行政院國家科學委員會專題研究計畫　成果報告

基於自我相似性的 DWDM 網路架構之研究

計畫類別：個別型計畫
計畫編號：NSC93-2213-E-009-122-
執行期間：93 年 08 月 01 日至 94 年 07 月 31 日
執行單位：國立交通大學電信工程學系(所)

計畫主持人：高銘盛

報告類型：精簡報告

處理方式：本計畫可公開查詢

中　華　民　國 94 年 9 月 7 日

行政院國家科學委員會專題研究計畫成果報告

基於自我相似性的 DWDM 網路架構之研究

A self-similarity based DWDM network architeture

計畫編號：NSC 93-2213-E-009-122

執行期限：93 年 8 月 1 日至 94 年 7 月 31 日

主持人：高銘盛 教授　　國立交通大學電信工程學系

一、中文摘要

我們提出一個基於自我相似性的 DWDM 網路架構. 它是由多層網路所組成, 在每一層網路, 一個或多個稱為 cell 的環狀網路為主要的組成單元. 此網路同時具有分封交換及電路交換的優點, 是一個簡單且非常有效率的網路. 我們在網路的底層進行分封交換, 而在其他階層只處理波長路由分配。因此, 各個節點及網路的複雜度可以大幅簡化. 最後, 我們進行效能分析以證實此網路的可行性.

關鍵詞：WDM 網路、封包交換、電路交換.

Abstract

In this report, a new approach for constructing a hierarchical DWDM network is proposed. It is comprised of multiple levels by using a special ring topology. On each network level, one or several ring structures, named as cells here, are employed. The multi-level DWDM network keeps the efficiency of packet-switched network and the simplicity of wavelength-routed network. We perform packet switching at some particular physical nodes on the bottom level. On all upper levels, wavelength routing is performed. As a result, the node configuration and network complexity can be simplified apparently. The performance analysis is provided to verify the feasibility of the proposed approach.

I. INTRODUCTION

With increasing demands on communication bandwidth, wavelength division multiplexing (WDM) technology is an excellent means to provide broadband services. Owing to the huge bandwidth offered by WDM, the bottlenecks in the delivery of data services can be relieved significantly. Moreover, the benefits of efficient resource sharing and high-speed data services accompanied with its high degree of configurability are also provided. Therefore, the introduction of WDM not only dramatically increases the point-to-point transmission capacity but also brings lots of potentials to carry out broadband all-optical networks [1].

According to the scales and coverage of communication networks, they can generally be sorted into wide-area networks (WAN), metropolitan-area networks (MAN), and local-area networks (LAN). WDM technology can be applied not only in trunk networks but also in subscriber loops [2]. A large WDM network is generally hierarchy-structured with multiple network levels. Several crucial issues such as wavelength routing, wavelength reuse, wavelength conversion, packet/circuit switching, survivability,…etc on each network level have to be taken into account in network design.

The purpose of this paper is to provide a simple network topology and an efficient wavelength management scheme for designing multi-level DWDM networks. As the network topology is concerned, simple ring structures are spread horizontally on the same level and vertically on different levels with the features of flexibility and loop-back protection. In addition, those critical themes related to the wavelength management mentioned above will be investigated.

This article is organized as follows. The network configuration and operation will be introduced first in Section

II. Next, in Section III, an input smoothing approach for modeling the switching system within an edge node is introduced, and the corresponding queueing performance is analyzed. Finally, a conclusion related to this network is presented in Section IV.

II. Network Configuration and Operation

The configuration of the proposed DWDM network is shown in Fig. 1. This network is designed based on a simple network topology, and employs an efficient and uniform wavelength management scheme. As illustrated in Fig. 1, the dual-ring topology is used because it can cover a wide area and has the property of self-healing [3]. Moreover, the proposed network is consisted of k levels, wherein the 1st level is the bottom level and the k th one is the top level. All the nodes within a ring are connected with an inner ring and an outer ring fiber links. This dual-ring structure is called a "cell". Actually the idea of cell is originated from wireless communications wherein a specific frequency band is allocated to a cell to deliver messages. In this design, however, a specific wavelength band (λ-band) will be assigned to a cell to deliver packets, which will be explained in detail later.

