Remote Provisioning of a Reconfigurable WDM Multichannel Add/Drop Multiplexer

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***Abstract*— Remote provisioning of a nonblocking reconfigurable multichannel wavelength-division-multiplexed add–drop multiplexer (ADM) is experimentally demonstrated. The ADM add/drop multiplexer supports many features required by the ITU optical channel layer including lightpath routing, signal conditioning and network/channel monitoring. Specifically, the node supports multichannel optical bypass and add/drop functions as well as optoelectronic 2R regeneration and channel drop-and-continue with wavelength translation. Provisioning of a slave node from a remote master node is achieved via a subcarrier encoded control channel. The control channel can set the full state of the ADM and demonstration of switching between two states is reported. A reconfiguration time of the order of 10 μs and BER below 10^{-9} are shown in both configurations. This performance meets the requirements of next-generation reconfigurable/restorable optical networks.**

***Index Terms*— Optical add–drop multiplexers, optical subcarrier multiplexing, optical transport network, optical network monitoring, optical protection switching, optical transport networks, wavelength-division multiplexing.**

I. Introduction

Reconfigurable multichannel optical add–drop multiplexers (OADM's) are a critical subsystem for wavelength-division-multiplexed (WDM) fiber transport networks. OADM's must perform basic functions that support the optical network layer [1], [2] including lightpath routing and setup, network and channel monitoring, remote provisioning and signaling, protection switching, signal conditioning, channel equalization and some degree of digital transparency.

In this letter, we present the experimental demonstration of control, remote provisioning, and reconfiguration features of a nonblocking WDM add–drop node that employs a combination of digitally transparent multichannel optical and optoelectronic switching capabilities. This node architecture can be used to implement protection switching and survivability strategies in WDM networks due to its flexibility in the treatment of the input signals. An input optical signal can be optically bypassed to the output port, wavelength translated on the same port, dropped or sent to other optical networks. The node, shown in Fig. 1, is a part of the MOSAIC network demonstrator, whose architecture was described in [3]. Multichannel optical bypass and add/drop functions are realized using a novel dilated acoustooptic tunable filter (AOTF) configuration [4]. Digitally transparent drop-and-continue with wavelength translation and 2R regeneration is supported using an optoelectronic-optic (OEO) crossbar switch. The OEO switch consists of a multiwavelength laser transmitter [5], a WDM receiver and analog electronic crossbar switch with digital thresholding without clock recovery, providing digital transparency up to 2.5 Gb/s. Wavelength translation and 2R regeneration provide signal-reconditioning capabilities, channel blocking resolution and digital multicasting capabilities.

Manuscript received January 11, 1999; revised March 31, 1999.

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Publisher Item Identifier S 1041-1135(99)05918-2.

II. ADM Architecture

The OADM consists of four subsystems as shown in Fig. 1: a WDM optical crossconnect (OXC), an optoelectronic–optical crossconnect (OEOXC), wavelength division multiplexers/demultiplexers and a node control processor. The OXC utilizes a novel 2×2 dilated switch [4] based on 2×2 AOTF.

A unique feature of this architecture is the use of subcarrier multiplexing for remote provisioning and channel monitoring. Each network wavelength λ_i is encoded with a unique subcarrier frequency f_i that carries a 10-Mb/s digital control data stream for channel identification, node control and channel equalization. The coupling between wavelength λ_i and subcarrier frequency f_i allows us to identify and monitor optical channels by simply photodetecting the WDM signal without requiring any optical filtering. The use of subcarrier multiplexing to support distributed network functions enables the use of low cost electronics to interact with only that portion of electrical bandwidth needed for control and monitoring [3].

III. ADM Reconfiguration Demonstration

Remote node provisioning of the node was demonstrated using the setup shown in Fig. 1. A programmable control data sequence was transmitted at 10 Mb/s on a 3.5-GHz subcarrier encoded signal, using a directly modulated laser acting as a source master node and connected to the remote ADM by 25 km of fiber. This setup simulates a real configuration where a central master control node sends reconfiguration requests to slave network nodes.

We have demonstrated remote provisioning by defining two node "States" specified by two different control data sets (C_1 and C_2) that were generated by the master node. An input

