Migrating to a next generation WDM core network

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The main goal of this study is to examine the different options that arise when building a modern core transport network, considering the short to medium term evolutions planned by the manufacturers. After a short review of possible WDM network designs, a techno-economic analysis allows for benchmarking different architectural scenarios, providing some guidelines in building a future proof WDM core network. At last we highlight some of the challenges to relieve when migrating to an agile WDM infrastructure.

1. Introduction

The explosion of the long distance traffic and the convergence towards all over IP affect the requirements for the transport layer. FTTH may act as an accelerator of this phenomena, and the transport bandwidth required by backbone routers is quickly moving from 10 Gbps towards the 40 Gbps scale.

Network availability becomes also a critical issue, and whereas traditional implementations were based on protection at higher layer using diversely routed but unprotected transport resources, network operators start to investigate on multilayer resilience mechanisms to optimize the core network architecture. In this context, one must consider that the IP layer could benefit from protected transport bandwidth and/or reconfigurable topology.

This clearly makes WDM as the federating layer in the core transport network and WDM granularity seems to be adapted to the future needs, thus limiting the interest of deploying an additional intermediate layer in a pure aggregation perspective.

However following the explosion of the "Internet bubble", the downturn lead the different WDM equipment manufacturers to reduce the development of new products and advanced features. Some of them dramatically cut down on their R&D resources, which resulted in the freezing of advanced feature development, especially in the core transport WDM market considered as less profitable than in the metro space. The so promised control plane and associated end-to-end transparency and switching are still roadmap features.

The availability of WSS as components at affordable prices and the reduction of Photonic Cross Connect (PXC) per port cost are marking a turning point in the WDM market. It will provide the advanced switching features, needed to build transparent, or at least hybrid transparent WDM networks (see [1] for definition). It is now more a matter of industrializing these functions and developing the associated software.

At the same time, France Telecom WDM network is undergoing major changes. Extended Long Haul (ELH) systems have been introduced to lower the cost of the overall network, while increasing the capacity of the network, using systems of higher capacity (80 to 96 versus 32 channels) and generalizing 10 Gbps usage on the overall core network.

However, as for most of the "Legacy" Service Providers, many existing links are still equipped with systems of previous generation. They need to be replaced for different reasons:

- They have reached their maximum capacity.
- The systems have become End Of Life and generate high maintenance costs.
- They were purchased several years ago, at the cost of the market at that time and need to be disinvested because they generate very high cost through the business rates.

It is then rather important to manage correctly the upgrade of the legacy core network, considering all the coming WDM system evolutions and benchmarking all the possible solutions.

The remainder of this paper is organized as follows: architecture alternatives are presented in Section 2, the architecture benchmarking in Section 3. The challenges of migration are discussed in Section 4. Finally, Section 5 concludes this study.

2. Architecture alternatives

The latest evolutions of WDM equipments allow for building more efficient networks. As a first step, we will review the various options that can be selected to deploy a WDM core network, and evaluate their advantages and drawbacks.

Opaque network

In a pure opaque network, the signal is regenerated electronically in each node where the traffic is accessed. Depending on the option selected to perform regeneration, we can separate different classes of opaque networks: it can be implemented through back to back transponders or through an external equipment of a higher layer with or without colored interfaces (Router, Carrier Ethernet switch, OEO Optical Cross Connect...).

As far as ELH and Reconfigurable Optical Add Drop Multiplexer (ROADM) technologies allow for optically bypassing nodes in a very economic way, this architectural option might appear as completely obsolete. However, one shall note that some manufacturers have worked on reducing the cost of regeneration through the massive integration of optical components, making these configurations cost effective [4]. The benefits come then from the ability of such systems to provide switching at the electrical layer, releasing engineering constraints.

Transparent network

In a pure transparent network, the signals are transmitted end-to-end without any electronic regeneration. Wavelength channels may be switched through optical devices (WSS/PXC...) or manually, using specific high density patch panels. Suppressing regeneration shall reduce dramatically the cost of the overall network as far as the cost associated with the enhancement of the system performances, extending its reach, remains acceptable [2].

In practice, it is almost impossible to build a fully transparent network at the scale of a European network, especially when an existing legacy infrastructure is in place (old cables with large PMD values).

Hybrid network

In the framework of this study, transparent and opaque architectures must just be considered as reference models. The evolution of the WDM equipments allows now for building hybrid architectures that correspond to intermediate solutions, where part of the previously highlighted drawbacks (regeneration cost/reduced ability to tolerate large physical impairments) are circumvented using the latest technology developments.

Hybrid opaque network is an alternative of the opaque network in which ROADMs of degree 2 are deployed in some of the add/drop sites to reduce the number of regenerations and simplify network operation. It corresponds to the way most of the long haul WDM networks are built today.

Hybrid transparent network architecture is a variation of the transparent network in which intermediate OEO regenerations are allowed to relieve the cost of the network and simplify its engineering. The end-to-end connectivity is mainly achieved through optical switching, either manual or automatic.

