

Quantification of wavelength contention in photonic networks with reach variation

S. Meyer

Innovance Networks, 19 Fairmont Avenue, Ottawa, ON, K1Y 1X4, CANADA
Tel. +613 719 7956, Fax. +613 798 0954, email: smeyer@innovance.com

Abstract: The relationship between tunability, photonic reach and wavelength contention is investigated as it relates to practical photonic networks. Results are examined in a generic US backbone network setting.

©2001 Optical Society of America

OCIS codes: (060.4250) Networks (250.0250) Optoelectronics

1. Introduction

The subject of this paper is the effect full-range tunability has on wavelength blocking, and how this blocking rate changes with optical reach. As agile photonic networks come to the forefront of the optical networking community, it is timely to examine practical means of eliminating wavelength blocking.

Several papers have previously explored overall network blocking impacts on reference networks using pools of switched regeneration resources. In one such paper it was shown that the cost per bit in a network displaying a traffic pattern that is weighted towards high-growth IP traffic is very dependent upon increased transparency length [1]. The effect of limited range tunability on a network providing restoration capability has been theoretically described and modeled. The results indicated that even a limited tuning range of 30% of the full spectrum could achieve benefits of 80% of those obtained through full tunability [2].

In this work, we introduce a practical architecture which combines unconstrained wavelength assignment, switched regeneration / wavelength conversion as required and routing and control intelligence to eliminate connection blocking without the introduction of significant additional regeneration costs. Using a network topology and demand patterns reflecting typical US backbone networks, this paper shows that with the proposed architecture, the extra regeneration cost to eliminate wavelength blocking is less than 5% of the total OEO cost.

Overall utilization of a network is closely tied to the role that wavelength conversion plays in the design [3]. Network utilizations can rarely reach 100% in typical backbone networks. There are several key reasons for this:

- 1) Geographic and fiber connectivity
- 2) Evolving traffic patterns: Explosive growth of data traffic throughout the world [4].
- 3) Technology / traffic churn: As a result of technological advancements, systems are often overlaid with newer technologies prior to capacity exhaust.

2. Design Architecture

To obtain quantitative results, functional building blocks were modeled to characterize the network resources and blocking effects. In order to eliminate wavelength blocking, there must exist a way to dynamically assign and change needed resources. The figure below illustrates at a high-level the architecture chosen to carry out the study:

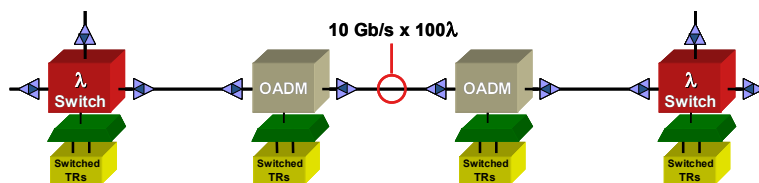


Fig. 1. Network components used for blocking analysis

The main components include fully tunable sources and filters. These are complimented on the optical layer by wavelength switches and optical add/drop multiplexers (OADM). At intermediate points, electronics are not required for signals except for regeneration or wavelength contention. This leads to the concept of switched pools of TR resources at each site. The demand inputs, and the control plane, determine the optimal usage of these resources. Advanced algorithms such as the ones utilized in this study are also important for the control and management systems. Due to dynamically assigned routes, the issue of wavelength contention is present in the network, but

actual occurrences of wavelength blocking are avoided by consuming tunable TRs to change the lambda color. The overall cost of the wavelength contention should be greatly minimized through this proposed architecture.

3. Modeled Networks

Two distinct network architectures were modeled, each of which covers the geographic United States. The first network consists of 111 network sites, representing a flat network architecture; the second consists of 20 nodes. These networks were chosen to examine the two distinct architectures that are present in typical North American carriers. The 111-node network represents a full carrier network, including all core sites, and collector, or OADM sites. The 20-node model is more representative of an express layer, where most traffic from non-core sites is back-hauled to the core nodes for transport over the network. In both of these network topologies, there is fairly limited fiber connectivity. The highest node degree (number of incident nodes) is four. This is expected to cause more wavelength contention than if the average connectivity were greater. In other studies, European networks were studied, displaying a higher average node degree and shorter connection length [5]. In order to impose a greater probability of wavelength usage on links, due to greater connection lengths, these US models were developed.

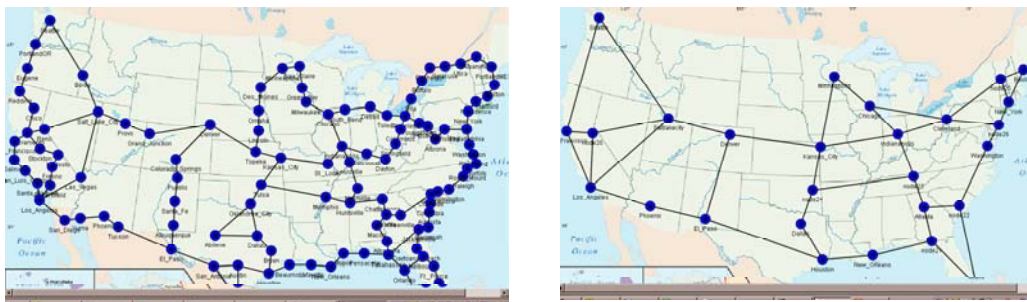


Fig. 2. Screen Captures depicting the two networks chosen for analysis; Left is the 111-node network, right is the 20-node network

Another aspect to the network analysis is the creation of traffic patterns suitable for the networks. A gravity-based traffic model was generated, utilizing the full 111 nodes. An input traffic volume of 3 Terabits was chosen. Gravity modeling techniques allow the traffic generated to be a close approximation to a real-world scenario of data-centric traffic or voice-based traffic. Distance between cities was considered less important than population, thereby modeling a data-oriented traffic pattern [6]. Some cities were also given higher relative weightings to reflect their disproportionate contribution to backbone traffic generation.

