3 shows the experimental network scheme used to test the OXC.

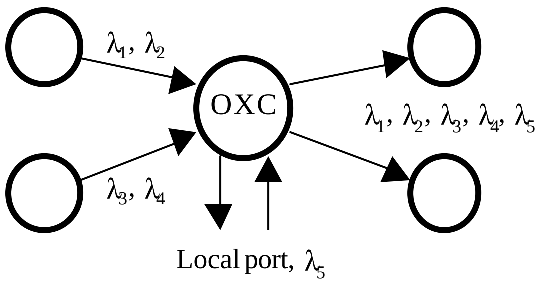


Figure 3 – Network scheme.

Figure 4 presents the optical spectra for one OXC configuration where the channel 2 is locally dropped, the channels 1 and 4 are routed to the output 1 and the channel 3 is routed to output 2.

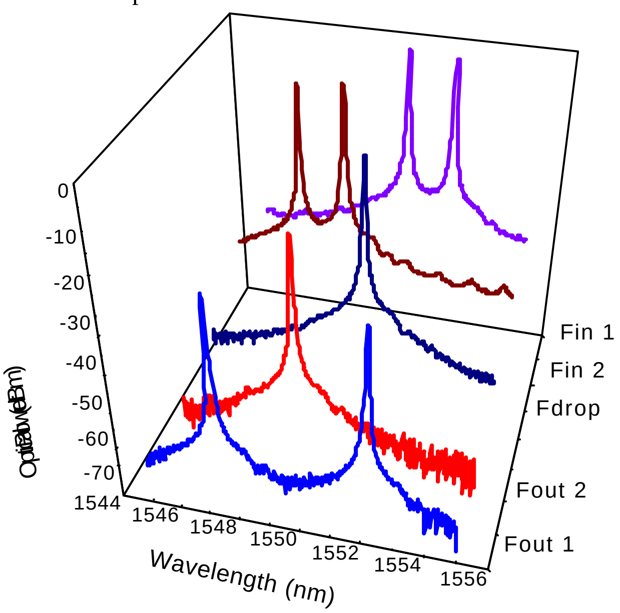


Figure 4 – Optical spectra for the a specific routing configuration

The optical signal-to-noise ratio (OSNR) degradation due to the OXC commutations was measured with a 12.5 GHz resolution of the OSA (optical spectrum analysed). The input OSNR of the input channels 1 to 4 was 36.71 dB, 36.90 dB, 36.80 dB and 36.78 dB, respectively. Then, the OSNR of the four channels were measured at the OXC outputs (before the EDFA's) for all the possible routing configurations. The output OSNR average value are 37.19 dB, 36.46 dB, 36.91 dB and 37.42 dB with standard deviations of 1.08 dB, 1.53 dB, 1.39 dB and 0.95 dB, for channels 1 to 4. These results are displayed in figure 5.

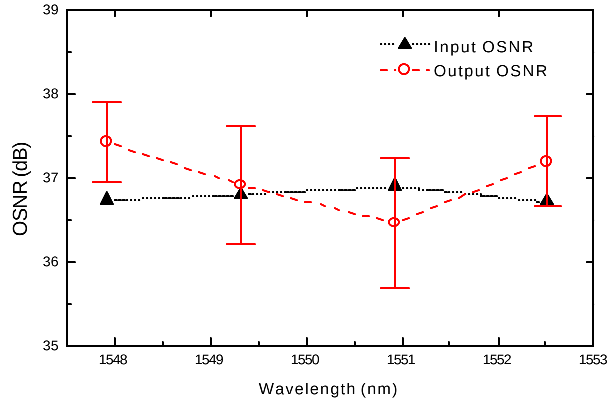


Figure 5 – OSNR degradation due to OXC commutation.

After propagation on 25 km of the G.652 fibre the channel were dropped locally at the OXC. The performance of our network is assessed by the BER (bit error rate) measurements of the channels against the receiver power. Figure 6 shows the optical spectrum at the local drop port, when the channel 1 is removed.

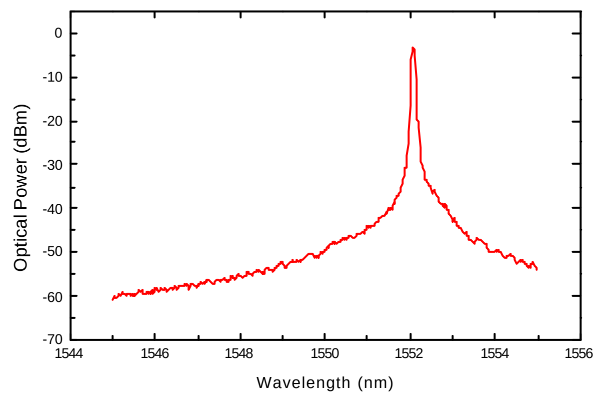


Figure 6 – Optical spectrum of channel 1 at the local drop port

Figure 7 display the BER performance of the channel 1 locally dropped. This result is compared with the BER performance for the same channel at the OXC input and the back to back receiver performance is also presented. The BER floor (experimental measurement limit) and the 10^{-9} BER are also indicated. The power penalty measured at a 10^{-9} BER is inferior to 0.1 dB, for the dropped channel at the OXC compared with the same channel at the OXC input after propagation on 25 km of fibre.

