Optical Node Architectures in the Context of the Quality of Service in Optical Networks

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Abstract—**We show a new generation reconfigurable add drop optical node architecture in the context of evolution of the flexible photonic layer in telco networks. We compare the proposed node architecture with the existing classic reconfigurable optical add drop multiplexer (ROADM) architectures and also directionless, colorless and gridless techniques. We focus particularly on various aspects of the quality of service in optical network, such as blocking probability and full automation including touchless provisioning of bandwidth and a reduction of manual errors. Additionally, we stress the benefits of the proposed node architecture in both near term and long term future.**

Keywords–DWDM network; node architecture; reconfigurable optical add/drop; CDC optical node; QoS; blocking probability.

I. INTRODUCTION

Optical networks are undergoing significant changes due to the exponential growth of traffic (e.g., internet traffic, increasing demands for multimedia and cloud computing). The continuous growth of customer IP traffic in combination with high-rate applications, such as video on demand, high definition TV, cloud computing and data center storage systems require cost-effective and scalable networking infrastructure. It is predicted that IP traffic will grow still rapidly in the next years [1]. This prompts for increasing the capacity and transport efficiency of optical networks in order to realize all client demands and to be able to guarantee high Quality of Service (QoS) that is crucial within a large corporation networking environment (i.e., financial corporation, banks, network providers). On the other hand, the design of a modern optical network has to have an ability to accommodate both large demands (e.g., 1Tb) and a small ones (e.g. 1 Gb). For example, multi-core processing network storage or cloud computing applications are requesting data flows from 1 Gb up to 1 Tb. Existing Dense Wavelength Division Multiplexing (DWDM) network operators provide 10 Gb, 100 Gb, 400 Gb and 1 Tb bit rates and therefore a flexible node architecture is needed.

In recent years, the reconfigurable optical add/drop multiplexers (ROADMs) have been widely deployed in DWDM networks [2]. ROADM enables in a flexible way to add and drop WDM channels without manual engineer intervention at the network operator site [3][4]. However, most current network operators have still ROADM nodes with limited automatic provisioning. ROADM architectures for colourless, directionless and contentionless (CDC) WDM nodes are of great interest for future generation optical networks since they allow access to any colour and arbitrary direction from any transponder within a network node [5]. Such architectures enhance network flexibility and increase QoS. Also they improve overall availability and simplify routing algorithms for network management. The deployment of advanced CDC ROADMs node architectures and implementation of generalized multiprotocol label switching (GMPLS) within control plane in DWDM networks are another significant advantages. Such activity causes the close cooperation among vendors and network operators [6]. It is currently one of the major drivers for network operators to deploy GMPLS in their DWDM networks, mainly because of failure survivability and very quick network restoration after a failure event. This significantly increases QoS of optical networks from the network customer point of view.

Flexible grid spectrum is another important feature of modern WDM networks and is a way for operators to future-proof networks that will ultimately need to content with transport speed beyond 100 Gb/s bit rate [7]. The proposed solution is a more granular version of the ITU grid that brakes spectrum down to 6.25 GHz granularities [8]. Low utilization in provisioning a lightpath becomes more severe when the frequency slot granularity becomes larger. For example, it is spectrally efficient for an optical channel with 12.5 GHz frequency spacing to carry a 40 Gb/s lightpath. However, it will be spectrally wasteful for the same lightpath if 25 GHz frequency spacing is applied. From this perspective, for better spectrum utilization a gridless allocation mode was evaluated [9].

One of the most profound engineering problems in optical network is refered to as the Routing and Spectrum Allocation (RSA) problem and essentially consists in finding currently unoccupied spectrum resources to establish a given set of lightpaths in a traffic efficient way with respect to a future demand. Due to the spectrum contiguity constraint, the RSA optimization problem is NP-hard, considerably more challenging than the corresponding Routing and Wavelength Assignment (RWA) problem in fixed-grid networks [10][11]. During the last decade the RSA problem attracted a considerable attention of the telecommunications community. In effect, numerous exact and heuristic approaches for solving various RSA instances are now available [12][13]. On the other hand, an important problem concerning optimal cost design of Elastic Optical Networks (EON) was investigated [14] - namely the problem of optimizing the configuration of sliceable-bandwidth variable transceivers (S-BVT) in the EON nodes. In our opinion, however, all those approaches have a common drawback in that, they do not effectively treat the optical node.

