Towards Software Defined Autonomic Terabit Optical Networks

Julio Oliveira, Juliano Oliveira, Marcos Siqueira, Rafael Scaraficci, Marcos Salvador, Leonardo Mariote, Neil Guerrero, Luis Carvalho, Fabian Hooft, Giovanni Santos, Eduardo Magalhães, João Januário
CPqD Foundation. R. Dr. Ricardo Benetton Martins, s/n, CEP 13086-902 – Campinas – SP, Brazil
Author e-mail addresses: julioce, jrfo, siqueira, raugusto, marcosrs, lmarioite, neilg, lhecker, fabian, eduardom, jjanuario@cpqd.com.br

Abstract: This paper presents an Optical SDN architecture and implementation enabled for virtual optical networks, supporting adaptive and cognitive algorithms to enhance QoT. The paper also shows experimental results of a software-defined autonomic flexible transponder.

Keywords: Optical communications; Optical networks; SDN; Auto-configuration; Autonomic operation; Virtualization; Silicon photonics.

1. Introduction

Optical networking is constantly evolving in order to accommodate growing traffic demand and new services. Nowadays, 100 Gbps optical transponders are already being deployed while the first 400G/1Tbps are demonstrated in field and laboratorial trials [1]-[3]. The need for deploying services quickly, efficiently and at low costs is driving a change in optical DWDM from static point-to-point to dynamic mesh networks. Previously simple routines such as spectrum equalization, optical amplifier gain control, channel instantiation and even the GMPLS control plane have to be re-visited, in order to be adapted to this new scenario. SDN (Software Defined Networking) have promising benefits including overall network simplification, virtualization and automation capabilities via programmable interfaces, and easier deployment based on control-plane defined features implemented in software. In this context, in [4] we proposed transport SDN architecture, enabling optical network virtualization and autonomic operation. This paper presents new features for devices, network elements, and SDN applications, in order to enable optical networks to support new services and virtualization with required flexibility and scalability. Experimental results are shown, as use cases, where the optical network adapts itself for sustaining QoT (Quality of Transmission) in the advent of optical impairments, and future optical networks vision/challenges are depicted at the paper conclusion.

2. Towards Terabit Optical Systems

CPqD is continually developing state-of-the-art network elements for reconfigurable DWDM optical networks such as optical transponders, WSS ROADMs and Multi-Cast Switch (MCS) add/drops for CD and CDC add/drop respectively. In this context, next generation optical fiber transmission technologies with bit-rates up to 400 Gb/s and 1 Tb/s are being intensively investigated [1][2]. Those systems may employ high order modulation formats, spectral shaping, and densely packed multicarrier transmitters (superchannels) in order to increase overall system capacity with comparison to current 100G technology, as demonstrated in our recent works [1][3]. Regarding amplifier technologies, our current works [5][6] investigate hybrid optical amplifier obtaining a counter-propagating distributed Raman/EDFA hybrid topology and developing its respective hybrid automatic gain control loop, achieving lower noise figure levels together with spectral gain flatness for all amplifier dynamic operation region.

The utilization of new modulation formats decreases accuracy of out-of-band OSNR measurement, since noise floor becomes more difficult to detect. Therefore, we developed a mechanism where current OSNR is obtained with an in-band OSNR monitor insensible to first order dispersive effects for coherent and non-coherent signals through the properties of polarization diversity and coherence difference between signal and optical noise from erbium doped fiber amplifier [7]. Fig. 1(a) depicts the proposed OSNR monitor schematic; Fig. 1(b) shows the experimental results get from the setup present in the Fig. 1(a); and in Fig. 1(c) it was developed eight different interferometers in silicon photonics in order to evaluate the performance of the proposed OSNR monitor.

Fig 1. (a) CPqD OSNR monitor schematic (b) OSNR estimation performance (c) Silicon photonics integrated DLIs.
3. Software Defined Optical Networks

By employing model-based development and graph-based algorithms at the component level (WSS, OCM, EDFA, MCS, etc), potent abstractions can be created, hiding the complexity of subsystems and allowing these to be easily integrated to SDN architecture. The graph-based approach provides a basis for alarm correlation and advanced path computation, as described in our current work [8]. It also provides the information needed for multi-agent oriented problem solving, which with the currently installed hardware is not feasible.

The proposed Transport SDN architecture, shown in Fig. 2, includes a Transport Network Operating System (T-NOS), allowing SDN applications to access topology and measurements required for its operation and to perform the required configuration and interactions with transport network elements. Additionally, the T-NOS implement the concept of network slicing, allowing the implementation of VON (Virtual Optical Networks). As many features provided by GMPLS are not initially supported by pure SDN approaches, such as network discovery, link state advertisement and OIF UNI/NNI, we have virtualized our ASON/GMPLS implementation to run at the SDN controller on top of the T-NOS. The T-SDN controller provides a network functions API for plugging control applications to perform specific tasks, taking advantage of the network abstraction.

