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Effects of Nodal Blocking Probability on Degree of Tunability, Regeneration, and Intelligent Control Plane in GMPLS Environment

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Abstract: The main objective for optical networks running under the GMPLS framework is to support fast end-to-end optical light paths. In the current GMPLS framework, topology and resource discovery are limited to a single domain, however, as the network size grows, different domains must be interconnected. The constraints to flood topology information across the domains and the exact type of information to exchange between domains also are investigated. This paper evaluates the use of Multi-Granularity Optical Cross-Connects (MG-OXC) on wavelength blocking, and proposes a technique to minimize the effects of this blocking. It also discusses the related issues of wavelength blocking in the GMPLS environment based on using the new cross connect architecture. Decreasing the tunable resources and maximizing the overall utilization of the core network by determining the nodal blocking probability is investigated. The characteristics of the network that employs MG-OXC within the GMPLS environment and quantify the effects of using such architecture, simulations of the mathematical model are preformed using different size topologies to verify results and test the merits of partially substituting the tunability option with MG-OXC.

I. INTRODUCTION

The introduction of the Multi-Granularity Optical Cross-Connects into the optical networks environment has advanced the fine grain switching capability of optical traffic. This advancement combined with the facilities offered by the Generalized Multi-Protocol Label Switching framework (GMPLS) [1] has opened a new era for the control and management of the DWDM photonic core networks and helped migrating most of the switching burden into the optical domain, in order to exploit the scalability property provided by optical technology and transmission capacity, which leads to effective decoupling between transmission/switching in the optical domain and the routing/forwarding functionalities in the higher level network layer. This paper evaluates the use of Multi-Granularity Optical Cross-Connects (MG-OXC) on wavelength blocking, and proposes a technique to minimize the effects of this blocking. It also discusses the related issues of wavelength blocking in GMPLS environment based on using the new cross connect architecture.

II. GENERALIZED MULTI-PROTOCOL LABEL SWITCHING FRAMEWORK (GMPLS)

GMPLS bridges IP layer to the optical layer as an essential step for scalable future optical data networks. It dynamically associates the conventional transport infrastructure and the IP layer in a more unified peer model. Its generalized concepts of Label Switched Path (LSP) hierarchy and bundling results in sufficient flexibility in supporting segregation of control and data planes. Aiming to transport large volumes of traffic, the flexible intelligence of GMPLS will prove essential in any solution. GMPLS deploys an end-to-end path by merging existing control plane technique with the point-to-point provisioning capabilities and eliminating the avoidable network layers by using available IP management tools. Intelligence needs to be added to enable the internetworking of all network components that are available to build the optical transport networks. The results explained in this paper will contribute in enhancing the degree of intelligence required by the unified and common control plain in GMPLS environment.

III. TUNABILITY AND REGENERATION

The assessment to eliminate the wavelength-blocking problem is an essential step to have a less transparent optical control and management planes. Furthermore, wavelength contention is a prominent problem, which leads to an expensive solution such as wavelength conversion, which in turn causes signal quality degradation if it is not done in a 3-R regeneration site. The idea of multi-granularity optical cross-connects was introduced in an Internet Draft in mid 2001 [2]. Further studies have to consider this switching structure as a prospective alternative for the present day legacy cross-connects for reasons mentioned in this paper. The results of limited range tunability of the full spectrum on a network providing restoration capabilities could achieve benefits of 80% of those obtained through fully tunable optical core [3]. This paper shows that even a limited use of MG-OXC in selected sites in the optical core could achieve a higher level of benefits if combined with limited range of wavelength conversion. This means that the deployment of an intelligent core would be more cost effective in the foreseeable future.

The core lambda-switching layer of the MG-OXC, illustrated in Figure 1, could incorporate wavelength conversion capabilities for further minimization of the blocking probability of the optical node. The nodal blocking probabilities are considered to allocate the new

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cross-connect architecture with full compliance with tunability, regeneration, and reach variation requirements in the core. Regeneration is identified as a necessary tool to significantly increase reach variation for scalability purpose. A transparent all optical cross-connect employing only re-amplification (1R regeneration) will likely propagate a loss-of-signal fault condition to its downstream nodes. Most electro-optic cross-connect employing re-shaping/re-timing (2R/3R regeneration) that offers free tunability generates an idle signal to downstream nodes. An increase of the end-to-end reliability of traffic transmission is obtained by considering the architectural aspects of the new MG-OXC node structure: less signal distortion due to less electronic intervention for wavelength conversion, and less traffic fluctuations due to multi-level tunneling (bypassing intermediate nodes). The multi-level tunneling ability, which bypasses the optical traffic over multiple concatenated DWDM fiber or waveband links, plays an important role in dynamic traffic routing with less signal degradation. This will trivialize the end-to-end survivability problem considering a dynamic alternative routing in the multi-level tunneled core.