In this hierarchical DWDM network, nodes on upper levels are corresponding to cells of the lower level, i.e., a cell on the j th level is considered as a node on the $(j+1)$ th level. With such a virtual cell concept, the design and analysis of the network will be simplified dramatically.

An efficient and uniform wavelength management scheme for all network levels is crucial for the proposed network. Here the idea of "λ-band" is used to achieve this objective. A λ-band is comprised of a number of wavelengths that carry packets to identical destination. Namely, the wavelength carriers heading to the same destination cell will be merged as a λ-band. Once a λ-band is constructed, it will be managed as a sole unit before reaching the destination cell, and hence all the wavelengths within it will be routed altogether within the network. By dealing just with λ-bands instead of individual wavelength carriers, the wavelength management adopted in the multi-level network is simple and efficient. It can be observed that the number of wavelengths contained in a λ-band increases and the number of λ-bands to be managed decreases as the network level increases.

In order to understand the network operation, the trip that a packet would experience in such a network is also shown in Fig. 1. Let a packet-Z be generated by a source node (n_s) contained in a bottom cell (C_i) will be delivered to a destination node (n_d) located at another bottom cell (C_j). In the first place, the packet-Z starts off from the node n_s and is sent to an edge node of C_i. At the edge node, those packets heading to destination nodes inside C_j are switched together, wavelength converted, and then merged to be a level-1 λ-band. This λ-band will be managed as a sole unit within the network before reaching the destination cell C_j.

Next, the level-1 λ-band containing the packet-Z is delivered to the 2nd level via the edge node. As mentioned previously, the bottom cell C_i would be treated as a virtual node belonging to a particular level-2 cell on this level. The level-1 λ-band is then sent to an edge node of this level-2 cell and merged with other level-1 λ-bands destined to a specific level-2 cell containing C_j as a level-2 λ-band. The level-2 λ-band of interest is once more transferred to the 3rd level and the same operations as those on the 2nd level are executed again on this level. Such a wavelength management for delivering packets will be performed repeatedly until the packets reach the top level.

At the top level, the packet-Z is carried by a specific level-$(k-1)$ λ-band. This level-$(k-1)$ λ-band is delivered to the node containing the destination bottom cell C_j directly. Then this level-$(k-1)$ λ-band is transferred to the $(k-1)$ th level and decomposed into several level-$(k-2)$ λ-bands heading to different destination nodes of this level. Here the level-$(k-2)$ λ-band containing the packet-Z would be dropped by a node that C_j is included. Next, this level-$(k-2)$ λ-band is further delivered to the $(k-2)$th level via an edge node on this level and decomposed into several level-$(k-3)$ λ-bands. The same work is done repeatedly until the level-1 λ-band containing the packet-Z reaches the bottom cell C_j. At the edge node of C_j, the packet-Z is switched to an output port corresponding to the destination node n_d by a switching system and converted its wavelength to be the receiving one of n_d by a wavelength converter. Finally, the packet-Z is transported to the destination node n_d via the dual-ring network on the bottom level.

For illustrating the operation of edge node on a bottom cell, a representative edge node, as shown in Fig. 2, is provided [4]. This edge node is responsible for communicating with the other 10 bottom cells. Moreover, the number of wavelength carriers required for the cell-to-cell traffic on the bottom level is 4. In Fig. 2, a total of 40 wavelengths are received from the nodes inside this bottom cell. These wavelengths containing packets destined to all the nodes in the multi-level network. The switch fabric denoted as the switching system A has 40 inputs, being used to switch packets to appropriate output ports. The wavelength carriers in the 40 output ports are further wavelength-converted and then multiplexed to be the level-1 λ-band, a total of 10 level-1 λ-bands are obtained with each consisting of 4 wavelengths. Each level-1 λ-band carrying packets destined to a particular bottom cell and will be managed as a sole unit within the network.

III. Performance Analysis of A Particular Switch Fabric

In this paper, an input smoothing approach is used to model a particular switching system inside an edge node on a bottom cell to estimate the queueing performance of the switch fabric [5-6]. The schematic diagram of this model is illustrated in Fig. 3. In the following analysis, the simulation work is performed in accordance with the switching system A given in Fig. 2. In addition, the packets arrive at the N inputs of the switch are modeled as independent and identical Bernoulli processes. Namely, the probability of a packet arriving at a specific input is p in any given time slot, and successive packet arrivals are independent.

