Network Segmentation and Design Algorithm for Large-Scale Optical Path Networks based on Traffic Distribution Information

Takuya Yamamoto, Hiroshi Hasegawa, Ken-ichi Sato
Nagoya University, Furo-cho, Chikusa-ku, Nagoya, 464-8603 Japan
t_yamamo@echo.nuee.nagoya-u.ac.jp, {hasegawa, sato}@nuee.nagoya-u.ac.jp

Abstract *We propose a network segmentation and design algorithm based on traffic distribution information. Numerical experiments demonstrated that the proposed algorithm can greatly reduce network cost.*

Introduction

The continuous rapid growth of Internet traffic is spurring the development of a bandwidth-abundant backbone network. ROADM-based photonic networks in which optical signals are routed without O/E and E/O conversion are being introduced all over the world. Large-scale photonic networks require 3R regeneration at regular intervals. In order to effectively minimize OA&M (Operation, Administration and Maintenance) cost, the network can be divided into many areas, within each of which optical signals are transported transparently; electrical regeneration and wavelength conversion are done at boundary nodes. We call here such an area a “segment” [1]. How to determine segment boundaries will greatly impact total network cost, however, it has only been discussed for a limited topology, the regular mesh network. This paper discusses cost-effective segmentation on a more general network topology with non uniform traffic distribution, which has not been clarified so far.

For cost-effective segmentation, it is essential to reduce the costly O/E/O operations at the segment boundary nodes. The amount of traffic across boundaries can be reduced by expanding the segment area whereas the segment must be small enough so that optical signals can be transmitted between any node pair in the segment without regeneration. Moreover, the amount of such traffic heavily depends on the traffic distribution and segmentation. In this paper, we propose a segmentation algorithm that effectively resolves these contradictory requirements simultaneously. The proposed segmentation algorithm iteratively searches for the largest subgraph that minimizes the amount of traffic across the boundary while keeping the size that assures required optical signal quality. Based on the result, we can develop segmented photonic networks by establishing electrical/optical paths and fibers in each segment with minimum cost. A numerical experiment demonstrates that the proposed algorithm realizes up to 25% reduction of costly transit (relay) operations at boundary nodes compared to random segmentation.

Segmentation and design of large scale photonic networks

Preliminaries

Suppose that we have a network equivalent to the 2-connected planer graph $G(V,E)$ whose property guarantees the existence of working/backup path pairs [2]. Note that this network can be divided into the smallest independent simple loops that share edges as their boundaries [2] (See Figure 1(a)). In the following, we say that two subgraphs are adjacent if they share at least one edge. Hereafter, we try to divide the original graph into several 2-connected planner subgraphs $G_i(V_i,E_i)_{i=1,2,\dots,I}$ where no pair of subgraphs share any nodes/edges except for their boundaries. We call such subgraphs segments and each of these is derived by connecting adjacent smallest loops.

We assume a hierarchical structure that consists of optical fibers, higher-order paths (OPs: Optical Paths) and lower-order paths (LSPs: Electrical Label Switched Path). For each node pair, the number of LSPs necessary to transmit traffic demand is given. The objective is to establish these LSPs and OPs/fibers cost-effectively. As we expect transparent optical transmission in each segment, 3R regenerator, E/O and O/E converters, and electrical routing/forwarding functions are only equipped at the boundary nodes of the segments.

LSPs may traverse multiple segments. Within each segment of each LSP, a pair of disjoint working/backup paths for 1+1 protection is set up. Let $\mathrm{hop}_{\max}$ be the maximum transmissible hop count of optical signals without 3R regeneration. Thus the hop count between any node pair must be equal or smaller than $\mathrm{hop}_{\max}$. This threshold essentially restricts the size of segments. That is, we have

$$\max_{u,v\in V_i} \mathrm{hop}(u,v) \le \mathrm{hop}_{\max} \quad \text{for all } 1 \le i \le I \qquad (1)$$

where $\mathrm{hop}(u,v)$ is the minimum hop count between node pair (u,v) .

Segmented Network Design

Segmentation provides simple network operation and reduces OA&M cost; the costly relay operations are concentrated at the boundary. Perfect joint optimization, i.e. determining boundaries and routes of LSPs, is hard to achieve. Usually (boundary) node cost dominates network cost, and hence it is effective to determine segment boundaries so that the number of relay operations is minimized.

The number of relay operations at the boundary can be reduced by minimizing the number of LSPs whose source and destination nodes are in two different segments (inter-segment LSPs). Based on this observation, we propose a segmentation algorithm that consecutively minimizes the number of inter-segment LSPs. We then establish the photonic network for derived segmentation as in [1]. The details are summarized as follows.

