Semi-Reconfigurable OADM node design for the CARISMA ASON/GMPLS Network

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Abstract. Reconfigurable Optical Add-Drop Multiplexer (ROADM) is a key network element enabling flexible and remote handling of optical resources. The ROADM has become a standard part of long-haul networks, and it is also becoming of importance in the metro networks. In this paper, a semi-Reconfigurable OADM functional and physical design supporting GMPLS-based control plane is presented.

Keywords: ASON, GMPLS, ROADM

1. Introduction

The introduction of OADMs in the optical layer allows the network to be configured in ring topologies, similar to the SONET/SDH ring-based networks. OADM function consists of providing cost-effective access to a portion of the traffic on the fiber arriving at a node. This way, an OADM allows dropping a signal onto a specific wavelength out of the bundle of DWDM-multiplexed signals and adding another signal. The advent of flexible reconfigurable OADMs (ROADMs) at a low cost in which the dropping and adding of wavelength channels can be remotely controlled, has signified a very important breakthrough on optical networking technology [1]. The main advantages of ROADMs are:

- The planning of entire bandwidth assignment need not to be carried during initial rollout. The configuration can be done as and when required.
- ROADM allows for remote management and reconfiguration.
- ROADM allows for automatic power balancing.

Ring-based networks can be built using ROADMs as optical node elements. The ring topology allows protecting against link or node failures and their benefits include simplicity, flexibility and potential fast recovery. In fact, ring architectures are well-known for their inherently fast protection switching capabilities. This way, optical rings are playing a crucial role in the migration to the more dynamic ASON/GMPLS paradigm [2][3].

An Automatically Switched Optical Network (ASON) [2] is an optical transport network that has dynamic connection capability. This functionality is accomplished by using a control plane that performs routing, signaling and resource discovery. The transport plane layer, referred also to as data plane or forwarding plane, represents the functional resources of the optical network which convey user information between locations. Call and connection control functions are automated based on that the control plane which includes automatic discovery, routing and signaling. The management plane functions comprise the supervision of the transport and control planes performance, as well as the coordination of the whole system operation.

Generalized Multiprotocol Label Switching (GMPLS) [3] is a technology that provides enhancements to Multiprotocol Label Switching (MPLS) to support network switching not only at the packet level but also at time slot, wavelength, or even fiber level. In particular, GMPLS provides a control plane in support to optical networking. GMPLS is based on the Traffic Engineering (TE) extensions of RSVP-TE [4] signaling protocol and intra-domain link-state OSPF-TE [5] routing protocol. The use of technologies like DWDM (Dense Wavelength Division Multiplexing) implies that we can now have a very large number of parallel links between two adjacent nodes (hundreds of wavelengths, or even thousands of wavelengths if multiple fibers are used). To solve this issue the concept of link bundling was introduced. Moreover, the manual configuration and control of these links, even if they are unnumbered, becomes impractical. The Link Management Protocol (LMP) [6] was specified to solve these issues.

In this paper we will describe the functional and physical design of a semi-Reconfigurable OADM (hereafter sROADM). This sROADM will be part of the ASON/GMPLS CARISMA testbed network [7].

The CARISMA GMPLS control plane uses the RSVP-TE protocol for signaling, the OSPF-TE protocol for routing and the LMP protocol for Control Channel Management and Link Property Correlation. The OCCs have been implemented using Linux-based routers. Each pair of OCC communicates through the use of a single IP control channel implemented with full duplex Fast Ethernet links. Finally, each OCC has also a CCI interface for communicating with the optical nodes.

The NMS [8] have been implemented using a distributed client/server web architecture. It is able to receive and execute requests for establish and releasing both permanent and soft-permanent optical connections. In the latter, the control plane is responsible for accepting requests and forwarding them through the network by means of routing and signaling protocols.