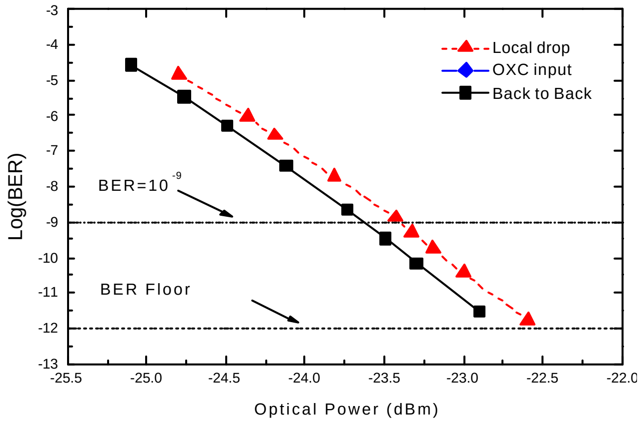


Figure 7 – BER performance for the channel 1 locally dropped

At the OXC the channel 3 and 4 were routed to output 1 and propagated over 20 km of fibre. Then the BER performance of the channel 3 was evaluated. Figure 8 shows the optical spectrum at the receiver input after propagation over 45 km of the channels 3 and 4.

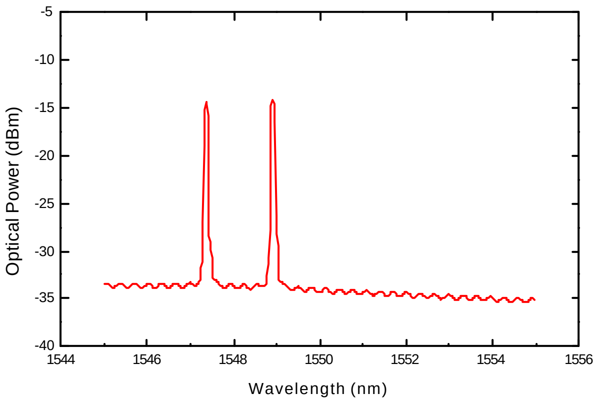


Figure 8 – Optical spectrum at the receiver

Figure 9 shows the channel 3 BER performance, against the receiver power, for the back-to-back operation (0 km), for the mid span routed channel on the OXC and for the same channel after just propagation on 45 km of fibre (without being routed on the OXC). The BER floor and the 10^{-9} BER are also indicated.

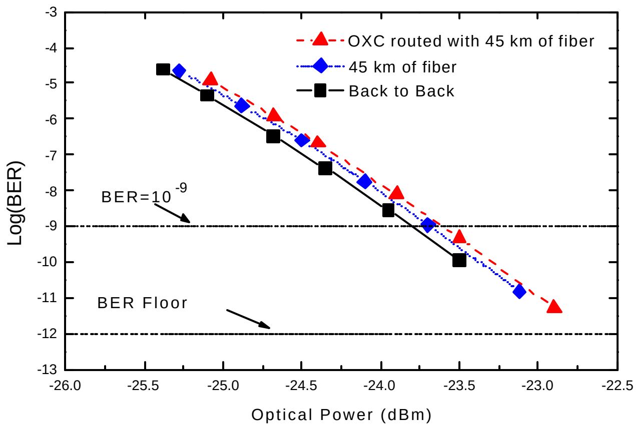


Figure 9 – BER performance for the channel 3.

The power penalty measured at a 10^{-9} BER is inferior to 0.1 dB, for the routed channel compared with the same channel after propagation on a equivalent fibre distance.

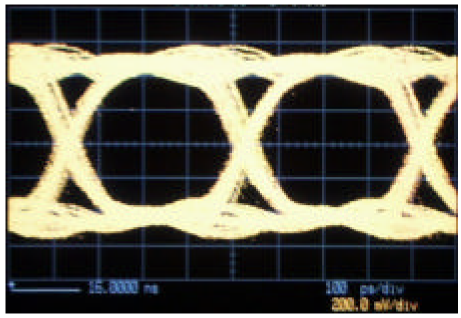


Figure 10 – Eye diagram for the channel 3

Figure 10 shows the detected eye diagram of the channel 3, for a 10^{-9} BER. In this case, a direct-detection without receiver electrical filter was used.

IV. OXC SIMULATION

The experimental implemented network was simulated in a commercial photonic transmission simulation tool, *PTDS*Ó. In order to estimate the BER characteristics a gaussian assumption for the noise and a total of 1024 data bits were used.

