行政院國家科學委員會專題研究計畫　成果報告

GMPLS 網路架構下的網路流量控衡

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計畫主持人：陳健

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行政院國家科學委員會補助專題研究計畫 ■ 成 果 報 告 □期中進度報告

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Abstract

The objective of the project is to study the traffic engineering issues in the GMPLS (Generalized Multi-Protocol Label Switching) network and develop promising algorithms to maximize the network resource utilization and throughput while minimizing both the end-to-end delay and network instability. GMPLS is extension of MPLS (Multi-Protocol Label Switching). With some modification and additions to the MPLS routing and signaling protocol, the GMPLS can be used not merely with router, but also with newer device like OXC (Optical Cross-Connect). The wavelengths in OXC can be treated as labels. These modifications are being standardized by the Internet Engineering Task Force (IETF). However, there are remaining challenges to adapt a traffic engineering scheme, which optimize network utilization, under a dynamic change of real IP traffic in GMPLS network, such as logical topology design problem, routing and wavelength assignment (RWA) problem, protection/restoration problem, etc.

In this report, we present two heuristic algorithms to solve RWA problem in the networks that utilize multi-granularity optical cross-connects (MG-OXCs) as their node architecture. Simulation results are also shown to validate our algorithms.

Keywords: Generalized Multi-Protocol Label Switching (GMPLS), traffic engineering, routing and wavelength assignment (RWA), multi-granularity optical cross-connects (MG-OXCs)

中文摘要

本計畫的目的在於學習 GMPLS (Generalized Multi-Protocol Label Switching) 網路的傳出工程以及發展出適合的演算法來增進網路資源的利用率與流量，以及將網路傳輸的延遲及不穩定性降到最低。GMPLS 為 MPLS (Multi-Protocol Label Switching) 的延伸，原本 MPLS 上的路由協定與信號協定經過一些修改與增加之後，GMPLS 不僅能適用在路由器上，而且也能適用在像 OXC (Optical Cross-Connect) 等較新的設備上，因為波長在 OXC 上就被視同為原本 MPLS 上的標籤。目前 IETF 正在進行 GMPLS 相關協定的修改與標準化。然而，動態的 IP 流量在 GMPLS 網路之下，仍然存在著一些網路傳輸工程的挑戰需要被克服，例如邏輯拓僕設計問題、路徑與波長分配問題、網路保護與修復問題等等。

在這篇報告裡，我們提出了兩個啟發式演算法來解決 MG-OXC (multi-granular optical cross-connects) 網路上的路徑與波長分配問題。報告也將展示我們的模擬結果來證實我們的演算法的可行性。

關鍵詞：流量控衡，路徑與波長分配問題

1. Research Objectives

With the advance of electrical and optical technologies, high-performance IP routers and high-capacity OXC systems have been widely deployed in today's core network. The routers perform packet forwarding, traffic aggregation, and demultiplexing and thus achieve high link utilization. The OXCs set up optical label switching paths (OLSPs, i.e., lightpaths) between the IP routers based on the IP traffic between the routers. Because of fluctuation of IP traffic, it is necessary to measure IP traffic and monitor network congestion status to dynamically configure the OLSPs so as to maximize network resource utilization. This is so-called traffic engineering. GMPLS (Generalized Multi-Protocol Label Switching) [1] signaling/routing protocols provide the necessary linkage between the IP and photonic layers, allowing interoperable, scalable, parallel, and cohesive evolution of networks in the IP and photonic dimensions. Therefore, we propose using GMPLS to perform traffic engineering on future telecom network.

Our major focus in the first year is on the problem identification. We study the issues of network scalability and cost saving for different optimization algorithms for RWA, load balancing, and protection/restoration with different network parameters to optimize the network performance. We found that the topics stated above are worth applying on the hierarchical wavelength-division-multiplexed optical networks [2-6].

Hierarchical optical cross-connects, also called multi-granularity optical cross-connects (MG-OXCs) have gained considerable attention for its control and cost benefits. However, the solutions to satisfy lightpath requests, to some extent, become different to that of the conventional WDM networks. We present two heuristic algorithms to handle the RWA problems in the networks comprising of the OXCs as Fig.1 [5] and the OXCs Fig.2 [6]. We denote the MG-OXC in Fig. 1 as MG-OXC1 and in fig. 2 as MG-OXC2. Detailed description of these two MG-OXCs can be found in [5] and [6]. We briefly describe some of their characteristics.