The remainder of the paper is organized as follows: Section 2 provides the functional design for the semi-Reconfigurable OADM. Section 3 is devoted to a discussion about management interfaces. In Section 4 the physical design for the optical node is presented. Finally, Section 5 draws the main conclusions of this work.

2. sROADM functional design

The functional design for the Semi-Reconfigurable Optical Add Drop Multiplexer is shown in Fig. 1. This optical node allows dropping two wavelengths out of the bundle of DWDM-multiplexed signals and adding two new wavelengths to the DWDM-multiplexed bundle. In order to simplify subsequent figures, the schematic icon shown at the bottom in Fig. 1 will be used.

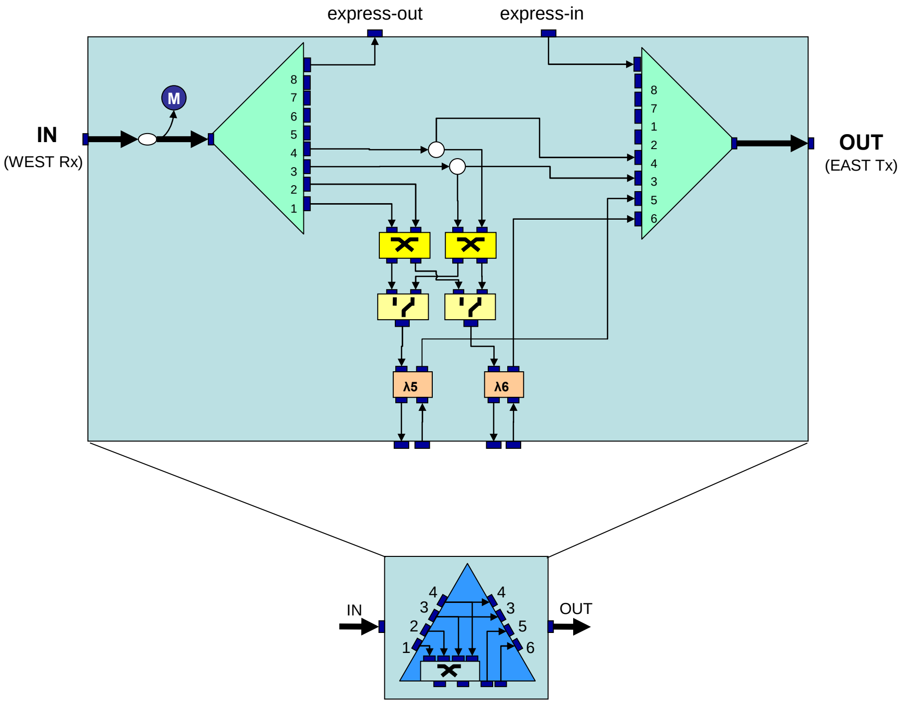

Fig. 1. sROADM functional design

The monitoring device extracts a small part of the incoming optical power, transforms the sample into a digital value by means of an A/D converter, and stores the converted value in a register. The monitoring sweep time is 10 µs.

Two demultiplexer/multiplexer modules from Bookham [9] have been used in order to extract/insert 8 contiguous DWDM 100GHz separated wavelengths. Although 8 wavelengths are extracted, the optical node is only able to use only 4 of these wavelengths, due to economical reasons. The mux/demux module has insertion losses lower than 3.5 dB. All remaining channels are reflected onto the express port. We plan to use the express port to connect a full Reconfigurable OADM module in the near future.

The sROADM node is equipped with a 4x2 optical switch fabric, in order to select the wavelengths to drop. The 4x2 optical switch has been built using the simplest 2x2 and 2x1 optical switches. The switching device, from Sercalo [10], has a very fast response time below 1ms and has insertion losses lower than 0.9 dB.

The 2 dropped wavelengths are transformed into 1300nm monomode optical signals, in order to provide a standard interface to client signals. This task is performed in the transponder module.

