行政院國家科學委員會專題研究計畫　成果報告

一個混合分封交換及電路交換的分波多工網路架構

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一個混合分封交換及電路交換的分波多工網路架構

A hybrid packet-switched and circuit-switched WDM network infrastructure

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一、中文摘要

我們提出一個具有簡單型態及有效波長管理機制的混合分封交換及電路交換的分波多工(WDM)網路架構。此網路能有效整合不同網路階層並且保證良好的存活率。此多階層網路的最底層是一個分封交換網路而其餘階層則為電路交換網路。我們將分封交換集中在一些特別的節點以簡化節點結構及波長路由的設計, 並應用 **λ-band** 的概念使各個階層有相同的波長處理機制。最後我們進行網路分析以證明所提網路的可行性。

關鍵詞:WDM 網路、封封交換、電路交換.

Abstract

We propose a hybrid packet-switched and circuit-switched WDM network with a a simple network topology and an efficient wavelength management scheme. The proposed architecture can accommodate different network levels and ensure good survivability. The resulting multi-level network is a compound packet-switched and wavelength-routed network, with packet-switching on the bottom level and wavelength-routing on all upper levels. We concentrate switching operation at some special nodes on the bottom level, thereby significantly simplifying node configuration and wavelength routing. We apply the idea of λ-band to unify wavelength management on all network levels. We further perform network analysis to illustrate the feasibility of our approach.

二、緣由與目的

The continuous progress in optical components and system technologies makes a fiber be able to deliver several Tbits/sec data via dense wavelength-division multiplexing (DWDM). The introduction of WDM not only significantly increases point-to-point transmission capacity but also brings a lot of potentials to realize broadband all-optical networks [1]. The tremendous wavelength carriers simultaneously transmitted along a fiber are valuable resources of photonic networks. Indeed, the capability of transmitting hundreds of wavelengths along a single-mode fiber makes the realization of a simple and efficient high-capacity DWDM network become feasible.

In principle the function of WDM networks is simple, which just routes specific wavelength carriers from source nodes to appropriate destinations. In practice, however, WDM networks are rather complicated. A large communication network is essentially a hierarchical structure consisting of multiple network levels. As WDM networks are finding applications not only in trunk systems but also in subscriber networks [2], we have to consider special merits on different network levels in designing DWDM networks. Many critical issues such as wavelength routing, wavelength reuse, wavelength conversion, packet/circuit switching, survivability,… etc, all have to be taken into consideration in network design.

Here we propose a novel DWDM network architecture and investigate its related issues. Our idea stems from the fact that if a simple structure can be reproduced horizontally on the same level and vertically on different levels, it eventually becomes a complicated structure and is able to accommodate related complexities, as we had seen in the field of fractal geometry in mathematics [3] or cellular automata in computer science [4]. It is possible to integrate different network levels by the same approach to construct a simple and efficient multi-level DWDM network.

To accomplish the proposed architecture, we have to reconsider basic issues of WDM networks. First, as mentioned the principal function of WDM networks is to route wavelengths along lightpaths defined by optical fibers. Thus the network topology defined by fiber interconnections is the fundamental issue in network design. Second, we need an efficient wavelength management scheme to route wavelengths adequately and efficiently in the network. Therefore wavelength management (including wavelength assignment, wavelength routing, wavelength reuse and wavelength conversion) is another fundamental issue to be addressed. Hence our effort is focused on designing a simple network topology and an efficient wavelength assignment scheme, which can be applied to all network levels and can accommodate varied requirements on different levels.

三、結果與討論

A. The cell

On the physical layer, a WDM network is composed of many fibers with a number of wavelength carriers propagating along them. The interconnection of fibers, i.e. the network topology, defines lightpaths wherein wavelength carriers can propagate. Thus the first step in our design is to find a network topology which can be applied to all network levels. Owing to the simplicity we desired, some complicated topologies such as Shufflenet and Manhattan street network (MSN) are not considered [5,6], instead simple topologies like ring, star, bus and tree topologies are of interest. The star topology had been intensively studied before [7], but the inherent weakness in survivability makes it not be a good candidate for high-capacity networks. Also it is difficult to practically implement a star network covering a wide area. Both bus and tree topologies had been employed in local-area networks and subscriber loops, but they are not suitable for wide-area networks as well. In contrast, the ring topology can cover a wide area and loop-back protection can be performed easily [8,9]. It is also suitable for metropolitan- and local-area networks with low implementation cost. Thus we take the ring topology as our choice.