Regenerator positioning is calculated for each path, depending on the physical impairments that it experiences, and is no more constrained by the architecture of the nodes like in an opaque network. Thus, the regenerations can be distributed on the network.

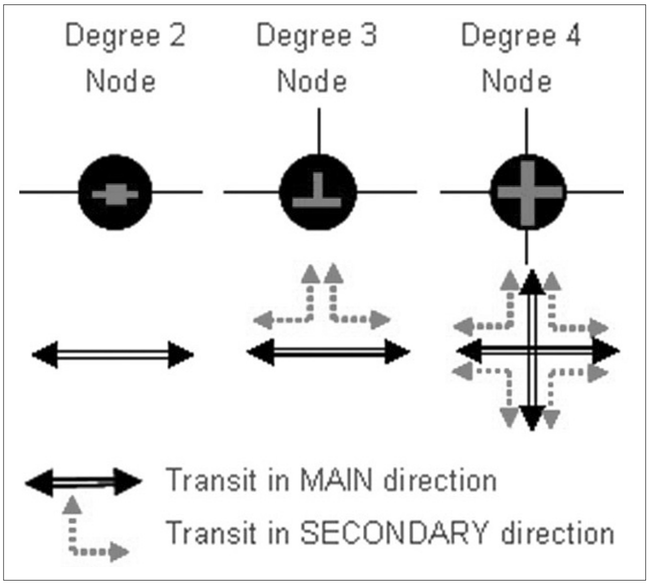
This approach does not prevent from defining specific points of regeneration in order to limit the number of nodes where regenerations are allowed. This will simplify the migration to a fully agile core network where regenerations might be needed to solve wavelength contention or performance issues after a channel has been rerouted. In this perspective, limiting the number of sites where regenerations are implemented allows a better sharing of resources, appropriately placing some pools of active and standby transponders.

3. Architectures benchmarking

A. Studied Scenarios

The most promising architectures have been benchmarked in the favorable context of a green field deployment. Five different scenarios have been defined according to the transit options. We will differentiate in the following sections two types of transit, main and secondary as depicted in *Figure 1.* Costs for main and secondary transits may be different according to scenario and equipment cost model.

Figure 1. Node transit type definition



The *first scenario "Hybrid opaque"* is used as a reference and corresponds to a hybrid opaque architecture, which can be deployed today considering existing WDM equipments. Wavelength Blockers (WB) are used to provide the transit function in main direction(s) for nodes of degree 2, 3 and 4. We consider that regenerators are used for the channels that transit from the main direction to a secondary direction.

The *second scenario, "Hybrid transparent"* corresponds to an architecture, where transits in secondary directions are performed using passive optical bypass. This function can be implemented with different elements (patchcords, optical amplifiers, multiplexers/demultiplexers...) depending on whether it is done at the band level or the wavelength level.

The *third scenario "WSS"*, is built on a hybrid transparent architecture where Wavelength Selective Switches (WSS) are used in nodes of degree 3 and 4 for the transit of the channels from one WDM link to another.

In the *fourth scenario "Fully tunable"*, we also consider the use of WSS to perform multiplexing and demultiplexing of the Add/Drop channels.

In the *fifth scenario,* the architecture of the nodes is selected node by node, so that the resulting network is the most cost effective one. Thus any configuration from the previous scenario can be selected, independently for each of the nodes.

B. Network topology

The network topology has been defined according to the existing France Telecom fiber infrastructure. All related physical constraints (site locations, attenuation, PMD, Chromatic Dispersion...) have been considered in the network model. The network model includes a total of 92 nodes spread in France and on the European Backbone Network (EBN) as follows:

Degree	1	2	3	4
Number of sites	16	48	25	3

The main characteristics of the topology are given as follows:

STUDIED NETWORK TOPOLOGY

Network size	92 nodes	99 links	
Maximum shortest path	15 hops	1982 km	
	Average	Minimum	Maximum
Linklength	226 km 3 spans	2 km 1 span	797 km 11 spans
Span length	72.91 km	2 km	129 km
Degree of node	2.15	1	4

Using the results of preliminary internal studies, the topology was designed by partitioning the network into several subnetworks. This approach allows for releasing engineering constraints, by reducing the network perimeter for each subnetwork. Since most of the traffic converges to the Paris area all subnetworks covering France include Parisian nodes. The Parisian nodes constitute gateways where regeneration allows for crossing the different subnetworks. In such subnetworks several paths allow for getting to Paris, which includes 8 nodes spread out among 4 main sites.

The proposed architecture is based on an analysis of the main traffic contributions and on the flow distribution. The subnetworks were defined according to this, in order to limit the probability for wavelength contention to happen, by reducing their perimeter and increasing their meshing level. The fiber infrastructure was also considered, so that the break points introduced by the network partitioning correspond as far as possible to the best compromise according the PMD level on the different links.

