Letters

Optical Path Design Software for Photonic MPLS Networks

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Abstract

NTT Service Integration Laboratories has developed optical path design software for setting optical paths between start and end routers in wavelength-division-multiplexing-based photonic multiprotocol label switching networks. This article gives an overview of this software.

1. Introduction

Photonic multiprotocol label switching (MPLS) networks [1] based on wavelength division multiplexing (WDM) are suitable for transferring large volumes of information at high speeds, and the need for networks of this type is increasing year by year. A photonic MPLS network consists of photonic MPLS routers connected by optical fiber links. It features optical label switched paths (OLSPs) [2], or simply optical paths, each part of a fiber link connecting two routers as start and end points. One of the key issues for achieving a high-performance and reliable photonic MPLS network is the development of an optical path design algorithm [3]. Here, "optical path design" means optimizing the OLSP routes and the wavelengths to minimize the cost or number of wavelengths required in the network while taking into account various restrictions.

Optical path design must consider several new restrictions that are not issues in path design for synchronous digital hierarchy (SDH) networks. To begin with, the concept of "wavelength" comes into play because the target of design is, after all, an optical path. In optical path design, one wavelength is allocated to one optical path. Thus, in addition to satisfying the link-capacity restriction as before, another restriction is that multiple paths with the same wavelength cannot exist on the same link. We must also consider that some of the photonic MPLS routers making up the network will have a wavelength conversion function, and that there will be an upper limit on both the number of wavelengths that can be used over the entire network and the number of wavelengths that can be converted at routers having this wavelength conversion function. These restrictions are all intertwined, making the problems of optical path design all the more difficult.

Against this background, we have developed an optical path design algorithm and software for photonic MPLS networks for the conditions described above. This article describes its basic concepts and functions.

2. Requirements in optical path design

There are several requirements in optical path design.

(1) Working and backup paths

First, path design must be performed for both working and backup paths. The working path is the primary path that is normally used, while a backup path is a redundant path for backup that is activated to maintain network traffic if the working path becomes inoperable due to a fault occurring or maintenance work being performed.

"Fault scenarios" must be considered in the design of backup paths. A fault scenario represents a set of routers and links becoming unusable because of one or more faults. These scenarios must be envisioned

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beforehand at the design stage and working and backup paths set accordingly so that, in the event of a fault, the system can switch from the working path to the backup path corresponding to that fault. This will prevent network operations from being interrupted.

(2) Independent routes

It is no use if a fault disables the backup path as well as the working path. When multiple paths are required between the same two routers acting as start and end points, they should be set along at least two independent routes to ensure that at least one path remains usable in the event of a link fault. This will prevent the worst-case scenario of total communication breakdown from occurring. Therefore, we need a function that can set independent paths from the viewpoint of risk dispersion.

(3) Multiple protection systems

We must consider setting backup paths of various reliability levels according to the importance of the paths. For example, if traffic must be maintained under any circumstances, the backup path should have the same reliability level as the working path (1+1 protection). A system with lower priority could share one backup path for several working paths (m:n protection) or have no backup paths at all (unprotected paths). Design work must accommodate such a mixture of protection systems according to the importance of the traffic being carried.

(4) Partial wavelength conversion function

In partial wavelength conversion, the set of wavelengths that can be used across the entire network is divided into several wavelength groups, each of which is assigned a group number. Wavelength conversion may be performed within a group but never between groups.

For example, if we divide wavelengths λ_1 to λ_{16} into four groups of four wavelengths each in order of ascending wavelength number, then wavelength conversion may be performed among wavelengths λ_1 to λ_4 in group-1 but not between λ_1 and λ_5. This is an implementation-dependent restriction but must nevertheless be supported.

In short, path design must consider the importance of backup paths, the independence of paths, multiple protection systems, and implementation-dependent partial conversion. This makes the path-design problem difficult. To solve it, we take the following approach.

3. Modeling

3.1 Network modeling

First, we model the target network using an undirected multigraph. In the graph, nodes represent the routers in the network and edges represent the fiber links that interconnect the routers. The path-design problem can therefore be treated as a graphical problem involving these nodes and edges (Fig. 1).