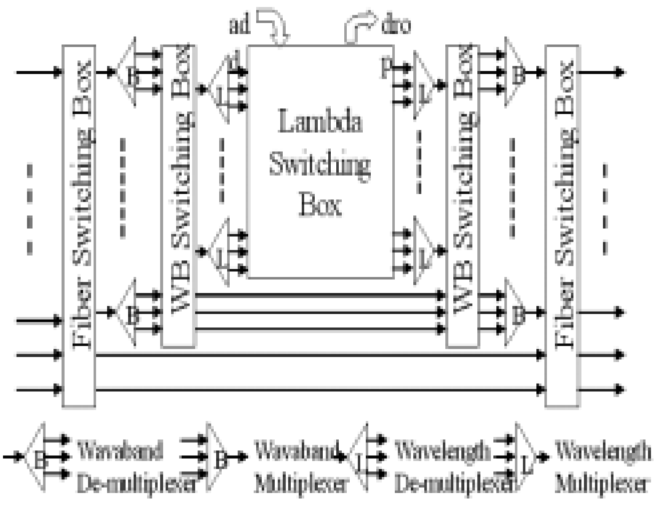

Fig. 1 Architecture of MG-OXC1

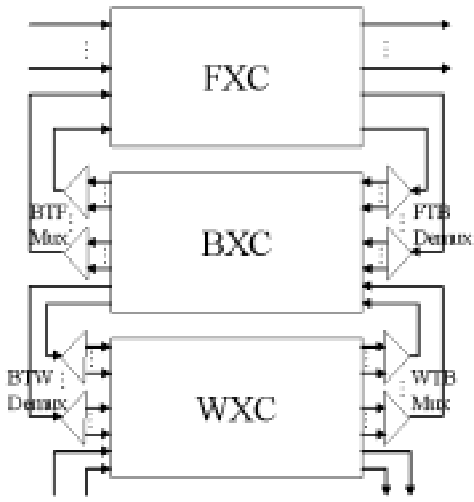

Fig. 2 Architecture of MG-OXC2

For MG-OXC1, we define the *tunnel* as a group of consecutive wavelength channels bundled and switched together, which is either a fiber or waveband tunnel containing a fixed number of wavelength channels. In the network consists of MG-OXC1, A directional link consists of F fibers, where F_1, F_2, and F_3 fibers are assigned as fiber-switched, waveband-switched, and lambda-switched fibers respectively (i.e. $F = F_1 + F_2 + F_3$). All the channels in a waveband or a fiber-switched fiber must be switched together. Lambda-switching is required when a lightpath enters or exits a tunnel, so that other traffic can be grouped or degrouped as well. One of the problem to be solved in this network is when given a network (whose parameters include topology, number of ports in each node, traffic matrix of the lightpath requests, etc.), how to allocation tunnels in the physical network so that maximum throughput can be achieved.

For MG-OXC2, we define two terms: *fiber pipe* and *waveband pipe*. A fiber pipe is a tunnel-like passage for the traverse of waveband pipes, starting from the Waveband–To-Fiber (BTF) Mux of the source node, bypassing through the intermediate nodes' FXCs, and ending at the Fiber-To-Waveband (FTB) Demux of the destination node. Similarly, a waveband pipe is a tunnel-like passage for the traverse of lightpaths, starting from the Wavelength-To-Waveband (WTB) Mux of the source node, traversing a set of fiber pipes, and ending at the Waveband-To-Wavelength (BTW) Demux of the destination node. Most research papers focus on how to satisfy the traffic demands while minimizing the total number of required ports for the network composing of MG-OXC2s. While this is meaningful when building a new network, however with the exist networks usually a MG-OXC2 with fixed number of port is added incrementally. Therefore, a more challenging problem is that when the number of ports in MG-OXC2s are fixed and given a lightpath traffic matrix trquests, minimize the number of the blocking requests so that maximum throughput can be achieved. We'll describe our research methods and results in the following section.

2. Research Methods and Results

(A) MG-OXC1-based network

In our observation, if the traffic demands distribute uniformly over the network, allocating tunnels uniformly is a good scheme since the tunnels would not prefer certain part of the network. However, the traffic in real network is non-uniform and our scheme takes this into account to improve the performance. The heuristic algorithm we proposed is based on the max-flow min-cut theorem, which states that

> *The maximum possible flow between a pair of vertices s and d is given by the capacity of the minimal cut.*

The idea is that since the maximum flow from a source s to a destination d is constrained by the capacity of their minimal cut, the more tunnels allocated across the cuts, the less likely their demand will be blocked. Fig. 3 gives a high level description of our tunnel allocation algorithm, named Min-Cut based Static Tunnel Allocation (MCSTA).