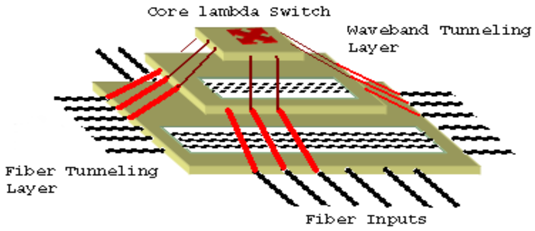

Fig. 1 Illustrates the Architecture of the MG-OXC

IV. GROOMING AND CONTROL PLANE INTELLIGENCE

The preliminary assessments of the new MG-OXC architecture has confirmed the need for higher rate of traffic aggregation through the optical node and relatively lower need for tunability. MG-OXC also incorporates multi-level traffic grooming in the GMPLS environment supporting a hybrid optical core through various routing and tunneling allocation schemes [4]. Efficient traffic grooming, multiplexing smaller traffic streams into higher capacity tunnels, increases the over all utilization of the system. MG-OXC offers a better architecture for traffic grooming in DWDM optical networks, which minimizes the number of transceivers for better impact on network utilization and the complexity of control requirements. The huge optical capacity places an incredible burden on each node to process all these information, while optical channel-to-tunnel grooming saves electronic processing time.

These routing and tunnel allocation schemes are being introduced to better capacity and bandwidth usage to maximize the optical core utilization and to optimize the control and management methods for semi-transparent control plane. The desire to provide more intelligence into the optical domain for more autonomous network operation, the enormous growth in transport technology in the optical domain, and the increasing capacity have exposed wavelength as the fundamental ingredient of the transport component. A promising next generation transport network element such as MG-OXC will have full control of wavelengths, their carrying, and their operational status. Such intelligence embedded in the network switching element would create self-regulating networks and help delivering services intelligently to the end user depending heavily on the distributed algorithms and protocols offered by GMPLS. Figure 2 shows a common control plane based on the GMPLS framework running over different elements of the GMPLS environment.

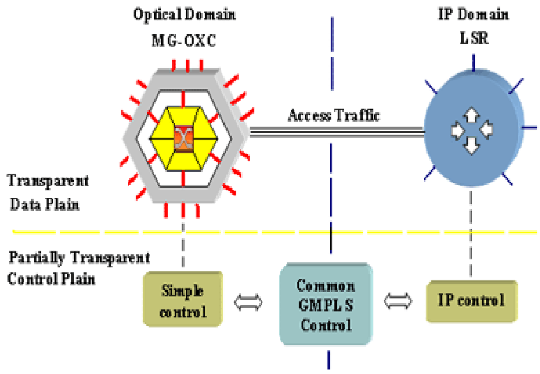

Fig. 2 GMPLS Based Control Plane Running over MG-OXC

The term intelligence covers transport level aspects such as intelligent optical transport plane, distributed intelligent control plane that resides in network elements, and network management plane that complies with GMPLS framework. GMPLS supports the realization of intelligent optical core that adopts an IP based protocols in the optical control plane in a generalized sense. This adaptation by the optical network of a simpler IP-over optical architecture is due to the predominance of IP-based traffic in the core. The enhanced embedded intelligence in the optical control plane would elevate the dumb physical layer devices to intelligent network level devices. The IP community and the optical networking community are reaching a general agreement that the way to control such networks is by using control plane technology constructed around the GMPLS framework. The distributed approach offered by GMPLS framework can facilitate the enhancement of the required intelligence to control different networking domains integration. The wavelength agility and configurability offered by such control plane intelligence embedded in MG-OXC substantiates the need for further research to explore the full potential of such optical cross-connects aggregating and grooming of optical traffic. Reducing wavelength blocking probability will contribute to the enhancement of the control plane in terms of the required intelligence.

