2004

Maximizing Resource Sharing in WDM Mesh Networks With Path-Based Protection and Sparse OEO Regeneration

Xi Yang
University of Nebraska - Lincoln, xyang@cse.unl.edu

Byrav Ramamurthy
University of Nebraska - Lincoln, bramamurthy2@unl.edu

Lu Shen
University of Nebraska - Lincoln, lshen@cse.unl.edu

Yang, Xi; Ramamurthy, Byrav; and Shen, Lu, "Maximizing Resource Sharing in WDM Mesh Networks With Path-Based Protection and Sparse OEO Regeneration" (2004). *CSE Conference and Workshop Papers*. 115.
http://digitalcommons.unl.edu/cseconfwork/115

Optical Fiber Communication Conference, 2004. OFC 2004
Volume: 2
Digital Object Identifier: 10.1109/OFC.2004.1362129
Publication Year: 2004

Maximizing resource sharing in WDM mesh networks with path-based protection and sparse OEO regeneration

Xi Yang, Lu Shen and Byrav Ramamurthy
Department of Computer Science and Engineering, University of Nebraska-Lincoln
115 Ferguson Hall, UNL, Lincoln, NE 68588-0115, Tel: (402) 472-1779, Fax: (402) 472-7767
Email:{xyang, lshen, byrav}@cse.unl.edu

Abstract: We propose a resource-sharing scheme that supports three kinds of sharing scenarios in a WDM mesh network with path-based protection and sparse OEO regeneration. Several approaches are used to maximize the sharing of wavelength-links and OEO regenerators.

OCIS codes: (060.4250) Networks; (060.4510) Optical communications

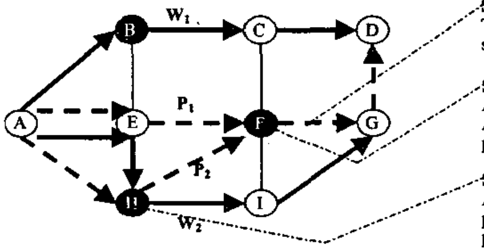
1. Introduction

With advances in optical switching technologies, next-generation optical backbone and metropolitan networks will employ wavelength routing to provide wavelength-level connections that cross multiple nodes and links in a mesh topology. Such a network faces the high risk of losing large amounts of data due to failures. Service providers (or carriers) have to use backup or redundant network resources to protect their networks against this risk. On the other hand, efficiently utilizing network resources is among the top priorities for service providers. They need to reduce their investment by using a minimum number of redundant resources.

Backbone and metropolitan service providers also deploy optical-electrical-optical (OEO) regenerators widely in their networks. These expensive OEO regenerators are required to overcome the physical impairments introduced by optical fibers and optical amplification, (de)multiplexing and switching components. The physical impairments impose fundamental constraints on the quality of signals in WDM optical networks. In the current phase, only OEO regenerators can provide the full capability of reamplification, reshaping and retiming and guarantee the transmission quality. In addition, OEO regenerators can be used as an alternative to wavelength converters to resolve wavelength contention. Previous studies proposed to place OEO regenerators sparsely in a network to reduce the OEO cost [1]. This technique is called "sparse OEO regeneration".

In this study, we address the problem of optical connection provisioning in WDM mesh networks in a resource-efficient manner by exploiting the benefit of resource sharing. We consider a network with both path-based protection and sparse OEO regeneration. In path-based protection, a link-disjoint protection path is used to prevent the services on the working path from disruption. Because protection paths usually use redundant network resources, sharing the resources on the protection paths will not interfere with services on the working paths. Many previous studies have considered minimizing the use of wavelength-links by sharing some of them between protection paths [2][3][4][5]. Our study further shows that not only wavelength-links can be shared, but the OEO regenerators can also be shared by the protection paths. In addition, OEO regenerators can be shared between a working path and its protection path. This is because the working and protection paths do not need OEO regeneration at the same time. Only if a link failure occurs (note that we do not consider node failures), should an OEO regenerator that was assigned to the working path be used by the corresponding protection path.