A. The Input Smoothing Model

In Fig. 3 those packets within a frame of b time slots are stored at each input and then enter the switching system together on separate input ports. Owing to the symmetry of this switch fabric, there are also b output ports connecting to each output. Furthermore, the N outputs of the switch fabric are divided into several groups, and the number of outputs in each group (X) is identical. Here X corresponds to the number of wavelength carriers in a level-1 λ-band. Notice that the assumption that the parameter N is a multiple of the parameter X is made. Let the number of packets entering the switch destined to a given output group be denoted as A_g. Therefore, we get

$$\Pr[\,A_g = k\,] = \binom{Nb}{k}\left(\frac{pX}{N}\right)^k \left(1-\frac{pX}{N}\right)^{Nb-k} \tag{1}$$

If k ($> Xb$) packets destined to a given output group are sent to the switching system, eventually ($k - Xb$) packets will be dropped. Accordingly, the probability of a packet being lost within the switch fabric is given as follows:

$$\begin{aligned}\Pr[\,packet\ \ loss\,] &= \frac{1}{Xbp}\sum_{k=Xb+1}^{Nb}(k-Xb)\binom{Nb}{k} \cdot \left(\frac{pX}{N}\right)^k \left(1-\frac{pX}{N}\right)^{Nb-k} \\ &= 1-\frac{1}{p}+\frac{1}{Xbp}\sum_{k=0}^{Xb-1}(Xb-k)\binom{Nb}{k} \cdot \left(\frac{pX}{N}\right)^k \left(1-\frac{pX}{N}\right)^{Nb-k}\end{aligned} \tag{2}$$

Meanwhile, simulation results for packet loss performance of this input smoothing model are shown in Fig. 4. The packet loss probabilities of a given output group are plotted against the frame size. The packet loss probability of the tagged output group increases with N, however, if N is large, there is little difference between different switch sizes.

After switching operation, packets are sent to output ports and then buffered to be served. Accordingly, the mean waiting time $\overline{W}$ of a packet destined to the given output group can be calculated as

$$\overline{W} = \frac{b-1}{2} + (b-1) + \frac{f_1 + f_2}{f_3}$$

$$f_1 = \sum_{k=1}^{Xb-1} \left(\frac{[\frac{k}{X}]-1}{2} \cdot [\frac{k}{X}] \cdot ((1+[\frac{k}{X}])X - k) + \frac{[\frac{k}{X}]}{2} \cdot ([\frac{k}{X}]+1) \cdot (k - [\frac{k}{X}]X) \right) \cdot \Pr[A_g = k]$$

$$f_2 = \frac{b-1}{2} \cdot Xb \cdot \Pr[A_g \geq Xb]$$

$$f_3 = \sum_{k=1}^{Xb-1} k \cdot \Pr[A_g = k] + Xb \cdot \Pr[A_g \geq Xb] \qquad (3)$$

where "[z]" denotes the integer equal to or smaller than a real number z.

The parameter $\overline{W}$ is measured in packet time slots. The first term on the right-hand side of the first formula in (3) is the expected value of time a packet has to wait until a frame of size b is constructed at the inputs. The second term is the delay caused by the fabric running at $1/b$ the speed of the inputs and outputs. The last term shows the expected amount of time a packet belonging to an output group waits to be served at the outputs. By (1), we can reformulate (3) as

$$\overline{W} = \frac{3(b-1)}{2} + \frac{f_1' + f_2'}{f_3'}$$

$$f_1' = \sum_{k=1}^{Xb-1} \left(\frac{[\frac{k}{X}](([\frac{k}{X}]-1) \cdot ((1+[\frac{k}{X}])X - k) + ([\frac{k}{X}]+1) \cdot (k - [\frac{k}{X}]X)) - Xb(b-1)}{2} \right) \cdot \binom{Nb}{k} (\frac{pX}{N})^k (1 - \frac{pX}{N})^{Nb-k}$$

$$f_2' = \frac{Xb(b-1)}{2} \cdot \left(1 - (1 - \frac{pX}{N})^{Nb} \right)$$

$$f_3' = Xb - \sum_{k=0}^{Xb-1} (Xb - k) \binom{Nb}{k} (\frac{pX}{N})^k (1 - \frac{pX}{N})^{Nb-k} \qquad (4)$$

A numerical result for the mean waiting time $\overline{W}$ of the input smoothing model against the offered load p is plotted in Fig. 5. Meanwhile, the parameter N is set to be 40 and b is varied from 2 to 4 in this figure. Apparently, the mean packet waiting time $\overline{W}$ grows proportionally with the offered load p and the frame size b.