978-1-4244-2229-6/08/$25.00 ©2008 IEEE

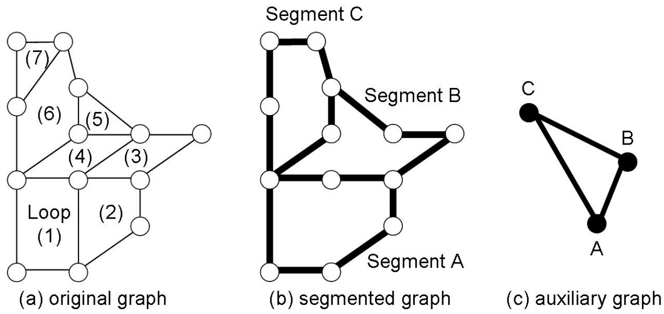

Figure 1: Segmentation and translation to auxiliary graph

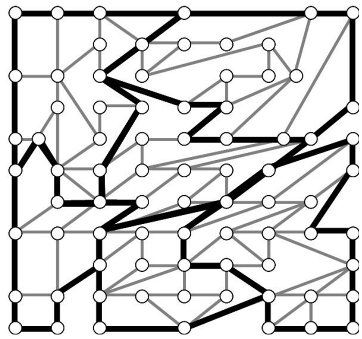

Figure 2: Segmented BT network

Segmentation and Design Algorithm

Step 1. initial segmentation

Let R be a subgraph of G that consists of all loops not belonging to already established segments. For each node n in R, let $S(n)$ be a set of all nodes in R that can be reached from n within fixed hop count ($\text{hop}_{\max}/2$). Find a subgraph $\tilde{G}_n(\tilde{V}_n,\tilde{E}_n)$ that consists of adjacent loops in R and $\tilde{V}_n \subset S(n)$. Among all the maximal graphs in $(\tilde{G}_n)_n$, select the one that minimizes the number of LSPs, where either source/destination nodes of each LSP are in the graph, and let the selected graph be a new segment. Repeat the above procedure until all loops belong to some segment.

Step 2. reoptimization of minimum segments

For each segment that consists of only one loop, try to merge it with an adjacent segment where the merged segment satisfies the hop limit constraint (See Figure 1(b)). If multiple adjacent segments satisfy the constraint, choose the one that minimizes inter-segment traffic.

Step 3. relay node selection

Define an auxiliary graph $G'(V',E')$ where V' is a set of nodes that stand for segments and E' is an edge set that represents direct connectivity between segment pairs (See Figure 1(c)). For each inter-segment LSP, apply Dijkstra's algorithm to $G'(V',E')$ so as to find a sequence of segments for LSP placement. Selection of relay nodes on the segment boundaries is done so that the all nodes have uniform traffic load and LSP length is short. Because of a lack of space, we omit the details.

Step 4. establishment of photonic network

Find the shortest pairs of routes connecting relay nodes for inter-segment LSPs and source/destination nodes for inner-segment LSPs (LSPs whose source and destination nodes are in the same segment). Establish LSPs on the routes and OPs/fibers that accommodate the LSPs.

Numerical examples

We employed BT network topology show in Figure 2 [3]. Each fiber accommodates 16 wavelengths and OP bandwidth is set at 2.5 Gb/s; LSP bandwidth is set constant at 100Mb/s. The length of all links are uniformly set at 500 km. Optical signal transmission

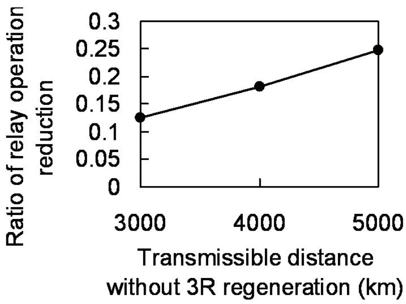

Figure 3: Reduction of relay operations

length without 3R generation was set at 3000, 4000, and 5000 km. We assumed that each node accommodates the same population except for 10 randomly selected nodes that accommodate a 10 times larger population. LSP demand was randomly distributed where the probability of assignment to each node pair was proportional to the product of the populations at the end nodes. Average traffic volume between node pairs was set at 4 Gb/s. For comparison, we also tested a randomly segmented network where the traffic distribution information was not considered and the shortest routes were assigned to LSPs.

The segmentation obtained by the proposed algorithm is shown in Figure 2. Figure 3 illustrates that the proposed algorithm reduced the relay operations at the boundaries by 12-25%. This reduction significantly reduces the cost of boundary nodes, a dominate component of total network cost.

Conclusions

We proposed a network segmentation and design algorithm for the construction of cost-effective large scale photonic networks. Numerical experiments demonstrated that it reduced the number of costly relay operations at segment boundaries by up to 25%. Segmentation may be done considering local administrative considerations and other factors, however, the proposed algorithm provides important knowledge on the cost benefit of ideal segmentation.

Acknowledgement: This work is partly supported by NICT.

References

1. K. Sugimura et al., Proc. Optics East, (2005), vol. 6012
2. B. Korte and J. Vygen, *Combinatorial Optimization*, Springer, 2002
3. A. Lord, Workshop on the Future Optical Networking, OFC 2006, Anaheim, 2006