Multi-Granularity Optical Networks

Multiplexing and Switching connections in new dimensions

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Abstract: Considering the telecommunication traffic boom, one can wonder if routing nodes will provide the corresponding switching capacity. Introducing Multi-Granularity Optical Networks concept, this paper gives a cost-effective solution. First, a MG-OXC architecture is proposed, then the “natural” distribution of the traffic among the granularities is presented. Finally, a Multi-Granularity planning process is described. Based on the most advantageous feature of optical technologies, the proposed approach solves the switching matrix size limitation.

1. INTRODUCTION

Nowadays, we are witnessing a new telecommunication traffic boom, for which very high transmission and switching capacities are required. Tbit/s transmission capacity can be achieved thanks to optical fibres. The number of transmitted wavelengths in one fibre which has recently been demonstrated in research laboratories exceeds 100 wavelengths per fibre and even more for terrestrial transmission (for example 150x10 Gbit/s over 400 km, see [1]) and even for submarine transmission (for example 100x10.7 Gbit/s, see [2]). Some suppliers announce commercial systems with 80, 160 and even 256 wavelengths per fibre. In optical networks, the optical cross-connects (OXC) will have many fibres, each one carrying many wavelengths. The switching of such a high capacity raises severe scalability issues for OXC design.

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In this paper, we first describe a Multi-Granularity Optical Cross-Connect (MG-OXC) solution to switch all this high-capacity traffic. This solution is based on wavelength, band and fibre switching and squeezes the most out of optical technologies. Then we study what can be the distribution of the traffic between wavelength switching, band switching and fibre switching on the basis of a typical meshed network. Finally, a planning methodology is described: it optimises the grooming to avoid too much multihopping between the different granularities through the optical backbone network, which decreases the required number of optical ports and the OXC switching matrix size, and thus the cost of the OXC-based network.

2. MULTI-GRANULARITY OPTICAL CROSS-CONNECT

2.1 Required capacity for wavelength-switching cross-connect

For very high capacity backbone networks (may be up to Pbit/s for future networks), with large number of fibres with over 100 wavelengths carried by each fibres, the optical cross-connects (OXC) will have many input/output fibre ports, each one carrying many wavelengths. An OXC may have for example 100 input fibres with 160 wavelengths each, each wavelength carrying 10 Gbit/s data. The total throughput to be switched by such a node is 160 Tbit/s. The total number of input wavelengths is $N=16000$. If one wants to switch all the wavelengths individually, the require space-switching matrix is 16000×16000 . A mono-block switch with this size is not achievable because of the high number of cross-connection points: $256 \cdot 10^6$ (N^2). A Clos architecture may be used, but this requires a first stage with 180 “90x180” switches, a second stage with 180 “180x180” switches and a third stage with 180 “180x90” switches. The total number of cross-connection points ($4N\sqrt{2N}$ for Clos architecture) is still high: about $12 \cdot 10^6$. Space-switch matrices with such high number of cross-connection points cannot be envisaged because of the high number of required components and because of the complexity of the electrical control of such a matrix.

2.2 Solutions to decrease the port number

To be able to switch all this traffic (160 Tbit/s), one should group this traffic to higher granularity to decrease the number N of switched entities.

2.2.1 To increase the capacity of each wavelength

One first solution is to carry higher bit-rate on each wavelength like in SONET/SDH networks: the granularity can go from OC-3/STM-1 (155 Mbit/s) to OC-12/STM-4 (622 Mbit/s), OC-48/STM-16 (2.5 Gbit/s) and OC-192/STM-64 (10 Gbit/s) today. Transmission of 40 wavelengths with 40Gbit/s (future OC-768/STM-256) carried by each wavelength has already been achieved ([3]). To increase the wavelength bit-rate impacts the transmission. Issues encountered are chromatic dispersion, non-linear effects, polarisation mode dispersion: the higher the per-wavelength bit-rate is, the more detrimental these transmission effects are. Moreover simple transmitters and receivers at such high bit-rate are not yet available.