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V. MG-OXC AND NODAL BLOCKING PROBABILITY

One of the main performance aspects of MG-OXC, which is based on a reconfigurable, re-arrangeable, and strictly non-blocking switching fabric architecture, is the nodal blocking probability, which determines the amount of traffic that could pass through the node in contrast to a similar sized conventional cross-connect. One of the prominent problems in the optical domain is the handling of wavelength contention when two or more incoming wavelengths are directed to the same output. The functional building blocks for the three layers of the MG-OXC shown in Figure 3 were modeled to characterize the blocking probability, which caused by wavelength contention, of the node considering the nodal degree and with comparison to the conventional cross-connect. The dynamic wavelength, waveband, and fiber assignment and switching eliminates or minimizes the blocking effect of the MG-OXC node. In a highly loaded optical core, the cross-connect could be complimented with tunability option, which will further eradicate the blocking factor resulted from wavelength contention.

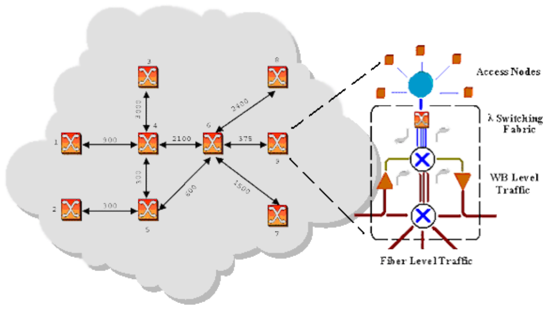

Fig. 3 Illustrates the Switching and, Tunneling, and Grooming Levels of the MG-OXC

All the intermediate nodes do not require electronics except for regeneration or wavelength conversion, which leads to the concept of allocating these electronic resources according to the load demand on each individual node. The nodal blocking probability is calculated to determine the sites that would require tunability option in the conventional cross-connect core. Tunability incorporated in practical WDM optical switches and wavelength resource information must be considered in the routing process [5]. The problem of choosing a wavelength and any degree of conversion is often formulated as complex optimization schemes, which usually very computation-intensive, such as integer-linear programming or multi-commodity flow problems. The objective is to optimize various performance criteria such as blocking probabilities, number of wavelengths, and tunability [6, 7, 8, 9]. Path computation, also, requires topology information about the network as well as the pertinent network elements information such as the MG-OXCs. Such a high level of details introduces scalability problems in the routing algorithms, since they are disseminated in the LSAs. The use of the new MG-OXC architecture, which significantly minimizes the wavelength blocking probability, considerably reduces the complexity added by tunability requirements, thus enhancing scalability, control plane intelligence, and resources management. For the time being, resource and topology discovery is limited to a single specified domain for security, scalability, and policy reasons using IGPs**.**

Considering the routing scheme, end-to-end reach variation between alternative routes, and the need of tunability, the regeneration points are mapped in to the core. This step enhances the control and management functionalities utilized by the GMPLS framework. The dynamic assignment of routes increases the occurrence of wavelength contention, which could be avoided by allocating a MG-OXC and complementing it with tunability option in severely loaded nodes. This greatly reduces the cost of wavelength contention and minimizes the need for electronic resources in the core while achieving a semi-transparency for easier GMPLS based control algorithms, which might be capable of optical header recognition for the IP over DWDM case.

VI. NODAL BLOCKING PROBABILITY MODEL

Carriers are using the lowest cost per connected bit-mile as a metric for deploying new services in the optical domain. This fact indicates that the ability to provide an enhanced control over the optical infrastructure is far more important than the available raw capacity due to the abundance of bandwidth in the DWDM environment. Accordingly, it is essential to eliminate or minimize the effects of connection blocking with significantly minimum tunability and minimum additional regeneration cost. The high utilization of the multi-level optical tunnels-a higher traffic aggregation- and the relatively smaller wavelength switching fabric offered by MG-OXC decreases the blocking probability and increases performance and agility, which simplifies the task of more intelligent control plane to dynamically provision the meshed optical backbone. The following is the worst case blocking probability model for MG-OXC that does not support tunability:

$$B_f = \frac{(n-1)*f_n - t_1}{(n-1)*f_n} \cdot \frac{(n-1)*f_{nl}*w_f - t_2}{(n-1)*f_{nl}*w_f} \cdot \frac{(n-2)}{(n-1)}$$