In Figure 1, we illustrate our resource-sharing scheme in a WDM mesh network with path protection and sparse OEO regeneration. In this illustration, two connections are created from the node A to D and from A to G. Their working and protection paths are labeled with W_1, W_2 and P_1, P_2 respectively. Our resource-sharing scheme supports three kinds of resource-sharing scenarios, which are described in Figure 1. In the remainder of this study, we will present solution approaches to maximize the resource sharing based on these three sharing scenarios.



Scenario 1: Wavelength-Link Sharing
The link (F-G) is shared by the protection paths P_1 and P_2. Any protections can share the same wavelength-link given that their working paths are link-disjoint.

Scenario 2: OEO Sharing between Protection Paths
An OEO regenerator at the node F is shared by the protection paths P_1 and P_2. Any protections can share the same OEO regenerator given that their working paths are link-disjoint.

Scenario 3: OEO Sharing between Working and Protection Paths
An OEO regenerator at the node H is shared by the working path W_2 and its protection path P_2. A working path can only share an OEO regenerator with its protection path.

Figure 1. An illustration of our resource-sharing scheme and three kinds of resource-sharing scenarios.

Optical Fiber Communication Conference, 2004. OFC 2004
Volume: 2
Digital Object Identifier: 10.1109/OFC.2004.1362129
Publication Year: 2004

2. Problem formulation and solution approaches

While provisioning a number of optical connections in a WDM mesh network (denoted by a graph $G = (V, E)$), we consider two kinds of linear physical impairments: polarization mode dispersion (PMD) and amplified spontaneous emission (ASE) noise [6]. Each network node (j) is associated with a certain number (R_j) of O/E/O regenerators. Each network link (i, j) supports a fixed number (W) of wavelengths. A link is also associated with a link length in kilometers, and two impairment parameters $PMD_{i,j}$ and $ASE_{i,j}$, which represent the PMD and ASE noise values on this link respectively. We use $<s, d, x>$ to denote the x-th connection request from the node s to the node d. Our objective is minimizing the number of O/E/O regenerators and wavelength-links consumed by all the connection requests. This objective is formulated as:

$$\text{Minimize} \quad \Delta \times \sum_{\forall j \in V} \sum_{1 \le k \le R_j} r_{j,k} + \sum_{1 \le w \le W} \sum_{\forall (i,j) \in E} \Big(\sum_{\forall s,d \in V} \sum_{1 \le x \le X} F_{i,j,w}^{s,d,x} + m_{i,j}^{w} \Big)$$

where $r_{j,k}$, $F_{i,j,w}^{s,d,x}$ and $m_{i,j}^{w}$ are binaries. $r_{j,k} = 1$ denotes the *k-th* OEO regenerator on the node j is used (or shared) by some working and/or protection paths. $F_{i,j,w}^{s,d,x} = 1$ denotes that the wavelength w on the link (i, j) is used by the working path of the connection $<s, d, x>$. $m_{i,j}^{w} = 1$ denotes that the wavelength w on the link (i, j) is used (or shared) by some protection paths. We set the multiplier Δ to be $W \times |E|$, the maximum number of wavelength-links in the network, to ensure that minimizing the number of O/E/O modules takes priority over minimizing the number of wavelength-links (Note that we can also tradeoff between these two objective terms by setting Δ to other values.). We use both integer linear programming (ILP) and heuristic approaches to solve this problem.

2.1. Constraints and ILP approach

In addition to the conventional network conservation constraints, wavelength continuity constraints, and path diversity constraints used in previous studies [3][4][5], two categories of new constraints are added in this problem.

1. *Resource-sharing constraints:* The constraints on the shared resources (OEO regenerators and wavelength-links) have been described in the three resource-sharing scenarios in Figure 1.
2. *Physical impairment constraints*: The sum of the PMD and ASE noise values on the links of each regeneration segment (on each working and protection path) should not exceed the predefined thresholds.