In this problem, each link is given "distance" and "cost" functions as supplementary information. The distance function, as the name implies, is proportional to the actual length of the link, while the cost function is based on the link length, bandwidth, and other attributes. The distance and cost of a path are obtained by summing the distances and costs of all the links in the path, respectively.

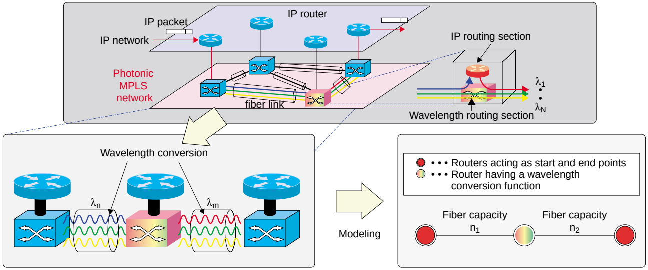

Fig. 1. Model of a photonic MPLS network.

3.2 Formalization

The input information is listed in Table 1. This information is used as a basis for formalizing the problem using state variables. A search is then made for a solution that satisfies the following restrictions.

- Paths must not exceed the fiber capacity of each link.
- The maximum number of wavelength conversions that is set for each router must not be exceeded.
- More than one path of the same wavelength must not exist on the same link.
- A path must not be duplicated on a link.
- The distance of a path must not exceed the maximum allowed length.

3.3 Target function

The target function is the “total path cost.” The objective is to find, from among those that satisfy the above restrictions, the set of paths that minimizes the total path cost.

4. Proposed heuristic solution

Since the path design problem must take various functions into account, it belongs to a class of nonlinear integer programming problems referred to as “NP-hard” (NP: nondeterministic polynomial). Exact solutions to problems of this type are thought to be impossible.

In general, if the scale of the target network is relatively small and if we consider only working paths and no wavelength conversion, a solution could be output in a realistic period of time even by an exact algorithm (all solution patterns are found and the optimal solution is determined.) Experiments have shown that this is possible if the network scale is on the order of ten nodes. As the network scale increases, however, computational time increases exponentially, so it becomes difficult to output a solution in a realistic period of time. Therefore, we must consider some other way of finding the best solution in a reasonable period of time.

To this end, various heuristic algorithms have been proposed. Our study places particular emphasis on searching for and outputting a solution in a realistic time period, so for this reason, we considered a heuristic algorithm that combines “solution-space intensification” with a “random multi-start local search.”

The algorithm randomly selects a path from solution candidates in a subset of solution space and subjects that path to a neighborhood search to find a local solution that minimizes the total cost (Fig. 2). This process is repeated a predetermined number of times to produce multiple local solutions, and the one with the lowest cost is output as a suboptimal solution (i.e., a solution that is not necessarily optimal).

This heuristic algorithm consists of the following steps.

① Set the number of repetitions R: Determine the number of times that an initial solution is selected and subjected to a neighborhood search.

Table 1. Input information.

Wavelength	Number of wavelengths that can be used over the entire network
	Information on wavelength groups
Router	Number of routers
	Maximum number of wavelength conversions for each router
Link	Number of links
	Capacity of each link
	Length of each link
	Cost of each link
	Router ID number at each end of each link
Path	Router ID number at each end of each path
	Number of required paths
	Intensification coefficient in solution searching for creating path candidates
	Maximum distance
Specified path * Necessary for inputting as an existing path	Path number
	Wavelength number
Fault scenario * Necessary for designing backup routes	Routers that might fail
	Links that might fail

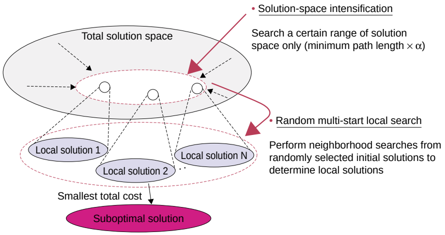

Fig. 2. Approach to solution searching.

② Intensify the solution space: Narrow down the solution space to paths that are α times the minimum path length (from start point to end point).

③ Find a solution that satisfies the link-capacity restriction: From the intensified solution space, randomly select a path that satisfies the capacity restriction of each link (Wavelength is not considered at this stage).

④ Find a solution that satisfies the wavelength-conversion restriction: Using the path obtained in step 3 as a starting point, determine a path that does not exceed the maximum number of wavelength conversions at each router.

