

# Network Topology Effect on QoS Delivering in Survivable DWDM Optical Networks

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**Abstract**—The quality of service (QoS) is an important and considerable issue in designing survivable dense wavelength division multiplexing (DWDM) backbones for IP networks. This paper investigates the effect of network topology on QoS delivering in survivable DWDM optical transport networks using bandwidth/load ratio and design flexibility metrics. The dedicated path protection architecture is employed to establish diverse working and spare lightpaths between each node pair in demand matrix for covering a single link failure model. The simulation results, obtained for the Pan-European and ARPA2 test bench networks, demonstrate that the network topology has a great influence on QoS delivering by network at optical layer for different applications. The Pan-European network, a more connected network, displays better performance than ARPA2 network for both bandwidth/load ratio and design flexibility metrics.

**Keywords**—dedicated path protection, DWDM, network topology, optical networks, QoS, survivability.

## 1. Introduction

The provision of acceptable service in the presence of failures and attacks is a major issue in the design of next generation dense wavelength division multiplexing (DWDM) networks as backbones for future Internet protocol (IP) networks with enhanced quality of service (QoS) [1]. In DWDM technology a fibre can potentially provide multiple terabits per second (Tbit/s) transmission rate by multiplexing different wavelength channels [2], so a fibre cut can lead to tremendous traffic and venue loss which dramatically affect the network QoS delivering to applications [3]. Therefore maintaining a high level of resiliency is an important and crucial issue to design fault tolerant DWDM optical networks against component failures [4]. A survivable network can operate at an acceptable level of performance in the event of failure by failure covering through anticipated redundant resources [5]. This problem is known to be NP-hard [6]. The integer linear programming (ILP) [6], [7] and heuristics approaches [8]–[12] are employed by network researches and engineers to design optimal survivable backbones for different applications such as data, voice and videos.

In survivable networks the working and spare lightpaths established between each node pair must be link disjoint to guarantee that upon any single link failure both paths will not fail simultaneously. Therefore the spare path is able to protect the working path in the event of any single link

failure. The dedicated path protection architecture is an offline survivability approach where the working and spare lightpaths are established before network operation. The backup resources along the spare lightpaths are specifically dedicated to a particular lightpath and can not be utilized by other spare lightpaths.

The resource reservation algorithms provide working and spare paths which minimize the bandwidth utilization and they may not be suitable to accommodate the QoS requirements, while QoS requirements will extend network resource utilization [13]. The quality of service refers to the ability of a network to enforce preferential treatment to an application, through a series of classification. Although QoS is not directly responsible for ensuring that the network is up and running all the time, it has a direct impact on the survivability of the network [14]. In general QoS requirements extend network resource utilization, assured through bandwidth trading. The primary contribution of this paper is the investigation of the effect of network topology on delivering QoS in survivable DWDM optical transport networks for bandwidth and delay sensitive applications.

The rest of the paper is as follows: Section 2 presents mathematical formulation for bandwidth management and QoS propagation delay requirement. Section 3 describes the results obtained for a heavy load demand matrix and analyzes the effect of network topology, while overall conclusions are presented in Section 4.

## 2. Problem Statement

The network topology is represented as a directed graph  $G(N, L)$ , where  $N = \{n_1, n_2, \dots, n_{\hat{N}}\}$  is the set of nodes and  $L = \{l_1, l_2, \dots, l_{\hat{L}}\}$  is the set of connecting links in the network. The  $W = \{\omega_1, \omega_2, \dots, \omega_{\hat{W}}\}$  is the set of wavelengths per link. The demand matrix  $T[d_{(o,d)}]_{\hat{N} \times \hat{N}}$  aggregates demand between origin and destination node pairs  $(o, d)$ . The sets of eligible working paths,  $\kappa_{o,d}^w$ , and spare paths  $\kappa_{o,d}^s$ , between each node pair before and after of the event of failure are precomputed using the  $K$ -shortest paths algorithm [15].