In this paper, we focus on the optical node architectures in optical DWDM networks. We compare them and show the benefits of such solution in the near term and long term future of optical DWDM networks.

The rest of this paper is organized as follows. In Section II, we present optical node architectures. Then, in Section III we focus on the benefits of the architectures. Last Section concludes the paper and shortly describes our future work.

II. OPTICAL NODE ARCHITECTURES

New Generation Reconfigurable Optical Add Drop Multiplexers (NG ROADM) consist of four functionalitiess: directionless, colourless, contentionless and flex grid (CDC-F). The functions can be deployed all together or in different combinations, such as CD, CDC or CDC-F.

A. Conventional ROADM

Classic ROADM architectures have two important limitations. Firstly, they are coloured. This means that each transponder coresponds to a fixed wavelength. The second constraint is that the add/drop process is directional. This means that outband direction of the add signals is limited to the same degree and can not reach other ROADM degree. This prevents the added signals to be routed to different optical paths and thus limits the flexibility of the node and the network. An illustrative example of conventional ROADM is depicted in Figure 1.

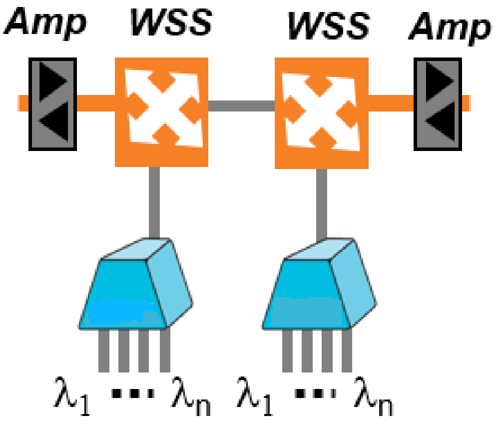

Figure 1. Conventional ROADM. Designed for metro to long haul infrastructures with mesh connectivity.

B. Directionless ROADM

The NG ROADM needs to have the directionless functionalities. It is defined that for any channel dropped at the local node, the coresponding add channel can go to any output port, regardless of which input port it comes from. The directionless feature allows more efficient sharing of transponder in a node among different ports, and therefore improves the protection process. Figure 2 shows the functional schematic of directionless feature.

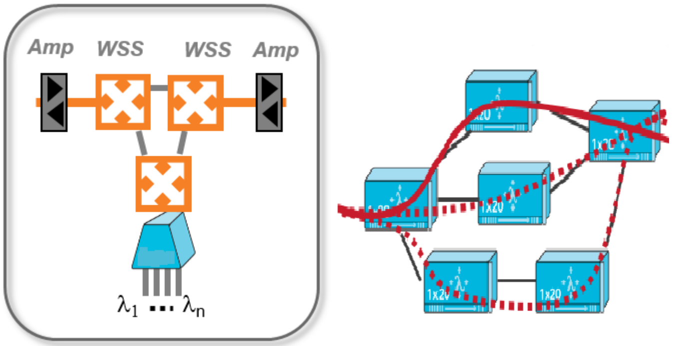

Figure 2. Directionless ROADM. Remotely route wavelenghts across any viable path.

C. Colourless ROADM

Network operators are demanding colourless functionality for NG ROADM, where the add/drop ports are not wavelength specific and any transponder can be tuned to any channel (colour). This feature allows full automation of wavelength assignment. Colorless feature also allows the network operator to use different wavelength for different sections in the optical paths to avoid congestion situation in the network. Directionless and colourless ROADMs are increasingly being discussed together as “must haves” for true optical layer flexibility.

Colorless ROADM node architectures automate the assignment of add/drop wavelength functionality. There are several variations for building colourless ROADMs. Regardless of architectures approach, the final result is that any wavelength (colour) can be assigned to any port at the add/drop site, completely by software control and tunable transponders, now widely deployed, without any technician intervention on site. An example of colourless ROADM architecture is depicted in Figure 3.