The site connectivity degree has been limited to 4, since the roadmaps provided by different WDM equipment manufacturers show a possible limitation in the short to medium term implementations.

Each demand that terminates in 2 different subnetworks shall be regenerated. There is one exception to the previous generic rule with the defined topology: 2 of the subnetworks are bridged and allow on one path some channels to cross them without being regenerated.

Figure 2 shows the topology which was used for the present study.

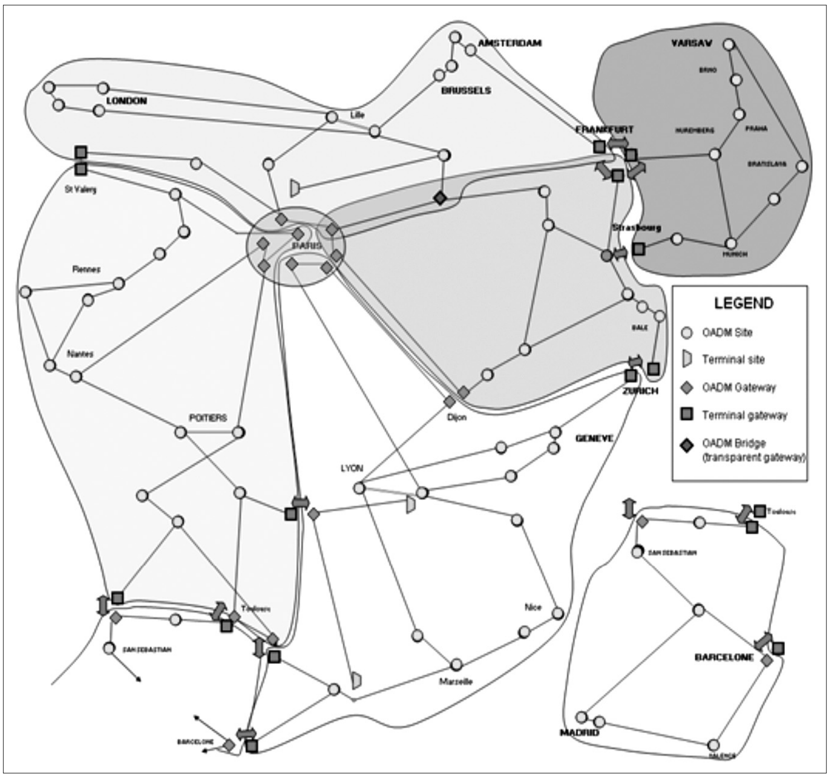
C. Traffic model

The traffic model was built considering that all the existing traffic has to be migrated (if not already supported by new systems) on the NG WDM network. The traffic contributions include ATM and SDH traffic which are quite stable, and L2 and L3 traffic that cross the core network. Part of this last corresponds to residential traffic; the other part corresponds to business services. *Figure 3* gives the traffic distribution from 2007 to 2010.

D. Cost assumptions

The costs used in this study correspond to the costs provided by the equipment manufacturers for the WDM systems sourced by France Telecom. They are revised regularly according to the contractual conditions. They include hardware, software, Installation and Commissioning (I&C) costs.

Figure 2.
Network topology: Hybrid transparent partitioned network



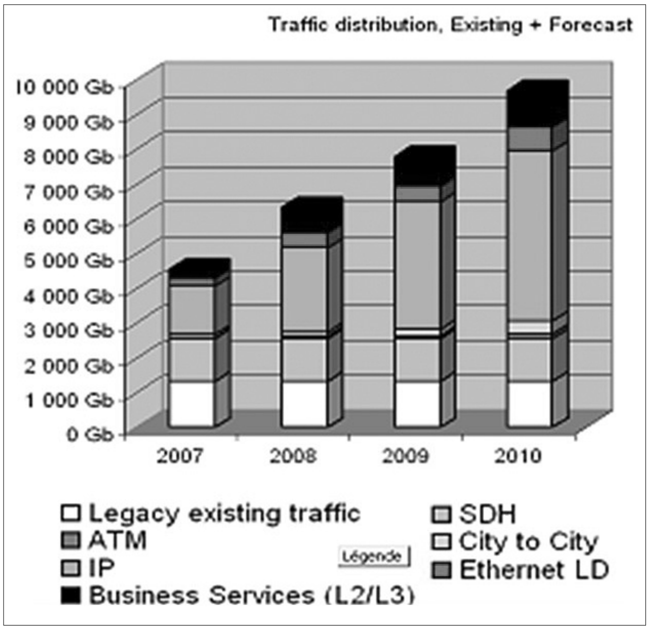
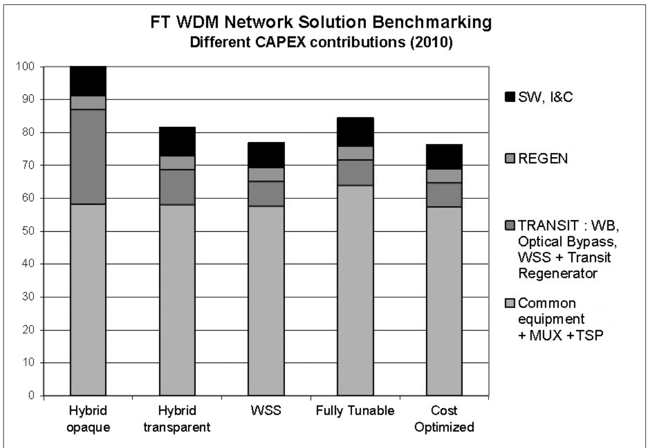