### 2.1. Bandwidth Optimization

Delivering the required QoS requires a trade-off between network bandwidth and application requirements. The economic objective of the establishment of suitable resilient working,  $P$ , and spare,  $S$ , paths entails the discovery of

routes with minimum bandwidth occupation to working,  $b_{od}^p$ , and spare,  $b_{od}^s$ , paths between node pair  $(o, d)$  may be written as

$$B = \text{minimize} \left\{ \sum_{(o,d)} (b_{od}^p + b_{od}^s) \right\}, \quad (1)$$

$$b_{od}^p = \sum_{l \in P} \sum_{\omega \in W} \omega_w^{k,od}, \quad \forall (o,d) \in T, \quad (2)$$

$$b_{od}^s = \sum_{l \in S} \sum_{\omega \in W} \omega_s^{k,od}, \quad \forall (o,d) \in T. \quad (3)$$

The decision variable  $\omega_w^{k,od}$  ( $\omega_s^{k,od}$ ) is set to 1 if the  $k$ th working (spare) path between node pair  $(o, d)$  uses wavelength  $\omega$ , and to 0 otherwise.

**The link-capacity constraint.** The total number of occupied wavelengths, working and spare, on each link is bounded by the number of wavelengths per link  $\hat{W}$ .

**The satisfaction constraint.** Each link of the working and spare paths that is assigned for a connection request between each node pair  $(o, d)$  must satisfy the demand between that node pair.

**The wavelength utilization constraint.** Each wavelength can be utilized only by working paths or by spare paths.

**The disjoint constraint.** The working path and the spare path,  $(P, S)$ , between each node pair  $(o, d)$  must be link disjoint (so will not fail together) to accommodate single link failure.

## 2.2. Quality of Service Requirements

The QoS requirement for delay sensitive applications is to find resilient paths that minimize the propagation delay of working,  $d_{od}^p$ , and spare,  $d_{od}^s$ , paths between  $(o, d)$ :

$$D = \text{minimize} \left\{ \sum_{(o,d)} (d_{od}^p + d_{od}^s) \right\}, \quad (4)$$

$$d_{od}^p = \sum_{l \in P} d_l, \quad \forall (o,d) \in T, \quad (5)$$

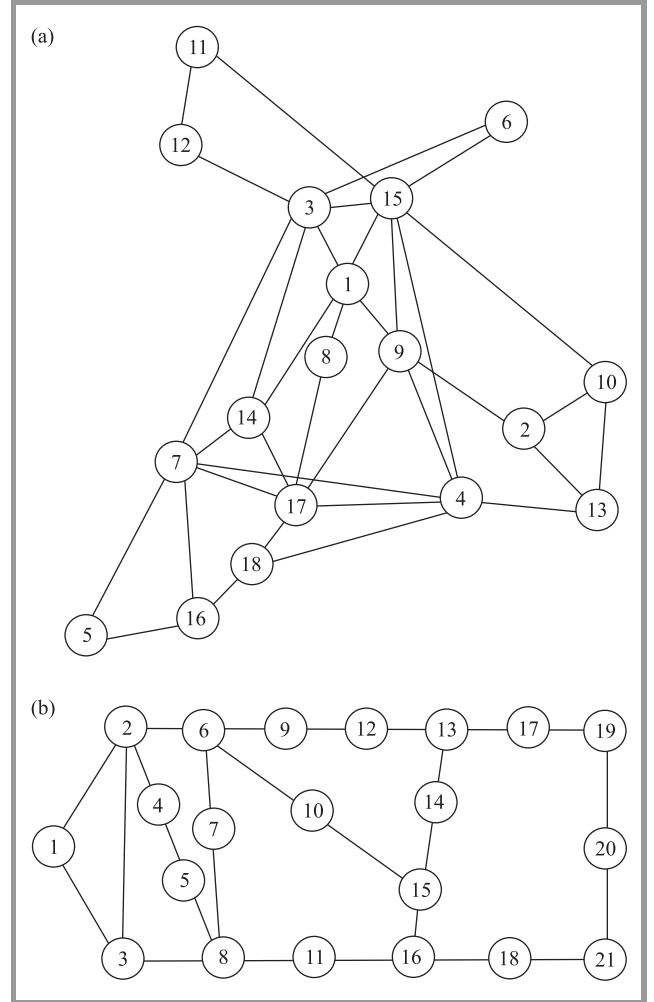
$$d_{od}^s = \sum_{l \in S} d_l, \quad \forall (o,d) \in T, \quad (6)$$