It shows that the average nodal degree plays a significant role in determining the worst-case nodal blocking probability. The actual blocking probability model for MG-OXC that does not support tunability shows a considerable improvement due to a higher utilization and traffic aggregation though the upper level tunnels as it follows:

$$B_f = \frac{(n-1)*f_n - t_1}{(n-1)*f_n} \cdot \frac{(n-1)*f_{nl}*w_f - t_2}{(n-1)*f_{nl}*w_f} \cdot \frac{(n-1)*w_{nl}*\lambda_w - w_{nl}*\lambda_w}{(n-1)*w_{nl}*\lambda_w + \delta}$$

Where n is the nodal degree, fn is the number of fibers per node, t1 is the number of fibers being tunneled, fnl is the number of fibers being transferred to the Waveband

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stage, wf is the number of wavebands per fiber, t2 is the number of wavebands being tunneled, wnl is the number of wavebands being transferred to the lambda switching stage, λw is the number of wavelength per waveband, and δ is a factor of 1 that is present when the switching fabric level is not used and zero otherwise.

The ability of configuring the number of tunnels in the fiber and the waveband levels by the control plane significantly influences the blocking probability of the node and adds more intelligence to the core. The core lambda switching fabric in the MG-OXC has the dominating effect on the blocking probability. The top tunneling layers reduce the need for a big switching fabric, which means less lambda contention and blocking. The lambda switching core of MG-OXC could be based on the OEO optical switching technology, which offers 3R regeneration, long range transmission, wavelength conversion, and reliability functions. It also could be on the OOO optical switching technology, which offers bit-rate and protocol independent switch fabric, low latency switch fabric, scalable to 40 Gbps, small footprint, and low power consumption.

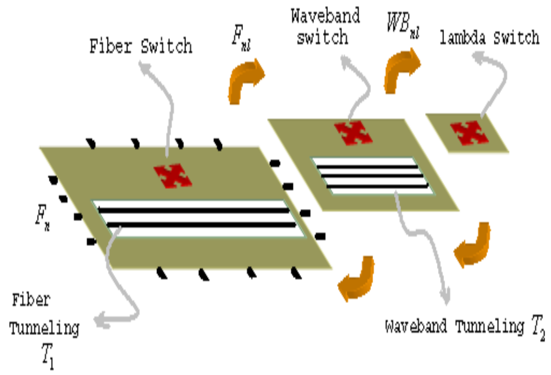

Fig. 4 Internal Architecture of the MG-OXC with Nodal Degree of 4

VII. RESULTS

To further study the characteristics of the network that employs MG-OXC in selected site within the GMPLS environment and quantify the effects of using such architecture, simulations of the mathematical model were preformed using different size topologies to verify results and test the merits of partially substituting the tunability option with MG-OXC. Figure 5 shows a topology of nine nodes that employs different degrees of Shortest Path First (SPF) algorithm as alternative routes for the optical traffic depending on the distance in case of link capacity exhaustion. The essential regeneration sites were determined in advance in accordance with reach variation requirements and complemented with free tunability functions. Different schemes are used to implement SPF routing algorithm such as random traffic routing, highest traffic first, and longest path traffic first. Simulation results showed that the Longest Path Traffic First based OSP routing presented less need for traffic deflection and fragmentation.

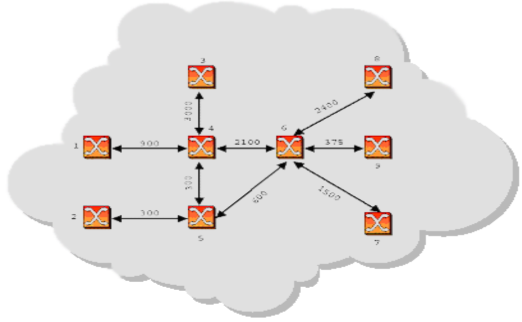

Fig. 5 Topology used for experimental validation

All results of the nodal blocking probability model confirmed the essential need for lambda conversion capability or a change of the cross-connect architecture to MG-OXC at node 6. Accordingly, node 6 was selected as a potential regeneration point considering all the distances in the examined topology. The use of MG-OXC in site 6 increased the amount of traffic aggregated through the node comparing to the conventional cross-connect, which confirms the mathematical model for the nodal blocking probability resulting from using MG-OXC. With the significant decrease in nodal blocking rate, the need for tunability and signal regeneration requirement have decreased, which clearly indicates that the better traffic utilization through intermediate nodes using configurable multi-layer tunnels, the higher the overall performance of the optical core.

