Multi-granularity Switching Structure Based on Lambda-Group Model

YiYun Wang, Qingji Zeng, Chun Jiang, ShiLin Xiao, and Lihua Lu

ABSTRACT—We present an intelligent optical switching structure based on our lambda-group model along with a working scheme that can provide a distinctive approach for dividing complicated traffic into specific tunnels for better optical performance and grooming efficiency. Both the results and figures from our experiments show that the particular channel partition not only helps in reducing ports significantly, but also improves the average signal-to-noise ratio of the wavelength channel and the blocking performance for dynamic connection requests.

Keywords—GMPLS, multi-granularity, lambda-group, OXC, traffic grooming.

I. Introduction

In order to achieve a generalized label switched path (LSP) in generalized multiprotocol label switching [1], which subdivides the switching types and traffic granularities, items such as a Lambda LSP and waveband LSP have been added onto a new multi-granularity switching node as discussed by many recent studies. Kolarov and others [3] studied the waveband routing and wavelength assignment problem in hierarchical mesh networks with optical cross-connect (OXC) that can route multiple granularities. Zhu Keyao and others [4] present four optical grooming switching architectures that imply that the connection bandwidth-granularity distribution has significant impact on network throughput and network resource utilization. However, the simple OOO+OEO model [3], cyclic MUX–DMUX [6], and three-layer multi-granular (MG)-OXC [7] could not provide enough support on multi-node configuration under a dynamic traffic environment with complex contribution. We have conducted a thorough research and presented new features to meet future networking needs. 1) Support the variable-length waveband and the logical granularity to handle the remaining channels in addition to the obvious local wavebands. 2) Support the granularity operation among multiple fibers and permit the combination and disassembly of homogeneous granularities, that is, virtual granularity. Previous studies of the waveband switching structure prefer to recognize continuous co-directional channels as a waveband, without easing the burden of WXC. Virtual granularities can, however, reduce the times of multiplexing and demultiplexing greatly in switching nodes, and improve the channels' average signal-to-noise ratio (SNR). 3) Remove some inefficient modules and layers in a multi-granularity model, for example, the fiber cross-connect layer.

II. Concept of Lambda-Group Switching

Numerous adjacent nodes, high capacity fibers, and complex traffic in a mesh topology are the basic characteristics of a multi-granularity switching node. The front module of the node should be capable to confirm the scale of wavebands existing in input fibers, and evaluate the possibility of forming advanced granularities (such as waveband) among different fibers. We think that if a fiber has already reached a certain scale of homogeneous wavelength channels (for example, 1/3 of fiber capacity) and has enough potential to form a larger waveband with the help of other fibers, the routing direction (the label of the node) is an 'executing direction' (ED) of this fiber. This fiber is also the 'executing fiber' (EF) of the ED. Besides a waveband with continuous channels, the above definition also allows for a special waveband in which some channels are loaded with nothing: If a waveband in a fiber has a few channels without traffic load, we define the waveband as a new logical granularity, namely a lambda-group; if the virtual waveband (from multiple fibers) has a few channels without

---

Manuscript received Aug. 20, 2005; revised Dec. 20, 2005.

YiYun Wang (phone: +86 215 0859837, email: wyy@sjtu.edu.cn), Qingji Zeng (email: qjzeng@mail.sjtu.edu.cn), Chun Jiang (email: cjiang@sjtu.edu.cn), ShiLin Xiao (email: xiaoshilin@hotmail.com), and Lihua Lu (email: Lu_lihua@sina.com) are with Center of Broad-band Optical Networking Technology, Shanghai Jiaotong University, Shanghai, China.