⑤ Repeat and determine the solution: Repeat steps 3 and 4 R times to obtain multiple local solutions and treat the one with the smallest total cost as a suboptimal solution.

5. Evaluation experiment

5.1 Preparation

To achieve efficient path design, α and R must be set to optimal values. With this in mind, we performed simulations to observe the effects of varying these two parameters using the software that we prepared. This evaluation targeted the network topologies shown in Fig. 3 for paths that interconnect routers in a full-mesh pattern (a total of 153 paths). As a precondition of this evaluation, there were no routers with a wavelength conversion function. In addition, distance was allocated appropriately among the links and cost was assigned proportionally to distance. Plan 1 had one fiber link between routers and Plan 2 had two.

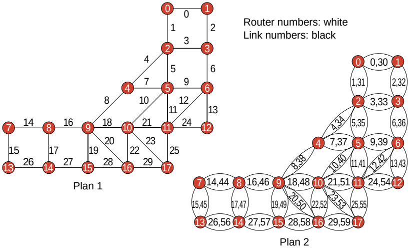

Fig. 3. Examples of network topology.

5.2 Intensifying solution space

Figure 4 shows the results of simulating intensification coefficient α versus the number of path-candidate combinations. The number of path-candidate combinations, i.e., the solution space, grew exponentially as α increased.

Under the above network conditions, a solution could be output for α = 1.1. As α was made smaller, however, the solution space became overly restricted and a solution that satisfied the conditions became more difficult to obtain. Conversely, when the solution space was made too large, a suboptimal solution was located farther out and finding it took more time. It is therefore important to set an appropriate range for the size of the solution space for which path design can be performed while giving due consideration to link capacity and other restrictions so that a good solution can be output in a reasonable time.

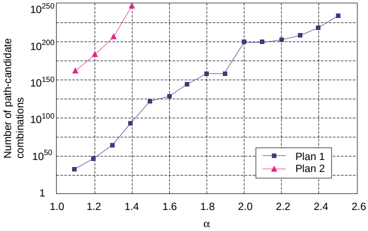

Fig. 4. Change in number of path-candidate combinations versus intensification coefficient α.

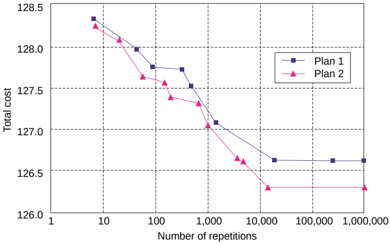

Fig. 5. Change in total cost versus number-of-repetitions R.

5.3 Number of repetitions

Figure 5 shows the change in the total cost of the path when varying R, the number of independent search runs (number of repetitions). The total cost decreased as R increased and there was a tradeoff relationship between them. Considering that a solution must be output in a reasonable period of time, however, an efficient method here is to find a value of R above which the cost does not easily drop. Under these simulation conditions, a cost ceiling appeared at about 10,000 search runs (3 minutes and 35 seconds for Plan 1), which makes this a good value to set as R.

6. Conclusion

This article introduced the basic concepts of optical path design software developed by NTT Service Integration Laboratories for photonic MPLS networks taking into account both photonic-MPLS and implementation-dependent restrictions. Optical path design belongs to the NP-hard class of optimization problems. For a very small-scale network (on the order of ten nodes), a solution can be found by an exact algorithm, while for a large-scale network, a suboptimal solution can be obtained using the heuristic algorithm introduced here. In future research, we plan to study more efficient and faster heuristic algorithms.

References

[1] Y. Yamabayashi, M. Koga, and S. Okamoto, "Autonomously Controlled Multiprotocol Wavelength Switching Network for Internet Backbones," IEICE Trans. Commun., Vol. 83-B, No. 10, Oct. 2000.

[2] K. Sato, S. Okamoto, and H. Hadama, "Network Performance and Integrity Enhancement with Optical Path Layer Technologies," IEEE Journal on Select. Areas Commun., Vol. 12, No. 1, pp.159-170, 1994.

[3] N. Nagatsu, Y. Hamazumi, and K. Sato, "Optical Path Accommodation Design Applicable to Large Scale Networks," IEICE Trans. Commun., Vol.E-78-B, No. 4, 1995.

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