2.2.2 To group the wavelengths

Another solution is to keep the 10 Gbit/s bit-rate for each wavelength, and to group the wavelengths to bands to switch them together. For our example one band can be composed of 16 wavelengths, each fibre carrying 10 bands. The total number of bands to switch is then $N=1000$ and the total throughput of the OXC is still 160 Tbit/s.

The required switching matrix is then 1000×1000 . A mono-block switch with this size may be achievable (see [4] for 576×576 matrix), the number of cross-connection points is 10^6 (N^2). A Clos architecture can be used and requires a first stage with 45 “23x45” switches, a second stage with 45 “45x45” switches and a third stage with 45 “45x23” switches. The total number of cross-connection points ($4N\sqrt{2N}$) is quite low: about $220 \cdot 10^3$. Optical space-switching matrices with such a number of cross-connection points have already been envisaged [5].

2.3 Multi-Granularity OXC architecture

With a lot of fibres at each OXC, the band granularity may sometimes be too small, and the switching may be done at the fibre level. More generally, one may want to switch a part of the total traffic at the fibre level, another part at the band level and a last part at the wavelength level. What we need in this case is a Multi-Granularity Optical Cross-Connect (MG-OXC). The figure 1 shows a possible architecture for such a MG-OXC.

Figure 1. Multi-Granularity Optical Cross-Connect (MG-OXC)

The optical signals are first switched at the fibre level, in the Fibre Cross-Connect (FXC): some fibres are directly added/dropped towards the clients (they may be demultiplexed to wavelengths for clients, but the demultiplexers are not represented on the figure), others are directly switched to output fibres, few ones are added/dropped to the band level. These add (resp. drop) fibre ports of the FXC are connected to the output (resp. input) band ports of the Band-Cross-Connect (BXC) through band-to-fibre multiplexers (resp. fibre-to-band demultiplexers). Some input bands of the BXC are directly added/dropped towards the clients, others bands are directly switched to output ports of the BXC, and few ones are added/dropped to the wavelength level. These add (resp. drop) band ports of the BXC are connected to the output (resp. input) wavelength ports of the Wavelength-Cross-Connect (WXC) through wavelength-to-band multiplexers (resp. band-to-wavelength demultiplexers). Some input wavelengths of the WXC are added/dropped towards the clients, others wavelengths are switched to output ports of the WXC.

On the figure, we did not represent optical amplification which will be needed inside the OXC and at the input and output fibres. 3-R regeneration may also be required at the input and/or output fibres. Wavelength (resp.

band) conversion will also be needed at the output ports of the WXC (resp. BXC) but they have not been represented to simplify the drawing.

The figure 2 gives an example of what could be the distribution of the traffic in the MG-OXC, for 160 Tbit/s external throughput (100 input/output fibres, with 10 bands per fibre, 16 wavelengths per band, 10 Gbit/s data on each wavelength). We also have add/drop traffic (add/drop ports): 10 fibres (16 Tbit/s), 30 bands (4.8 Tbit/s) and 80 wavelengths (0.8 Tbit/s). The total throughput to be switched by the node is thus 181.6 Tbit/s. We will see later that the aggregate capacity of the switching matrices is higher because of internally generated traffic for grooming purpose.

Figure 2. Example of traffic distribution in the MG-OXC

Among the 100 input fibres (we don't take into account the 10+20=30 add fibre ports of the FXC), 70 are cross-connected to the output fibres at the FXC level, 10 are directly dropped and 20 are dropped to the BXC input ports. The 10 add fibre-ports and the 20 fibres coming from the outputs of the BXC are cross-connected to the 30 remaining output fibres of the FXC. The 20 fibres dropped to the BXC represent 200 bands, among which 140 are cross-connected to the output ports of the BXC (grooming, to rearrange the bands inside some fibres), 30 are directly dropped and 30 are dropped to the WXC. These 30 bands correspond to 480 wavelengths, among which 400 are cross-connected to the output ports of the WXC (grooming at the wavelength level) and 80 are directly dropped. The 60 add ports of the BXC (30 add band-ports and the 30 bands coming from the output ports of the WXC) are cross-connected to the 60 remaining output ports of the BXC, and

the 80 add wavelength-ports are cross-connected to the 80 remaining output ports of the WXC.