Figure 6 shows the worst case blocking probability vs. the nodal degree of the MG-OXC with configurable multi-layer fiber and waveband tunnels. The MG-OXC is connected to six bidirectional fibers that have 4 wavebands per fiber and 4 lambdas per waveband. As expected, the results confirm the merits of using tunnels, where it shows how the blocking probability decreases with the higher degree of tunnel usage and bypassing functionality. The conventional cross-connect presents the highest nodal blocking rate at all times with respect to the nodal degree.

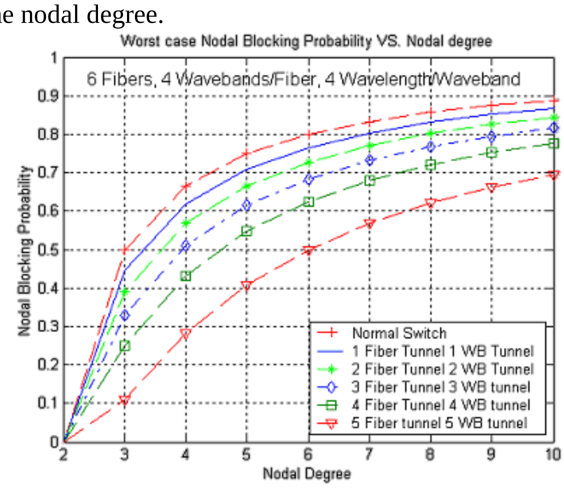

Fig. 6 Nodal Blocking Probability vs. Nodal degree for MG-OXC

Furthermore, the impact of the different tunneling levels was studied. It is essential to understand the effect of these two tunneling degrees on the wavelength

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blocking probability, utilization, and the scalability of the optical system. A MG-OXC that is connected to 20 bidirectional fibers that have 4 wavebands per fiber and 4 lambdas per waveband was considered to determine the impact of these tunneling levels and their different possible configuration. It gives an indication of the proper reconfiguration schemes needed to optimize the utilization and the scalability of the optical core. This determination enhances the intelligence of the control plane and simplifies the wavelength assignment problem. The nodal degree of the MG-OXC plays the dominating role in determining the nodal blocking probability behavior, but its impact could be moderately adjusted by reconfiguring the different levels of tunnels that lie on top of the core switching fabric of the MG-OXC.

The blocking probability vs. fiber tunnels with waveband tunnels set to 1 is compared to the blocking probability vs. fiber tunnels with waveband tunnels set to 7 for different nodal degrees. The results showed that the waveband level tunnels have a superior impact on the system than the fiber level tunnel due to the natural grooming degree progression offered to the lower level lambda switching fabric, but the difference is not significant in case the waveband level tunnels are not present. The two extreme cases of having one level tunneling were studied to confirm with previous results. The case of blocking probability vs. waveband tunnels with fiber tunnels set to 0 for different nodal degrees gave better results than the opposite case where the waveband tunnels are set to zero with the presence of fiber level tunnels. This confirms that the more utilization possible for existing tunnels, the better the performance is. This complies with the fact that waveband tunnels are utilized in a faster manner than the fiber tunnels, which results in better performance. But even having one level tunnel adds a significant improvement in terms of blocking probability to the conventional OXC. As a result, it was concluded that the waveband tunnels has a greater impact on the system for reconfiguration purposes. Figure 7 shows the nodal blocking probability vs. a dominating fiber tunnels and a dominating waveband tunnels with consideration for different nodal degrees.

