

# Optical Backbone Topology Design under Traffic Aggregation and Flexibility Constraints

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**Abstract:** We present an analysis and propose a heuristic-based approach for the major issue of localization of traffic aggregation points for optical networks. The method is applied on a US topology showing granularity and by-pass effects.

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## 1. Introduction

The introduction of WDM technologies in the transport backbone networks faces the predicted traffic explosion. The bandwidth-rich optical highways are the unique transmission solution, provisioning enough resource to transport the growing traffic. The first approach was to introduce point to point WDM links, solving the transmission capacity problem[1] without care of switching capacity bottlenecks in the electronic domain. Nowadays, WDM has to be considered with a large panel of switching granularities internetworking with SDH/SONET, IP/MPLS or legacy networks. Our purpose here is to build an optimized integrated architecture taking into account potential redundancy of resource in the networks and the jumps of capacity and granularity between optical and electronic domains. Although, we demonstrate that squeezing the most out of WDM introduction requires a well defined strategy for the optical backbone design.

## 2. Multi-Granularity networks in an internetworking framework

Optical technology allows to face the predicted traffic growth with multi-Terabit/s point-to-point links. With numerous wavelengths coming through backbone nodes, the switching capacity have to be increased in order to fit the new amount of traffic. Considering that optical capacity is growing faster than electronic, a switching technology compliant with optical transmission has to be introduced in the backbone nodes allowing very large node capacity. For the first stages, this role is ensured by Optical-Cross-Connects (OXC), which can switch hundreds of wavelengths in a single matrix. Switching with optical technologies can also be enlarged to other granularities such as bands of wavelengths [2], fibers, optical packets or bursts. Most of topologies issues are generic and common for all the possible optical switching granularities, in the following we focus on the SDH/SONET over OXC case, but results can easily be extended to other scenarios.

In order to take benefits from this new switching granularity (wavelength), the previous transmission-based approach is not applicable anymore. Indeed, when a 10 or 40 Gbit/s wavelength is switched, it implies that the equivalent amount of traffic has been planned to justify a wavelength connection going through the backbone network. Hence, the main question is to arrange the spatial distribution of traffic flows on the topology in order to create connections at the optical granularity. Here we assume that flows, candidates for transport inside the optical backbones, have time distribution compliant with circuit switching scheme.

The intrinsic properties of a typical backbone network give us good perspectives to achieve this goal. The relative small number of nodes that compose a backbone network (tens of nodes) and the relative small connectivity (3-5 neighbours per node) let us assume that there will be a strong correlation between flows of traffic inside the network. In other terms, it means that, assuming an efficient planning, numerous flows (e.g. STM1 or IP flows) have to be processed in the same way in the nodes. Thus, this should give the opportunity to establish wavelength connections and process most of the traffic staying in the optical domain. The design and planning of backbone networks should therefore avoid as much as possible the switching in the electronic domain which is intrinsically not required. Otherwise, some capacity bottlenecks will appear and more than this, the cost of the backbone network will increase in a unjustified way.

The bad scenario consists in dropping wavelengths, demultiplexing the wavelengths at each node, switching small granularities in the electronic domain and multiplexing again to reach the wavelength rate and add the wavelengths. In this case, the network provides redundancy of switching resource in both electronic and optical layer and requires more equipment for multiplexing functions. We call it "multihopping scenario". If network planning and design is done by addition of point-to-point systems, all the transmission capacity is then switched (ADD/DROP) at each node and finally no gain can be obtained with switching in the optical domain all the traffic capacity being switched in DXC, IP routers or other electronic equipment.

In the next sections we will show that larger switching granularity and specific heuristic for aggregation point localization can significantly impact the global cost of the network.

### 3. Constraints and method

In the last section, we have seen that a consistent filling of wavelengths with correlated flows can mainly impact the cost of the network. Hence the network design and the planning have to be done including those constraints.

The first step is to find the best location for optical backbone nodes, with the objective of optimising the  $\lambda$  filling ratio and being cost efficient. On the one hand switching many flows of traffic at the same time using optical granularities should reduce dramatically the number of ports in the network. On the other hand, the optical layer should allow to by-pass numerous electronic nodes and to implement a cut-through strategy also saving numerous ports in the network. As a short explanation, we can just observe that number of flows will grow faster than the number of nodes in the topology. Hence the connectivity staying relatively poor the correlation between flows increases justifying and larger granularities.

The second step consists in the definition of links between optical nodes, taking into account flexibility constraints without breaking the correlation created between flows of traffic.

The last step is more planning than design-oriented. The traffic is routed in the new integrated architecture, generating a new distribution of flows compliant with the principles employed during the design.

An entire process (the case study is illustrated by the SDH/SONET over OXC scenario) has been defined as shown in figure 1.