The objectives of the simulation were the assessment of the experimental network performance by comparison with the simulation results and to verify the cascadability of the OXC. By cascading, a total of 30 nodes separated by 50 km each.

To assure that the network performance degradation was only originated by the crosstalk and by the ASE (amplified spontaneous emission) noise, the fibre segments between the cascade OXC were replaced by passive attenuators with a loss equivalent to 50 km of fibre (10 dB). Therefore the chromatic dispersion and the non-linear effects of the optical fibre were ignored, although that these two effects will place a maximum limit on practical implementation.

Figure 11 shows the BER versus receiver optical power for the channel 2 after the cascading of several OXC

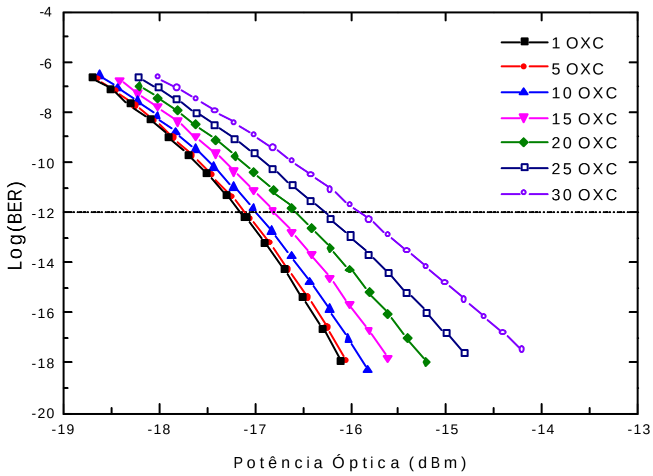
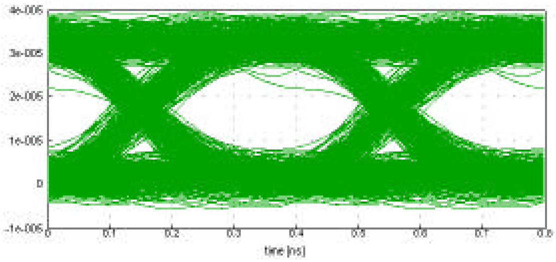


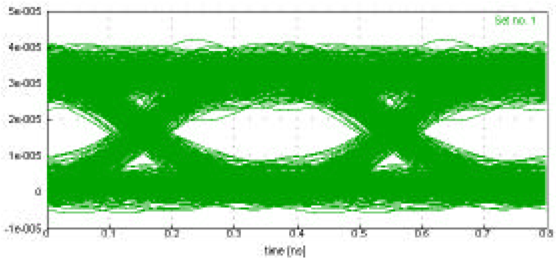
Figure 11 – BER performance of channel 2 after being cascade on several OXC.

The power penalty for a 10^{-12} BER was 1.4 dB when a total of 30 nodes were cascade. This penalty due to crosstalk and ASE noise accumulation is small, when compared with other architectures, such as the ones reported in [6], due to the high isolation and low crosstalk of the used components (MUX, DEMUX and optical switches) and the low noise figure of the EDFA's.

Figure 12 a) and b) shows the detected eye diagram for the channel 2 after 1 node and 30 nodes, respectively.



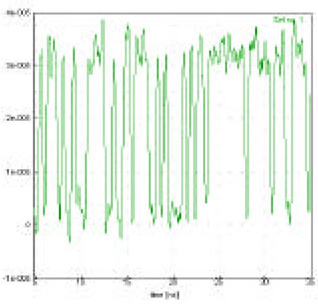
a)



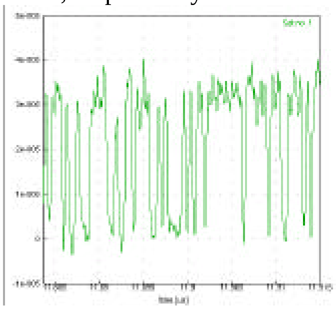
b)

Figure 12 – Eye diagram of the detected channel 2: a) after 1 OXC, b) after 30 OXC's.

Figure 13 a) and b) presents a detected sequence for the channel 2 after 1 node and 30 nodes, respectively.



a)



b)

Figure 13 – Sequence of the detected channel 2: a) after 1 OXC, b) after 30 OXC's.

These results show an insignificant receiver sensitivity degradation, indicating that the signal quality is practically independent of the number of nodes.

V. CONCLUSIONS

We proposed a strictly non-blocking OXC architecture based on the half *Spanke* switching matrix and passive optical coupler, for wavelength path networks. An experimental prototype was implemented in a demonstration network and the system performance was verified. The experimental network was simulated and the cascadability of the OXC verified.

These results point to the feasibility, cascadability, and compatibility with significant transmission distances of the proposed OXC architecture.

The OXC performances were comparable with the characteristics of commercial available systems.

VI. REFERENCES

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