Min-Cut based Static Tunnel Allocation (MCSTA)

1. Find the source-destination pair (*s*, *d*) with the maximum load according to the given traffic matrix.
2. Find the min-cut for the (*s*, *d*), and randomly allocate tunnels cross the cut if possible. The number of tunnels we try to allocate depends on the traffic load of the (*s*, *d*) over the total traffic load. Note that there is a constraint on the hop count of the tunnels (i.e., each tunnel should have the same length.).
3. Set load of (*s*, *d*) to 0.
4. If all elements in the traffic matrix are 0, stop, else, go to Step 1.
5. Perform a makeup process that fills each fiber-switching layer with tunnels as full as possible.

Fig. 3 Details of MCSTA algorithm

Note that we put a constraint on the length of tunnels H_{min}, which is set to the minimum integer that is larger than the average number of hops between nodes. This is because lightpath requests usually do not have to go through “long” tunnels to get to their destinations. On the other hand, if tunnels are too short, the effect of port saving would become less obvious.

We compare our algorithm with the uniform allocation scheme in different traffic distribution and traffic load. Fig. 4 gives the definition that the distribution is equal to (traffic load in A) / (total traffic in traffic matrix). Fig. 5~Fig. 7 shows Blocking probability versus traffic load in the 16-node network [5] under the distribution 0.625. (*F1*)F(*F2*)B(*F3*)L stands for the experiment with F1 fibers for fiber switching, F2 fibers for waveband switching, and F3 fibers for lambda switching.

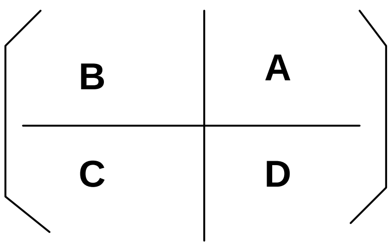

Fig.4 Traffic matrix example

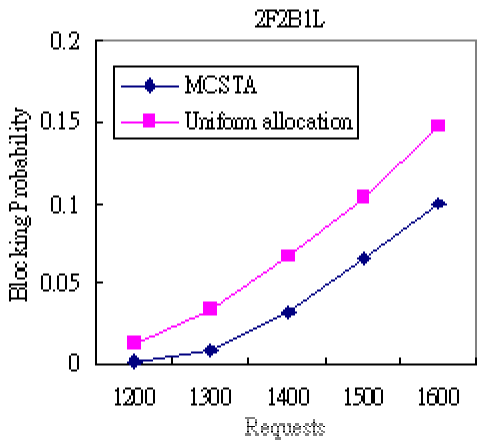

Fig.5 Blocking probability versus number of request under 2F2B1L

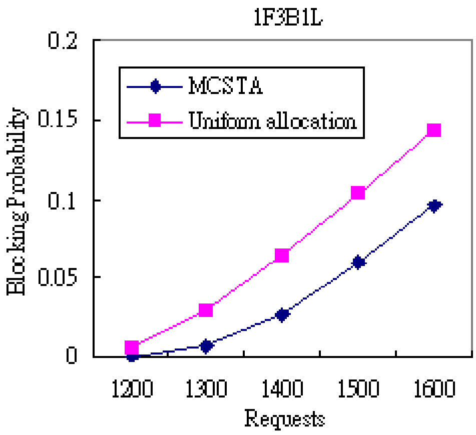

Fig.6 Blocking probability versus number of requests under 1F3B1L

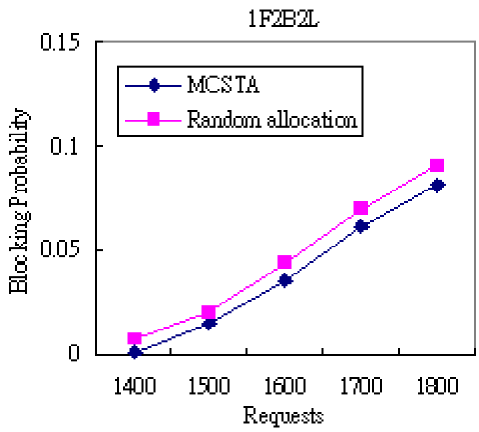

Fig.7 Blocking probability versus number of requests under 1F2B2L

It can be observed that when the percentage of waveband and fiber switching increased, MCSTA had better performance over uniform allocation. Comparing Fig. 6 and Fig. 7, with the percentage of lambda switching increased, the blocking probability reduced. The reason why two curves in Fig. 7 are closer than those in Fig. 6 is that the numbers of tunnels we can allocate in Fig. 6 are more than those in Fig. 7.