To accommodate varied requirements on different network levels, we design a special ring topology as shown in Fig. 1 in which all the nodes within the ring are connected by an inner ring and an outer ring. We call such a dual-ring network as a "cell" hereafter. The idea of cell is adopted from wireless communications wherein a cell uses a specific frequency band to deliver message [10]. As will be clear later, a dual-ring network in our approach will use specific wavelength bands (named as the **λ-bands**) to deliver packets, so we name such a dual-ring network as a cell to distinguish it from common ring networks.

We consider a multi-level WDM network and the cell topology will be applied to all network levels. A node in a cell can be a physical node or a virtual node. A physical node is a real node and a virtual node is actually a cell of the lower network level. On the bottom level of the network, a cell consists of physical nodes only. On upper levels, a cell is generally composed of a combination of physical nodes and virtual nodes. The inner and outer rings make neighboring nodes in a cell have two connections in between, which are named as the "logic connections". The logic connections can be specially implemented on different network levels. For instance, depending on actual traffic and survivability requirements, two logic connections between neighboring nodes can be implemented by two fibers within a cable, or two separate cables with each consisting of many fibers. The introduction of virtual nodes and logic connections is aimed at providing a uniform topology while being able to accommodate varied requirements on different network levels. We will further clarify this idea later.

There are two special nodes in each cell, being responsible for the delivery of wavelength carriers to/from upper levels. We call these special nodes as edge nodes, and the others are named as inner nodes. Edge nodes will serve as bridges between adjacent network levels. Two edge nodes will manage wavelengths carried by the inner ring and the outer ring, respectively, which can also enhance network survivability.

B. Network hierarchy

Next we consider a large DWDM network consisting of many levels and apply the cell concept to all network levels as shown in Fig. 2. The network consists of k levels in which the 1st level is the bottom level and the kth level is the top level. In practice there is no limit on the number of levels, being determined by actual requirements. On the bottom level, a cell is composed of several physical nodes with logic connections in between. The logic connections provide lightpaths for packet transfer. There are many peer cells on this level (named as "**bottom cells**" hereafter), which form the basis of this large network. A bottom cell is a basic unit in the network and specific λ-bands will be assigned to each cell for delivering packets. A λ-band is composed of a group of wavelengths, to be used as transmitting wavelengths of the corresponding cell. A λ-band is managed as a sole unit on upper network levels before reaching the destination cell, that all wavelengths in a λ-band are routed altogether and simultaneously. Detail wavelength assignment and routing algorithm will be explained later.

On the 2nd level, there are several level-2 cells with each consisting of several nodes. A node on this level could be a physical node or a virtual node. A virtual node on this level is actually a bottom cell of the 1st level. In practice a physical node on this level could be a bigger node with larger traffic compared with that of a physical node on the bottom level. Although the construction of physical nodes and virtual nodes are different, they are equally treated on this level. Again specific λ-bands are assigned to each cell as transmitting λ-bands, which will be managed as a sole unit on upper network levels.

The same idea is applied to all the other levels. The resultant network consists of multiple levels, in which each level consists of several cells and each cell is composed of several nodes. Except the bottom level, a node could be a physical node or a virtual node. A virtual node on the jth level is actually a cell of the (j-1)th level. In practice, as the network level increases, the number of cells on the level decreases whereas the mean distance and the traffic between nodes increase.

The concept of virtual nodes and logic connections is aimed at accommodating varied requirements on different levels. For instance, the coexistence of virtual nodes and physical nodes makes it easy to accommodate a single high-traffic node and the output of a group of low-traffic nodes together on the same level. To fulfill varied survivability and traffic requirements, logic connections can be specially designed on different levels. Also the number of nodes in every cell and the number of cells on different levels are specified by actual requirements without special constraint. Thus using the cell concept with virtual nodes and logic connections, we have a simple and uniform topology to construct a large network.

