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WDM 網路上之路徑選取與波長分配問題
Routing and Wavelength Assignment in WDM Networks

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摘要

在本篇論文中，我們專注於 WDM 網路上了兩個主要問題：波長分配以及路徑選取。針對波長分配，我們提出兩種基於優先權的分配法：靜態與動態策略。我們有也發展出一套路徑選取演算法來降低中斷率。

Abstract

In this paper, we focus on two key problems in the WDM networks: the wavelength assignment and routing problems. We propose two priority-based methods for the wavelength assignment problem: static and dynamic strategies. We also develop a routing algorithm to reduce the blocking rates.

1 INTRODUCTION

Communication networks have significant impact our daily life. Abundant information can be accessed via networks. One of the main issues of using communication networks is the availability of network bandwidth. As the number of network connections increases, the available bandwidth becomes less and the quality of information service goes down. Therefore, new network techniques that support such high-bandwidth requirements are needed.

To solve the problem of the bandwidth insufficiency, the optical networks have been advocated to be the choice for the networks of the next generation. The virtues of the optical networks are high bandwidth, high speed, and reliability. New components for optical networks are developed. Wavelength-Division-Multiplexing (WDM) is the technology that utilizes multiple wavelengths to transmit multiple data streams concurrently and independently on a single optical fiber link (rewrite WDM definition). WDM networks are able to provide the high bandwidth in the range of terabits per second.

We propose two wavelength assignment strategies and a routing method for WDM networks. Our main objectives are to satisfy requirements of different types of quality of service (QoS) and to reduce the blocking rates. The connection requests are prioritized to support connections with different QoS requirements. Priorities are the index of assigning a wavelength to a given request. The proposed static wavelength assignment method pre-allocates a set of wavelengths for each priority class of requests and chooses one wavelength for a given request based on its priority and the available wavelengths for the given priority. The dynamic wavelength assignment method selects a wavelength dynamically among all the available wavelength, but it controls the number of assigned wavelengths for a given priority class of requests by a pre-defined quota. The proposed routing algorithm builds a routing tree for a given connection request which includes possible paths. Based on the routing tree, it finds a non-blocked route by backtracking.

This paper consists of five sections. Section 2 surveys the background. In Section 3, we present our methods on the wavelength assignment and routing problem. In Section 4, we conduct simulations to evaluate the performance and discuss the simulation results. The conclusion is drawn in Section 5 as well.

2 BACKGROUND

Researchers propose various architectures for WDM networks. Two main kinds of networks are the single-hop and the multihop WDM networks. Single-hop WDM networks require a lightpath to use the same wavelength on all links of the path without buffering or optical-to-electronic conversion [3, 4, 5, 6]. The blocking rate increases dramatically as the number of links in a lightpath or the network complexity increases. Multihop WDM networks allow wavelength conversion to ease the restriction of wavelength continuity. Such networks scale well and block less traffic [7].

Huang *et al.* propose an architecture for interconnecting WDM-based start networks [1, 2]. The star coupler bridge (SCB) is used to interconnect two broadcast-and-selective networks, transmitting and receiving data through a dual bus between the two interconnected networks. Wavelengths are carried by time division multiplexing (TDM). Each node in the interconnected networks can either receives data or transmits data via one wavelength at a given time slot. They consider the path assignment problem for isochronous and asynchronous requests and develop solutions based on the proposed architecture. The wavelength encoded multichannel optical bus (WEMCOB) is proposed by Chen and etc. [8]. They study a backbone network based on WEMCOB and show that such network can offer the transmission rate of the order of gigabits per second.

Ramaswami and Sasaki study the WDM networks with limited wavelength conversion [9] and show that the throughput can be improved significantly for such networks. The WDM networks with wavelength conversion are equivalent to circuit-switched networks. Hence, several works on evaluating routing algorithms originated from circuit switching [10,11]. Fixed routing and fixed alternate routing methods [12] are studied. These two methods block a request if any link in the pre-defined path(s) has no available wavelength. The proposed routing algorithm searches, in the time complexity of $O(|E|)$, where $|E|$ is the number of links in the network, the possible paths for a given request to find a non-blocking route.