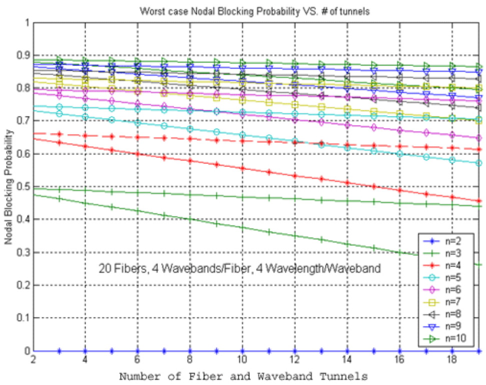

Fig. 7 Nodal Blocking Probability vs. Different Tunnel Levels

Figure 8 shows the effect of MG-OXC fiber tunnels with a nodal degree of 5 on the overall nodal wavelength blocking probability. The number of the incoming fibers per node is constant. In this case, it is apparent that the relationship between fiber level tunnels and waveband level tunnels is inversely proportional in terms of quantity. It shows that the operational region lies between 15 and 18 fiber tunnels for a MG-OXC with a nodal degree of 5. This region represents the number of fiber tunnels required to obtain the lowest wavelength blocking probability of a node with a certain nodal degree.

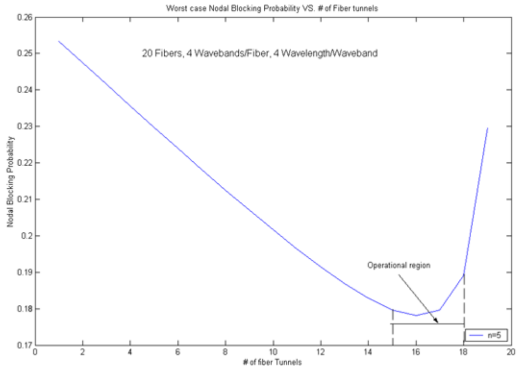

Fig. 8 Effects of Fiber Tunnels on Blocking Probability

The next figure shows that the operational region for the same MG-OXC system with a fixed incoming number of fibers per node is wider with respect to the required waveband level tunnels. It also shows that waveband level tunnels have a greater impact on the system than the fiber level tunnels. With the increase of the nodal degree, for the same number of incoming fibers per node, the effects of the waveband level tunnels get dominant, which plays the governing role in reducing the nodal wavelength blocking probability.

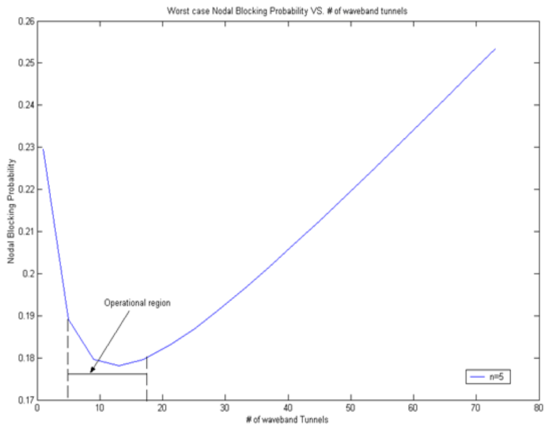

Fig. 9 Effects of Waveband Tunnels on Blocking Probability

It is essential to reduce the complexity of the system to enhance the control plane intelligence, thus affecting every aspect related to wavelength contention, wavelength assignment, tunability, regeneration, and optical traffic grooming to reduce the scalability problems in the routing algorithms and to comply with the GMPLS frame work.

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VIII. CONCLUSIONS

The main objective for optical networks running under the GMPLS framework is to support fast end-to-end optical light paths. Resource discovery, path selection, and path management are the three main components involved in setting up a channel. In the current GMPLS framework, topology and resource discovery are limited to a single domain, however, as the network size grows, different domains must be interconnected. Several new IETF drafts have appeared on this topic [10, 11, 12, 13], and it is expected that more issues related to inter-domain routing will emerge. The constraints to flood topology information across the domains and the exact type of information to exchange between domains also need to be resolved. Accordingly, the future intelligent optical control plane requires less transparency and higher degree of control to transport fine grain optical traffic across the DWDM domain using GMPLS framework. Decreasing the tunable resources and maximizing the overall utilization of the core network by determining the nodal blocking probability to allocate the MG-OXC switch is introduced in this paper. The new cross-connect architecture enables the enhancement of the control and management algorithms that comply with GMPLS. The need for tunability and signal regeneration requirement decreases with using configurable multi-layer tunnels caused by better traffic utilization though the MG-OXC.

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