We incorporated the above objective and constraints into an ILP formulation, which transforms the problem into an ILP problem. We used CPLEX to solve the ILP problem. The ILP approach produced optimal solutions for some small-scale problems (e.g., the problems in a 6-node 9-link 4-wavelength network under a few connection requests), but failed to obtain optimal or even feasible solutions for large-scale problems.

2.2. Heuristic solution approaches

We developed a greedy heuristic to find a feasible initial solution for this problem, based on which we developed a local optimization heuristic (LOH) and a tabu search heuristic (TSH) to improve this solution. Both LOH and TSH reduce the number of used O/E/O regenerators and wavelength-links by increasing their sharing.

A greedy heuristic

This heuristic provisions the connection requests one by one according to the non-ascending order of the length of their shortest paths. To increase the chance of success, k-shortest paths are chosen as the candidates for the working path of each connection on the network graph G. Then, a provisioning procedure is repeatedly called using one of these k-shortest paths as input until it succeeds. In the provisioning procedure, the links on the input working path are removed to ensure diversity. A new weight that favors OEO and wavelength-link sharing is assigned to each link on the residual graph, based on which another set of k-shortest paths is chosen as the candidates for the protection path. A greedy wavelength and O/E/O assignment algorithm is used to assign wavelengths and O/E/O regenerators along the working and protection paths.

Local optimization heuristic (LOH) approach

The local optimization heuristic improves a feasible initial solution by reconfiguring some existing connections in multiple iterations. The reconfiguration releases the resources consumed by a connection and provisions alternate resources to recreate it. During the reconfiguration, sharing OEO regenerators and wavelength-links is given preferential consideration. In each iteration, we first use a reconfiguration evaluation procedure on each existing connection to examine the objective value improvement that can be achieved by reconfiguring this connection. Then, the connection that has been evaluated to generate the most amount of improvement is chosen to be reconfigured. Each iteration starts from the new solution obtained in the previous iteration. This heuristic executes a number of such iterations until no improvement on the objective value can be obtained. The local optimization heuristic stops at local optima, which exist in a local search region close to the initial solution.

Tabu search heuristic (TSH) approach

Tabu search is a meta-heuristic for solving hard combinatorial optimization problems. Given a problem with a minimization objective function, the tabu search will look for an optimal or close-to-optimal solution i in the

Optical Fiber Communication Conference, 2004. OFC 2004
Volume: 2
Digital Object Identifier: 10.1109/OFC.2004.1362129
Publication Year: 2004

solution space S. $\dot{S}$ represents the set of all the possible solutions. A search operation from one solution to another is called a "move". The tabu search is carried out through a number of such moves. If a move results in a better solution than the current best solution, it is called an improving move. Otherwise, it is a non-improving move. In our heuristic, a move is realized by using the same reconfiguration procedure as in the local optimization heuristic. In this heuristic, penalties are imposed on those non-improving moves to facilitate global search.

3. Numerical results

We conducted simulation experiments on a 24-node 43-link USA network (see Figure 2). A number (W) of OEO regenerators are placed at each double-circled node, where W is the number of wavelengths. Table I shows the number of used OEO regenerators (#OEO) and wavelength links (#WL) under different heuristics in different experiment cases. R represents the number of connection requests. Figure 3 shows their average resource usage that is normalized to the initial solutions obtained by the greedy heuristic. Both LOH and TSH show significant improvement over the initial solutions. We can also observe that TSH outperforms LOH. Table II shows the resource-sharing rate for OEO regenerators and wavelength links. The resource-sharing rate is defined as the ratio of the number of network resources actually used under our resource-sharing scheme to the number of network resources used without taking advantage of sharing (obtained by counting the used resources path by path).