The simplest way of wavelength assignment is the first-come-first-served (FCFS) method. Whenever a traffic request arrives, an attempt is made to reserve a wavelength from available bandwidth for this traffic request. The incoming traffic requests can be accepted until all wavelengths are allocated. Rare research consider the QoS requirement in wavelength assignment. In this paper, we prioritize and classify the connection requests based on their QoS requirements. The objective of our wavelength assignment strategies is to minimize the blocking rates for different classes of requests.

3 OUR APPROACH

The objective of our approach is to reduce the blocking rates of the connection requests in the WDM networks. To support multimedia data transmission, the connection requests are prioritized by their QoS requirements. Priorities are the index of assigning a wavelength to a given request. For the networks without wavelength conversion, the blocking rate increases dramatically as the number of links in a route increases. Hence, we propose wavelength assignment methods which allow wavelength conversion. Our routing algorithm considers the possible routes for a given request to reduce the blocking probability.

3.1 The Proposed Wavelength Assignment Methods

The basic idea of the proposed methods is that the connection requests are treated differently according to their QoS requirements. The connection requests with higher QoS requirements should have higher priority and hence should incur lower blocking probability. Two wavelength assignment methods are proposed: the static and dynamic wavelength assignment methods.

3.1.1 Static Assignment Method

Assume that the network bandwidth contains m wavelengths, λ_i, $i = 1, .., m$, and the system have n priority values, $p_1, p_2, \dots, p_n$, where p_1 is the highest priority. The proposed method pre-defines a preferred wavelength set for each priority class. Let WP_i be the preferred wavelength set for a priority class p_i. The static method chooses an available wavelength for a request of a priority class p_i from its preferred wavelength set, WP_i, and WP_j for $j = i+1,\dots,n$, if the wavelengths in WP_i have been assigned. The constraints on the preferred wavelength sets are listed as follows.

1. $WP_i \cup WP_j = \varnothing$, $\forall\ i \neq j$. Each wavelength can only be included once in a preferred wavelength set.
2. $\bigcup_i WP_i = \{\lambda_i \mid i = 1, .., m\}$. All wavelengths are used.
3. $|WP_1| \geq |WP_2| \geq \dots \geq |WP_n|$, where $|WP_i|$ is the number of wavelengths in the preferred wavelength set of priority class p_i. The number of available wavelengths for a higher priority class is not less than that of a lower priority one.

For a request of priority p_i, the proposed method finds a wavelength first from WP_i. If no wavelength is available in WP_i, then it checks from WP_{i+1} to WP_n until an available wavelength is found. If no available wavelength is found in WP_i to WP_n, the request is considered to be blocked.

Figure 1 illustrates an example. The illustrated system has three priority classes of connection requests ($n = 3$) and three wavelengths ($m = 3$). Suppose that, λ_1 is preferred to be assigned to priority p_1, that λ_2 is preferred to be assigned to priority p_2, and that λ_3 is preferred to being assigned to priority p_3. The dash lines shown in Figure 1 indicate the possible assignment for the higher priorities. We observe that λ_3 can be assigned to a connection of priority-p_3 as well as one of higher priorities as indicated by dash lines.

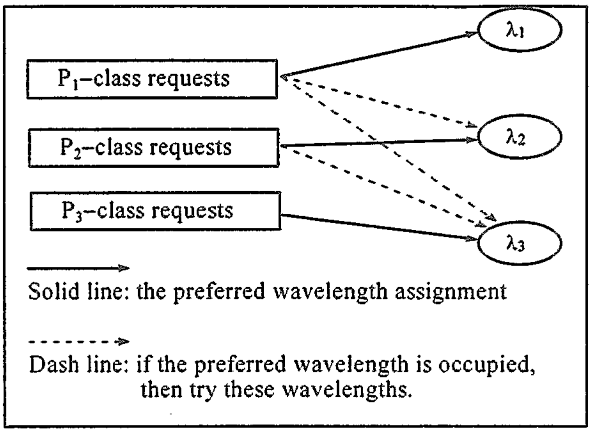

Figure 1. An example of the Static Assignment Scheme

3.1.2 Dynamic Assignment Method

Unlike the static assignment method, the dynamic assignment method does not specify the preferred wavelength sets. A wavelength can be assigned to a connection request of any priority. To control the number of wavelengths assigned to a priority class, the dynamic method pre-sets a wavelength quota for each priority class. Assume that the network bandwidth contains *m* wavelengths, λ_i, i = 1, .., *m*, and the system have *n* priority values, $p_1, p_2, \ldots, p_n$, where p_1 is the highest priority. Let q_i denote the wavelength quota for priority class of p_i or lower. The constraints on the quotas are stated as follows.