with  $d_l$  being the delay for link  $l$ , which is proportional to its length. Also,  $d_{od}^p$  ( $d_{od}^s$ ) must be less than the maximum acceptable delay on the working and spare lightpaths for a request between node pair  $(o, d)$ . The delay should also be less than  $D^{\max}$ , the maximum acceptable delay for the demand matrix (this condition will weed out very poor solutions from the population with minimal computation).

## 3. Simulation Results

This section describes some simulation results of designing survivable DWDM optical networks for both bandwidth and propagation optimization schemes. For this a program-

ming code has been implemented using MATLAB. To illustrate the effect of network topology on QoS delivering, two contrasting networks are considered here, both are established benchmarks and are shown in Fig. 1. The Pan-European network is a highly connected example, comprising 18 nodes and 35 links. The ARPA2 network is a much less connected topology, containing 21 nodes with 25 links.



**Fig. 1.** The benchmark topologies: (a) the Pan-European and (b) the ARPA2 network topology.

These topologies are representative of popular mesh topologies employed in survivable optical mesh network design. All links in the physical layer were bidirectional and all nodes were capable of full wavelength conversion. The adjusted delay on each link is assumed to be  $5 \mu\text{s}/\text{km}$  [16]. The number of shortest paths considered during each iteration were  $\kappa_{od}^w = 4$  for working paths and  $\kappa_{od}^s = 6$  for spare paths. The simple but efficient first-fit (FF) algorithm has been employed for wavelength assignment. It should be noted that the efficiency of the first-fit algorithm is not an issue here since the full wavelength conversion is considered for all nodes. In fact, in such scenario, where there is no wavelength continuity constraint, any wavelength assignment algorithm will achieve the same performance.

**3.1. Evaluation the Bandwidth/Load Ratio**

The effect of the bandwidth optimization scheme (BOS) and the propagation delay optimization scheme (DOS) on the routing wavelength assignment (RWA) problem was investigated via a heavy load traffic model. The arrival requests at all nodes are sent to all of the other nodes in the network. The wavelength requested per node was  $\lambda = 5$ . The results are compared for BOS and DOS in Tables 1 and 2, where the whole load of the network is  $\hat{\lambda} = \lambda \hat{N}(\hat{N}-1)$  and  $\hat{N}$  is a number of network nodes. For both optimization schemes, the working paths occupy less bandwidth than the spare paths and exhibit reduced latency time.

Table 1  
Bandwidth and propagation delay for BOS

Network	$\hat{\lambda}$	Working bandwidth	Working propagation delay [s]	Spare bandwidth	Spare propagation delay [s]
Pan-European	1530	3570	30.75	4770	41.15
ARPA2	2100	7325	44.00	13475	81.45

Table 2  
Bandwidth and propagation delay for DOS

Network	$\hat{\lambda}$	Working bandwidth	Working propagation delay [s]	Spare bandwidth	Spare propagation delay [s]
Pan-European	1530	4290	27.50	4835	40.45
ARPA2	2100	7400	43.75	13485	81.40

It may be seen that the type of optimization scheme has more influence on working bandwidth and propagation delay than spare bandwidth and delay. To examine this difference, it is useful to calculate the bandwidth/load ratio (BLR) given by the bandwidth allocated divided by the total network load  $\hat{\lambda}$ .