In summary, Fig. 4 shows that to achieve a low packet loss probability for an input smoothing switch fabric requires a large frame size b, a small switch size N, and a low offered load p. However, a large frame size leads the mean packet waiting time to be worse, as shown in Fig. 5. Therefore, in order to get the better throughput-delay performance for this switching model, those crucial parameters such as N, b, p and X, should be evaluated deliberately based on the practical network configuration.

IV. Conclusion

The proposed multi-level network keeps the efficiency of packet-switched networks but releases network operations from complicated packet-switching by concentrating switching operations on the edge node of the bottom level. Simple wavelength routing on λ-bands instead of individual wavelength carriers is performed on upper levels. Consequently, the resulting hierarchical network is indeed a nice joint of packet-switching and wavelength-routing. In addition, the performances of the DWDM network are illustrated with the simulation results. In accordance with these numerical results, the parameters for designing such a DWDM network can be decided definitely.

References

[1] P. Green, "Progress in optical networking," *IEEE Commun. Mag.,* vol. 39, pp. 54-61, Jan. 2001.

[2] A. A. M. Saleh and J. M. Simmons, "Architecture principles of optical regional and metropolitan access networks," *J. Lightwave Technol.,* vol. 17, pp. 2431-2448, Dec. 1999.

[3] J. Manchester, P. Bonenfant and C. Newton, "The evolution of transport network survivability," *IEEE Commun. Mag.,* vol. 37, pp. 44-51, Aug. 1999.

[4] M. S. Kao and S. T. Kuo, "A simple and efficient approach for constructing future high-capacity DWDM networks," submitted to *J. Lightwave Technol.*.

[5] H. ElGebaly, J. Muzio and F. ElGuibaly, "Input smoothing with buffering: a new technique for queueing in fast packet switching," *IEEE Pacific Rim Conference on Communications, Computers, and Signal Processing,* pp. 59-62, May 1995.

[6] M. G. Hluchyj and M. J. Karol, "Queueing in high-performance packet switching," *IEEE J. Select. Areas Commun.,* vol. 6, pp. 1587-1597, Dec. 1988.

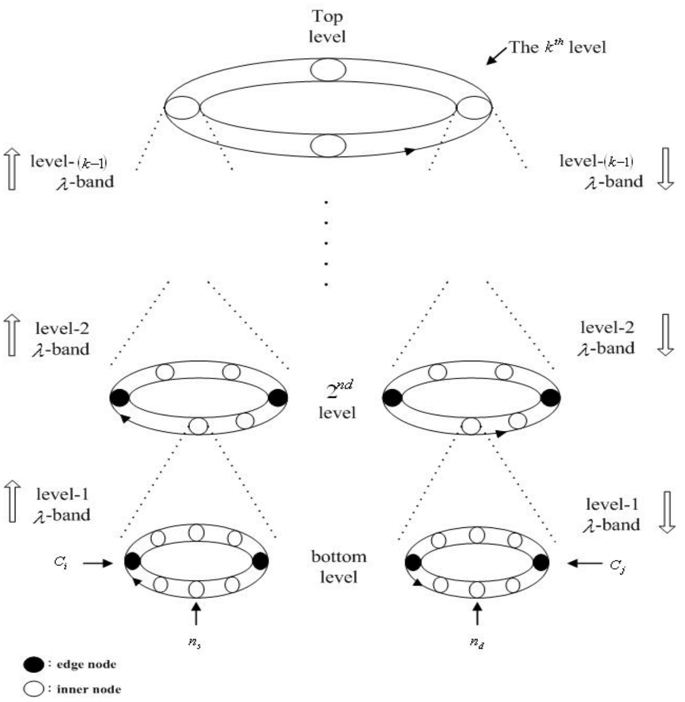

Fig. 1 The dual-ring network topology and the typical trip a packet would experience in the hierarchical network.