1. $m = q_1 \geq q_2 \geq \ldots \geq q_n \geq 1$.
2. $q_1 - q_2 \geq q_2 - q_3 \geq q_3 - q_4 \geq \ldots \geq q_{n-1} - q_n \geq q_n$.

The value of $q_i - q_{i+1}$ indicates the number of wavelengths initially reserved for the requests of priority p_i, and the value of $q_1 - q_2$ indicates the number of wavelengths exclusively allocated for the requests of priority p_1.

The dynamic method can assign at most q_i wavelengths to the requests with the priority p_i. Wavelength quotas limits the number of wavelengths to be assigned to the requests of a given priority. In Constraint 2, the proposed method gives higher priority requests more wavelengths such that they have less chance to be blocked. To examine the used quota for each priority class, the wavelength assignment method keeps track of a counter for each priority class which records the number of wavelengths currently assigned to the requests of the priority class.

For example, assume that the system has three priority classes and that the bandwidth contains three wavelengths. Suppose the dynamic method sets the quotas as follows: $q_1 = 3$, $q_2 = 2$, and $q_3 = 1$. At least one wavelength and at most three wavelengths can be assigned to the p_1–class requests, since $q_1 - q_2 = 1$ and $q_1 = 3$. The method assigns at most two wavelengths to p_2–class requests and at most one to p_3. Note that p_2–class and p_3–class requests may get zero wavelength.

Unlike the static scheme where each wavelength is 'hardwired' to a preferred wavelength set, the dynamic scheme has the flexibility of choosing a wavelength among all the available wavelengths. A simple solution to it is to pick up the next available wavelength in the system.

3.2 The Backtrack Routing Algorithm

The proposed routing algorithm requires the routing nodes to maintain their routing tables. A routing table records the information about the preferred outgoing ports for each destination. A routing node determines the outgoing ports for a given destination under various link conditions. The routing tables must be carefully maintained to avoid cyclic paths. The process of initializing the routing tables for all nodes is called the vectorization of the routing tables. Based on the network shown in Figure 2, Figure 3 illustrates an example of the routing table for Node 5.

The proposed routing algorithm finds a route based on the depth first search (DFS) traverse and backtracking of a routing tree. A routing tree for a pair of source-destination contains the possible routes, where the source is the root of the routing tree and all leaf nodes are the destination. The information of routing trees is distributively stored in the routing nodes in the network. During the traverse of a routing tree for a given pair of source-destination, the routing algorithm assigns the currently traversed node a wavelength, if there is one available, and it proceeds in the DFS order until a leaf node is reached. However, if any link during the traverse to a leaf cannot be assigned to a wavelength, the algorithm backtracks to the up-stream link and continues the route finding process. The connection request will be blocked, if the routing algorithm cannot find a route after the corresponding routing tree is completely traversed. The time complexity of the proposed routing algorithm is $O(|E|)$, where E is the set of links in the network.

Figure 4 shows an example of the route tree for a connection from Node 1 to Node 4. Suppose the links (1,2) and (2,3), are assigned to a wavelength. The algorithm proceeds to the down-stream link (3,4). If the assignment fails, link (2,5) is visited. If the assignment for this link fails again, the algorithm backtracks to link (1,2), and then link (1,6).

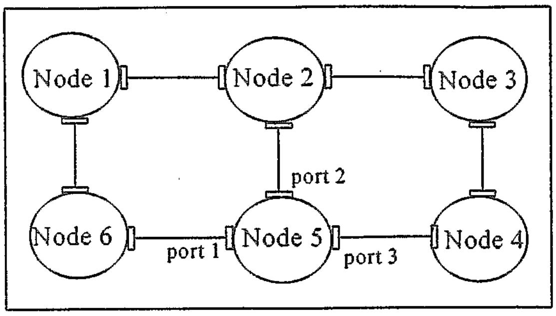

Figure 2. An example of a WDM network with 6 nodes

Destination	Preferred Outgoing Port	Next node
NODE 1	PORT 1	NODE 6
	PORT 2	NODE 2
NODE 2	PORT 2	NODE 2
NODE 3	PORT 2	NODE 2
	PORT 3	NODE 4
NODE 4	PORT 3	NODE 4
NODE 5	----------------	--------------
NODE 6	PORT 1	NODE 6