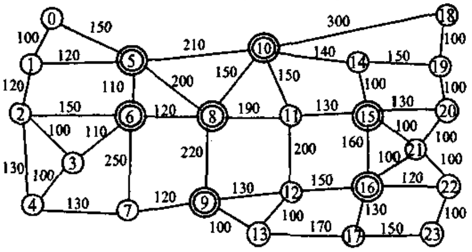


Figure 2. The USA network with sparse OEO regeneration.

Case #	W	R	#OEO		#WL	
			LOH	TSH	LOH	TSH
1	8	40	17	17	267	255
2	8	50	21	19	312	302
3	8	60	19	18	300	301
4	16	50	20	20	306	297
5	16	70	22	22	393	378
6	16	90	22	18	481	470
7	32	110	37	37	645	591
8	32	140	58	50	840	796
9	32	170	60	55	983	915

Table I. Number of used OEO regenerators and wavelength-links.

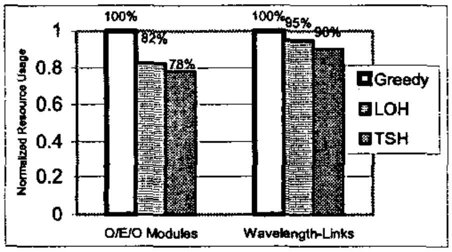


Figure 3. Normalized number of used OEO regenerators and wavelength-links under different heuristic solution approaches.

Case #	W	R	OEO		WL	
			LOH	TSH	LOH	TSH
1	8	40	62.2%	63.8%	26.6%	30.9%
2	8	50	67.7%	62.7%	33.3%	31.5%
3	8	60	69.4%	60.9%	37.5%	34.7%
4	16	50	61.5%	61.5%	32.2%	31.4%
5	16	70	68.6%	70.3%	31.7%	34.6%
6	16	90	73.2%	77.2%	32.0%	34.0%
7	32	110	63.0%	64.1%	28.3%	33.9%
8	32	140	62.3%	67.7%	30.9%	34.3%
9	32	170	64.3%	68.9%	30.8%	35.6%

Table II. Resource-sharing rate for OEO regenerators and wavelength-links.

4. Conclusion

In this study, we proposed a resource-sharing scheme that supports three kinds of resource-sharing scenarios in a WDM mesh network with path-based protection and sparse OEO regeneration. We developed several solution approaches to maximize the benefit of sharing and thus minimize the total number of used OEO regenerators and wavelength-links. In most experiment cases, the sharing rate for O/E/O regenerators is remarkably high (over 60%), so is the sharing rate for wavelength-links (over 30%), which indicates great savings in network cost.

References

[1] B. Ramamurthy, H. Feng, D. Datta, J. P. Heritage and B. Mukherjee, "Transparent vs. opaque vs. translucent wavelength-routed optical networks," in *Proceedings of Optical Fiber Communications (OFC 1999)*, San Diego, CA, Feb. 1999.

[2] B. Doshi, et al., "Optical network design and restoration," *Bell Labs Technical Journal*, vol.4, no.1, 1999.

[3] H. Zang and B. Mukherjee, "Path-protection routing and wavelength-assignment (RWA) in WDM mesh networks under duct-layer constraints," *IEEE/ACM Transactions on Networking*, vol. 11, no. 2, pp. 248-258, Apr. 2003.

[4] H. Zang, R. Huang and J. Pan, "Methodologies on designing a hybrid shared-mesh-protected WDM network with sparse wavelength conversion and regeneration," in *Proceedings of SPIE*, Vol. 4910, pp. 188-196, Sep. 2000.

[5] L. Shen, X. Yang and B. Ramamurthy, "Shared risk link group (SRLG)-diverse path provisioning under hybrid service level agreements in wavelength-routed optical mesh networks: formulation and solution approaches", to appear in *SPIE OptiComm 2003*, Dallas, TX.

[6] J. Strand, A. L. Chiu and R. Tkach, "Issues for routing in the optical layer," *IEEE Communications Magazine*, Vol. 39, No. 2, Feb. 2001.