A High-Degree Photonic Cross-Connect for Transparent Networking, Flexible Provisioning & Capacity Growth

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Abstract *Photonic cross-connects with duplex-port count exceeding the nodal degree enable transponder steering and span relief for traffic growth. We demonstrate a fully-loaded degree-6 PXC, supporting 2.4 Tb/s in 40 wavelengths, built from wavelength-selective switches.*

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Introduction

The advantages of wavelength-routed networks are well-known [1], and are rooted in the ability to accomplish higher-layer functions at the low cost-per-bit of the optical layer. Ring networks with reconfigurable optical add-drop multiplexers (ROADM's) are being widely deployed in order to minimize electronic regeneration. In mesh networks, where many nodes may be connected to three or more other nodes, an all-optical photonic cross-connect (PXC) can provide similar advantages. We propose using a PXC with a duplex-port count (fiber degree) greater than the degree of the node it is within. PXC's with enhanced fiber degree will be needed to achieve the full benefits of transparent mesh networking, including flexible span relief, flexible reuse of deployed transponders, and M:N protection schemes. We demonstrate a fully-reconfigurable, fully-loaded, optically transparent PXC with a fiber degree of 6 that can grow in-service to a fiber degree of 8.

Fiber Degree vs. Nodal Degree

One important application of PXC's with enhanced fiber degree is span relief: the ability to serve traffic that has grown beyond the capacity of a single fiber in one direction[2]. Figure 1 shows a network where the traffic demands between nodes A and D are greater than the demands between node A and nodes B or C. As traffic grows, a new line system must be deployed between nodes A and D. If this new line system cannot be served by the PXC at node A, it will be isolated from the existing optical domain, and many of the advantages provided by transparent optical networking will be lost. A PXC architecture with a growable fiber degree avoids this isolation of new capacity and ensures robust networks that are tolerant of uncertain traffic forecasts.

Figure 1 also highlights transponder steering, a second major application of PXC's with enhanced fiber degree. There are two transponder banks, each connected to its own port on the PXC. Each transponder in these banks can connect to any of the 4 fibers leaving node A, enabling both dynamic provisioning with the minimal number of transponders and new M:N restoration schemes in which transponders' signals can be rerouted to any fiber as needed [3]. One transponder bank would be unacceptable, as the connection between the PXC and the transponder bank would be a single point of failure at node A. Additional transponder banks may be desirable, depending on the fraction of traffic terminating at node A.

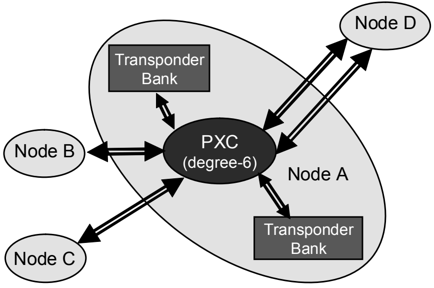

Figure 1: Node A has a degree of 3, yet the PXC has a fiber-degree of 6.

The Photonic Cross-Connect

We constructed a PXC with a broadcast and select architecture using six 8-way optical splitters (one per input port) and six wavelength-selective switches (WSS) (one per output port). By adding two additional splitters and WSS this degree-6 PXC could be upgraded to a degree-8 PXC while in service. The entire degree-8 PXC is sufficiently compact that it would fit within a single Advanced Telecom Computing Architecture (ATCA) shelf.

This application requires 8x1 WSS with low crosstalk. The six WSS used were Capella WavePath 4500. They have 100 GHz channel spacing, a single output fiber and nine input fibers (with the exception of one of the six, which had one non-functioning input, yet it still met the requirements for this PXC). These devices use a diffraction grating to separate the incoming light into wavelength channels. Two-axis micromirrors are then used to guide each wavelength channel from the chosen input to the output port, and to provide variable optical attenuation for each channel. Integrated optical channel monitors in each WSS enable closed-loop control and monitoring of each wavelength on each PXC output port.

Laboratory Demonstration

Our experimental configuration is shown in Fig. 2. The PXC was set in a pre-determined configuration where each wavelength at each input port of the PXC was assigned to a randomly selected output port.