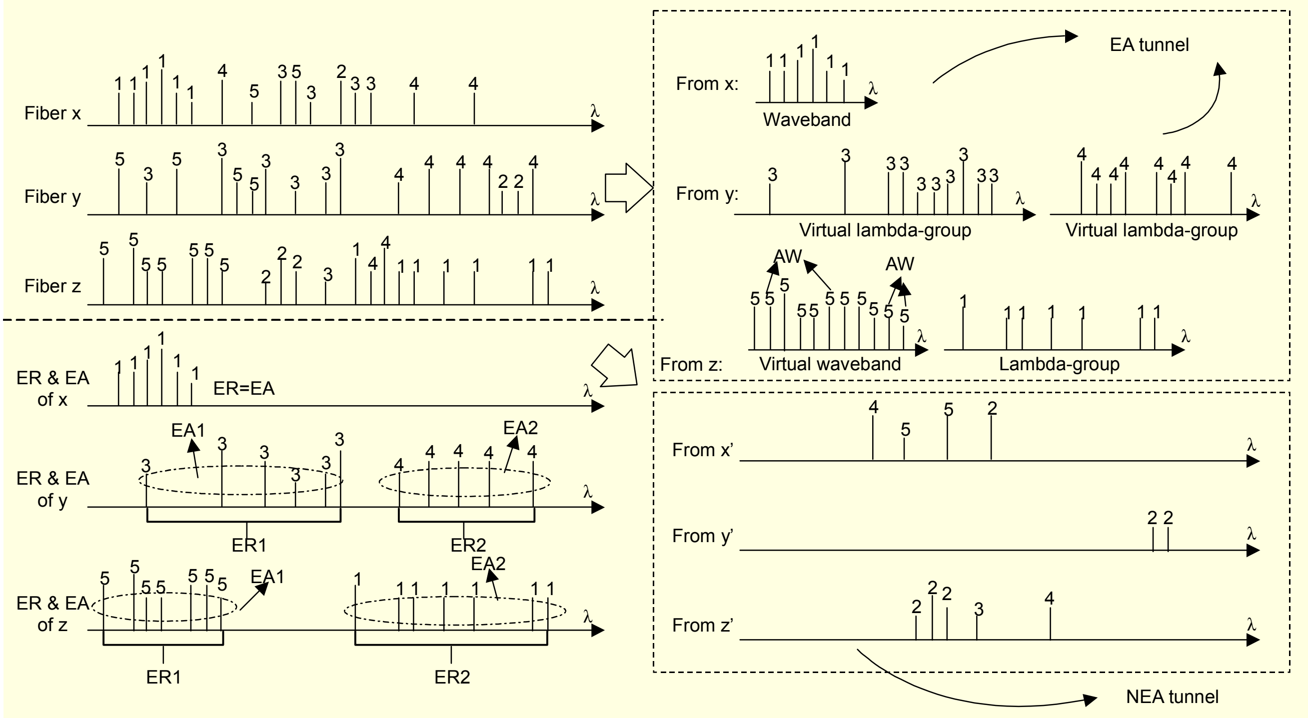


Fig. 1. Example of lambda-group switching.

traffic load, we define the waveband as another logical granularity, namely a virtual lambda-group. Also, the definitions of ED and EF involve four kinds of waveband: normal waveband, virtual waveband, lambda-group, and virtual lambda-group. Note that when recognizing a virtual waveband or virtual lambda-group among fibers, we have to abandon what may impair the channel performance when the realization of advanced granularity causes excessive optical treatment. There may be several EDs in a fiber. One fiber is called a 'non-executing fiber' (Non-EF) if no executing direction exists in this fiber. After the static algorithm of the configuration confirms all EDs of the fibers, we can estimate the size and number of all advanced virtual granularities among the fibers. Here, the frequency range of a logical granularity or an advanced virtual granularity possible in a fiber is defined as the executing range (ER), including existing wavelength channels with ED and channels to be filtered for granularity. The former channels are specified as an executing area (EA), which must be within the corresponding ER; all other channels except EA channels in the fiber are channels of a non-executing area (NEA). A few wavelength channels to be filtered in order to expand another fiber's waveband or lambda-group are called assistant wavelength channels (AWs).

Figure 1 provides a vivid explanation of all symbols. The numbers from 1 to 5 denote the routing direction or label of a neighboring node. According to our definition, '1' is the ED of fiber x, '3' and '4' are the ED of fiber y, and '1' and '5'are the ED of fiber z. In other words, the EF of '1' is fiber x and fiber z, the EF of both '3' and '4' is fiber y, the EF of '5' is fiber z, and '2'has no EF. The ER and EA of every fiber are also shown in the figure. There is no Non-EF here.