For this example, this will require a 130x130 space-switch matrix for the FXC (208 Tbit/s), a 260x260 space-switch matrix for the BXC (41.6 Tbit/s) and a 560x560 matrix for the WXC (5.6 Tbit/s). The aggregate capacity is about 255 Tbit/s, which is higher than the total throughput to be switched by the node (181.6 Tbit/s). This is due to the fact that for the presented architecture, the same signals are switched at different granularities, and some may go through one stage twice for grooming purpose. The total number of cross-connection points is only about 400.10^3 even without Clos architecture. With Clos architecture for each space switch, this number is then only about 110.10^3 . With such a MG-OXC architecture, the complexity of the space-switch matrix is decreased by a factor of about 100 compared to an only wavelength switching matrix for the whole traffic, and we have still some flexibility to switch a part of the traffic at the wavelength level.

2.4 Required technologies

To implement this MG-OXC, some key technologies are required : space-switching, multiplexing/demultiplexing, wavelength or band translation and in-node amplification.

First, we need a technology to switch the wavelength (WXC), a technology to switch the band (BXC) and a technology to switch the fibres (FXC). One may envisage electronic switching matrix for wavelength switching (WXC), with opto-electronic interfaces. A lot of optical technologies are also available to do the wavelength-switching ([4-6] for several wavelength switching technologies). For the band (BXC) and fibre (FXC) switching, electronic cannot do it, only optical technologies can. Moreover, the same technology can switch wavelengths, bands and fibres, provided that the optical bandwidth is large enough to switch all the wavelengths (typically 1500nm~1620nm, or even 1300nm~1620nm). This ability to switch everything from a single wavelength to a whole fibre multiplex is interesting on the up-gradability point of view : the same matrix technology firstly switches wavelengths when the traffic through the OXC is low (~1 Tbit/s), it can switch bands when the traffic begins to increase (~10 Tbit/s), and it will be able to switch fibres later when the traffic becomes very high (~100 Tbit/s). Some possible technologies are the Micro-ElectroMechanical System technology (MEMS, see for example [5]), system based on index-matching injection (see for example [6]) or bulk optomechanical free-space switches (see [4] for instance).

At the BXC and WXC input/output, some (de)multiplexing devices are required. Wavelength (de)multiplexers are now current WDM devices. Some

devices can (de)multiplex up to 100 wavelengths [7]. Their design can be adapted to the demultiplexing of bands of several wavelengths.

Wavelength converters are already existing devices. They can be optoelectronic devices (photodiode-receiver cascaded with classical transmitter working at the new wavelength) or all optical converters [8]. Band converters can be simply made with a demultiplexer cascaded with n ($n=16$ in our example) parallel wavelength converters followed by a multiplexer.

In-node optical amplification may use the same technology as the amplification for transmission, with some simplifications to have low-cost amplifiers because requirements may be relaxed inside the node.

3. “NATURAL” DISTRIBUTION OF THE TRAFFIC IN THE MG-OXC

3.1 From mono-block node to sub-nodes stack

On a network point of view, the 3 granularities are “naturally” detected, demonstrating their usefulness. Although the planning is only based on the wavelength granularity, we can observe that, in each OXC, a large amount of traffic can be processed at the band and fibre levels, as if it was a “natural” behaviour.

To quantify this, there is first to obtain an initial planning and second to detect, in each node, which part of the traffic can be processed in which sub-node. The network is planned without specification on the nodes. The traffic routing is based on a Shortest Path in distance algorithm. The resources allocation is done at the wavelength level. The wavelength assignment process keeps as far as possible the same wavelength along each path, so that the wavelength translations are minimised. Then, starting from this simple initial network planning, it is possible to focus on the nodes. Looking at each resulting switching matrix and, without changing anything to the routing and resources allocation, each node is divided in a stack of sub-nodes (figure 3). The traffic distribution among the sub-nodes results from the detection of traffic correlation in the node, correlation in term of band or fibre. For example, wavelengths with the same input and output fibres, without any wavelength translation, are detected as composing a fibre port of the FXC.