In the transmission direction, the sROADM node can add two wavelengths to be assembled by the optical multiplexer into a DWDM-multiplexed bundle. Additionally, two splitters allow performing multicast.

Using these unidirectional sROADM nodes, it will be possible to deploy unidirectional ring networks, as shown in Fig. 2. As fixed lasers will be used, each node of the ring will have unique behavior.

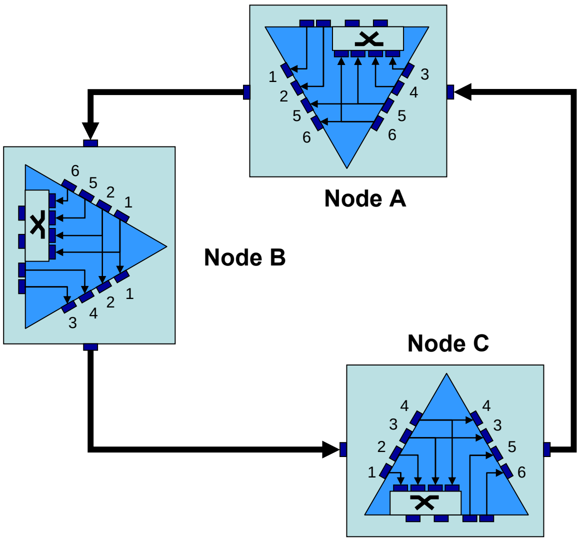

Fig. 2. Unidirectional ring with three sROADMs

Each node is able to drop 2 incoming wavelengths from the ring and can add 2 exclusive wavelengths to the ring. It is possible to choose among 4 different incoming wavelengths in order to drop 2 of them. Two incoming wavelengths are selected in a fixed way and 2 wavelengths more in a flexible way by using the splitters.

Using the defined sROADM design, a three sROADMs unidirectional ring can be built. First, a node inserts an exclusive wavelength into the ring, the next node in the ring drops in a flexible way this wavelength and the third node in the ring extracts this wavelength in a fixed way.

Both flows of a bidirectional lightpath are routed on the sides of the ring, using different wavelengths. There is no possibility to reuse wavelengths on the ring due to the internal architecture of the nodes. As the nodes are equipped with two transponders belonging to a collection of 6 different wavelengths, the maximum capacity that can be allocated on a three nodes ring is limited to three bidirectional channels.

Depending on the traffic pattern to be transported, this kind of unidirectional ring will support a different number of bidirectional channels. Let us analyze two different traffic patterns. The first one represents one bidirectional communication between adjacent nodes in the ring and it is able to transport up to 3 bidirectional optical channels, the maximum traffic capacity. The second traffic pattern represents two bidirectional communications between two nodes in the ring and it is able to transport only up to 2 bidirectional optical channels. Fig. 3 shows both traffic patterns for bidirectional communications.

