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A Novel Modular ROADM Node with Traffic Aggregation/Disaggregation for Ultra-high Capacity SDM Metro Networks

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Abstract We present a novel modular ROADM for ultra-high capacity SDM metro networks with aggregation/disaggregation traffic operation based on space switches, photonic integrated wavelength selective switches, and bandwidth-variable transmitters. Experimental results validate the concept by dynamically disaggregating/aggregating traffics from/to multi-core fibers.

Introduction

Boosted by cloud, IoT, and 5G applications next generation metro networks should be able to dynamically and efficiently handle large heterogeneous data traffics. Ultra-high capacity space division multiplexing (SDM) systems have demonstrated multi Pb/s transmission exploiting multi-core fibers. Therefore, it is envisioned that metro network nodes should be able to do reconfigurable switching for amount of traffics carried by SDM multi-core fibers in an efficient and scalable way. Modular reconfigurable add/drop multiplexers (ROADM) with color-less, direction-less and contention-less (CDC) are the main candidate to transparently switch SDM systems and several recent works are presented in [1- 3]. The main challenges in CDC-ROADM is the cost and complexity of the (wavelength and space) switching sub-systems as the wavelength channels count and thus the traffic scales. This is even more exacerbated in SDM systems with multi-core fibers. Therefore, novel, efficient and scalable ROADM for SDM system exploiting modular architectures and low cost photonic integrated wavelength and space switching are currently investigated [1, 4].

In this work, we demonstrate a novel modular ROADM architecture for SDM employing a photonic space switch with express (bundled traffic) and add/drop ports, photonic integrated wavelength selective switches (WSS) aggregation/disaggregation functions for

merging/dropping the network traffic, and photonic integrated multi-cast switch (MCS). The modular approach enables to scale the architecture in a pay-as-you-grow approach and employs photonic integrated devices for wavelength and space switching to implement the modules of the ROADM. Moreover, the novel ROADM exploits the MCS for bundled traffic with common destination by disaggregating first specific traffic and then aggregates the channels for bundling traffic to same destination, so that at the next node, express ports can transparently direct the traffic without any process, saving resources and power consumption.

System operation of the SDM ROADM

The proposed modular ROADM for SDM system is shown in Fig.1. The ROADM node consists of a photonic space switch matrix (PSM) providing connectivity between the input and output MCFs. Some of the ports of the PSM directly connect the input/output MCFs (express ports), while other ports are used to drop and to add traffics. The drop ports are connected to the aggregation/ disaggregation switch which separates the wavelength sets to be dropped to the local end users and those which are aggregated and added via the Add switch to the express traffic. In other words, the Agg/disaggregate switch bundles traffic that goes to the Add switch and to the MCS based

Fig. 1: Schematic representation of a modular optical switching node with ROADM functionality.

Fig. 2(a): (a) Experimental Setup, InP-WSS (b) functional representation (c) microscopic picture (d) dropped traffic (λ_1 :1536.8 nm) at InP WSS-O4 (measured after the tunable filter) (e) aggregated traffic (λ_2 :1540 nm) at InP WSS-O1 (measured after the tunable filter)

on their wavelengths. Therefore, this block is implemented using simple 1x2 WSS. By bundling traffic to the same destination, efficient utilization of resources (ports of PSM, and MCF) is realized. The traffic that has to be dropped to local end-users is directed to the MCS which enables contention-less operation (via its broadcast and select feature) as shown in Fig.1. In this way, any of the available receivers in the coherent receiver modules (CRM) can be used to receive any wavelength leading to efficient utilization of the receivers. For adding the traffic, bandwidth variable transmitter (BVT) provides the capacity to variably allocate the bandwidth of locally generated traffic at the particular node. The locally generated traffic and aggregated traffic are merged as added traffic by the Add switch. The Add switch is based on $M_{add} \times 1$ WSS, where M_{add} is its number of input ports. In the event of contention, the Add switch sends multiple traffic flows in the same wavelength channel to separate output ports. Then, the traffic of the Add switch is inserted into the network via the PSM add ports. Due to bundle at next node the aggregated traffic goes transparently through the express port, saving resources since no processing of this traffic is needed. The scalability of the SDM ROADMs node is ensured by a modular approach in a “pay as you grow” principle, where new more modules are added to accommodate the increase in traffic. The use of software defined networking (SDN) control plane provides programmability of components of the node to achieve the level of

flexibility, channel bandwidth, path, and energy requirement of the metro network.