A first traffic-based function calculates the potential of each node of the client layer (electronic) to become an OXC. This evaluation is based on the ADD/DROP of the node itself, the ADD/DROP of an associated area around the node and an approximation of the transit traffic.

At each iteration, the respective merits of each candidate node are evaluated by a second function taking into account the approximation of the number of ports saved and the penalty due to re-routing of traffic to the OXC which is the access to the backbone. The node, which gives the best gain, is then fixed with the associated area (i.e. the one, which allows aggregating enough traffic, represented by gray shadows in fig.2).

The operation is repeated until a gain can be obtained by the introduction of a new OXC.

When all optical node locations are known, an algorithm is in charge of creating links between the OXC. The rules employed here are to link OXC belonging to adjacent areas plus some additional links by-passing an area if the gain in terms of path length (km) is greater than a given value.

Finally, the traffic is routed according to a Two-Criterion Shortest-Path algorithm (first number of hops, then length in km). This routing is a kind of constraint-based routing because most of the traffic coming

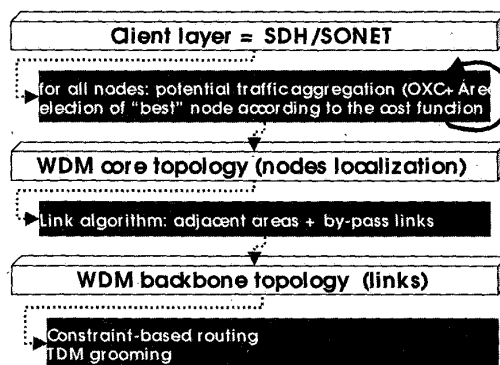


Figure 1: Overall Process

from an electronic node has to go to the backbone through a dedicated OXC. The method described above can be modified in order to take into account new parameters specific to IP or other equipment.

**4. Application to a US Network model**

The following results, obtained using the implementation of the previous method in a dedicated planning tool, are given for a 137 SDH/SONET nodes client layer. A 21-nodes WDM network is generated. The aggregated input for all the network is 101.058 Tbit/s and the traffic matrix is population based. The average traffic between two SDH/SONET nodes is 5.424 Gbit/s. The figure 2 shows the topology built starting from the SDH/SONET network (thin links for SDH/SONET, thick links for WDM) and the table 1 gives some numerical indications on the gain obtained using the optical layer.

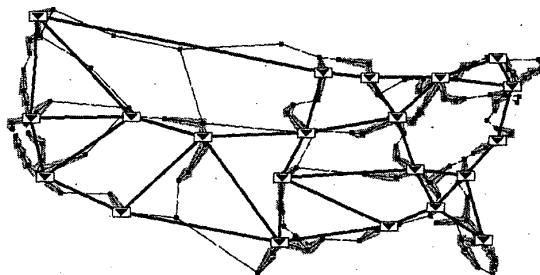


Figure 2 : topologies

Scenarios	# SDH ports (STM16)	#λ ports (10Gbit/s)	Conn. Lgth (# hops)
Single SDH net.	553394	--	12.58
SDH + WDM nets.	221467	38594	3.37+3.21

Table 1: Gain in terms of ports

The average filling ratio of 10 Gbit/s wavelength connections is 97.96% and 89.86% of the traffic is going through the backbone.

The gain is more than 50% in terms of ports for the SDH/SONET layer. The positive effect of the WDM layer is due to the switching granularity which allow to switch four STM16 at the same time and to the implicit cut-through WDM topology which by-passes numerous SDH/SONET nodes. The gain should be more important if the number of SDH/SONET nodes was higher.

**6. Conclusion**

The benefits from the introduction of a WDM backbone including optical granularities has been demonstrated. As a specific integrated architecture issue, the quality of the results depends on the process used to distribute the optical capacity in the "client" topology. The process proposed in this paper tries to take into account traffic and cost constraints using intermediate approximations for the potential traffic and the gains. Moreover the number of ports in the WDM layer [3] can be significantly reduced using WDM grooming in order to handle Bands of wavelengths or fiber (multiplex) connections. Finally, results shown were carried out starting from SDH/SONET layer but the method is generic and applicable to an IP over WDM scenario (changing the cost functions).

**7. References**

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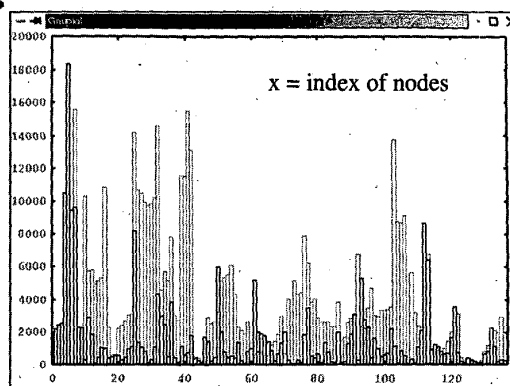


Figure 3 : Distribution of SDH ports (grey=single,black=2-layers)