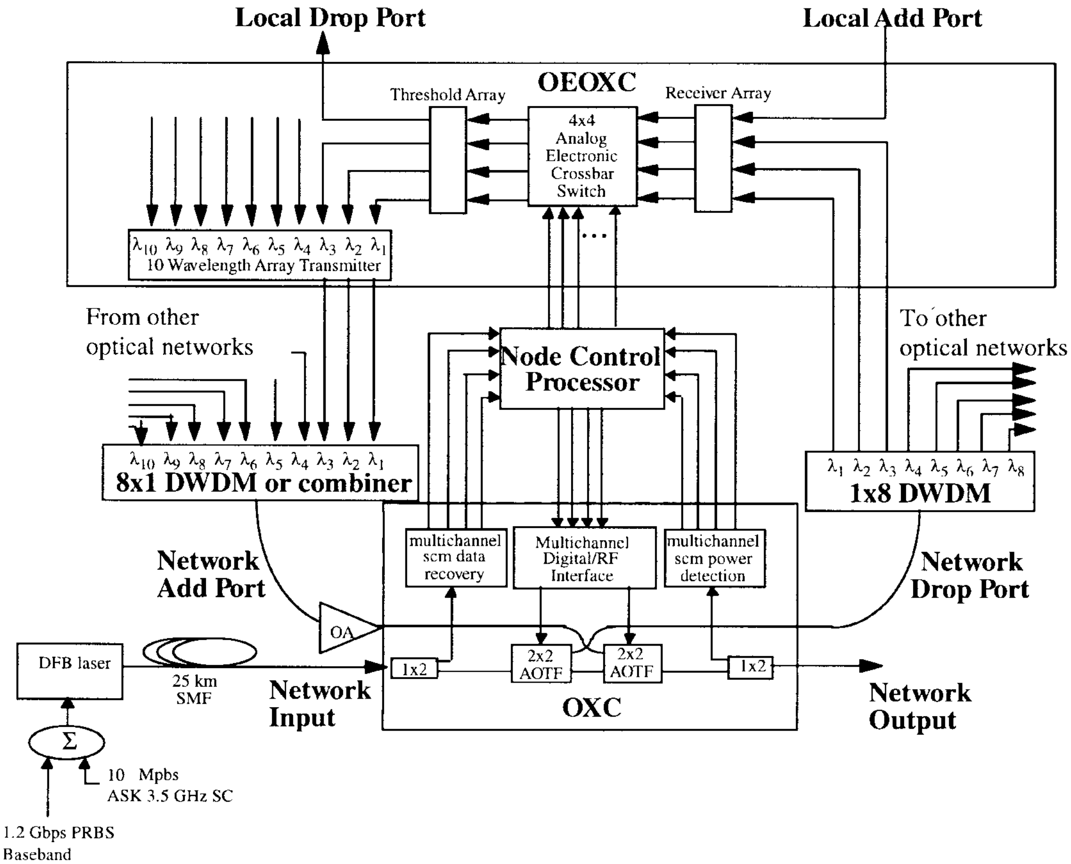


Fig. 1. MOSAIC node architecture.

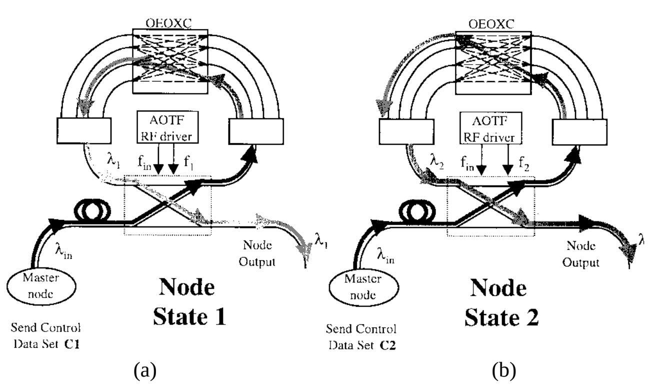


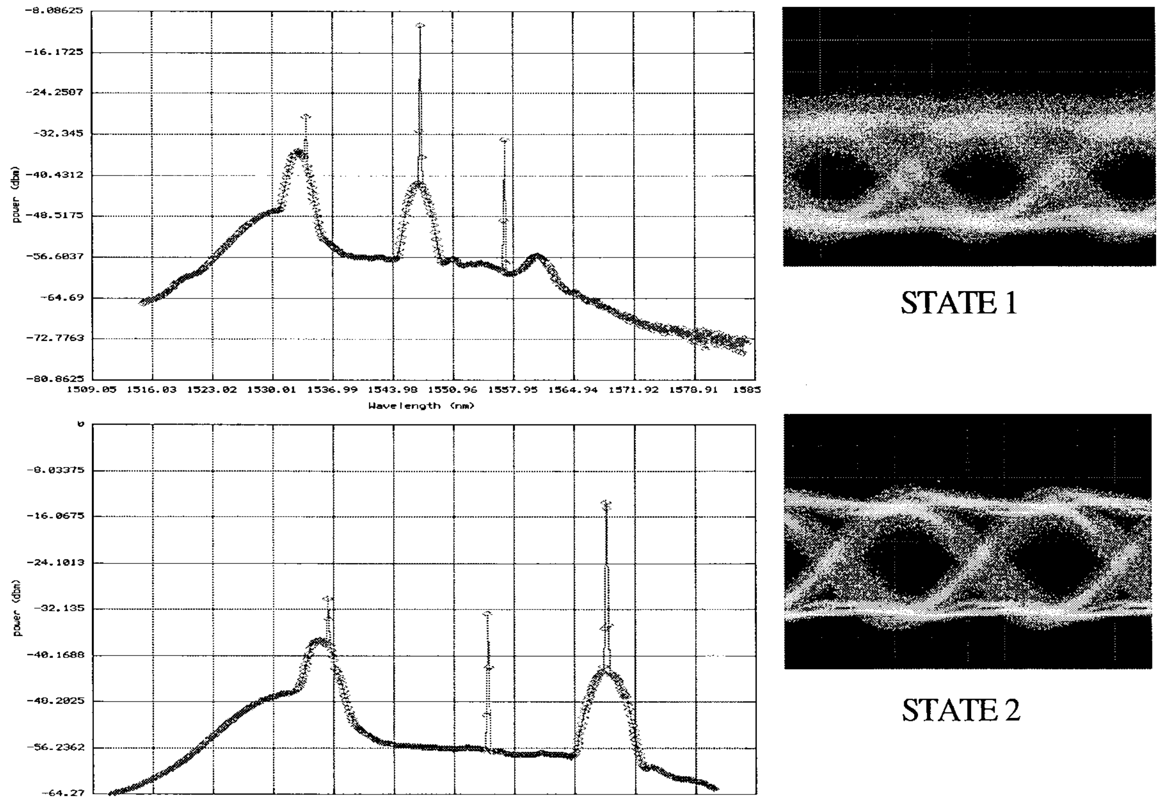
Fig. 2. Graphical representation of (a) Node State 1 and (b) Node State 2. Thin lines show physical connections while thick lines show signal path on different wavelengths.

