Demonstration of Bidirectional Add Drop Multiplexers and Mixed Signals in a DWDM Mesh Architecture

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Abstract

We demonstrate network integration of passive BADMs using Dense Wave Division Multiplexing (DWDM). Full duplex transmission in a fully interconnected fiber ring architecture supports analog and digital data transmission.

Introduction

Numerous studies have examined methods of implementing optical Wave Division Multiplexed (WDM) architectures including topologies, wavelength assignment, and devices [1-3]. Most focus on minimizing metrics: hops, cost, interconnects or wavelengths. These solutions are often targeted at aggregating traffic for long haul optical networks. We have proposed a potential solution for a smaller scale fully interconnected all optical mesh architecture that minimizes both wavelengths and hops [4]. This architecture could be used as a metropolitan area or local area network that serves as a high speed, low latency backbone supporting connections between many users. Here we focus on the bidirectional add drop multiplexer (BADM) used to implement this architecture, that when coupled with wavelength conversion also achieves low latency [5].

Optical components in this study include the passive BADMs and fixed wavelength laser transmitters. A test bed was constructed with a single fiber ring capable of transmitting a digital signal over an arbitrary topology without any optical-electrical-optical (OEO) conversion in the path. Laboratory tests were designed to produce worst case conditions for various types of data. The target topology could scale to an *n*-dimensional mesh of fully interconnected rings requiring *n* hops between backbone nodes.

Network Devices

In the proposed topology, each node in a ring is connected to every other node via a distinct wavelength. Each ring uses thin film filter-based BADMs, which are highly adaptable for other topologies. With the BADM, two wavelengths can be added, two can be dropped and one (or more) is passed through the device. As illustrated in fig. 1, λ_3 and λ_4 are added, λ_3 and λ_1 are dropped and λ_2 is an express wavelength. The device is passive and reciprocal, drop (add) ports can also be configured to add (drop) wavelengths depending on the topology.

Performance – Analog and Digital

Before installing the BADMs in the network, tests verified that the insertion losses ranged between 1.1 and 1.9 dB per BADM dependent on the path. In initial

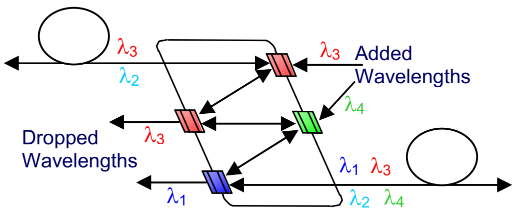

Figure 1. Bidirectional Add Drop Multiplexer Example

tests in a network, the BADMs were configured in a fiber ring to implement an eight-node perfect shuffle using four wavelengths [6]. Quadrature amplitude modulated (QAM-16) data, digital data (2.5 Gb/s), and analog data were transmitted in this network. The digital channel achieved a 10^{-14} bit error rate in three days of testing, and a signal to noise ratio of 28 dB was achieved in the QAM channel without using linearized modulators or optimized receivers.

Next, since it is desired that the network supports both analog and digital data, a worst case test was setup to check for crosstalk on two adjacent channels while transmitting both analog and digital data through an erbium doped fiber amplifier (EDFA) that was placed between two BADMs. The test setup is described in fig. 2. This is not representative of any particular topology; it was contrived to present the worst case scenario for mixed signal data on the same fiber through the BADMs.

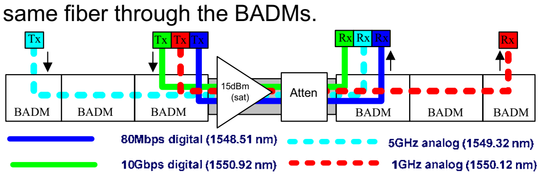

Figure 2. Mixed Signal Gain and Crosstalk Test Setup

The test included four signals (two analog, two digital) propagating through the network on four different wavelength channels. The signals consisted of 80 Mbps (1548.51nm) and 10 Gbps (1550.92 nm) digital signals, and analog signals of 1 GHz (1550.12nm) and 5 GHz (1549.32nm). A total of six BADMs were used to add/drop the correct wavelengths. The measurements were taken at the drop point of each wavelength and after all signals had been added to the network. The resulting optical spectrum is in fig. 3. For the 10 Gbps signal, a 2^{31} -1 psuedorandom bit pattern was transmitted. Data at 20 Gbps was also tested. Eye diagrams are shown in fig. 4.

