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A Wavelength and Converter Assignment Scheme for Decreasing Blocking Probability in Wavelength-Routed Networks

Yukinobu Fukushima, Takahiro Ooishi, and Tokumi Yokohira

The Graduate School of Natural Science and Technology, Okayama University, 3-1-1, Tsushimanaka, Okayama-shi, 700-8530, Japan
Tel: +81-86-251-8248 FAX: +81-86-251-8255 Email: {fukusima, takahiro, yokohira}@net.cne.okayama-u.ac.jp

Abstract— We propose a wavelength and converter assignment scheme for decreasing blocking probability in wavelength–routed networks. Our scheme avoids the competition of wavelength converter reservation by considering the wavelength converter usage history and the number of idle converters.

I. Introduction

Wavelength-routed networks consisting of reconfigurable wavelength routing nodes interconnected by wavelength-division multiplexed (WDM) fibers (Fig.1) are emerging as a promising candidate for high speed backbone networks. In wavelength-routed networks, a *lightpath* [1] is established between source and destination edge nodes to transmit data.

It is preferable for nodes to set-up or tear-down lightpaths in a distributed manner for scalability and reliability [2]. In addition, dynamic configuration of lightpaths is required for effective utilization of wavelength resources. A *backward reservation protocol* is used for distributed and dynamic control of wavelength-routed networks. When the protocol sets up a lightpath, it first gathers wavelength and wavelength converter availability information on the route with a control packet from the source node to the destination node. Next, at the destination node, it determines which idle wavelengths and converters to be assigned to the lightpath. Then it reserves the idle wavelengths and converters from the destination node to the source node.

The wavelength conversion improves lightpath blocking probability by eliminating the *wavelength continuity constraint* (i.e., the constraint that the same wavelength must be assigned to a lightpath on links along a route). However, because wavelength converter cost remains expensive in the near future, the number of wavelength converters deployed in the network is limited. Therefore, we need to realize as low blocking probability as possible with limited number of wavelength converters.

In [3], FLR (First-Longest lambda-Run), which is a wavelength and converter assignment scheme for a backward reservation protocol, is proposed. The FLR tries to decrease lightpath blocking probability by minimizing the number of converters assigned to a lightpath. However, because the FLR only uses the number of wavelength conversions and does not consider the competition of wavelength converter reservation among node-pairs, it does not always decrease lightpath blocking probability.

In this paper, we propose a wavelength and converter assignment scheme for decreasing blocking probability. Our scheme achieves this objective by 1) not interfering with other node-pair's wavelength conversion based on converter usage history, and 2) selecting to perform wavelength conversion on intermediate nodes with more idle converters, when setting up a lightpath.

II. FLR algorithm

The FLR [3] decreases blocking probability by minimizing the number of wavelength conversions in setting up a lightpath. Given 1) route of a lightpath and 2) wavelength and wavelength converter availability information on the route, the FLR determines wavelengths and converters to be assigned to the lightpath.

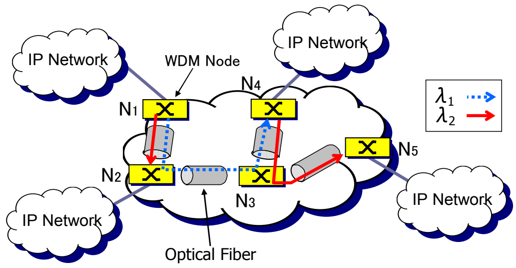

Figure 1 Wavelength-routed network

The FLR uses the concept of *lambda-run*. A lambda-run is a sequence of the same wavelengths that are idle on successive links. In addition, a lambda-run satisfies the following conditions: 1) originating from the source node of a lightpath or an intermediate node with at least one idle converter, 2) terminating at the destination node of a lightpath or an intermediate node with at least one idle converter, and 3) being as long as possible.

The FLR repeatedly selects the longest *lambda-run* from the source node to the destination node. At the terminal of each lambda-run, it performs wavelength conversion. If a set of lambda-runs from the source to the destination is found, the lightpath is successfully set up, otherwise, blocked. It is proven that this simple policy leads to minimizing the number of wavelength conversions in setting up a lightpath [3].

Figure 2 shows an example of 5-hop physical route used by a lightpath. Nodes *s* and *d* are the source and destination of the lightpath, respectively. Each wavelength converter (WC) can convert any input wavelength to any output one. Intermediate nodes v_2 and v_3 have two and one idle converters, respectively. Nodes v_1 and v_4 have no idle converter. There are three lambda-runs r_1, r_2, and r_3. For instance, r_1 consists of three same wavelengths, λ_1 s on links e_1, e_2, and e_3. Note that r_1 does not terminate at v_2 because lambda-run should be as long as possible. In this case, the FLR first selects r_1, that is, the longest lambda-run among those originating from node *s*. Then, it performs wavelength conversion at node v_3. Finally, it selects r_2 from node v_3 to node *d*.

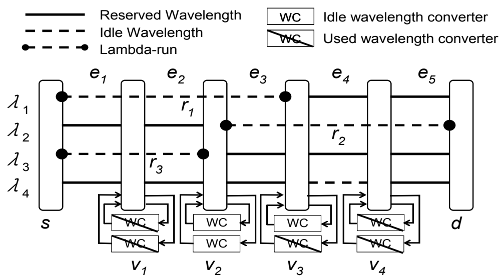

Figure 2 5-hop physical route of a lightpath

Although the FLR minimizes the number of wavelength conversions in setting up a lightpath, the minimizing policy does not always lead to decreasing lightpath blocking probability. In the above example, it used the last wavelength converter on node v_3, which may results in interfering with other node-pairs that need to perform wavelength conversion on node v_3 (e.g., node-pair (v_2, v_4)).