1.2 Gb/s baseband signal on λ_{in} generated at the master node was dropped at the slave node. The received optical signal was optoelectronically converted to λ_1 for State 1 (data set C_1) or to λ_2 for State 2 (data set C_2). The two different configurations are shown schematically in Fig. 2. These states were chosen since they require the reconfiguration of both the optical (AOTF) and electrical (OEOXC) sections.

The node control processor (see Fig. 1) continuously monitors the incoming subcarrier control signal and, after receiving the control data set C_1 or C_2, sets the OEO Crossbar Switch and reconfigures the AOTF switches via a multichannel digital/RF interface. The interface generates RF signals at frequency $f_{\text{RF,in}}$ and $f_{\text{RF},1}$ to set wavelength λ_{in} and λ_1 in the cross-state for Node State 1, and $f_{\text{RF,in}}$ and $f_{\text{RF},2}$ to set wavelengths λ_{in} and λ_2 in the cross-state for Node State 2. The reconfiguration time for the AOTF and its driver was of the order of 10 μs, corresponding to the time required to the AOTF to reach steady state operation after a change in driving RF signals.

In addition to reconfiguration of the AOTF, it is necessary to set the OEOXC to send the incoming signal to one of two different outputs corresponding to λ_1 and λ_2 of the multiwavelength laser array. The OEOXC showed extremely fast reconfiguration time, since the discrete monolithic GaAs switches used for the OEOXC board had switching time on the order of tens of nanoseconds. The resulting global reconfiguration speed was thus limited by the AOTF section, resulting in a reconfiguration time of the order of 10 μs.

The experimental results are shown in Fig. 3; the upper traces and lower traces are for node states 1 and 2, respectively. The total optical spectrum at the ADM output port (without optical filtering) shows the channel state change and the associated control signal. Eye diagrams of the ADM output port outputs are shown to the right for each configuration, illustrating remote multichannel control. The eye diagrams were measured without an optical filter to demonstrate rejection of unwanted channels at the OADM network output. The measured bit-error rate (BER) for the 1.2-Gb/s pseudorandom sequence (pattern length $2^{31}-1$) was better than 10^{-9} in each state.



(a) (b)

Fig. 3. Remote reconfiguration of multichannel ADM node. Upper traces are for State 1 and lower traces for State 2. (a) Optical spectrum at the ADM output port and (b) measured eye diagram at optical output port.

IV. Discussion and Conclusion

We have demonstrated real time remote provisioning of a reconfigurable multichannel OADM with channel monitoring. Reconfiguration times on the order of 10-μs promise to support the requirements of future reconfigurable transport networks. We have demonstrated the switching of a single input wavelength to two different output wavelengths through provisioning of a multichannel optical add–drop switch and an OEO drop-and-continue subsystem with wavelength conversion and 2R regeneration. This technique is based on transmission of in-line subcarrier encoded control signals from a master node to the OADM. The node add–drop multiplexer node capabilities are not limited to single wavelength routing since groups of wavelengths can be independently and simultaneously handled.

The fast reconfiguration time of this OADM architecture is well suited for protection switching in both ring and mesh configurations. Channel, link, and node protection can be supported using loopback and span protection. As shown in [3] and schematically in Fig. 1, the node can operate in many different ways including routing the dropped wavelengths to other networks.

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