Figure 3. The routing table of Node 5

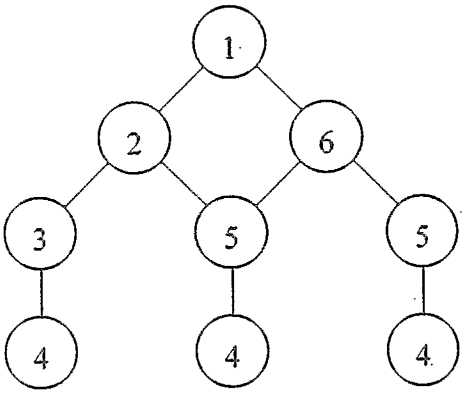

Figure 4. The route tree for a connection from Node 1 to Node 4.

4. SIMULATIONS AND RESULTS

4.1 Wavelength Assignment

We evaluate the performance of the proposed wavelength assignment methods by simulation. The wavelength assignment methods are evaluated on a simplified network with only one link. The simulated network has 5 priority classes and the bandwidth contains 80 wavelengths, λ_1 to λ_{80}. The related simulation parameters for the proposed wavelength assignment methods are listed below.

1. $WP_1 = \{\lambda_i \mid i = 1, \ldots, 16\}$, $WP_2 = \{\lambda_i \mid i = 17, \ldots, 32\}$, $WP_3 = \{\lambda_i \mid i = 33, \ldots, 48\}$, $WP_4 = \{\lambda_i \mid i = 49, \ldots, 64\}$, and $WP_5 = \{\lambda_i \mid i = 65, \ldots, 80\}$.

2. $q_1 = 80$, $q_2 = 64$, $q_3 = 48$, $q_4 = 32$, and $q_5 = 16$.

We generate two traffic patterns: Binomial and Poisson. In the first traffic pattern, at each time unit, a decision is made about whether a request shall be generated. The probability of generating a request at each time unit is 0.1. If a request is to be generated, it has equal opportunity of being one of the five priority classes. The wavelength holding time for a request has the exponential distribution of mean = 100 time units. (i.e. $u = 0.01$). If a request is generated and there is no available wavelength for it, it is considered to be blocked and dropped off from the system. For the above traffic pattern, 20 runs are generated and simulated to compute the averaged blocking probability for each priority class. The time taken to simulate each run is the time to simulate 10,000 requests. The blocking probability of each priority class is obtained by dividing the number of blocked requests over the total number of issued requests. The averaged blocking probability for a priority class is the averaged value of the blocking probability of each priority class over 20 runs. We present the comparison between the two assignment algorithms in Figure 5.

In the second traffic pattern, the arrivals of the requests follow the Poisson process with the rate of 0.07 (i.e. $r = 0.07$). Given a arrival, the opportunity for it to be one of the five priority classes is 0.2. The wavelength holding time also has the exponential distribution of mean = 100 time units. Totally 20 runs are simulated in which each run has 10,000 requests. The computation of the averaged blocking probability for a priority class is the same that described at the last paragraph. The simulation results are given in Figure 6.

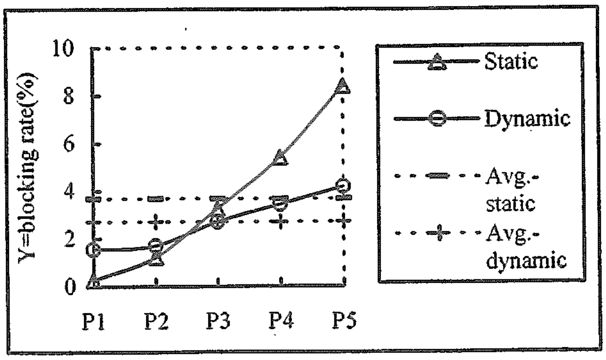

Figure 5. The blocking rates for Binomial traffic pattern.