III. New Switching Structure

In this section, we present a smart multi-granularity switching structure based on IETF models [1]. All input traffic is first recognized and divided by the partition module into six kinds of logical granularities through the EA tunnel and NEA tunnel, respectively. According to the static algorithm of configuration, the six kinds of granularities are the executing area in executing fiber (EA@EF), assistant wavelength channel in executing fiber (AW@EF), non-executing area within executing range in executing fiber (NEA:ER@EF), non-executing area out of executing range in executing fiber (NEA: $\overline{\text{ER}}$ @EF), assistant wavelength channel in non-executing fiber (AW@NEF), and non-executing area in non-executing fiber (NEA@NEF). Granularities including EA@EF, AW@EF, and AW@NEF are led to the core switching layer through the EA tunnel directly, while granularities including NEA:ER@EF, NEA: $\overline{\text{ER}}$ @EF, and NEA@NEF through the NEA tunnel are then processed by the clean module. After the front fiber adapter layer (FAL), three clusters of granularities are large wavebands and lambda-groups along the EA tunnel, complex λ-groups along the NEA tunnel, and separate wavelengths along the NEA tunnel. The three different parts in

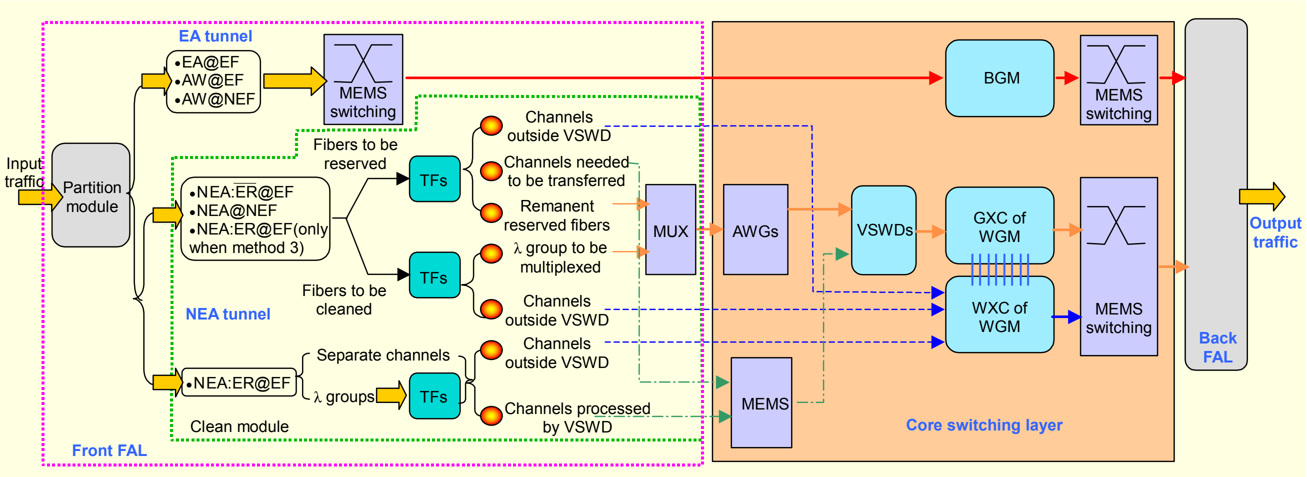


Fig. 2. Architecture of an LGS node.

the core switching layer will be responsible to switch these granularities, respectively. Since the EA tunnel can provide a higher average SNR of the channel than what the NEA tunnel can, the overall channel performance will be improved when the main traffic is processed by the waveband cross-connect/lambda-group cross-connect (BMG) module with good algorithms of configuration in relation to traffic grooming and the rearrangement of granularities. Finally, the back FAL makes up output fibers with measures for good optical properties as shown in Fig. 2.

Table 1. Comparison of port savings.

Condition	Trad. WXC	Port saving of MG-OXC than trad. WXC (%)	Port saving of LGS OXC vs. trad. WXC	
			Input (%)	Output (%)
16ch/F, n+5, n\2 pair	192 × 192	12.5	37.0 (121)	85.9 (27)
16ch/F, n+5, n\3 pair	288 × 288	12.5	43.4 (163)	85.4 (42)
16ch/F, n+5, n\4 pair	384 × 384	12.5	39.1 (234)	85.4 (56)
16ch/F, n+3, n\2 pair	128 × 128	12.5	32.8 (86)	85.2 (19)
16ch/F, n+4, n\2 pair	160 × 160	12.5	32.5 (108)	85.6 (23)
16ch/F, n+5, n\2 pair	192 × 192	12.5	37.0 (121)	85.9 (27)
16ch/F, n+5, n\3 pair	288 × 288	12.5	43.4 (163)	85.4 (42)
24ch/F, n+5, n\3 pair	432 × 432	4.2	42.1 (250)	89.4 (46)
32ch/F, n+5, n\3 pair	576 × 576	3.1	39.2 (350)	92.0 (46)