(B) MG-OXC2-based network

Since no matter how the lightpaths are routed on the network, the network will be finally filled with fiber pipes, waveband pipes, and lightpaths. Observing this allow us to devise a hierarchical method to solve the problem that first, allocate fiber pipes, second, allocate waveband pipes, and finally route the lightpath requests. Fig. 8 describes our algorithm.

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1. From the given traffic matrix T, derive two additional matrix F, fiber matrix, and B, waveband matrix such that each element in F and B are $T_{i,j}/W$ and $T_{i,j}/WB$, where W is the number of wavelength in a fiber and WB is the number of wavelength in a waveband.
2. Use the algorithm in [7] to route F in the fiber layer of the network and then perform a makeup process to further utilize the residual resource.
3. Use the algorithm in [7] to route B in the waveband layer of the network and then perform a makeup process to further utilize the residual resource.
4. Route T using the algorithm in [7].

Fig. 8 Details of band-based routing algorithm

We define two parameters to specify the number of ports in each node: α, the percentage of ports coming from/going to other nodes that can drop/add to/from the BXC, β, the percentage of ports coming from/going to FTB demux/BTF mux that can drop/add to/from the WXC. The two parameters can be tuned to determine the whole network cost. The simulation result is shown in Fig. 9 and Fig. 10. Fig. 9 displays the blocking probability versus number of requests under different values of β. We can see that the effect of increasing β (i.e. the network cost) is getting less obvious as β grows to some extent. Fig. 10 compares the performance when different routing algorithms are used in our heuristic. Shortest First represent the algorithm in [7] that choose the shortest request to route first. Heaviest First represent the algorithm that chooses the source destination pair with the heaviest traffic to route first.

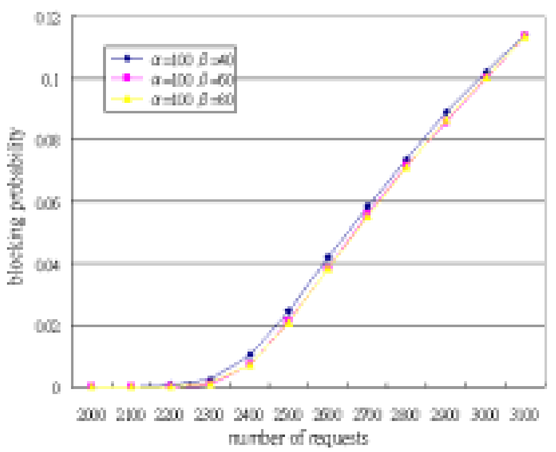

Fig.9 Blocking probability versus number of requests under different values of β

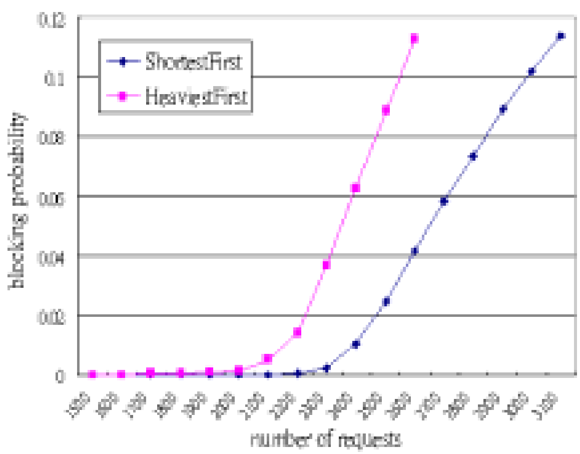

Fig.10 Blocking probability versus number of requests under SF and HF algorithms

3. Project Self-Evaluation

Technology is so rapidly changing that it is nearly impossible to keep up with the changes. We have endeavored to capture a substantial subset of the key problems and known solutions to these problems. Based on the knowledge we acquired this year, we have even proposed our own optimization algorithms to solve the recently discovered RWA problems in the MG-OXC networks. We are preparing to publish our works in some of the first-class conferences. In the near future, we would like to extend our research on the protection/restoration as well as logical topology design in the MG-OXC networks. By executing this project, we expect to bring the most advanced research in the world to Taiwan, and potentially will become the performance benchmark for the design of next generation GMPLS networks.

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