Benefit and Applicability Analysis of OXC Based Solutions in Transport Networks

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Introduction

Over the last year a number of network operators have actually engaged in serious considerations of deploying Optical Cross Connects (OXCs) as key architectural elements for their next generation optical transport networks. OXCs facilitate the switching of individual wavelengths at the nodes of a DWDM-based network [1,2]. Early products in the market utilise tiny mirrors steered by electromechanical means – they perform space switching of individual beams - although alternative approaches are also developed and will probably hit the market as available products in the near future. Some service providers have actually started a number of field trials to evaluate the early products that appeared in the market.

There are several advantages in using these recently available systems. The advantages are based on new features and potential revenue generating services that they introduce to transport networks. Many of these have been discussed during early development and positioning of the business case for OXCs. However, the recent downturn in markets have made service providers more reluctant to cost-justify introduction of OXCs into their transport networks.

In this paper we concentrate on an analysis of the trade-offs introduced with deployment of OXCs in service provider networks. We focus on discussing the properties of this technology. The benefits of these architectures vs a non OXC based optical transport network architectures are discussed and the features that can be realised with such solutions only are analysed. A case study is employed with OXC and non-OXC based architectural approaches examined. The results of this study clearly indicate the trade-offs which the service providers need to consider when examining the deployment opportunities for OXCs in their networks. Finally the issues brought up with the analysis of the trade-offs are discussed and recommendations are made.

OXC Technology

Network operators are starting to consider Optical Cross Connects as the architectural basis for their next generation optical transport networks. Optical Cross Connects (OXCs) facilitate the switching of individual wavelengths at the nodes of a DWDM-based network. Coupled with DWDM wavelength demultiplexer and multiplexer units, it is possible to switch any individual channel from one fibre to another.

The first group of Optical Cross Connect systems has a photonic (optical) switch fabric. An OXC with a photonic fabric (no electronic devices in the optical path) is transparent to optical signal rate, format and protocol. Initial designs utilise tiny mirrors steered by electromechanical means – they perform space switching of individual beams. The second group of Optical Cross Connect systems has an electronic switch fabric. Because these systems use an electronic fabric, they are sensitive to optical signal rate, format, and protocol. A change in any of these parameters requires a change in the opto-electronic components of the switch.
Figure 1. Micro mirrors technology

Few products belonging to the first group, have appeared in the market as the first representatives of this technologies and define high capacity all-optical cross-connect system (O/O/O). These are true optical cross-connect system with an optical switching fabric rather than an electrical switching fabric. Utilizing Micro Electro Mechanical Systems (MEMS) technology, they provide protocol and bit-rate independent switching of unidirectional or bi-directional channels. MEMS Technology relies on arrays of electrically configurable microscopic mirrors as shown in figure 1. Switching is possible because these mirrors can be rotated around micro-machined hinges. The mirrors have 0.5mm diameter and less than 1mm spacing between them. The series of these mirrors put together the form the mirror arrays, as seen in figure 2, which are the core of the available OXCs today. The optical connections to these mirrors are accessible for field cabling, if required (field cabling is required in the initial installation of the Diverse Duplex configuration). The Switch Shelf (SWS) contains the MEMS mirror arrays, optical lenses, fiber, and connectors required for optical transmission. An example of optical space switching can be seen in figure 3.

The all-optical cross-connect system provides advantages over Optical-Electrical-Optical (OEO) systems. The all-optical cross-connect provides transparency of the signals presented to the system at the interface, as well as through the switching fabric. The transparency of the fabric allows the system to scale with the capacity of the signals it carries. A single path through the switching fabric can be used to carry 2.5Gbps, 10Gbps, 40Gbps, or even a DWDM signal – on a single port. Thus, the capacity of the system in an example 224 port configuration can scale from 560G, 2.24Terabits, 9 Terabits all the way through 100s of Terabits – in a small footprint with low power consumption. A comparably equipped OEO system, utilizing a 2.5G fabric, actually decreases the capacity of the system by a factor of 4, as the bit-rate of the interfaces provided to the system increases by the same factor of 4. However, OEO approaches might be more applicable in a number of cases, especially in todays environments, where the is still significant sub-lambda traffic in the core and where the growth and resilience requirements of lambda traffic are not significant.
Figure 2. MEMS based mirror array of an OXC (WS Lambda Router case)

There are several alternative technologies which are however very early in the development stage for use in optical switching systems [3]:

- **Bubble switch** technology developed by Agilent uses the creation of a bubble in gel contained in a planar waveguide to change the index of refraction of the material and reflect a beam from a fiber.