It has to be noticed that no preparation of the traffic to favour high granularities is done. To favour fibres or bands of wavelengths, a first solution could be to use a dedicated wavelength allocation process filling up first fibres, second bands before considering the wavelength level. A second solution could be to prepare the traffic starting from the routing, as described in section 4.

Two kinds of traffic are differentiated: the *internal* traffic and the *external* traffic. The internal traffic corresponds to the traffic between the sub-nodes while the external traffic is the traffic coming from / going to the node's neighbours or to the clients. This internal traffic increases the size of the sub-nodes and represents the flexibility of the global node. For example, the architecture figure 1 is more flexible than the architecture figure 3. Figure 3, all the fibres go through the FXC, thus, it is possible to select the fibres going to the other sub-nodes. The architecture figure 3 is based on dedicated fibres directly connected to the right sub-node: this is less flexible but also less port consuming.

Figure 3. Sub-nodes piling up

3.2 Traffic distribution evaluation

To evaluate the amount of traffic processed by a sub-node, two parameters are identified: the *number of ports* and the *capacity*. The number of ports allows to compare the size of each sub-node. But, for example, a fibre port carries 32 wavelengths while a band port carries 8 wavelengths and a wavelength port only one. A port does not represent the same capacity. Considering the capacity means comparing the number of equivalent

wavelengths switched by the sub-nodes. It allows to compare the amount of traffic treated in each sub-node. The difference is illustrated in the figure 4.

The capacity parameter has been chosen to study the part of traffic which could be switched at a granularity other than wavelength. More precisely, the traffic distribution is evaluated in capacity percentage, percentage calculated from an average on all the nodes of the network.

Figure 4. Comparison ports and capacity percentages

3.3 Traffic distribution results

The study has been done on the European optical network model COST239 [9] composed of 19 nodes (figure 5). The traffic matrix is complete, uniform or non-uniform according to the studied situation. A 32 wavelengths multiplex has been considered.

Figure 5. COST239 network

The following curves (figure 6) represent the percentage of capacity switched in the FXC, BXC and WXC for several traffic matrix multiplications (from one to 64) in several situations (uniform / non uniform traffic, with / without protection, 8 / 4 bands per fiber).

Figure 6. Percentage of capacity switched in the sub-nodes

For example, when the traffic demand is equal to 24 times the initial non uniform traffic matrix, without protection and 8 bands per fibre, the average distribution of the traffic in the sub-nodes is: 48% in FXC, 42% in BXC and 10% in WXC.

First visible result: 100% FXC, 0% BXC, 0% WXC when the traffic demand corresponds to 32 times the initial traffic matrix. This result is not surprising, and even expected. There are 32 wavelengths per fibre and each traffic demand between 2 nodes is a multiple of 32, in other words, the traffic demand between each pair of nodes corresponds to a demand in fibres.

Second visible result: when the traffic matrix is multiplied by $N \times 4$ (respectively $N \times 8$) and with a number of wavelengths per band equal to 4 (respectively 8), we expect to obtain only BXC because the traffic corresponds to a demand in band. It is easy to understand that FXC are

obtained when several bands have the same direction. But what about the WXC? 40% to 15% of the capacity is still switched in the WXC. The main cause is the wavelength-granularity based planning process: the wavelength allocation process does not impose the same wavelength conversion, neither in the same node nor with the same wavelength shifting, to connections with the same source and destination. Thus, one wavelength conversion can occur in a band leading to the de-multiplexing in the WXC sub-node. In other words, the results obtained here are **lower than what we could obtain for the FXC and BXC and can be improved with an adapted planning process** taking into account the fibre and band granularities.

Third visible result: the shape of the curves are similar for all the situations. They are following almost the same behaviour, with the same peaks and troughs. We can also observe a kind of **pattern** on a range corresponding to the number of wavelengths per fibre with a low slope (around +0.3 for FXC, -0.1 for BXC and WXC). We can conclude that the traffic (uniform / non uniform, protection / no protection) and the band size have only an impact on the offset of the curve. This **offset** corresponds to a **gap in the multiplication coefficient of the traffic matrix**.