Experimental Results

The experimental setup validating the operation of the ROADMs node is shown in Fig. 2(a). The input traffic to the ROADMs is generated by six WDM transmitters at 40 Gb/s (Tx). The 4 output ports of a fully reconfigurable 1x4 WSS was employed to emulate a MCF and to dynamically assign the WDM channels to two different input ports of the PSM, namely λ_1 and λ_2 to I-1, and λ_3 and λ_4 to I-2 (spectrum shown in Fig. 2(a)). The channels λ_5 , and λ_6 were used as add channel emulating traffic generated by the local BVT. The port I-3 of the PSM is used for the add traffic (wavelengths shown in red). The output port O-1 and O-2 of the PSM are used as express port, while O-4 as drop port. The PSM is based on MEMS technology, but it can be replaced by photonic integrated chips [5, 6]. The InP-WSS is used as aggregate/disaggregate switch. It is based on a wavelength blocker with (de)multiplexing AWGs and SOA gates as shown in the functional diagram in Fig. 2(b). Due to the presence of multiple InP-WSS integrated on the same photonic chip (an inherent $1 \times N$ splitter) is used to emulate the MCS functionality. The microscopic picture of 4 modules of the WSS with 4 inputs and 16 outputs is shown in Fig. 2(c); the employed WSS for the aggregate/disaggregate switch in this experiment is WSS-1. The details of the InP WSS are given [7]. Of the two input wavelengths, λ_1 and λ_2 , λ_1 is locally dropped

Fig.4 (a) BER measurement for the drop traffic InP WSS O-1 (b) BER measurements at Express out traffic at PSM-O1 (c) BER measurements at Express out traffic at PSM-O2

Fig. 5: BER measurement for aggregated traffic

while λ_2 is aggregated with λ_5 and λ_6 by an Add switch. The Add switch is replaced by a power combiner (PC) in this experiment due to the availability of a single InP-WSS chip. The added wavelengths are sent out as express traffic at O-2 of the PSM. The optical spectrum at drop port and aggregate port of InP WSS are given in Fig.2 (d) and (e) respectively. Afterwards, BER measurements are conducted for 40 Gbps and 20 Gbps OOK NRZ data at different point in the set-up: *a*: back-to-back, *b*: express traffic after the switch, *c*: local drop traffic and *d*: aggregated traffic. Results are given in Fig. 4 and Fig.5. Fig. 4(a) shows the BER measurement for λ_1 and λ_2 at 1536.8 nm and 1540 nm for measurement points *c* and *d* indicated in Fig. 2(a), respectively. A power penalty of only 1 dB is incurred in case of the aggregated wavelength $\lambda_2=1540$ nm at 20 Gb/s and 1.5 dB for 40 Gb/s data. The power penalty increases to 3.5 dBs in case of dropped $\lambda_1=1536.8$ nm because of the extra path loss in O-4 of InP-WSS (unpacked devices with large fiber-to-chip coupler have been employed in the experiments). Fig. 4(b) shows the BER measurement at express out traffic of MEMS-O1, point *b*, ($\lambda_3:1552$ nm, $\lambda_4:1554$ nm) incurring penalties of less than 1 dB at both data rates. BER measurements for

added wavelengths at express port MEMS-O2 are given in Fig.4 (c) and Fig.5. Power penalties for BVT wavelengths $\lambda_5:1538$ nm and $\lambda_6:1556$ nm is less than 1 dB. The power penalty increases to 1.8 dB for $\lambda_2=1540$ nm since it passes through the PMS twice and InP-WSS once.

Conclusions

We have experimentally verified a novel ROADMs functionality of a switching node in the context of a modular architecture as applicable in a high capacity metro core network. Key switching functionalities are deployed by an InP WSS PIC. Experimental results verified a node capacity of 6 wavelengths $\times$ 40 Gbps/wavelength.

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