III. A WAVELENGTH AND CONVERTER ASSIGNMENT SCHEME FOR DECREASING BLCOKING PROBABILITY

A. Algorithm description

We propose a wavelength and converter assignment scheme that tries to decrease lightpath blocking probability by preventing node-pairs from competing for the wavelength converters on the same node. Our scheme achieves this by 1) not interfering with other node-pair's wavelength conversion, and 2) selecting to perform wavelength conversion on intermediate nodes with more idle converters.

Given the same inputs 1) and 2) as the FLR, our scheme first calculates $Cost(v_i)$, *wavelength conversion cost* of each intermediate node v_i along the route of the lightpath to be set up. Then our scheme determines idle wavelengths and converters to be assigned to the lightpath so that the sum of wavelength conversion costs is the minimum. If such wavelengths and converters are found, the lightpath is successfully set up, otherwise it is blocked.

In determining the idle wavelengths and converters with the minimum sum, we make the layered-graph [4] consisting of *assignable wavelengths* on the route and apply Dijkstra's algorithm to it. The assignable wavelength resembles a lambda-run, but it may not be as long as possible because we do not always select the longest assignable wavelength.

We define the wavelength conversion cost of intermediate node v_i as follows:

$$Cost(v_i) = \frac{U_i}{A_i} \quad , \tag{1}$$

where U_i is the proportion of the node-pairs except the source-destination pair of the lightpath that used wavelength converters on node v_i in M latest entries of wavelength converter usage history, and A_i is the number of idle converters on node v_i.

Figure 3 depicts an example of establishing a lightpath with our proposed scheme. The number of entries in wavelength converter usage history (M) is three. The wavelength converter usage history on node v_2 consists of node-pairs (s, d), (v_1, d), and (s, v_4). This means that these node-pairs performed wavelength conversion on node v_2 in the past. Similarly, the history of node v_3 has (v_1, d), (v_2, d), and (v_2, v_4). In this case, $Cost(v_2) = (2/3)/2 = 1/3$, and $Cost(v_3) = (3/3)/1 = 1$. By applying Dijkstra's algorithm, our proposed scheme selects the following wavelengths and converters with the minimum cost; λ_1 s on links e_1 and e_2, a wavelength converter on node v_2, and λ_2 s on links e_3, e_4, and e_5. When there are multiple wavelengths with the same wavelength converter cost, our scheme selects the wavelength with the minimum index (i.e., First-Fit policy).

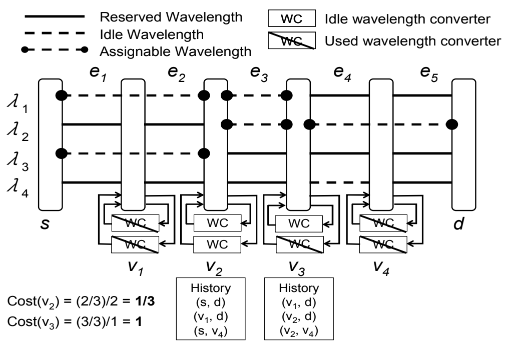

Figure 3 5-hop physical route of a lightpath and wavelength conversion cost of node v_2 and v_3

B. Simulation results

We show our simulation model in Table 1. Figure 4 describes lightpath blocking probability when the number (N) of converters deployed per node is changed. When N is 2, 3, and 4, our proposed scheme decreases blocking probability by 7~24 % compared with the FLR. On the other hand, when N is 1 or larger than 4, our scheme shows almost the same blocking probability as the FLR. When N is 1, because N is too small, generally there is little difference in blocking probability between the two schemes. On the other hand, when N is more than 4, because N is large and each node has redundant converters, the location of performing wavelength conversion does not affect the blocking probability. In addition, a wavelength assignment policy also does not affect the probability because the wavelength continuity constraint is eliminated by the enough conversion capability. Therefore, in this case, there is also little difference in blocking probability between the two schemes.

Under the actual operation of the network, as few wavelength converters as possible to achieve the near optimum performance will be deployed for cost reduction. Because our scheme offers a blocking probability reduction when the probability is near the optimum, that is, N is 3 or 4, our scheme is attractive.

Table 1 Simulation parameters

Network model	12 node ring network
Wavelength number	16 wavelengths per fiber
Number of converters per node	Uniform
Converter type	Full-range converter
Lightpath request arrival	Poisson arrival with rate λ on every node-pair
Lightpath holding time	Exponential distribution with mean $1/\mu$
Traffic load	41, 45 Erlang ($=\lambda/\mu$)
Routing	LLR (Least-Loaded Routing)
Converter usage history size (M)	10

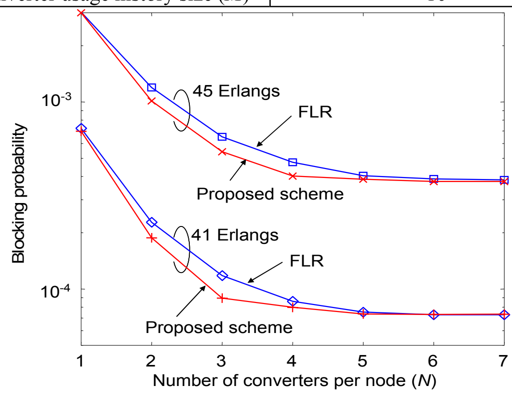

Figure 4 Lightpath blocking probability

IV. CONCLUSION

We proposed a wavelength and converter assignment scheme in wavelength-routed networks. Through the simulation experiments, we found that our scheme achieves a blocking probability reduction of about 7~24 % compared with the FLR scheme.

As a future research work, we plan to investigate the effect of wavelength converter usage history size on blocking probability.

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