Fourth visible result: in this network, with 32 wavelengths per fibre, the average distribution of the capacity is rapidly under 40% and mainly **15% in the WXC** (and can be reduced), more than 20% and mainly **40% in FXC** and **45% in BXC**. To go near to the distribution presented with the figure 2 (around 3% WXC, 16% BXC, 81% FXC), there is to shift around 80% of the capacity to a bigger granularity (WXC to BXC, BXC to FXC) and /or to have a huge amount of traffic. Both hypotheses are realistic.

Now, changing the number of wavelengths per fibre (64 and 128 wavelengths), the following curves are obtained (figure 7). The situation is without protection, non uniform traffic. Apart from some peaks or troughs, mainly due to a traffic demand corresponding to a demand of fibres as explained in the first visible result, the **distribution is in line with the previous curves** mainly for the FXC.

The BXC offset observed for the situations “128 wl – 16 bands” and “64 wl – 8 bands” comes from the small size of the bands compared to the size of the multiplex. More traffic is required to fill up the complete multiplex, so more traffic is remaining in the BXC. In the same way, the WXC offset observed for the situations “128 wl – 4 bands” and “64 wl – 4 bands” comes from the big size of the bands (16 and 32 wavelengths). More traffic is required to fill up the bands, so more traffic is remaining in the WXC. Small bands look interesting, but it means more band ports than with big bands, obviously.

Figure 7. increase of the multiplex size

The behaviour of the **capacity distribution in the sub-nodes is stable**, only the offset of the distribution is changing according to the amount of traffic and the multiplex composition (number of wavelengths / bands). With an adapted planning process, we expect to improve the results. **Today**, for the COST239 network, without preparation of the traffic to obtain bands and fibres, and without considering additional capacity for flexibility, we obtain on average **15% WXC, 45% BXC, 40% FXC**. For tomorrow, the goal is to decrease the amount of traffic processed in WXC by favouring FXC and BXC as described in the following section.

4. PLANNING PROCESS ASPECTS

4.1 A new framework for optical network planning

The proposed scheme is based on the opportunity to switch various granularities in the optical domain. It represents a new step for the WDM deployment trends, overtaking previous visions [10-12]. The principle driver for the emergence of new WDM technologies is still derived from the

increasing demand in terms of capacity. Before use of future combination with high-capacity packet switching (optical or not), the Multi-Granularities optical scheme remains a circuit-oriented approach with additional layers available. Therefore our goal is to define an exhaustive planning methodology where the whole range of circuit-granularity could be used at the right place with the right size. The evolution of optical node size and functionality has to face the evolution of demand, mainly in terms of amount of traffic. Our objective is to propose a flexible solution for the necessary migration of transport networks. While combining the very high capacity available in the optical domain and the flexibility given by the integration of Multi-granularity layers, we intend to squeeze the most out of optical technology. Many steps in this new approach have generic aspects, but in the following we focus on a dedicated planning method starting from an existing SDH/SONET layer which is at the present time the first potential client for a Multi-Granularity core optical layer.

4.2 A dedicated process is required

In the previous sections, we have shown that technological hardware solutions exist and can be available in short terms. Moreover, the analysis of planning according to typical topology and traffic evolution demonstrates that the architecture proposed is quite relevant for future transport network services. The concrete deployment of Multi-Granularity nodes within large optical core networks requires some associated planning methods in addition to the already well-known complexity of design [13].

A planning methodology is a complex problem including a lot of parameters, constraints and objectives. The introduction of new layers corresponding to new optical granularities has to be taken into consideration with care, otherwise the gain expected could be negligible. To be cost effective, an appropriate method has to be defined and has to reduce some unenthusiastic impacts of multihopping. The problem addressed here is the redundancy of resources in several layers that process the same traffic. From the switching point of view, it is cost-effective to switch in the same time numerous small-granularity connections multiplexed in a same high-granularity entity. In spite of this theoretical advantage, a bad multiplexing strategy may imply to de-multiplex a high-granularity connection in order to switch only few lower-granularity connections at another level. In this case, too many equipment are needed to process the same traffic.