Figure 2 depicts the BLR for DOS against the BLR for BOS. In both cases, the BLR is substantially less for

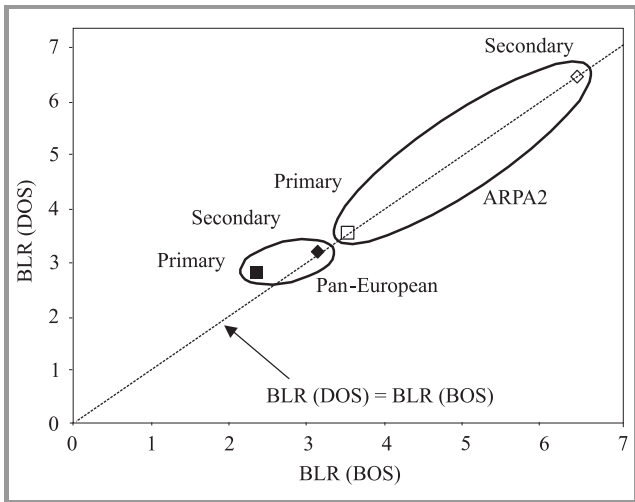


Fig. 2. Variation of BLR for DOS versus BOS.

the working paths than for the spare paths. For the ARPA2 network, there is a negligible difference in BLR between BOS and DOS. However, although this is true for spare paths in the Pan-European network BOS delivers a lower BLR for working paths as would be hoped. The lack of enhanced performance in the ARPA2 network emphasizes the role of connectivity in performance since there are few choices to be made regarding alternative routes in this network.

**3.2. Design Flexibility**

The behavior of delay versus bandwidth is not a simple one, so it is interesting to investigate the flexibility of the benchmark networks. To this end, we define the percentage design flexibility ( $\zeta$ ) in terms of the ratio of the absolute difference between the BOS solution ( $\chi^B$ ) and the DOS solution ( $\chi^D$ ) over the BOS solution ( $\chi^B$ ). The quantities  $\chi^B$  and so on may denote bandwidth or delay as appropriate:

$$\zeta = 100 \frac{|\chi^B - \chi^D|}{\chi^B} \tag{7}$$

The delay flexibility versus the bandwidth flexibility is shown in Fig. 3, for both working and spare paths. A clear difference between the two networks is apparent. Although

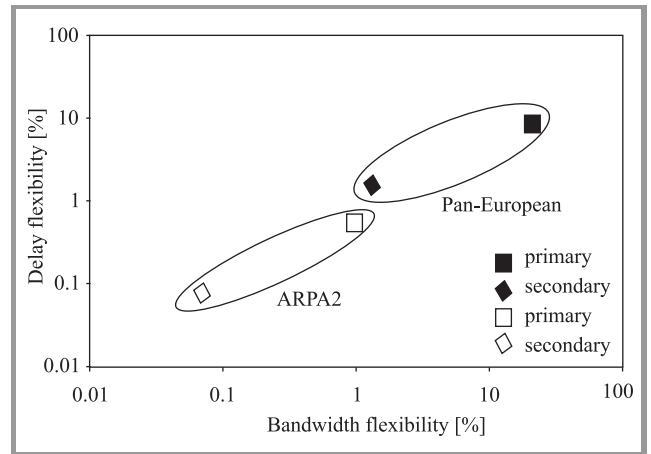


Fig. 3. Delay flexibility versus bandwidth flexibility.

there is much less flexibility in both cases for the spare paths, the Pan-European network has the highest flexibility (10.5%, 20.2%). The network planner can find out how much it is possible to optimize a survivable network for bandwidth or delay. Again, the network topology has a large influence on design flexibility, resulting in the large difference arising from the greatly differing node degrees of the networks considered.

**4. Conclusion**

Design of survivable DWDM optical networks for bandwidth and delay sensitive applications has been proposed. In the light of the importance of delay to QoS, the research

also considered solutions based on DOS in addition to BOS. The BLR has been employed to illustrate performance when using BOS and DOS, showing that there is a significant difference for working paths for the Pan-European network. In the case of spare paths, and for all paths in the ARPA2 network, BOS and DOS perform equally in their loading of the network. Furthermore, a design flexibility factor has been defined to demonstrate the large influence of network topology, or more precisely node degree, on the QoS delivered. A more interconnected network, such as the Pan-European, displays an order of magnitude more flexibility than one of limited degree such as ARPA2.