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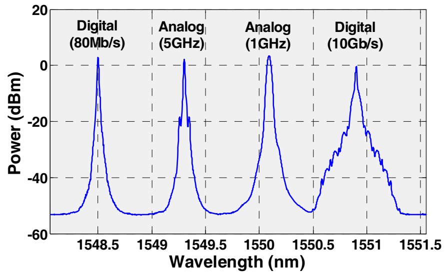

Figure 3. Spectrum after EDFA and attenuation.

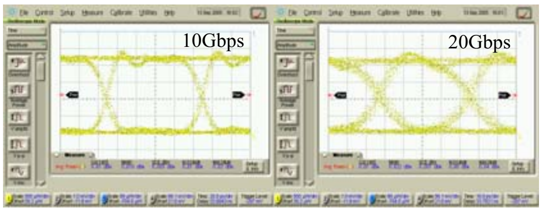

Figure 4. Optical eye at 10 Gbps and 20 Gbps.

For the analog signals, spur free dynamic range (SFDR) was measured using a two tone test. Multiple combinations of BADMs were configured to create the worst case loss characteristics through the network. Erbium amplifiers were used to compensate losses in some configurations. Results are shown in table 1. Link 1 corresponds to 1GHz linearized direct modulation with a 6MHz receiver bandwidth and 3.2dB optical loss. Link 2 corresponds to 5 GHz external modulation with a 300 MHz bandwidth and 5dB optical loss. As can be seen, the BADMs performed very well under all conditions.

Tests	Back-to-Back	Network	Network + Rx Preamp	Network + Mid-Stage Amp
Link 1	114.7	110.2	112.3	112.8
Link 2	103.7	98.5	101.3	101.0

Table 1. SFDR results - SFDR (dB-Hz$^{2/3}$)

The Mesh Topology

The proposed mesh topology combines fully interconnected rings where each node on a given ring is connected to every other node on the ring via a distinct wavelength [4]. Wavelengths are dropped/added at nodes using BADMs. The minimum number of wavelengths required on a ring with N nodes is λ_{min} = int$((N/2)^2)$. The architecture is scalable; a two-dimensional $N \times N$ mesh requires $2N$ fiber rings. The same wavelengths can be used in each ring. As an example, a 5×5 mesh consisting of ten fiber rings would require six wavelengths to achieve full interconnection in each ring.

A test bed has been designed and tests have begun to fully implement the two-dimensional 4×4 mesh architecture where each row and column is a fully interconnected four node network. The test bed will consist of 16 nodes and require 4 unique wavelengths. A row and column from the test bed is shown in fig. 5. As depicted in the figure, one application of such a network is as a backbone for local or metropolitan area networks. For twelve 10 Gbps links in each of the 8 rows/columns, an aggregate throughput of 960 Gbps could be supported in the 4×4 mesh.

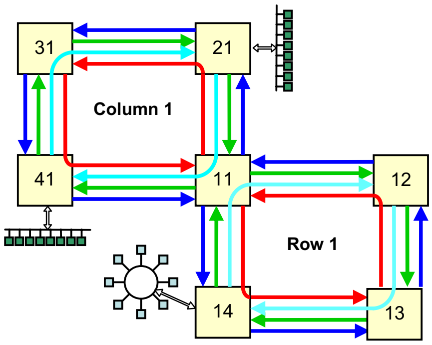

Figure 5. First row and column from a 4×4 mesh.

By implementing a mesh in this fashion the need for wavelength conversion on any given ring is eliminated (except for reconfiguration in the presence of a failure). Also, analog data could be restricted to a specific ring. Wavelength conversion is needed for all-optical routing between fiber rings in the mesh. We have implemented a cross gain modulated (XGM) semiconductor optical amplifier based wavelength converter and tested them with the BADMs, demonstrating reduced latency for digital data [5]. Future work will include the analysis of characteristics such as scalability and reconfigurability.

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