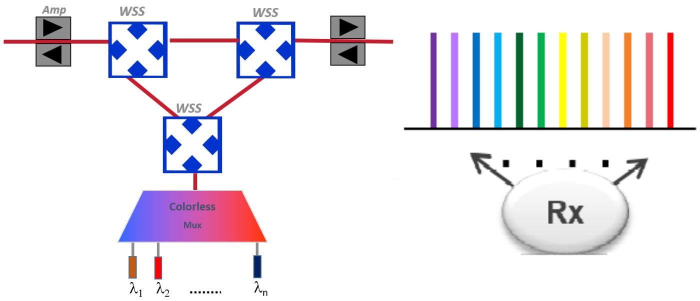

Figure 3. Colourless ROADM. Reconfigurable and restorable infrastructure. Receive any wavelength on any port.

D. Contentionless ROADM

The notions of colourless and directionless ROADMs have been discussed within the industrial research community and by optical network operators for a number of years now. The concept of contentionless ROADM networks, on the other hand, is fairly new and was introduced only relatively recently. The main driving the factor behind contentionless ROADMs is the fact that even with colourless and directionless functionality, a ROADM network still has severe limitations. Namely, in a colourless or directionless ROADM network a manual on site intervention may still be required. In other words, a colourless or directionless ROADM network is not fully flexible.

Another problem inherent to colourless and directionless ROADM networks is that a wavelength blocking event may occur when two wavelengths of the same colour arrive simultaneously at the same WSS structure, which results in wavelength contention. A network operator may avoid an occurrence of such wavelength contention events by partitioning the add/drop structure so that differently coloured wavelengths are associated with different structures. In this way the possibility of a simultaneous arrival of two identical wavelengths at the same add/drop structure is eliminated. However, it needs to be noted that whilst such solution eliminates an occurrence of wavelength contention from a channel provisioning perspective, it reduces at the same time the dynamic flexibility of the network. Further, an additional add/drop structure is required to handle the traffic when two wavelengths compete for the same WDM channel. Therefore, a more effective solution of the problem is an introduction of a contentionless ROADM architecture. The contentionless ROADM architecture, illustrated in Figure 4, by contrast, allows multiple copies of the same wavelength to be handled by a single add/drop structure.

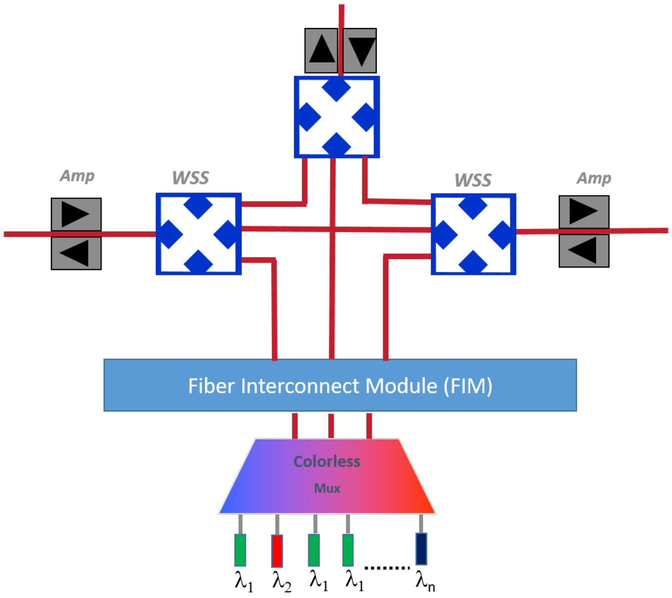

Figure 4. Contentionless ROADM is able to add and/drop the same wavelength on the same mux/demux module. In this particular 3-degree ROADM CDC architecture there is possible to add/drop 3 λ_1 (green colour) on the same mux/demux module.

Hence, a colourless/directionless architecture combined with truly contentionless functionality is the end goal from the perspective of any network operator that has deployed - or is planning to deploy - a ROADM network. Such architectures, namely colourless, directionless, contentionless (CDC), offer an ultimate level of flexibility in the optical layer.