Figure 3. Traffic distribution



	Hybrid opaque	Hybrid transparent	WSS	Fully Tunable	Optimized
Traffic up to 2007	100	85	80	89	79
	Savings /Ref	15%	20%	11%	21%
Traffic up to 2010	100	82	77	84	76
	Savings /Ref	18%	23%	16%	24%

Figure 4. Comparison of the benchmarked scenarios

E. Methodology

A specific tool was designed for the purpose of this study. The inputs of this tool are the network topology and the traffic matrix. As an output, it provides for all the sites the characteristics needed to calculate the cost of the network for the different scenarios (Channel/band Mux/demux, number of transits on the main and the secondary axes, regenerators...).

The methodology uses an iterative algorithm which is schematically the following:

- Find routes (or rings for protected demands) with the least number of regenerators according to engineering limitations of equipments and nodes regeneration possibility;
- Assign wavelength(s) to each demand according to possible blocking with other demands and to band filling strategy.

Two strategies for band allocation have been considered:

- Minimization of the overall number of used bands in the network.
- Minimization of the number secondary transits handled at channel level (in opposition to transit that can be handled at the band level) in each node.

The first one represents the minimum required configuration, without any consideration on wavelength management complexity in the nodes. It is adapted to flexible networks where degree 2, 3 and 4 nodes allow for channel management at wavelength granularity (Scenario 3, 4 and 5).

The second one, on the contrary, considers wavelength management complexity in priority, to the detriment of the global number of bands used. It models the specialization of bands that is desirable when nodes are not equipped with reconfigurable structures: bands are dedicated to a specific network path.

F. Economic Assessment

The main results of the techno-economic benchmarking of the different architectures are presented in *Figure 4.*

The cost of each scenario is detailed for several contributions: common parts, modules providing transit features, regenerators, software (SW), Installation and commissioning (I&C).

From the comparison between the first and the second scenario, we see that implementing optical bypass for transit in secondary directions allows for significant savings (up to 18%) since it allows for avoiding unnecessary regenerations. Optical bypass can be performed at the channel or at the band level. Going down to the channel level implies to cascade more devices and to increase the cost of the bypass. It is also associated with an increased operational complexity. First and second scenarios were studied using the second wavelength allocation strategy, minimizing mixed direction transit in the same band. This solution corresponds to what can be deployed today.

WSS based ROADM seems to be a really interesting option since it adds flexibility in the network. Providing the ability to handle each channel path separately and remotely, with the modules deployed at day one, it eases the network planning since the wavelength allocation is no more connected to the band structure of the WDM equipments. Additionally, the third scenario brings significant CAPEX saving (5 points) in comparison with the second scenario.

The full tunability increases significantly the global cost of the network. The configuration studied here is the simplest option and corresponds to a limited number of WSS in the node. WSS are used in place of channel Mux/demux, to improve the node flexibility and reduce the commissioning time. Thus, the interest of this kind of configuration is somewhat limited, since it does not provide the advanced features needed in the perspective of migrating to a fully agile network. As far as the bands are efficiently filled thanks to the use of WSS to switch channels from one link to another (as it was with the third scenario), the overspend associated with the use of WSS to replace the multiplexers/demultiplexers is not compensated by the savings on the number of ports and the number of modules used to perform channel add and drop.

The optimized solution, where the configuration is selected on a site by site basis allows for limited savings in comparison with the 3rd scenario (WSS based ROADM). WSS based ROADM could be deployed in every site to simplify network planning & engineering for almost no additional cost. One should note that with respect to OPEX, on site commissioning is required at both ends to add transponders and connect them to the WDM and the client equipment for all scenarios. It might also be needed on intermediate site(s) if regeneration is required (back to back transponders patching).

Last but not least, the gain observed for solutions 2 and 3 slightly increases with the network load: the gain presented in *Figure 4* (for 2010) is 3 points higher than the gain observed with the traffic up to 2007.

4. Challenges foreseen in getting to a next en WDM networks

In a more and more competitive environment, the WDM network shall be as inexpensive as possible, at both the CAPEX and the OPEX level, and the flexibility shall allow for reducing production time. Reducing the total cost of ownership while increasing the flexibility is feasible but really depends on the target we set: if solution 3 allows for significant savings, further increasing the flexibility through fully tunable solutions makes these two objectives antinomic. The WDM network shall be designed considering specificities that differ from one network operator to another.