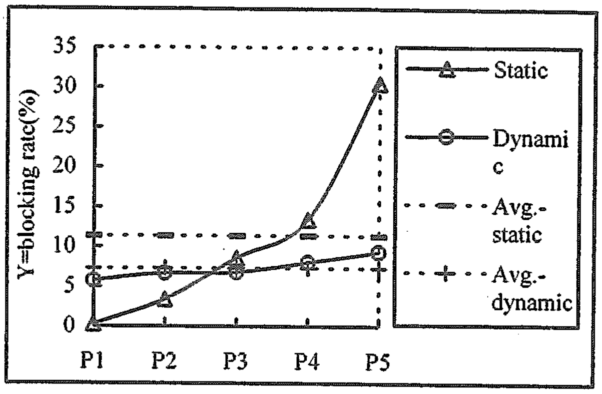

Figure 6. The blocking rates for Poisson traffic pattern.

Figures 5 and 6 plot the blocking rates and the averaged blocking rates for the two traffic patterns. The dynamic strategy has more balanced blocking rates than the static one, since the discrepancy between the averaged blocking rate and the blocking rate of a priority class is smaller in the dynamic strategy. The static strategy has smaller blocking rates for high priority classes, but the blocking rates increases sharply as the priority goes lower. Both figures show that the dynamic strategy performs better on the averaged blocking rate.

4.2 The Fixed Routing versus Backtrack Routing Algorithms

4.2.1 Simulation Design

In this section, we simulate the proposed backtrack routing algorithm with the dynamic wavelength assignment method. We study a 9 by 9 mesh network contains 81 nodes and 144 links. Each link has 16 wavelengths. The example in Figure 7 can demonstrate how the backtrack routing algorithm works. Upon the arrival of a connection request from N_{11} to N_{54}, the network contains several blocked links for the request represented by the bold line segments in Figure 7. Figure 8 represents the traversed tree nodes during the route finding. We evaluate our routing algorithm by comparing it with two base routing algorithms: the fixed routing (FR) and fixed alternative routing (FAR) algorithms.

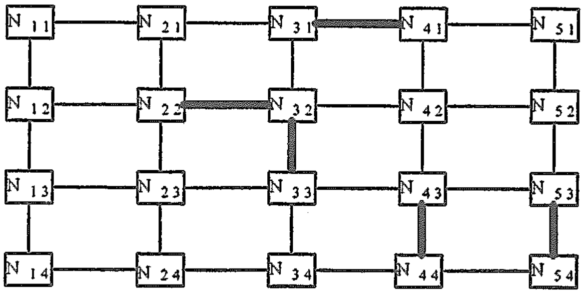

Figure 7. The related network status for the connection from node N_{11} to node N_{54}

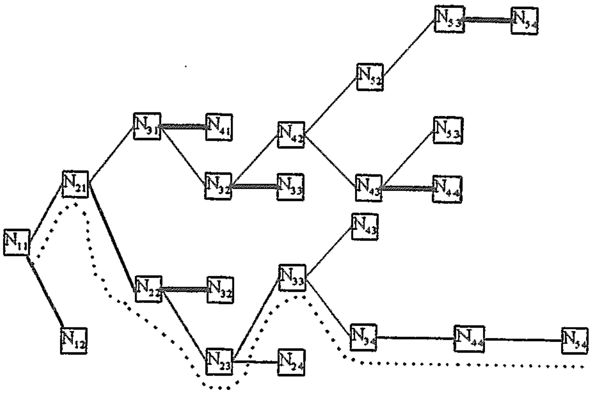

Figure 8. The traversed routing tree for the connection from N_{11} to N_{54}.

4.2.2 Simulation Results

The simulated network system has four priority classes. The dynamic wavelength assignment method defines the following quota values: $q_1 = 16$, $q_2 = 12$, $q_3 = 8$, and $q_4 = 4$. The connection requests at a node have the Poisson arrival rates CR and the connection holding time has the exponential distribution with mean $u = 100$. A connection request has equal opportunity of being one of the four priorities. The destination of a request is randomly decided.