The multihopping problem has an impact on the planning method but also on the migration strategy. If the network growth is only seen from a transmission point of view, an upgraded link is installed (e.g. WDM) according to the increase of traffic with an equivalent switching capacity at the source and sink nodes. In this situation, if the implementation of

resources, switching this capacity, is done at a lower granularity level (e.g. large SDH nodes or wavelength cross-connect,...) then the introduction of high granularity optical layers would handle most of the capacity, making the previous resources redundant and useless.

Finally, if we want to optimize the benefits from the introduction of new granularities in the transport network, we have to define a dedicated process focused on multiplexing issues.

4.3 Main Objectives, Principles and Overall Process Description

Our main objective is to define a methodology for a cost effective planning, taking into account the new granularities within the optical layer. We want to propose relevant solutions facing the demand of large amount of traffic but also flexibility and upgradability considerations.

The central problem is to multiplex small-granularity connections in higher level connections. Hence more traffic is switched at each node using less resources and allowing to reduce the node size. From the planning point of view, we have to define an efficient way to arrange the distribution of connections on the topology in order to manage the correlation between connections.

As mentioned before, our process is starting from an existing SDH/SONET layer. In a first step a partitioning is done which gives the localization of WDM nodes and associated areas. The intermediate objective is to aggregate enough traffic coming from the SDH/SONET layer and to minimize the number of WDM nodes needed for the transport network. Although, as a result, the partitioning create some interdependence between connections starting from the same area and ending in another area. In this step the whole WDM topology is identified (nodes, links) and the traffic demand is established for the optical layer. The next step is to route the connections inside both layers, electrical and optical. At that time, the multiplexing operations begin with the TDM grooming. The goal in this step is to group together connections that have similar destiny in the network. In fact we try to generate wavelength connection with as less as possible demultiplexing that imply a switching at the electrical layer.

In the same way we try to find the best arrangement of wavelengths in the network to groom wavelengths into bands with the least band-to-wavelength demultiplexing. The last multiplexing operation, still based on the same logical rules, is to groom the bands into fibers. Finally a phase of resource assignment is needed to have the complete network planning.

The process is as flexible as possible flexible, with the possibility to modify the inputs and functionality at each step. For instance when a cost

function is used, it could be replaced by real inputs or another cost function for a specific case.

4.4 Process description

4.4.1 Partitioning & Backbone topology definition

The partitioning problem is a traffic-based problem associated with topology and cost constraints. In order to decide if an initial SDH/SONET node should become a WDM node, first we have to evaluate the traffic that will go through this potential future WDM-node.

This traffic can be divided into 3 types:

- **ADD/DROP at the node**
- **ADD/DROP at nodes belonging to potential areas around the node.** It means that the node will catch the traffic of the area if it becomes a WDM-node.
- **Transit traffic at the node.** According to the node localization in the topology and the routing algorithm, the node will see more or less transit traffic. The amount of transit traffic has a major impact on the node size and has to participate in the decision whether or not the node should become a WDM-node.

Figure 8. Potential traffic aggregation

The final decision of area creation has to be cost-based. It is a difficult problem because we have to compare the merits of different possible areas according to criteria which are future consequence of the global partitioning. This cost comparison is mainly based on the ratio of multiplexing factor between the two layers, but takes into account the increase of the path length. Hence we can evaluate an approximate gain for each potential area and decide the localization of the WDM nodes.

The gain function is first an evaluation of the number of ports needed to transport the connections starting from an area with or without the optical layer. Then the cost ratio between SDH/SONET and WDM ports and the cost ratio between transmission and switching are used to balance the approximate number of ports and in the end to determine the best area. An rigorously exact value for the gain is not needed, because the evaluation is only used to compare relative gain among the possible areas.

4.4.2 Routing

When both network topologies –electrical and optical layers- are known, it remains to route the connections in the two layers. The routing can be divided into, three parts: starting SDH/SONET area, WDM backbone, ending SDH/SONET area. Those routings are quite independent, allowing some optimization in each part but the planner has to be careful not to break the strong correlation created between connections in the area-to-area part.