A. Challenges associated with transparency

Transponders and regenerators constitute the biggest cost item in a WDM network. The main reason for introducing transparency is to avoid unnecessary regenerations in order to reduce the total cost of ownership. Each time a channel needs to be regenerated, a break point is introduced in the network. Commissioning this channel currently implies human field operation in a location where the signal does not end. Rerouting a channel on an alternative longer path is also challenging as soon as regenerations are needed.

Nevertheless, increasing network transparency brings its lot of challenges and implies to deploy equipment with high performances.

At the equipment level, increasing the performance is a key element to reduce the network overall cost. There are three main axes we can play with: the capacity, the supported rates and the system's reach.

The highest is the capacity of the system; the lowest is the probability to get wavelength contention. Extending the capacity has a cost since it implies to improve the optical amplifier performances, or to reduce the system's power budget. Upgrading the capacity of the systems in place is most of the time traffic affecting. Another reasonable option to increase a link capacity is to add another trunk in parallel with the first one. In a hybrid transparent network, this translates in upgrading the node to a higher degree, which implies to have available ports on the WSS: 1:5 WSS may appear as rather limited considering this point, and most of the equipment manufacturers go for 1:9 components on the LH product range.

Increasing the rate of transported services helps in reducing the number of channels used in the network. It also structures the network architecture since the migration of a system to higher rates implies that the design has been made at day one considering engineering rules of tomorrow. As developed previously, adding regenerations to compensate for lower physical impairment tolerance is not a good option. In this context, the development of advanced modulation formats like DQPSK (Differential Quadrature Phase-Shift Keying) or Dual Polarization DQPSK which allow for higher tolerances in terms of CD and PMD make way for smooth migration since they solve part of the problem. Engineering constraint at 40 Gbps or even 100 Gbps could be lower than those at 10 Gbps for current technologies [7] in terms of CD and PMD tolerance. However, OSNR requirements will still be higher with this modulation format at 100 Gbps and even 40 Gbps.

Depending on their technology, cascaded WSS may degrade the signal with a wide spectral width, and their ability to support a mix of 50 GHz and 100 GHz spaced signals is an aspect to look carefully at when deploying a transparent network.

Regarding the reach, if Extended Long Haul (ELH) or Ultra Long Haul (ULH) systems have been introduced with the aim of lowering the cost of large backbone covering one or several states/country, one shall keep in mind that in the frame of highly meshed network, any possible path might be implemented. Even if the subnetworks cover apparently limited areas, the deployment of ELH or ULH systems may be justified to reduce the number of regenerations: in the case of France-Telecom EBN, using systems with a 15x25 dB reference power budget allowed for saving up to 230 regenerations compared with a system that has a 10x25 dB reference power budget.

At the network level, partitioning allows for releasing the constraint associated with the physical impairments and network engineering. This operation is complex and the main difficulty lies in sizing appropriately the subnetworks: the smallest the subnetworks are, the less constraint we get in terms of wavelength contention, and the weakest the physical impairments are. At the same time, reducing the perimeter of the subnetwork can lead to unnecessary regenerations needed when crossing 2 of them.

A part of the study was dedicated to the analysis of wavelength contention. Two simulations were launched for this purpose. In the first simulation, all the traffic from 2007 to 2010 is routed one shot, allowing for a global optimization. In the second one, the traffic is routed incrementally on a year by year basis, considering that the planning activity is made every year, using marketing forecasts.

No wavelength contention was observed in the two simulations. The link load reaches up to 81% on some links and the maximum number of bands is reached on several links. However, there was no need for channel suboptimized rerouting or wavelength conversion to solve contention. No significant change was observed on the global cost of the network for the different solutions, but the global number of channel Mux/demux used increases by 10% from 1st to 2nd simulation. One should note that the target of suppressing secondary transit that require handling channels separately was not reached, which would translate in strong operational constraints for the solutions where no switching device is used.

A third simulation was launched in order to find the threshold where wavelength contention starts to occur. We then considered the traffic up to 2012 which forecasts a 50% growth of the pure IP traffic from year 2010. We then started to see the first signs of wavelength contention on 4 links, corresponding to the main axes of the IP hierarchal network. Whereas the link load is of 58 to 87%, no wavelength can be found for additional required paths. We can then consider that the network partitioning was rather efficient since these first signs of wavelength contention appear quite lately and concern a limited number of demands.

B. Interoperability

France Telecom, as many service providers, has a dual source purchasing policy. This contributes to let the competition act, leading to significant cost reductions while reducing the risks, in case of equipment wrong design, or procurement issues. It also guarantees the network perenniality in case one of the manufacturers is not able to meet its obligations.