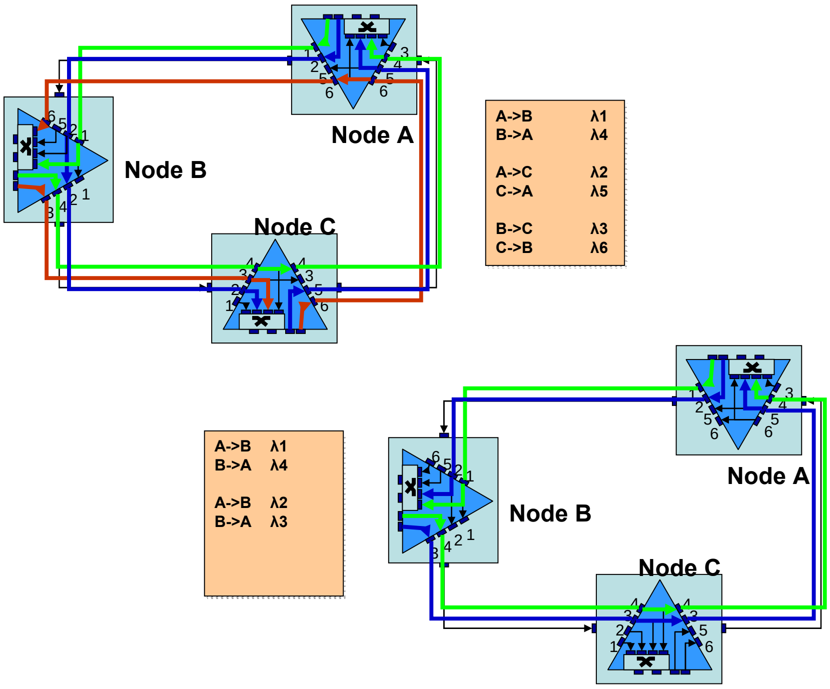

Fig. 3. Traffic patterns

The functional design of the 2x2,5 Gbps transponder card is shown in Fig. 4. It allows transforming two 2,5 Gbps client signals into fixed DWDM wavelengths to be added to a DWDM link.

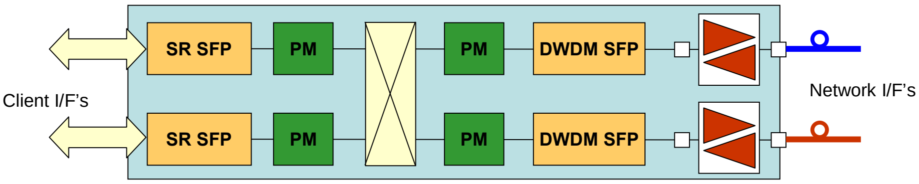

Fig. 4. 2x2,5 Gbps Transponder card

The transponder card integrates several modules:

- *SFP client transceiver*. It transforms a client 2.5Gbps optical signal into an electrical signal to be processed and vice versa. It supports up to OC-48 SONET/STM-16 SDH, G.709 FEC and GbE. The speed and protocol are selected through software.
- *DWDM SFP*. It transforms a fixed DWDM 2.5Gbps wavelength into an electrical signal to be processed and vice versa.
- *PM module*: It monitors for error in the link in a non-disruptive way. This module supports SONET/SDH or Ethernet Performance monitoring in both receiving

and transmitting paths. All necessary monitor functions for SONET/SDH and GbE are provided for OAM and Provisioning.

- *Integrated switch:* Allows reconfiguration and to perform loopbacks to the client and to the line. Loopbacks are used to test end-to-end signal continuity for the link and for the client.
- *Integrated Booster Amplifier:* Can be optionally placed at the nodes. It is possible to choose into amplify in a per wavelength basis or in a per link basis. If a per wavelength basis is chosen, booster amplifiers are integrated in the transponder card as shown in Fig. 4.

The transponder card supports both Add/Drop and Regeneration as shown in Fig. 5.