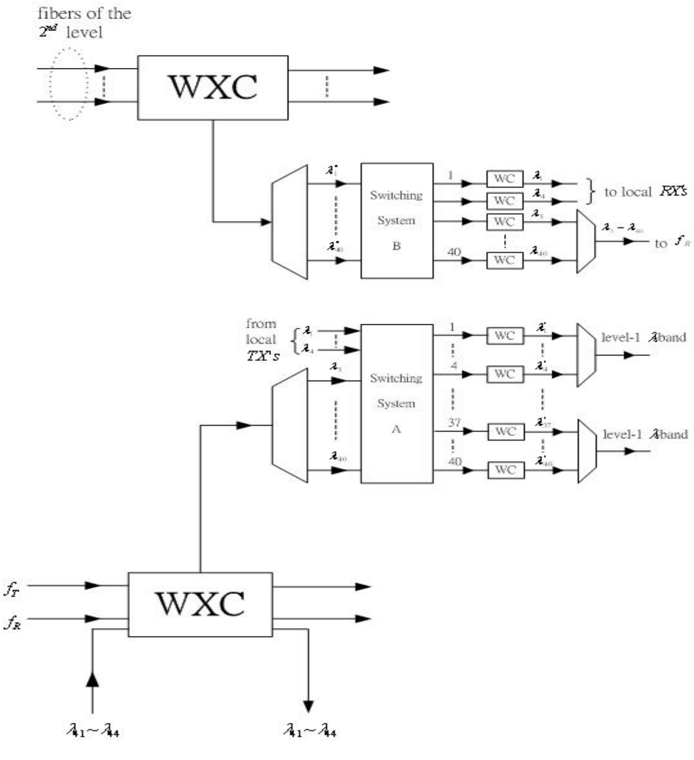

Fig. 2 The structure of an illustrative edge node on the bottom level.

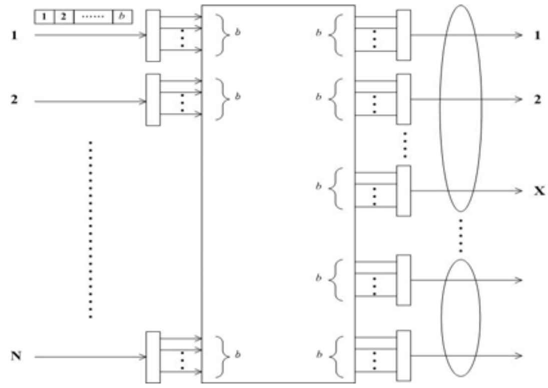

Fig. 3 The schematic diagram of the input smoothing switch fabric.

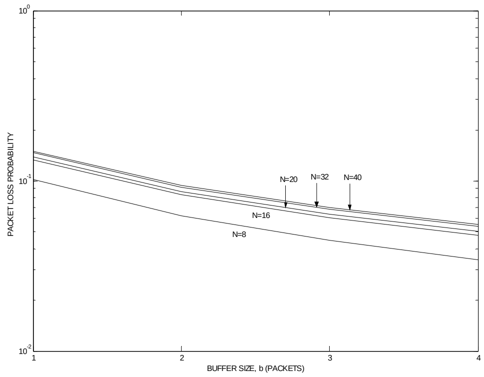

Fig. 4 The packet loss probability for input smoothing model against the frame size b with various values of switch size N for offered load $p = 0.9$.

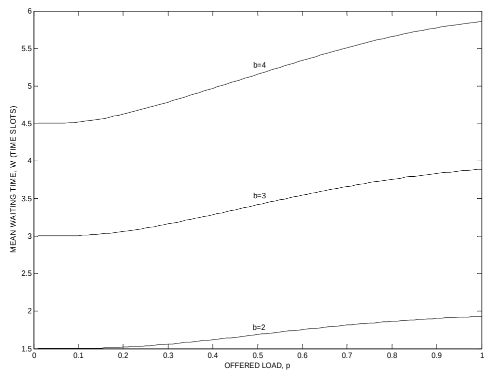

Fig. 5 The mean waiting time for input smoothing model against the offered load p with various values of frame size b for switch size $N = 40$.