A Dynamic Routing Algorithm for Multi-Domain Photonic Networks using Averaged Link Load Information

Kohei Shimada† **Soichiro Araki**†‡ **Hiroshi Hasegawa**† **Ken-ichi Sato**†
Department of Electrical Engineering and Computer Science, Nagoya University†
NEC Corporation‡
Furo-cho, Chikusa-ku, Nagoya, 464-8603 Japan†
1753 Shimonumabe, Nakahara-ku, Kawasaki, 211-8666 Japan‡
k_simada@echo.nuee.nagoya-u.ac.jp {hasegawa, sato}@nuee.nagoya-u.ac.jp†
s-araki@cj.jp.nec.com ‡

Abstract: We propose an inter-domain path routing algorithm for multi domain photonic networks. The proposed algorithm introduces a step-wise weighting technique and utilizes averaged link load information of each domain. Numerical experiments demonstrate that the proposed algorithm matches the blocking probability achieved without domain segmentation.

1 Introduction

Due to the rapid penetration of broadband access, backbone network traffic has been continuously increasing. This has spurred the introduction of photonic network technology that eliminates costly O/E/O conversion and electrical routing at intermediate nodes. The application of photonic network technology will continue to expand in the future, and optical paths will come to traverse multiple domains that may be operated/managed by different network carriers. In order to effectively operate such inter-domain paths, a protocol named BRPC (Backward Recursive PCE-based Computation [1]) is being standardized by IETF. BRPC is implemented by employing PCEs (Path Computation Elements). PCEs communicate with the other PCEs that manage other domains for inter-domain routing [2,3]. For each inter-domain path connection demand, PCE computes the optimal route by BRPC on a sequence of domains between the source and destination. However, BRPC assumes that the ordered series of domains is defined in advance and no algorithm has been published so far to find such a domain series that gives an approximately optimal route when BRPC is utilized. Please note that global optimization using global network resource information is not expected if each carrier/domain discloses only a limited range of information to other carriers/domains.

In this paper, we propose an algorithm that computes the domain series for inter-domain path demands considering load-balancing over the whole network. In order to realize load-balancing while keeping the details of each domain secret, we introduce two novel parameters. The first one is the average link utilization within a domain and the second one is the averaged utilization of each link set connecting a pair of adjacent domains. We also introduce a step-wise weighting function of the parameters so as to encourage the use of domain/links with large spare capacity when the traffic load is high. The proposed algorithm determines a domain series for an each inter-domain path demand so that the sum of weighting function is minimized. Finally, an exact route is assigned on the domain series by using BRPC. Numerical experiments demonstrate that the proposed routing algorithm selects nearly optimal paths and matches the blocking probability achieved in an equivalent network without domains.

2 Dynamic Inter-domain Routing Employing Step-wise Weighting Technique

In this paper, we assume a multi domain network where each domain is independently controlled by PCE, in other words, only a limited range of information is disclosed to the PCEs in other domains. Each pair of adjacent domains is connected by border links that provide wavelength conversion at each end; no wavelength conversion is assumed to be provided within each domain. End-to-end routing for a given path connection demand in the multi domain network is done as follows. First, a series of domains are selected and then the exact routing that includes intra-domain routing is determined. The latter is resolved by using BRPC, i.e. sequential route finding is performed on the given domain series. It is important to find a parameter that will effectively restrict the information to be disclosed and at the same time enables efficient routing.

In this paper, we propose the use of averaged link occupancy in each domain and each border link set, and the use of a simple weighting function that considers both minimum resource usage and load-balancing over all domains. Let the following step function be defined over [0,1]

$$w(x) = \begin{cases} \left\lfloor \dfrac{1}{1-x} \right\rfloor & (0 \le x < 1) \\ \infty & (x = 1) \end{cases}$$

where $\lfloor t \rfloor$ is the largest integer that does not exceed t. For a given path connection demand, we define a new graph where each domain of the original network is mapped onto a node and the set of border links connecting each domain pair is mapped to a link. The new source/destination nodes are those that include source/destination nodes in the original topology. All nodes and links in the graph are weighted by the above step function where parameter x is set to the average link usage in the original domain and the average border link usage respectively. Next we select the shortest route from the source to the destination on the new graph, i.e. minimize the total weight of nodes/links transited. The shortest route on the graph defines a sequence of original domains connecting the source/destination nodes. Finally, we derive an inter-domain path route by using BRPC.

3 Numerical Experiment

The topology examined is a 15x15 polygrid network divided equally into 25 rectangular domains; each domain consists of 9 nodes, see Fig. 1. Each adjacent node pair is connected by 22 pairs of unidirectional fibers, where each fiber can accommodate 40 wavelengths. The dynamic optical path connection requests are given. We assumed uniform traffic distribution over the network, the requests are generated as a Poisson process and the source/destination nodes are assigned randomly to each request. The holding time of each connection follows negative exponential distribution. A route is determined for each connection by using the proposed algorithm. If there is no route candidate, we count the request as blocked. We used Dijkstra's algorithm to find the shortest route for inner-domain routing.

As the benchmarks, we employed two reference methods: Search-all method and Shortest method. The former searches for the shortest route on the network that is not divided into domains and the latter always selects the domain series with the minimum domain hop count. Shortest method corresponds to conventional BRPC-based routing.

Figure 2 shows the blocking probability variations offered by the different methods. The proposed method achieves much lower blocking probability than Shortest method. The former basically matches the blocking probabilities of the Search-all method. The results prove that the proposed stepped weighting technique efficiently reduces blocking probability; load-balancing over networks is effectively attained to reduce blocking probabilities (this is more apparent when traffic loads are large). Moreover, it is demonstrated that with a very limited range of information, average traffic loads, good blocking probability performance can be attained for multiple domain networks.

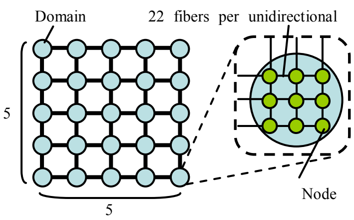

Fig. 1. Network Topology

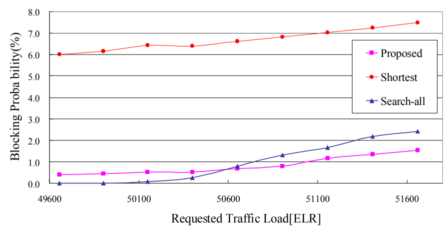

Fig. 2. Blocking Probability Variation

4 Conclusion

We proposed an inter-domain routing algorithm for multi-domain photonic networks. Numerical experiments elucidated that the use of our stepped weighting technique and averaged link load information of each domain efficiently reduce blocking probability while keeping secret detailed load information of each domain.

5 References

[1] IETF, RFC 5441, "A Backward Recursive PCE-based Computation (BRPC) Procedure to Compute Shortest Constrained Inter-domain Traffic Engineering Label Switched Paths," April 2009.
[2] IETF RFC 4655, "A Path Computation Element (PCE)-Based Architecture," August 2006.
[3] IETF, RFC 5440, "Path Computation Element (PCE) communication Protocol (PCEP)," March 2009.