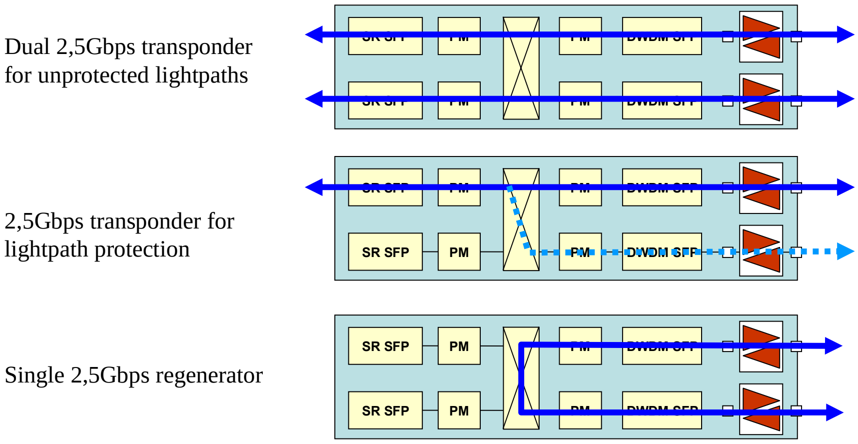

Fig. 5. Different uses of the transponder card

3. Management interfaces

The standard management framework currently used is the Simple Network Management Protocol (SNMP) [11]. It was introduced in the late 1980s and is widely supported by network devices. SNMP is a special-purpose management protocol that can be used to read and write simple typed variables. The software component that handles the associated Get/Set requests and accesses the internal data structures on managed devices is called an *agent*. In addition to processing such requests, an agent can also generate notifications under certain circumstances and send them as unsolicited messages to the management application (*manager*). This architecture is known as the *manager-agent* paradigm. Concrete data models for managing specific technologies or protocols are defined and standardized in management information base (MIB) modules, which are written in a language based on Abstract Syntax Notation 1 (ASN.1) [12].

However, SNMP has been used mostly in monitoring for fault and performance management, but has been hardly used for configuration management due to its limitations [13]. For example, the object identifier (OID), which is a naming mechanism of SNMP, is so simple and verbose that it is very inefficient in usage and implementation. Moreover, configuration tasks require several high-level management operations such as download, activation, rollback, and restoration. The SNMP Set operation can be used to realize such operations as side-effects, but it makes management applications very complicated. Therefore, with SNMP it is difficult to support various operations such as to load/restore configuration, activate a new configuration at a specific time, and roll back a configuration [14]. Finally, UDP is the preferred transport of SNMP for IPv4. The size of SNMP over UDP messages is usually limited by the size of the maximum transmission unit (MTU), which is insufficient for bulk configuration data transfers.

To overcome the shortcomings of SNMP, Extensible Markup Language (XML) technology can be used for configuration management. We have integrated a XML-based agent in our sROADM, implementing a proprietary XML-based protocol. The protocol is connection oriented, requiring a persistent connection between the manager and the agent. This connection provides reliable and sequential data delivery. Additionally, in order to provide a standard SNMP management interface, a module in charge of translating SNMP Get/Set request into XML commands and vice versa, has also been provided.

4. sROADM building blocks

The physical sROADM will be allocated in a chassis designed to be placed in a standardized 19-inch rack. In order to do so, the functionality depicted in Fig. 1 has been separated into several building blocks. Each building block has been conceived to be physically implemented as a separated insertable card, as shown in Fig. 6.

Three different blocks, or cards, have been defined: the Mux card, the Transponder card and the Optical Switching and Monitoring (OSNL) card.

Each active card in the optical node is equipped with an ARM7 32-bit RISC processor [15] running at 100MHz. The Processor Card controls the components in the card and manages the communication with the *Master Card*. The Master Card communicates through an internal RS422 serial bus with each of the cards in the optical node and through a fast Ethernet interface with the control and management planes. The Master card is based on the UNC90 microcontroller module [16], which is equipped with an ARM9 32-bit RISC processor [15] running at 180MHz. The UNC90 module includes, in addition to other elements, the RISC processor, 32 MByte SDRAM and 32 MByte Flash Memory. The internal architecture of the optical node is shown in Fig. 7.

The OSNL card processor includes an interrupt driven system to allow the CPU to continue processing instructions while some request from the Master Card arrives. In the mean time, the card processor is executing a polling loop to continuously read values of samples from the monitoring register. If the values for the samples read within 1 ms are considered as out of bound, the card processor declares a LoL condition. This condition has to be signalized to the Master card sending a proprietary message through the serial bus. The Transponder card processor executes commands from the Master Card related with switching on/off the lasers and controlling the electrical switch.