The applications that we develop and is continuously developing focus on cognitive and adaptive controls for autonomic optical algorithms which adapts network elements operation points, such as global equalization, cognitive EDFA gain control, DWDM system auto alignment, fault prediction and preventive actions. In a previous work [9] we have demonstrated a cognitive gain control mechanism for erbium doped fiber amplifiers, using GMPLS control plane to read and control amplifiers analyzing the transponders bit error rate in heterogeneous optical networks scenario. Additionally, we have implemented a global equalization mechanism for WSS ROADMs aiming at maximizing OSNR for all network wavelengths [10], and in the context of this work, an application for flexible autonomic coherent transponder modulation format adjustment is demonstrated.

4. Experimental results of a Software-Defined Autonomic Flexible Transponder

We have evaluated a software-defined flexible transponder with fixed bit rate of 448-Gb/s at two operation modes, described in Table 1. The optical signal consists in a WDM system composed of 40 optical carriers originated by 500 kHz linewidth distributed feedback (DFB) lasers, with 100-GHz channel spacing, and coupled together with the flexible transponder. The optical carriers were set to 100-GHz slots in the flexible-grid WSS, while the 448-Gb/s flexible transponder was set to 75-GHz or 150-GHz slots, with 5.6 and 2.8 b/s/Hz respectively, depending on the operation mode. The signals were transmitted through four flexible-grid WSS nodes with three 50 km-long standard SMF spans. EDFAs were used to compensate link losses. To emulate link failure induced ASE loading was done by coupling an extra EDFA with a variable optical attenuator. Next, the 448-Gb/s channel was received with an integrated polarization-diverse coherent optical receiver. The coherent receiver outputs are sampled using a 40-GS/s real time scope with 20-GHz bandwidth. Data sets with 400-kS were acquired, and the BER for each carrier is computed and processed offline by using a set of algorithms to recover transmitted information [11].

<table>
<thead>
<tr>
<th>Operation mode</th>
<th>Bit rate [Gb/s]</th>
<th>Baud rate [GBd]</th>
<th>Modulation format</th>
<th>Carrier spacing [GHz]</th>
<th>Number of carriers</th>
<th>Flexible-grid slot [GHz]</th>
<th>OSNR@1e-3 (per-carrier)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metro-haul</td>
<td>448</td>
<td>28</td>
<td>DP-16QAM</td>
<td>35</td>
<td>2</td>
<td>75</td>
<td>29</td>
</tr>
<tr>
<td>Long-haul</td>
<td>448</td>
<td>28</td>
<td>DP-QPSK</td>
<td>35</td>
<td>4</td>
<td>150</td>
<td>14</td>
</tr>
</tbody>
</table>

Initially, EDFA gain control [9] was employed to optimize the network power balance per link. Previous results showed that over six cascaded EDFAs the cognitive control used in the testbed to ensure BER below 7% FEC threshold under 6 dB attenuation penalty. After EDFA control actuation, if degradation continues increasing, the T-SDN controller flex-transformer application takes place, reconfiguring the transponders to new modulation format with a lower OSNR requirement but with the same data rate in order to maintain the same load.

As depicted in Fig. 2, the transponder was operating with high OSNR > 30dB, using DP-16QAM modulation format, occupying 75GHz of spectrum. When OSNR is degraded, and the FEC limit is reached, the SDN controller coordinated the ROADMs reconfiguration for moving the neighbor channel for spectrum defragmentation, and increasing the channel width to 150GHz, and reconfiguring the transponder modulation format to DP-QPSK.
4. Conclusion and Future Research Lines

This paper presented a proposal, implementation and validation of a SDN controller for Optical Networks, supporting, virtualization and autonomic operation via specific SDN applications implementing adaptive and cognitive algorithms for allowing the optical network to be self-adaptable, according to service requirements and network conditions. A flexible-transponder application has been demonstrated, which adapts modulation format and spectrum utilization in a coordinated way, according to network conditions. Nevertheless, despite the flexibility achieved by now with the introduction of CDC-ROADMs, flexible coherent transponders and SDN control, there are still many issues to be addressed.

Regarding optical systems, there are challenges in space, power consumption and cost regarding the current ROADM-CDC architectures, as well as switching time in the order of hundreds of milliseconds is still a major issue for re-routing traffic in the case of failures. Additionally, in order to increase the optical systems capacity in orders of magnitude, optical amplifiers technologies must evolve from single core EDFA to multi-pumped MCF-EDFA (using low loss fan-in to couple the signal and single-mode pump for each core inside the EDF-MCF) in a short term, evolving to innovative EDF-MCF designs (multiple single cores and a multi-mode or cladding EDF for pump) and multi-mode EDF (few modes) to build amplifiers using single multi-mode pumped instead multiple pumps. In the transmission area, new paradigms have been proposed, such as Multi-flow transponders [12], increasing flexibility and granularity. Finally, new challenges in transmission include the development of technology for multicarrier reception, joint DSP for superchannel detection, and nonlinear compensation.

Finally, we remark that SDN and optical networks virtualization have to evolve in many aspects, including interfaces standardization multiple layers integration, as well as resources isolation.

5. References