4.4.3 TDM Grooming

The composition of wavelength connections depends on the SDH/SONET switching capabilities. It means that a major part of the TDM grooming is done in the SDH/SONET domain . Hence the efficiency of TDM grooming in the WDM part is limited by the capacity of demultiplexing and re-arranging granularities with enough fineness at the SDH/SONET-WDM gateway. For instance if the gateway can not manage SDH/SONET connections at granularities smaller than STM1/STS3, those connections have to be composed with smaller connections going to the same area-destination. Otherwise multihopping will be needed to re-arrange the small connections implying more resource.

The TDM grooming process looks at each sub-path in the topology and aggregate SDH/SONET connections successively on the best sub-path in terms of number of ports saved. The same operation is done until all connections are groomed. The wavelength traffic matrix obtained is composed with a minimum of λ -connections staying in the optical layer as long as possible. All SDH/SONET connections are carried by a wavelength,

but non-indispensable multihopping is avoided. Hence the global number of ports (electrical + optical) is reduced. The fig. 9 represents a wavelength connection composed with SDH/SONET connections starting or demultiplexed at the first node, going through several other nodes without multihopping and ending or demultiplexed/remultiplexed at the last node.

Figure 9. TDM grooming

4.4.4 WDM Grooming

The WDM grooming is done using the same principle as the TDM grooming. The process tries to avoid as much as possible the “optical” multihopping, that is the demultiplexing of band in wavelengths or fiber in bands.

First the process allows to multiplex the wavelength into bands. For each sub-path the number of ports saved by multiplexing wavelength in bands is calculated. The best is selected with the concerned connections and the operation is repeated until all wavelengths belong to a band.

Figure 10. Grooming wavelength in bands

Figure 11. Grooming bands in fibers

Finally, Bands of wavelengths are groomed in fibers using a similar approach. Figures 10 & 11 represent the possible composition of a Band or Fiber connection and the transit along the path through others nodes without multihopping.

At each level, when multiplexing in a higher granularity, it remains some connections that do not fill completely the higher granularity. Below a given filling ratio, those connections can be re-routed in order to optimize the resource utilization ratio.

Finally, the outputs include the planning for each level. It gives the number of ports for each sub-node taking into account ports due to direct transit, ports due to internal add/drop between sub-nodes and ports due to direct add/drop.

Protection was not discussed so far. The introduction of several layer in the optical domain may justify some new schemes for protection. For instance like any connection, a band of wavelengths can be protected. In this case, while the traffic is already protected, it is no longer necessary to apply a protection scheme for each wavelength. This can be chosen for an objective of simplification for the global protection scheme. Anyway the protection scheme applied for a given level has to be done before the multiplexing into the higher level. Hence the resources dedicated to protection are also groomed and participate to the reduction of cost.

4.4.5 Final Resource assignment

Almost all the planning is done after the previous steps. It remains to allocate the resource with the classical approaches. In consequence of the introduction of wavelengths-bands, some band translations may be necessary in the network. This problem is entirely analogue to the classical wavelength conversion issue.

The gain expected from the introduction of several granularity in the optical layer can be improved with some dedicated algorithms integrated in the overall planning process. Some further analysis are expected to show that

more available granularities in the optical layer can participate to more flexibility and scalability of the network. But the first argument to the introduction of this technology is without doubt, the cost gain obtained by the reduction of the number of ports in the network.

5. CONCLUSION

This introduction to Multi-Granularity Optical Networks discussed the technical availability, the opportunity and finally a methodology relating to one of the most advantageous features of optical technologies. The aptitude to switch various granularities in a flexible and cost-effective way is effectively a promising perspective to build ultra-high capacity optical networks.

In the first part a realistic MG-OXC architecture has been proposed with possible associated technologies. Then a first evaluation of switching requirements versus the increase of traffic showed that high-granularities are a possible solution facing the traffic evolution in a typical meshed network. Finally a dedicated planning and design process was described in order to optimize the benefits gained from the introduction of the concept.

This global approach gives the ability to go beyond simple incremental wavelength-based optical network and designs efficiently optical networks facing the traffic explosion without cost explosion.

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