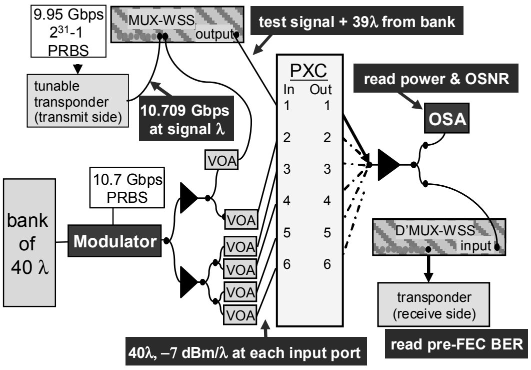

Figure 2: A schematic of the experiment. The switch was fully loaded (40 wavelengths input to each port of the PXC), and 40 BER curves were measured at each of the six output ports.

We used an Intel tunable G.709 transponder with a 9.9532 Gbps 2^{31}-1 PRBS client signal as the test signal. With standard forward error-correction, the transmission line rate was 10.709Gbps. Loading signals were provided by a channel bank of 40 lasers with a shared Mach-Zehnder modulator driven by a PRBS signal at 10.700Gbps. The loading signals were fed to input ports 2-6 of the PXC at a power of ≅ -7 dBm/wavelength. Besides the six WSS making up the PXC, two additional WSS were used as a tunable multiplexer and demultiplexer, to enable tunable add and drop functions. The multiplexer combined the test signal with the loading channels, and its output was sent to Input 1 of the PXC.

We measured the pre-FEC BER at each wavelength on every output port. The test signal power was varied by attenuating the transponder signal at the tunable multiplexer while holding the power in the loading channels constant in order to stress the crosstalk rejection performance of the PXC. Power and OSNR were measured at the demultiplexer input. For each wavelength and output port, the PXC's pre-set configuration was altered (if necessary) so that the transponder signal was routed to the output port under test, while the other 39 wavelengths remained in the pre-determined configuration. Thus, all BER tests were carried out with the PXC fully loaded. In addition to taking 240 BER curves through the PXC switch, we also took a set of BER curves bypassing the PXC, replacing it with an attenuator.

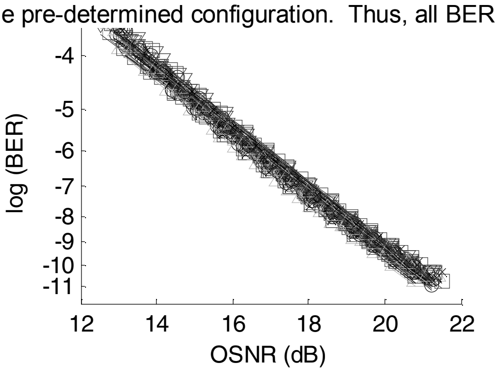

Figure 3: BER vs. OSNR measured at PXC output 1. The test signal power was attenuated in the multiplexer while holding the loading powers constant.

In Fig. 3 we plot the BER at output port 1, as a function of OSNR, for all 40 wavelengths. The curves show excellent uniformity, with no error floor on any channel, and the OSNR sensitivity is consistent with that expected for this transponder,

Figure 4 shows the threshold signal power needed for a pre-FEC BER=10^{-9} versus wavelength, compared to the power of the loading channels. In all cases, the threshold power was at least 9 dB below the loading channels. Except for wavelength channel 2 at output Port 6, the performance measured when the PXC was bypassed showed no significant difference, indicating that the PXC is not cross-talk limited. This demonstrates that input power dynamic range is at least 9 dB, without using the margin provided by FEC.

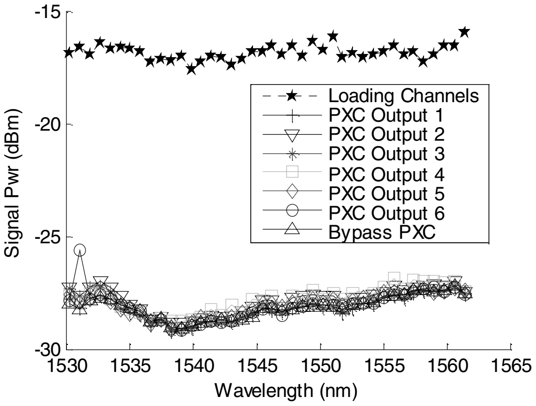

Figure 4: Signal power at pre-FEC BER=10^{-9} for each wavelength channel & each output port of the switch. The power in each loading channel is also shown.

Conclusions

We have demonstrated a fully-loaded, fully-reconfigurable, degree-6 PXC which could be expanded into a degree-8 PXC. The dynamic range measured at a pre-FEC BER = 10^{-9} with 10Gb/s signals was 9 dB, and typical values were greater than 10 dB. The growable PXC architecture in which the fiber degree is greater than the node's degree enables transponders to serve any direction, and capacity between nodes to exceed that of a single fiber.

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References

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