C. Discussion and Conclusion

Our motivation is to look for a simple and uniform architecture for DWDM networks consisting of multiple levels. To be simple, we need a simple network topology and a simple wavelength management scheme. To be uniform, the proposed topology and wavelength management scheme should be applicable to all network levels. After deliberate considerations, we adapt the idea of self-similarity and specially design the dual-ring topology with virtual nodes and logic connections. The design of dual-ring network is aimed at more lightpaths for packet delivery as well as better survivability under link failure. The idea of virtual node is to integrate cells/nodes on different levels, and to include high-traffic nodes and the output of a group of low-traffic nodes on the same level. The logic connections are focused on accommodating varied traffic volumes and reliability concerns on different levels. The results indicate that the dual-ring topology can be applied to all network levels, being the realization of self-similarity.

We also find that the idea of λ-band is the key to have a simple and efficient wavelength management scheme on all levels. Wavelength management actually includes wavelength assignment, wavelength routing, wavelength reuse and wavelength conversion, all had been discussed for a while and been believed to be critical issues in constructing WDM networks [14]. Here we take the λ-band as the core of our wavelength management scheme. Instead of dealing with all the nodes in the network, we concentrate on the bottom cell. That is, we take a bottom cell as the basic unit in network design. Using the cell-to-cell traffic as the basis on designing the level-1 λ-band, the wavelength assignment in a bottom cell can be easily specified as shown in our example. Once the wavelength assignment is done for a particular bottom cell, it can be applied to all the other cells. We also employ packet switching and wavelength conversion at edge nodes of bottom cells, which bring us two salient advantages: 1) all packets destined to the same bottom cell are merged as a level-1 λ-band so as to simplify wavelength routing on upper levels; 2) the number of TX/RX at each node is much reduced. Thus the benefits brought by switching and wavelength conversion are well justified.

Conventionally, all nodes in a packet-switched network perform switching function for all incoming packets and all nodes in wavelength-routed networks just perform wavelength routing. Our approach is a combination of packet-switching and wavelength-routing. On the bottom level, it is a packet-switched network in which every node can send/accept packets to/from all the other nodes in the network. However, switching function is concentrated on edge nodes of the bottom cell, but not on all the nodes. This much simplifies the node configuration of inner nodes. Except the bottom level, all upper levels are wavelength-routed networks whose function is to merge lower-level λ-bands into higher-level λ-bands and transfer them either to upper levels or to destinations within the mother cell directly. The constructed network turns out to be a nice joint of packet-switching and wavelength–routing with just two switching operations along the packet transmission.

An interesting result of our approach is that the higher the network level, the more the number of wavelengths contained in a λ-band, and the less the number of λ-bands to be managed. It implies that we just have to design high-level networks with simple wavelength routing performed simultaneously on a large number of wavelength carriers, but not on individual wavelengths or data packets. This is in fact the very feature we pursued in photonic networks and our approach can naturally realize it.

To be a reliable network, we design two logic connections between neighboring nodes within a cell to enhance network survivability. The logic connections can be specially implemented on different levels. For instance, as shown in the example of Section IV, we use a fiber cable consisting of four fibers to implement the logic connections on the bottom level. There are two working fibers and two spare fibers in the cable, and merely two working fibers are used under normal condition. On the 2nd and the 3rd levels, we use separate fiber cables to implement logic connections. In this case, it is unlikely that two cables would be cut simultaneously. Again loop-back protection can be employed in upper levels by spare fibers so that the victim cell can recover from failure promptly. A good feature of our cell approach is that, when failure occurs, only those nodes within the corresponding cell will be affected and all the other cells still can operate normally. Namely, the failure will be confined to a cell but not be spread to others.

This paper presents a novel architecture for DWDM networks by adapting the idea of self-similarity. The approach is based on a simple network topology and an efficient wavelength management scheme, which can be uniformly applied to all network levels. A dual-ring network topology consisting of virtual nodes and logic connections is designed and the idea of λ-bands is taken as the core of wavelength management scheme. The resultant multi-level network is a packet-switched network on the bottom level and wavelength-routed networks on all upper levels. It keeps the efficiency of packet-switched networks but releases network operation from complicated packet-switching by concentrating switching operations on edge nodes of the bottom level. On upper network levels, we just have to perform simple wavelength routing on λ-bands consisting of a number of wavelengths without dealing with individual wavelength carriers or data packets. Consequently, the operation and node configuration are much simplified. The constructed multi-level network turns out to be a nice joint of packet-switching and wavelength-routing. We further present a design example consisting of 200 high-speed nodes to show the feasibility of our approach. The results reveal that our proposal is a simple, efficient and practical approach to construct future high-capacity DWDM networks.

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