However, this can lead to interoperability issues, especially in the context of a transparent mesh network, where interoperability is not only required at the transponder level. Hybrid nodes built from equipments of different manufacturers seem difficult to operate, because automatic level adjustments, gain and power control are required for a consistent end-to-end configuration and management: thus, considering nodes of degree 3 or 4 which interconnect WDM trunks from different vendors is not reasonable. Mixing the equipments of two different vendors in a transparent network would lead to a heterogeneous network where different systems cohabit in the same area with no way to make them interoperate. Partitioning solves interoperability issues as far as we consider deploying only one type of equipment in a subnetwork.

C. Flexibility

Degree 2 ROADM built with Wavelength Blockers and higher degree nodes equipped with WSS should simplify dramatically network planning, by providing switching at the wavelength level. These components remove the constraints associated with band allocation, uncoupling the wavelength grid from the band grid. A path will no more need to be strictly mapped to a band, since a band can be added and dropped several times and contains channels that do not experience the same path with this kind of architecture. ROADM can be fully configured remotely by software, simplifying network provisioning since external patching between channels Mux & Demux is no more needed at intermediate points where channels are bypassed.

Getting further in improving network flexibility and lowering the OPEX, some WDM equipment manufacturers propose to introduce TOADM, standing for “Tunable” OADM sites, extending provisioning automation up to the ends of the paths.

In traditional ROADM, multiplexing functions are still performed by Array Waveguide Gratings (AWG) devices and optical access ports are fixed: a color is assigned to each port. A way to get the full tunability is to replace the Mux/Demux by couplers or splitters and WSS. This architecture provides a full tunability of the site: tunable transponders are no more connected to a dedicated port through mux/demux. This solution has been modeled and studied in the fourth scenario. Its main advantage is that everything can be configured remotely as long as sufficient resources have been provisioned.

Figure 5 (on the next page) shows the structure of a degree 2N node. Only one transmission direction is represented on each main axis to simplify the diagram. Ii and Oi_{+1} represent WDM line’s input and outputs on main transmission directions i-i_{+1}. Amplifiers are used at both the inputs and outputs as in standard OADM sites to compensate for WDM link and site modules losses. WSS allow for switching channels from one link to another. Some splitters (after the input amplifiers) provide the broadcast function, feeding the WSS as well as the drop modules with the incoming WDM multiplex. The drop modules associated with each branch are built using splitters and 1:9 WSS. Amplifiers are required to compensate for the losses introduced by these last. The add module is built with several stages of combiners. The added resulting multiplexes are connected to the nodes outputs through the (2N-1):1WSS.

The number of WSS used is rather limited: WSS are used to provide switching from one link to another, and to replace Add/Drop multiplexers. In the simplest configuration, the number of WSS, N_{WSS}, is as follows.

$$N_{WSS} = N + \sum_{i=1}^{N} \left[Int\left(\frac{Chi}{9} \right) + 1 \right]$$

For 1x9 WSS devices used as demultiplexers, with Chi = Number of A/D channel on branch i, N the node degree.