IV. Performance Simulation

1. Port Requirement of Different Structures

Table 1 shows the results of the port saving percentage in the core layer. Term 16 ch/F indicates 16 channels per fiber, n+5 means that the node n is connected with five other nodes, and n\2pair means that there are two pairs of unidirectional fibers between n and every connected node. It is apparent that the LGS design is more cost-effective.

2. Signal Quality and Blocking Performance

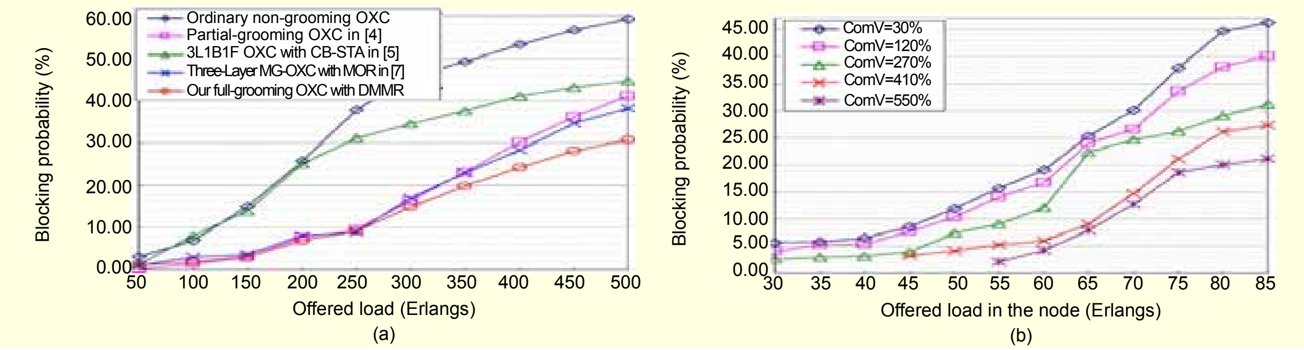
We simulate a dynamic network environment to evaluate the efficiency of different optical grooming OXCs and their corresponding working schemes based on the 19-node NSFnet topology. The network has no wavelength converter and each fiber can support 32 wavelength channels.

Since a great amount of measurements [2] have recently confirmed high-speed traffic of self-similarity, we assume that the connection-arrival process is self-similar and the connection-holding time follows a negative exponential distribution.

We compared the results of several representative structures from studies [4], [5], and [7] with those of our new design in Fig. 3(a) under the same dynamic environment. Figure 3(b) shows the results of a given node connected by five neighbor nodes, and the tendency of blocking performance with changing ComV at specific traffic loads. With the improved dynamic algorithm, we succeeded in decreasing the blocking probability below about 35% under high traffic load. Moreover, we also studied the average attenuation of every possible granularity at the peak access ratio using optimized algorithms as shown in Fig. 4. Results from various simulations verify the high performance and cost-effectiveness of the lambda-group switching fabric.