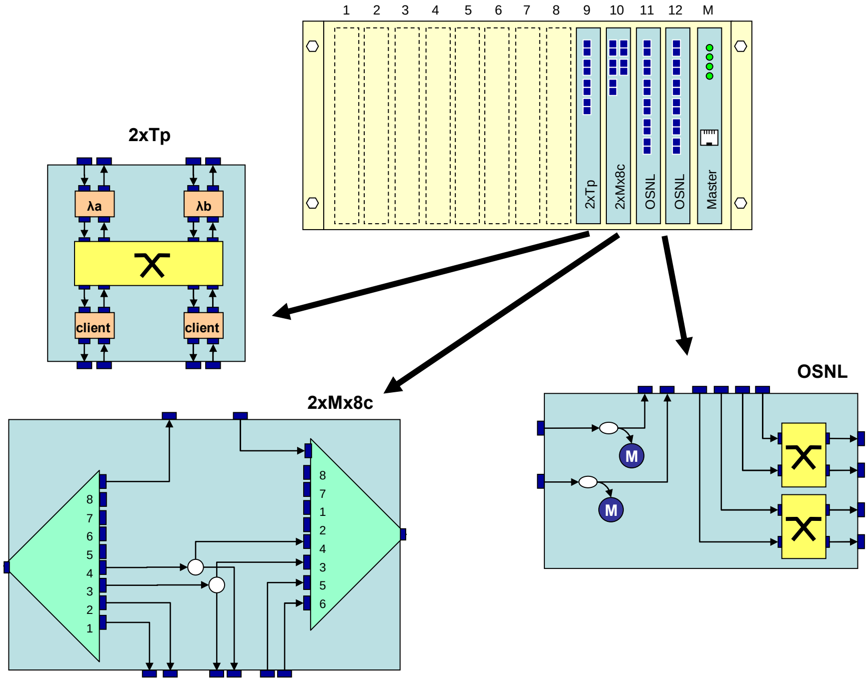

Fig. 6. sROADM physical layout and building blocks

The Master processor runs Linux Operating System. A node agent has been developed to manage the whole optical node, interfacing from the cards to/from the control and management plane. The agent listens for incoming data from serial and TCP/UDP ports. When a message through the serial port is received indicating the LoL condition, the application sends a SNMP trap which brings the related information to the OCC in the control plane and/or the NMS in the management plane.

The agent on the Master Card accepts request-response commands using both a XML-based proprietary protocol and the standard SNMP. When a message through a TCP/UDP port is received, the application decodes it and possibly initiates a communication with another card in the optical node through the serial bus.

Let us denote T_{config} as the configuration time of the optical node, that is, the time to process a request from the OCC (or the NMS) or to inform the OCC (NMS) upon any incidence. 5ms has been specified as the maximum for T_{config}. In order to optimize the system, some bottlenecks have been detected and corrected. One of the more important is the one related with the TTY device driver architecture in the Linux kernel [17].

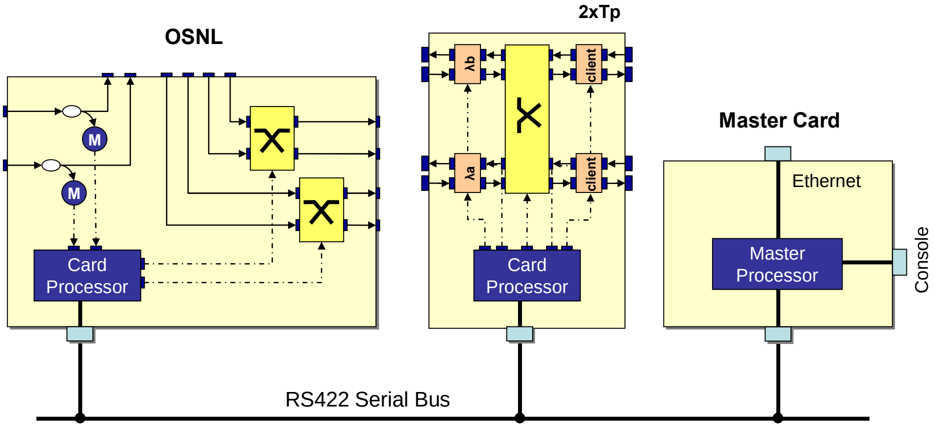

Fig. 7. Optical Node internal architecture

Fig. 8 shows the physical layout of the resulting OSNL and Master cards and the testbed where the complete architecture is being tested.