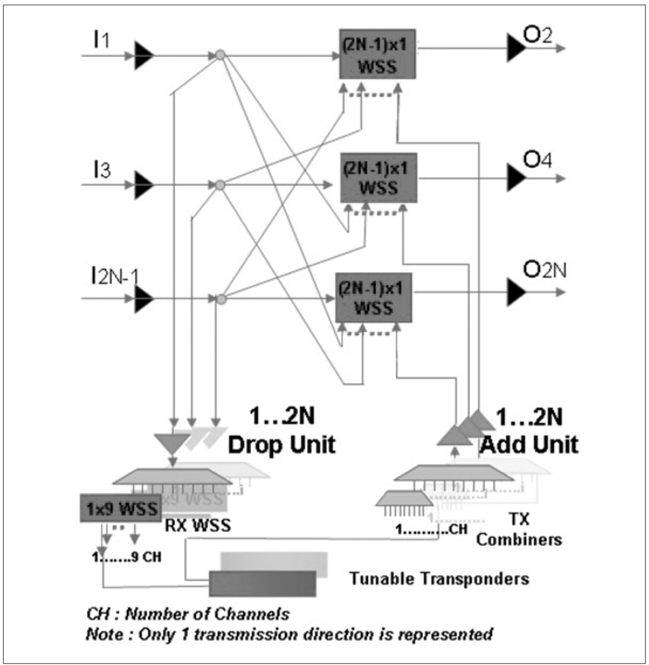


Figure 5. Degree 2N fully tunable ROADM

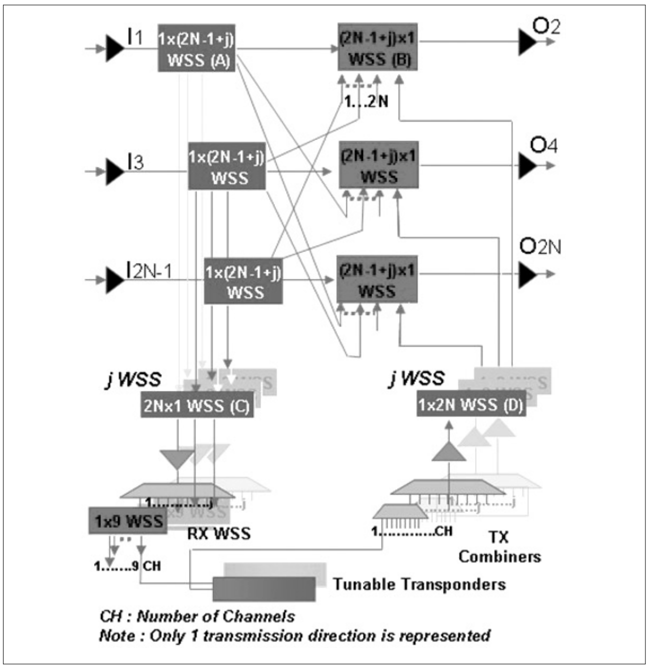


Figure 7. Directionless degree 2N fully tunable ROADM

If full tunability can help in reducing commissioning time, human on site operations are still required to connect client equipments and this configuration presents limited advantages [3]. Since a transponder is physically connected to one branch of a node; first and last hops can not be protected against failures through this configuration as shown in *Figure 6*.

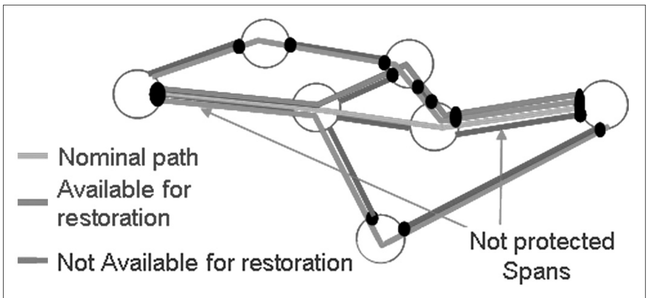


Figure 6. Protection limitations

The directionless feature allows for end to end protection or restoration. The corresponding configuration is presented in the *Figure 7.* The WSS which are added in respect to the previous configuration are represented in blue. The splitters that ensured the broadcast function are replaced by WSS (A). 2 stages of WSS are used in the Drop modules (A and C). The 1:2N WSS (D) of the Add and the Drop module provides the connectivity of the transponders to any of the node branches.

Some of the WSS are not strictly necessary since they could be replaced by combiners, but their use allows for adding flexibility and reducing losses on the different paths. One shall note that any channel must be unique at the output of C and at the input of D. Considering that the wavelengths will be provisioned sequentially and that each branch of the node will load according to the same planning rules, the probability that the same channels are used on different branches is high. Thus, we can assume that *j* will be close to 2N for the degree 2N node represented in Figure 7. This kind of architecture increases drastically the number of WSS. For a degree N node, the number of WSS will be:

$$N_{WSS} = AN + \sum_{i=1}^{N}\left[Int\left(\frac{Chi}{9}\right)+1\right]$$

With $A=2$ at the minimum and up to 4 if WSS are used at both the receiver (RX) side and the emitter (TX) side with $j=N$.

According to this, the extra cost for directionless full tunability could reach 45% of the global site cost, to which 15% must be added on the channel cost for each of them. The configuration becomes really complex and a high number of active equipments is crossed. It results in a significant increase of the power consumption and the footprint.

The configuration is directionless but is not fully non-blocking since a WSS and combiners used at the RX and TX side can not support twice the same channel. During a path reconfiguration (after a network failure), a transponder might be tuned to another wavelength to solve contention issues. It can not be tuned to the same wavelength as a transponder that is connected to the same WSS or combiner.

With flexible node architecture, a control plane could be used to provide shared protection or Dynamic Restoration (DR) as it is implemented in SDH networks. The savings on transport resources (capacity-distance) associated with the implementation of advanced restoration schemes at the SDH layer (VC-4) is in the order of 15 to 30% depending on the network characteristics [5,6]. Implementing DR at the WDM layer has an advantage since all the core traffic uses the WDM resources. The associated savings shall however be closer to the gain obtained with link restoration: 1 to 16% according to [5]. If protection is inherent to the SDH layer, additional modules must be added to standard WDM configurations to provide this feature, which would dramatically reduce the absolute cost savings as highlighted before. Additionally, handling dynamic restoration at the WDM layer implies to handle physical impairments. In this context, some pools of transponders need to be provisioned in almost every big site, not only for signal termination, but also for regenerations and wavelength conversions.

Focusing on costs and limiting us to the previously reviewed configurations which correspond to the solutions proposed by the different manufacturers, there is no choice but to accept that, full tunability will probably not meet savings expectations. Single stage WSS configurations will not bring dramatic OPEX savings since human field operations are still required on each end to connect client equipment, and reducing further the OPEX would imply the use of pools of transponders in most of the big sites. More complex WSS configurations add flexibility but increase dramatically the CAPEX: WSS costs will probably never reach the Mux/demux cost level.