V. Conclusion

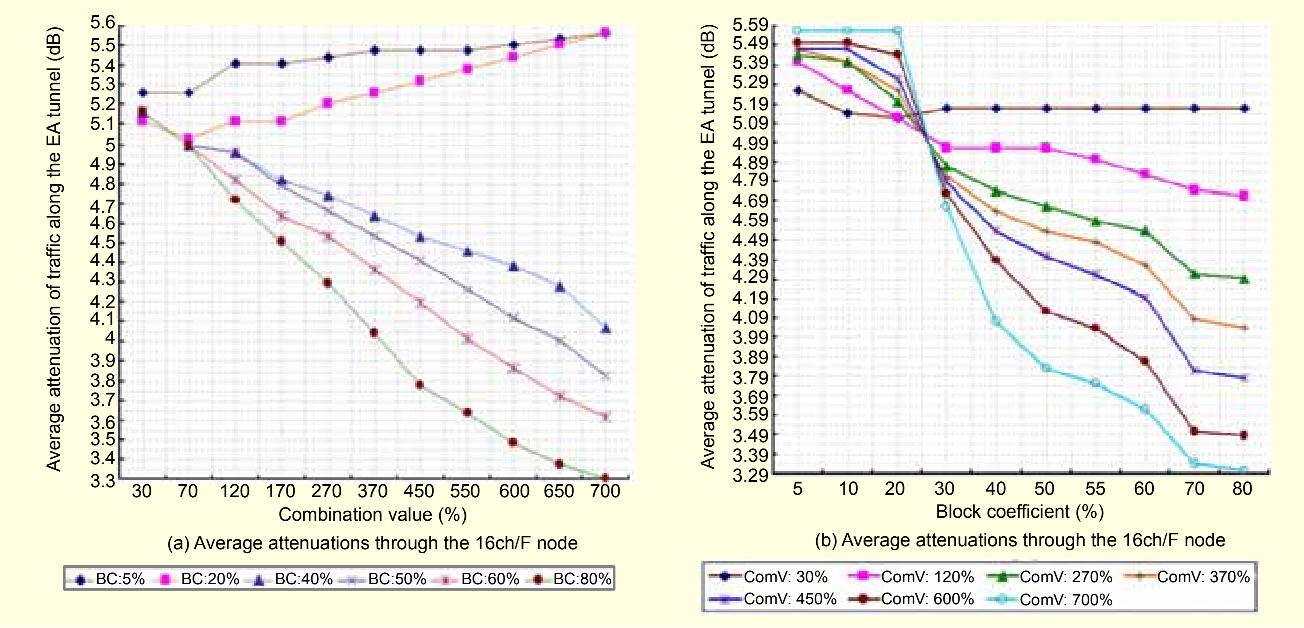
This paper first presents novel concepts such as the variable waveband, optical logical granularity, virtual waveband, and virtual lambda-group. In addition, we propose a smart optical switching structure with granularity pre-grooming, as well as



(a)

(b)

Fig. 3. Blocking performance with increasing load at different ComV's.



(a) Average attenuations through the 16ch/F node

(b) Average attenuations through the 16ch/F node

Fig. 4. Attenuation with changing BC and ComV along the EA tunnel.

the corresponding working scheme and algorithms of node configuration. The LGS structure can largely reduce input fibers entering the core switching layer, greatly improve the quality of the optical channel, improve the flexibility of multi-granularity switching, and enhance the self-adjustment of resource utilization.

References

[1] R. Douville, D. Papadimitriou, L. Ciavaglia, et al, "Extensions to GMPLS for Waveband Switching," Internet Draft, <draft-douville-ccamp-gmpls-waveband-extensions-05.txt>, Work in Progress, July 2004.

[2] Mark E. Crovella and Azer Bestavros, "Self-Similarity in World Wide Web Traffic: Evidence and Possible Causes," *IEEE/ACM Transactions on Networking*, vol 5, no.6, Dec. 1997, pp. 835-846.

[3] A. Kolarov, Wang Ting, Sengupta B., et al, "Impact of Waveband Switching on Dimensioning Multi-granular Hybrid Optical Networks," *Proc. Optical Network Design and Modeling Conf.* Feb. 7-9, 2005, pp. 371-381.

[4] Zhu Keyao, Zang Hui, and Mukherjee B., "A Comprehensive Study on Next-Generation Optical Grooming Switches," *IEEE J. on Selected Areas in Communications*, vol. 21, iss. 7, Sept. 2003, pp. 1173-1186.

[5] Pin-Han Ho, Mouftah H.T., and Wu Jing, "A Novel Design of Optical Cross-connects with Multi-granularity Provisioning Support for the Next-Generation Internet," *IEEE Int'l Conf. Communications*, *Proc. ICC 2003*, vol. 1, 11-15 May 2003, pp. 582-587.

[6] Kaman V., Zheng Xuezhe, Jerphagnon O., et al, "A Cyclic MUX-DMUX Photonic Cross-Connect Architecture for Transparent Waveband Optical Networks," *IEEE Photonics Technology Letters*, vol. 16, iss. 2, Feb. 2004, pp. 638-640.

[7] Cao Xiaojun, Anand, V., Xiong Yizhi, et al, "A Study of Waveband Switching with Multilayer Multigranular Optical Cross-Connects," *IEEE J. on Selected Areas in Communications*, vol. 21, iss. 7, Sept. 2003, pp. 1081-1095.