Route and Wavelength/Waveband Assignment for Creation of Compact Hierarchical Optical Cross-Connect for Multi-Ring Connection

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Abstract *We propose a route and wavelength/waveband assignment method for multi-ring networks linked by hierarchical optical cross-connects. Numerical experiments reveal that the switch scale is significantly reduced at the cost of a marginal drop in routing capability.*

Introduction

The large scale deployment of reconfigurable optical add-drop multiplexer (ROADM)-based ring networks has recently started in North America and Japan. At present, ring interconnection is done in the electrical layer with OE/EO conversion and electrical switches. Removing the costly and power consuming OE/EO stage can be realized by using OXC (Optical Cross-Connect) that offer optical path routing. OXC architectures that utilize multiple large scale (1xN; N>6-16) WSS (Wavelength Selective Switch) or optical matrix switches have been investigated, however, the high equipment costs of the OXCs prevents their introduction.

The application of waveband (bundle of wavelength paths) routing has recently been extensively studied[1]; it was shown to greatly reduce OXC switch scale if the Hierarchical OXC (HOXC) architecture is adopted. This is true irrespective of the HOXC architecture used; WSS-based[2] or matrix switch-based[3]. We have proposed a 2-ring connecting node architecture that adopts waveband routing only for inter-ring traffic[4] and shown that the node switch scale can be significantly reduced (ex. 80+% scale reduction when inter-ring traffic is 60 %). However, the previous work set the following limitations; (i) applicable only to two-ring connections, (ii) the ratio of the number of wavelengths reserved for inter-ring traffic to that for inner-ring traffic should be known prior to design; any deviation thereafter degrades the efficiency of the switch.

In this paper, we propose a new efficient optical path demand accommodation algorithm for multiple-ring networks. Hierarchical path routing is fully utilized for all traffic at the ring connecting nodes. This algorithm and the ring connecting node architecture can be applied to nodes that connect any number of rings, and no restrictions are imposed on the ratio between inter-/inner- ring traffic. Since the routing and wavelength/waveband assignment problem is computationally intensive, we developed a two-stage algorithm that provides the approximately optimal solution. A numerical experiment reveals that the routing capability reduction caused by the introduction of hierarchical optical path routing is marginal while node switch scale reduction available is significant (more than 70%) compared to single layer optical path routing.

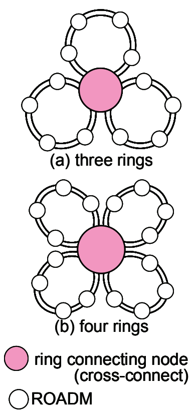

Fig. 1: Multi-ring topology

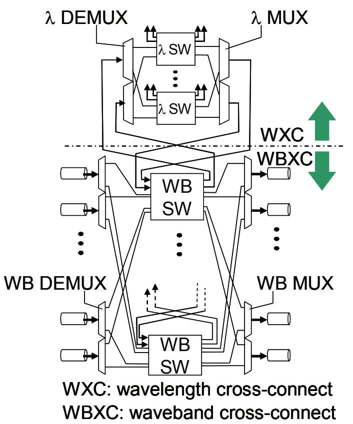

Fig. 2: HOXC node architecture

Multi-ring connected network and HOXC architecture

We assume that multiple 2-fiber bidirectional shared protection rings are connected at a cross-connect node. Examples are shown in Fig. 1. All nodes other than the ring connecting node are conventional ROADM nodes, so an arbitrary set of wavelengths can be added/dropped at these nodes. That is, the notion of the waveband is not introduced at the network level. The architecture of the connecting node, which adopts hierarchical optical path routing, is depicted in Fig. 2. Wavelength paths are routed as much as possible by the WBXC (Waveband Cross-Connect) part as a bundle, and when routing (grooming) or termination of each wavelength path is necessary, wavebands are demultiplexed and each wavelength path is routed or terminated through the WXC (Wavelength Cross-Connect) part. We have successfully developed a very compact size HOXC switch prototype; details will be presented in [5].

Route and wavelength/waveband assignment algorithm

A previous work[6] provides an ILP (Integer Linear Programming) formulation of the route and wavelength assignment (RWA) problem for a single ring network without protection. The objective is to minimize the number of required wavelengths while accommodating all traffic demands. The formulation consists of only two fundamental constraints; 1) every required connection must be established, 2) no two paths using the same wavelength pass through the same link.