We simulate three traffic load situations: light, medium, and heavy load. The light-load situation has CR = 0.0015, i.e. $\rho = 0.15$; the medium-load situation has CR = 0.015, i.e. $\rho = 1.5$; and the heavy-load situation has CR = 0.15, i.e. $\rho = 15$. The simulation results averages the blocking rates from 10 runs of a load situation. Each run generates 6000 requests. In each run, the simulation records the blocking rate for each routing algorithm at the time 1000, 2000, 3000, 4000, 5000, and 6000 requests are served. The results for the three load situations are shown in Figures 9, 10, and 11. The figures convey that the Backtrack algorithm outperforms the other two algorithms.

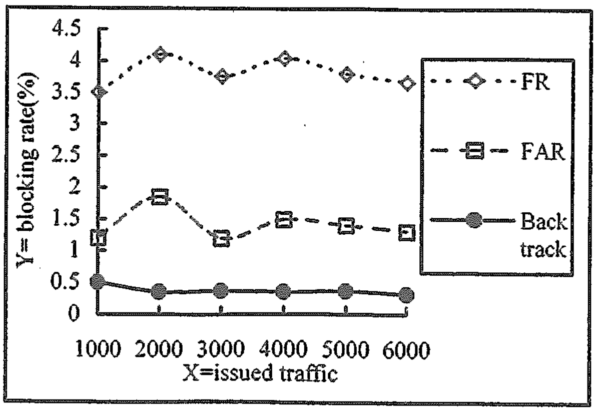

Figure 9. The blocking rates in light-load situation.

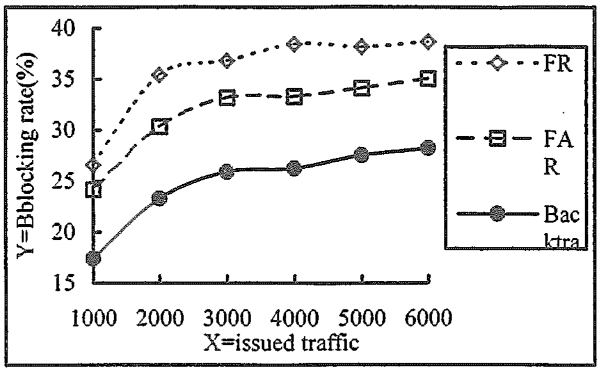

Figure 10. The blocking rates in medium-load situation.

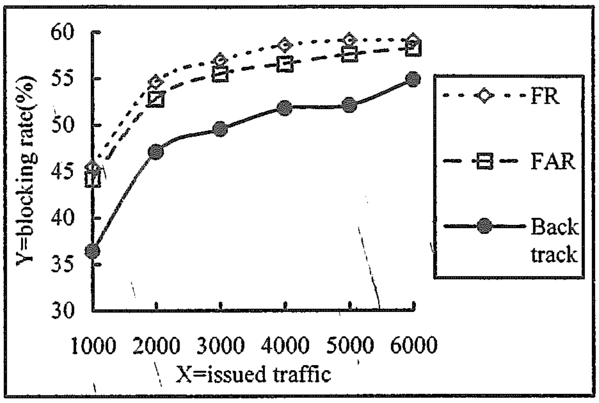

Figure 11. The blocking rates in heavy-load situation.

5. CONCLUSION

In this paper, we consider the wavelength assignment and the routing problems in the WDM networks. The connection requests to the WDM networks are prioritized according to their QoS requirements. We propose two strategies which use the priorities of the requests to perform the wavelength assignment. They are the static and the dynamic strategies. The static assignment preallocates a set of wavelengths for each priority class of requests. The dynamic wavelength assignment selects a wavelength dynamically among all the available wavelength, but it controls the number of assigned wavelengths for a given priority class of requests by a predefined quota. Simulation results show that the dynamic strategy obtains a lower blocking rate than the static one does.

The proposed solution to the routing problem is the backtrack routing. The backtrack routing algorithm along with the wavelength assignment are integrated to reduce the overall blocking rates in the system. The backtrack routing method builds a route tree for a given connection request. During the setup of a route, backtrack is allowed when some wavelength can not be assigned in a link. The proposed solution is compared to the FR and the FAR. The results show that our algorithm performs better in the light-, medium- and heavy-load situations. Experiments are also conducted to study the relationship among the number of wavelengths in a link, the load traffic in the system, and the averaged blocking rates, based on the proposed solutions.

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