E. Flex Spectrum

The fourth key concept in NG ROADM architectures, depicted in Figure 5, is the concept of a flexible spectrum (also called gridless WDM). The flexible spectrum is a way for operators to future-proof networks that will ultimately need to contend with transport speeds beyond 100 Gb/s. For speeds beyond 100 Gb/s - i.e., 400 Gb/s or 1 Tb/s - more than 50 GHz of spectrum may be required. Network operators would also like to be able to accommodate those future transmission speeds using the same 40 G and 100G ROADM networks.

In essence, gridless WDM is a more granular version of the ITU grid that breaks spectrum down to 6.25 GHz interchannel spectral distance. Thus, ROADM nodes supporting a flexible grid are capable of routing any WDM channel that has a bandwidth, which is a multiple of 6.25 GHz, e.g., 25 GHz, 75 GHz, etc. It is future-proof solution that prepares optical network for any higher capacity channel that needs more than 50 GHz spectrum.

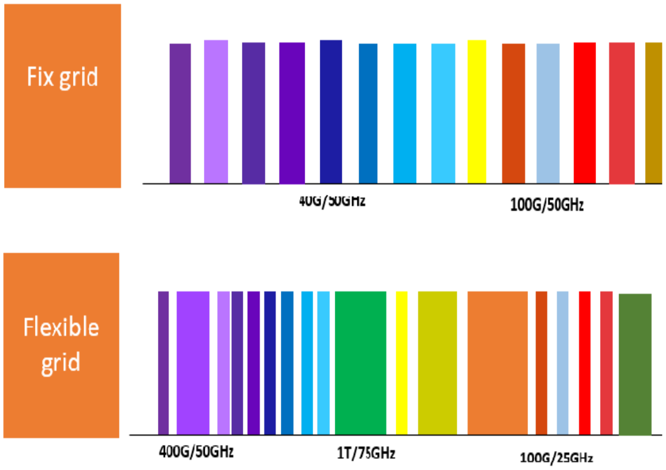

Figure 5. Fix grid and Flexible grid spectrum. Discover to increase network spectral efficiency.

III. BENEFITS OF NG ROADM ARCHITECTURES

NG ROADM architectures are of great interest to network operators since these network architectures allow connection of any wavelength from any transponder in any direction. This helps service providers to enhance network flexibility and survivability whilst reducing operational costs. Currently 100 Gb/s standard is beginning to move from long-haul networks to metro/regional networks. As operators move to metro coherent 100 Gb/s standard, they are simultaneously upgrading their layer 1 and photonic metro infrastructure. Advanced modulation schemes and super channels, enabled by coherent detection, are leading operators to future-proof their ROADM networks by deploying flex spectrum hardware today, in anticipation of variable channel widths in the future.

Another benefit is opex and capex reduction. Opex reduction is delivered primarily via the touchless provisioning and activation of network bandwidth and in particular by automating the activation of the end points of photonic layer circuits. As noted, a classic ROADM WDM system delivers a level of automation in the network by enabling touchless provisioning of bandwidth. CDC functionality eliminates the need for technician truck rolls, thus saving on labor costs as well as reduce the time to provision. Another important opex benefit delivered through automation is the reduction of manual errors and dirty connection - risks that can be completely avoided through automation.

There is also another advantage connected with the integration of NG ROADM with Optical Transport Network (OTN) solution. This solution allows network operators achieving almost optimal fiber bandwidth utilization. The gain resulting from an application of NG ROADM with OTN is significant because it provides for grooming of "smaller lambdas" (e.g., sub-wavelength level traffic like SDH, Gigabit Ethernet and Fibre Channel) and consequently the available wavelengths are utilized optimally before they are switched in the ROADM layer. Such solution leads to further capex savings by integration of OTN switches and CDC-F ROADMs within the same system. We also note that an application of a CDC-F ROADM layer allows for an implementation of Software Defined Networks (SDN) and thus allows for a multi-vendor and multi-layer integration.

IV. CONCLUSIONS AND FUTURE WORK

The implementation of the flexible optical layer in backbone network optical fiber based technology is currently on the way. NG ROADM allows end to automation and increases QoS through flexible provisioning of bandwidth, an elimination of technician visits on sites and of related human errors.

Our future work will be concentrated on the optimization of the optical node resources in optical networks and a comparison of various nodal architectures. For this purpose we intend to develop specifically tailored optimization algorithms including integer linear programing and heuristic approach.

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