In this paper, we extend this ILP formulation to multi-ring networks where several rings are linked by one

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connecting node. The constraints necessary in formulating HOXC processing were very tough to derive. First we explain the developed formulation applicable to a connecting node that uses a single layer OXC, and then one that uses an HOXC node.

A. For a connecting node with single-layer OXC

We recast the ILP formulation so that it can be applied to the assumed multi-ring network by adding the following two constraints. The first constraint is so-called wavelength continuity; a path that traverses multiple rings must use the same wavelength on all rings. The second constraint is for protection; wavelengths that are used for working paths traversing clockwise/counter-clockwise in one fiber are reserved for protection paths traversing counter-clockwise/clockwise in another fiber of the ring.

B. For a connecting node with HOXC

Since the introduction of hierarchical path structure makes network design much more complex, it is hard to derive direct forms that yield the optimal solution. Therefore, we divide the original problem into two-sequential optimization problems; each uses the ILP formulation. In the first step, the proposed algorithm accommodates inter-ring connection requests and inner-ring connection requests that are added/ dropped at the connecting node. The remaining traffic demands are accommodated in the second step. Summaries of these steps are given below.

step1: Accommodation of inter-ring path connection requests and add/drop path connections at the connecting node

This ILP formulation consists of four additional variables and more than twenty constraint functions. We explain below the two essential constraints because of space limits. The first constraint is that the wavelength paths are grouped so that the connecting node can switch them as waveband paths. In this constraint, we also consider wavelength level grooming if necessary. The second one is involves protection; each waveband in a fiber of one ring consists of either working paths or protection paths. This is an extension of the constraint for protection in case A. To derive an assignment that makes step 2 feasible, we minimize the total path length subject to these constraints.

step2: Accommodation of remaining requests

The remaining path requests are accommodated using spare capacities. This feasibility problem is formulated as an ILP.

Numerical examples

We assume three rings are linked by one connecting node where each ring consists of seven nodes including the connecting node. The traffic demand between nodes is randomly generated. Both single layer OXC and HOXC are considered for the connecting node. Suppose that 40 wavelengths are multiplexed in a fiber. For single layer OXC, we assume that any set of wavelength paths can be

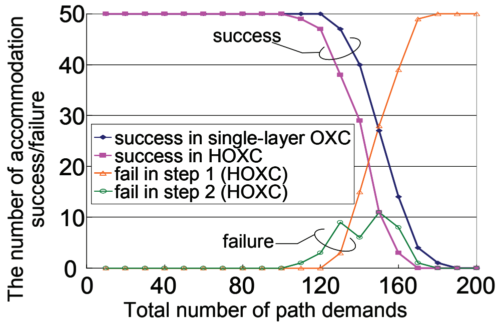

Fig. 3: Numerical result of RWBA

added or dropped at the connecting node. For HOXC connecting node, we assumed 5 wavebands per fiber and 8 wavelengths per waveband (i.e. 40 wavelengths per fiber). Up to one-thirds of incoming wavebands are demultiplexed into wavelengths for routing with wavelength granularity. Note that this HOXC node achieves 70% switch scale reduction compared to the single-layer OXC node.

The ILPs for the proposed algorithm were solved by CPLEX 11.2 and the result is shown in Fig. 3. We allowed a 20% duality gap to the optimal solution in Step.1 of HOXC connecting node case for faster computation. Fifty different random traffic demand patterns were tested for each number of path demands. The vertical axis plots the number of success/failure events in the 50 trials, and the horizontal axis plots the total number of path demands. The figure demonstrates that when the target success rate is 95%, the introduction of hierarchical routing supports 7.6% fewer maximum path demands, which is relatively small, while the switch scale reduction compared to the single-layer OXC is very large (70%).

Conclusions

We proposed an efficient route and wavelength/ waveband assignment method for multi ring networks connected by a HOXC node. A numerical experiment demonstrated that the introduction of waveband routing at the ring connecting node significantly reduces node switch scale with a very minor drop in routing performance. The large impact of introducing waveband routing into the ring connection nodes will resolve one of the key issues preventing the use of optical cross-connect systems in realizing ROADM ring connection. The hardware implementation of the HOXC will be presented elsewhere[5].

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