- **Liquid crystal switch**: An applied electric potential alters the polarization of a liquid crystal to steer a polarized beam.

- **Thermo-optic waveguide switch**: Heat alters the refractive index of a waveguide bending light from a fiber. This technology is useful for 2x2 switches.

- **Semiconductor optical amplifier (SOA)** based switches use splitters, combiners, and SOAs to perform virtually lossless optical switching by turning the amplifiers on or off to control the switch.

- **Holographic technology** is early in the development cycle for optical switch applications. One vendor, Trellis, has demonstrated a technology to control wavelength selective gratings in crystals to switch individual wavelengths out of a DWDM signal.

The second group of products, which has an electrical switching fabric, can be further split into two sub-groups:

1. Systems offering VC-4 grooming/switching capability
2. Systems offering a switching granularity of STM-16 and above.

Analysis of these systems is however beyond the scope of this paper.
Value Creation of OXCs

The greatest benefits realized by OXC based network solutions is the ability to automate the optical layer and to increase the revenue potential and profitability of service providers. When the various vendors in the market where competing in the late 90s on which one would bring first an all-optical switch to the market, the market dynamics where very different from today. The availability of an OXC would allow service providers to realise a number of new services that have been well defined and the market seemd to anticipate heavily. An OXC solution would allow for waveleghnt based services and management of the optical layer and service providers could, in the middle of the telecommunications boom of the last year, identify significant revenue potential associated with these new services.

Wavelength-based services are the next wave of services being deployed by carriers in order to keep pace with the unpredictable traffic demands and variety of traffic that their customers are placing on the network. These services, unlike traditional SONET/SDH services, provide superior bandwidth scalability and greater networking flexibility for today’s networking environment. Advanced Service Optical Networks (ASON) and Generalised Multi-Protocol Label Switching (GMPLS) are two approaches that are currently examined by standard bodies (ITU, IETF) and by numerous service providers as candidate approaches to fuel the optical networking services management [4,5]. These approaches could enable service providers to deliver a variety of new services and applications to their customers.

Indicative new services brought in by OXC based architectures are the following:

- Wavelength Provisioning (“Point-and-Click” Wavelength Service Provisioning)
- Pre-Qualification of Optical Connections
- Bandwidth Trading
- Optical Virtual Private Networks (O-VPNs)
- Optical Signaling Gateways
Dynamic Trunking
Optical Dialtone
Service Survivability and availability of protection classes
End-to-End Performance Monitoring
Service Level Agreements

All these new services can indeed offer significant revenue potential to service providers and would be in many cases adequate to justify the capital spending for introducing OXCs to most service provider's networks of some size a few years ago (should true OXCs were available back then). In today’s market situation however, service providers are more reluctant to invest based on anticipated revenue but rather pay significantly more emphasis on the possible cost savings from a capital investment. Although we see that a number of service providers already opting for OXCs architectures simply because their immediate business case requires some optical networking features that cannot be realised without an OXC solution, the majority of them would need to explore the cost savings of such solution in more depth.

Therefore, in today's market, the cost benefits for introducing an OXC based solution are looked at carefully and try to be quantified. Introduction of OXCs implies a direct capital investment expense but it results in cost savings for the operators' networks as well. These cost savings can be classified as direct and indirect.

Direct cost savings are associated with the elimination of expensive transponders (or optical translation units - OTUs) that perform OEO conversion and result from the ability of OXC based architectures to support shared protection (mesh or ring). Shared protection reduces the number of wavelengths that need to be provisioned for the transport of a given wavelength traffic load significantly reducing the number of transponders in the network. On a typical backbone network a shared protection approach would result in an average 30%-50% reduction on wavelength load in the optical layer. The degree of savings is very dependent on traffic and granularity properties of the network in question.

Indirect costs are much more difficult to quantify, however they represent potentially very significant savings on the network. First, the lower wavelength load of a shared protection approach allows for a significant breathing space before a major next overhaul/upgrade of the DWDM systems. Although this is very difficult to quantify since it depends on the future network growth it can be a substantial element in the financials of service providers since it can significantly postpone major investment requirements in the future. In the few cases where upgrades of DWM systems are required within an OXC study horizon, the cost savings implied are very obvious and can be clearly quantified and classified as direct cost savings. The bulk of indirect cost savings, which are always difficult to quantify, are OPEX savings. The manageability and servicability improvements of an OXC based solution arguably allows for major savings in the operating expenses of an optical network. These savings are related to reduced headcount and man-month requirements. It is very difficult for service providers to quantify the OPEX savings when they business case introduction of OXC based solutions although there is a common acceptance that the potential of these savings is very significant.