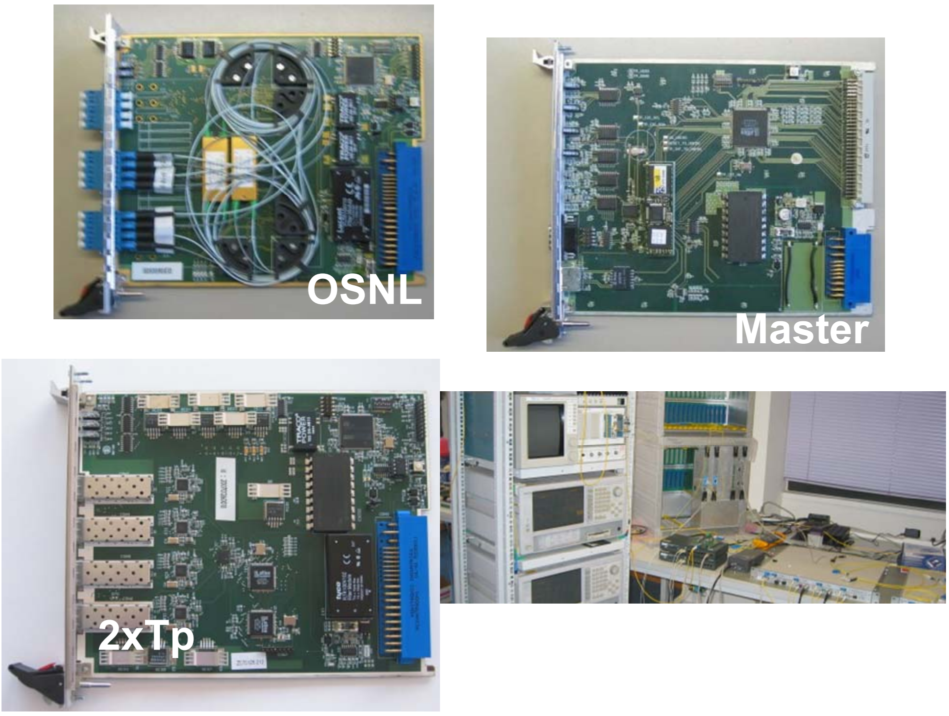

Fig. 8. Physical layout of OSNL, Transponder and Master cards and testbed.

5. Conclusions

In this paper we have presented a GMPLS-controlled semi-Reconfigurable OADM functional and physical design.

The sROADM consists of three stages, namely, optical demultiplexer, optical switch or add/drop stage, and optical multiplexer. Optical demultiplexer functions to separate wavelengths in an inlet fiber onto individual wavelengths. These wavelengths are then either dropped, connected to a 4x2 optical switch, or connected to an optical multiplexer through the optical splitters. The optical splitters allow for multicast connections. The last stage is optical multiplexer which is responsible for aggregating all those wavelengths either added, or coming from the optical demultiplexer, into an outlet fiber.

The described functionality has been split among several physical cards. Among them, we stress:

- The OSNL card is equipped with two optical switches and 2 optical power meters.
- The Transponder card integrates client and DWDM transceivers, a PM module, a switch for reconfiguration and an optional booster amplifier.
- The Master Card controls the complete optical node and interfaces with elements located in other ASON planes. Besides the standard SNMP protocol, the node implements a more efficient proprietary XML-based protocol.

Each card in the optical node is equipped with a card processor. A serial bus connects the cards in a chassis.

While developing the software, which is located in the different card processors, some low level tuning has been done in order to reach a very fast node response.

6. Acknowledgment

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