We must then consider that a NG WDM network shall support different ranges of services. Some of them are not protected because higher layer protection mechanisms are already used. Some others shall be 1+1 protected and require a high level of SLA. The cost of the additional hardware needed to implement shared protection is significant since it implies to deploy configurations with 2 stages of WSS. However, if it does not bring the expected savings on the WDM layer, it contributes to further increasing the availability of the services. Additionally, two stage WSS configurations bring the possibility to reduce production lead-times, increasing the network operator's responsiveness.

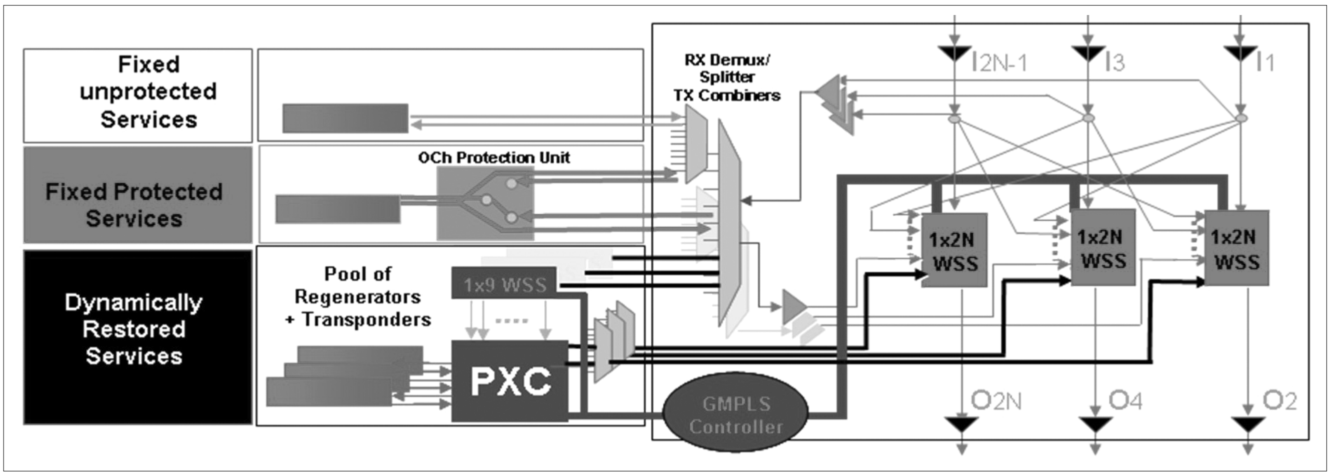
It seems then advisable to investigate alternative options to build more cost effective architectures considering that not all the services require the same treatment.

Figure 8 shows an example of a configuration that tries to minimize the number of costly units. It is based on a broadcast and select model.

With this architecture, unprotected services and 1+1 protected services are supported on a traditional configuration where fixed multiplexers/demultiplexers provides the add/drop capability. 1+1 transponder protection is performed through regular unit including a splitter and a switch, widely available through the different manufacturers. WSS units are used to provide the ROADM feature, as soon as the node degree exceeds 2. For dynamic services which shall represent a limited percentage of the whole services, splitters and WSS at RX side and combiners at the TX side are used to guarantee the colorless feature. A PXC connects a pool of transponders to the RX WSS and the TX combiners. Some additional amplifiers may be required to compensate for the insertion losses introduced by the different modules. The PXC sees any direction, and any transponders. It allows for saving a number of cascaded WSS (the number of WSS corresponds here to a one stage configuration). As far as we consider that not all the services pass through the PXC, its size maybe rather limited: a 64x64 PXC would handle 10% of the traffic in a degree 4 node. Using external combiners and splitters, we can also consider that this PXC will be closer to an automated patch-panel than to a complex PXC. The pool of transponders may be split in a pool of client transponders and a pool of transponders connected back to back through their client interfaces, acting as regenerators.

This does not prevent from partitioning the network in order to limit the number of regenerations and wavelength conversions used to face contention. The insertion loss of some of the components may challenge the engineering but all the components used in this configuration already exist and can be provided by optical component manufacturers. Thus providing this kind of configuration is more a matter of integration. A control plane shall be added in order to provide provisioning automation, and handle the potential dynamicity of the resulting configuration.

Figure 8. A possible option to provide partially tunable and directionless architecture



5. Conclusions

The implementation of transparent network at the scale of a European backbone remains utopian and NG WDM network architecture will be closer to hybrid transparent solutions, where regenerations are distributed in some predefined locations. In this framework, network partitioning will help solving wavelength contention, while releasing engineering constraints.

WSS used to switch channels from one link to another will efficiently complement degree 2 ROADM to add flexibility in the network. They could also help in reducing the total cost of ownership.

However, building a fully agile network which benefits from a control plane introduction will probably imply to consider new site architectures where the number of WSS is limited, to take up the challenge of keeping a reasonable total cost of ownership.

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