## References

- [1] D. Zhou and S. Subramaniam, "Survivability in optical networks", *IEEE Network*, vol. 14, no. 6, pp. 16–23, 2000.
- [2] B. Mukherjee, "WDM optical communication networks: progress and challenges", *IEEE J. Select. Areas Commun.*, vol. 18, no. 10, pp. 1810–1824, 2000.
- [3] J. Zhang and B. Mukherjee, "Review of fault management in WDM mesh networks: basic concepts and research challenges", *IEEE Network*, vol. 18, no. 2, pp. 41–48, 2004.
- [4] Y. S. Kaviani, W. Ren, M. Naderi, M. S. Leeson, and E. L. Hines, "Survivable wavelength-routed optical network design using genetic algorithms", *Eur. Trans. Telecommun.*, vol. 19, no. 3, pp. 247–255, 2008.
- [5] M. Medard and S. Lumetta, "Architectural issues for robust optical access", *IEEE Commun. Mag.*, vol. 39, no. 7, pp. 116–122, 2001.
- [6] J. L. Kennington, E. V. Olinicka, and G. Spiride, "Basic mathematical programming models for capacity allocation in mesh-based survivable networks", *Int. J. Manage. Sci.*, vol. 35, pp. 1–16, 2006.
- [7] S. Ramamurthy, L. Sahasrabudde, and B. Mukherjee, "Survivable WDM mesh networks", *J. Lightw. Technol.*, vol. 21, no. 4, pp. 870–883, 2003.
- [8] R. Shenai and K. Sivalingam, "Hybrid survivability approaches for optical WDM mesh networks", *J. Lightw. Technol.*, vol. 23, no. 10, pp. 3046–3055, 2005.
- [9] P. H. Ho and H. T. Mouftah, "A novel survivable routing algorithm for shared segment protection in mesh WDM networks with partial wavelength conversion", *IEEE J. Select. Areas Commun.*, vol. 22, no. 8, pp. 1548–1560, 2004.
- [10] C. Ou, J. Zhang, H. Zang, H. L. Sahasrabudde, and B. Mukherjee, "New and improved approaches for shared-path protection in WDM mesh networks", *J. Lightw. Technol.*, vol. 22, no. 3, pp. 1223–1232, 2004.
- [11] G. Lei, C. Jin, Y. Hongfang, and L. Lemini, "Path-based routing provisioning with mixed shared protection in WDM mesh networks", *J. Lightw. Technol.*, vol. 24, no. 3, pp. 1129–1141, 2006.
- [12] K. Ratnam, Z. Luying, and M. Gurusamy, "Efficient multi-layer operational strategies for survivable IP-over-WDM networks", *IEEE J. Select. Areas Commun.*, vol. 24, no. 8, pp. 16–31, 2006.
- [13] Y. Bejerano, Y. Breitbart, A. Orda, R. Rastogi, and A. Sprintson, "Algorithms for computing QoS paths with restoration", *IEEE/ACM Trans. Netw.*, vol. 13, no. 3, pp. 648–661, 2005.
- [14] K. K. Lee, F. Lim, and B. H. Ong, *Building Resilient IP Networks*. Indianapolis: Cisco Press, 2006.
- [15] S. Mittal and P. Mirchandani, "Implementation of  $k$ -shortest path Dijkstra algorithm used in all-optical data communication networks", SIE 546 Project Report, University of Arizona, Tucson, 2004.
- [16] R. D. Larson, G. Nicholas, and J. Paulter, "A measurement of propagation delay", *Metrologia*, vol. 44, pp. 64–68, 2007.



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**Mark S. Leeson** – for biography, see this issue, p. 62.

**Yousef S. Kaviani, Wei Ren, and Majid Naderi** – for biographies, see this issue, p. 66.

**Evor L. Hines** – for biography, see this issue, p. 67.