Overall, the value of OXC based architectures is a combination of the potential revenues associated with the new services introduced (and the appreciation of this revenue potential from service providers) and the direct and indirect cost savings implied. The following case study best demonstrates the issues discussed.
Value Creation Analysis in a Case Study

A case study based on a true Pan European optical network has been conducted to demonstrate the trade-offs between OXC based and non-OXC based optical network solutions. The study focused on the network of figure 4. Traffic was comprising of 3 10G wavelength between key node pairs with only 1 wavelength of each demand requiring protection. Four scenarios have been employed.

Scenario 1: Basic DWDM. Solution employing DWDM terminals only with 1+1 protection feature available from the terminals

Scenario 2: Basic DWDM with Single Node Interconnection. Same as scenario 1 where long distance traffic is closing and opening up protection at intermediate single nodes. That introduces single points of failure but improves overall availability figures with the avoidance of long cycles.

Scenario 3: Flexible DWDM. Same as scenario 2 but OXCs are introduced at key selected interconnection locations to provide Crossconnection and flexibility.

Scenario 4: Intelligent Optical Network (ION). OXC based architecture with OXCs at every node and a shared restoration algorithm allowing for protection.

After going into a thorough network planning exercise for each individual scenario, the broken down relative costs of each scenario are shown in figure 5 [6,7,8]. The cost structure is broken down to DWDM terminal cost, transponder (OTU) and optical amplifier (OA) cost, OXC fixed cost (FC) which is the cost of the OXC core equipment and OXC variable cost (VC) which is the cost of OXC ports. As a general trend the relative cost increase for the given network as features and flexibility are introduced. It is interesting to examine the trends implied by this study and also analyse the savings or revenues that are not captured by the relative cost calculations.
Figure 5. Relative cost break down of the case study scenarios

In scenario 1, seemingly the most cost-effective the service provider will achieve basic DWDM transport. Protection can be provided with the 1+1 feature of the DWDM terminals, however for service providers that cannot accept long protection cycles (i.e. London to Berlin cycle exceeds 4000 Kms) such an approach is simply unacceptable.

In scenario 2 we can have an improvement in overall availability figures (although we introduce a single points of failure, the high fibre failure rate and the long protection cycle lengths dominate the unavailability contributing components) at the expense of additional transponder cost in the interconnecting locations. However, the presence of single points of failure would make such a solution highly unlikely to be acceptable by service providers.

In scenario 3, additional cost is implied by the deployment of OXC s in selected locations. However something that is not captured in the cost analysis are the operating savings in these locations due to the flexibility of wavelength crossconnection and provisioning and also a degree of potential revenues from some limited introduction of services associated with OXCs.

Scenario 4 is actually the step function from the previous scenarios with a truly intelligent optical network being realised. There is additional cost related to OXC capital investment but what is key is a substantial decrease in the transponder costs. This is due, as explained in the previous section, to the shared protection capabilities of such an approach. The savings in this case are not by themselves adequate to leverage the additional investment required, but considering cases where protection requirements are higher (in our case study only 30% of wavelengths need protection) and as wavelength traffic grows the savings could possibly leverage the additional investment required. In addition to that this approach brings along a number of other cost savings issues that are not quantifiable. More specifically, load on the DWDM layer is lower significantly delaying the costly upgrade that will be required as traffic grows. Operating expenses should be drastically lower with much easier and faster provisioning of wavelengths but these savings cannot be included in the capital investment breakdown. Finally, this approach offers the realisation of the numerous potentially revenue generating services discussed extensively in the previous section and although
these potential revenues can only be associated with this scenario only, they have not been included in the cost analysis.

Conclusions

It is becoming clear that the market for OXC solutions is emerging. OXCs have already being offered in the market using MEMS technologies although other technologies are considered as well as discussed in this paper. Associated with the introduction of OXCs are a number of potentially significant revenue generating services that were the key drivers behind the investment and development of OXCs.

The case study examined indicates that the optimality of an OXC based solution vs one that maintains a build up of a basic DWDM layer using DWM terminals is very much dependent on the business case of each individual service provider. Proper recognition of the revenue potential of the services realisable by OXC based architectures and/or necessary features (i.e. shared restoration) that can only be offered by such architectures can by themselves justify OXC investment. For the service providers whose business case does not allow that only to justify such investment, it is the cost justification, which will be derived with higher traffic volumes and protection requirements, that will result in that justification.

The value creation of OXCs is becoming increasingly clear but the applicability (and timing) of this value will depend on the individual business cases of the services providers. It appears though that OXC based solution have significant potential and especially as traffic and protection requirements in the optical layer grow, it will become a key choice for most transport networks.

References