Edge grooming was assumed, consolidating multiple demands from each city to improve wavelength utilization. In order to create this wavelength demand pattern in the 111-node network, a commercial tool was used [7]. For the 20-node network, demand consolidation was performed to the core nodes of the network. This allowed the full traffic to be included as a superset of the hub-to-hub demands of the 20 nodes. It is acknowledged there are more sophisticated methods of performing demand grooming. The purpose of this modeling was to create a fictitious demand set to investigate the blocking characteristics, which has been accomplished with this model.

4. Results

Once the networks and demand patterns were prepared, an analysis of the resources required to satisfy the demand patterns was carried out. The algorithms employed first routed demands along a least-cost shortest path determined by input values by the users, and subsequently, wavelength assignment was carried out. To assign wavelengths, a graph coloring heuristic using simulated annealing was employed. This type of algorithm has previously been proposed and investigated in [8]. Every effort is made to assign continuous-path wavelengths, and in the case of reach regeneration, each segment of the photonic path is individually colored, thereby taking advantage of the full tunability. Where a regenerator is requested to solve a wavelength contention issue, the first step is to attempt a re-route on a different path that may exhibit a lower cost than inserting the regenerator. Of particular importance in this analysis was to understand the utilization and amounts of transmitter / receiver (TR) cards. The table below catalogs these results obtained for the large network model, using a link-groomed wavelength set.

Table 1. Variance of blocking resources required while changing reach distance in 111-node network (link grooming)

REACH OF TRs (km)	1000	1500	2000	2500	3000	3500	4000	4500	5000	Unbounded
Total TRs	7088	4962	3946	3446	3172	2806	2636	2566	2410	2288
Mid-Point TRs	4844	2718	1702	1202	928	562	392	322	166	44
TRs for Regeneration	4832	2670	1678	1174	852	532	354	216	126	0
TRs for λ-conversion	12	48	24	28	76	30	38	106	40	44

Through this table, it has been shown that using novel algorithms, proper cost structure, and utilizing full tunability, wavelength blocking can be eliminated. We do still have contention effects, but these are resolved through the tunable filters and TRs. From observation, we see the relationship of TRs to maximum transmission distance is not a purely linear relationship. In the above data set, there are slight peaks present at 1500km, 3000km and 4500km. These are linked to the demand length distribution. For this case, the average trail length was 1500km. This appears to cause higher quantities of resources at this distance, and multiples of this distance. To present these results in a graphical manner, the below charts show the results for the 20-node express network and 111-node network with link grooming respectively.

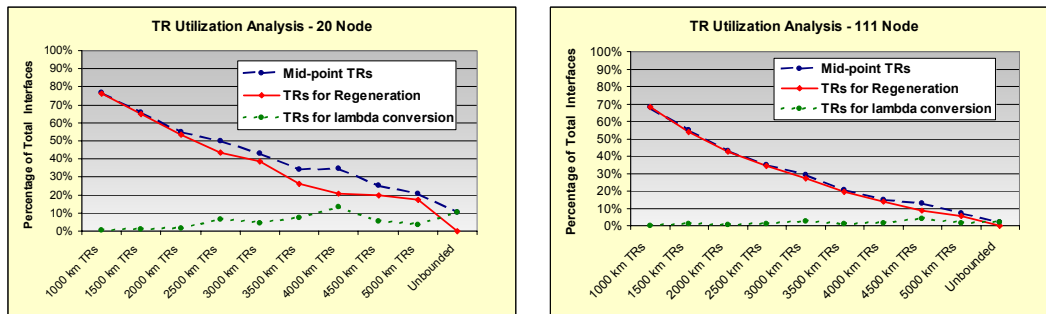


Fig. 3. Network-wide blocking percentages for 20-node and 111-node network

From these, it is shown that transmission distance clearly impacts the overall regeneration resources required in a given network. However, the percentage of resources required to solve wavelength contention issues remains fairly constant over the range. At the extremities of the profile, the overall behavior tends from zero to a maximum contention point. This is consistent with the assertion that regeneration resources can be exploited as wavelength converters where needed. The average blocking value sits at less than 5% of TR resources in a network. In terms of a network cost penalty, if we suppose that opto-electronics comprise 50% of network cost, we can state that 2.5% of network cost is incurred as a result of wavelength contention.

5. Conclusions

Intelligent optical networks that are currently coming to fruition today are taking advantage of many new technologies. Intelligent network control planes, fully tunable resources including filters and transmitters, increased-reach lasers and powerful optical amplifiers are all part of the arsenal. As networks evolve, transparency of wavelengths is paramount, and concerns over wavelength blocking issues arise. Using intelligent algorithms and careful resource planning and assignment reveals wavelength contention results in a 2-3% network cost. This cost is outweighed greatly by other operational and capital benefits offered by these new types of networks.

6. References

- [1] W. Van Parys, P. Arijis, O. Antonis, P. Demeester, "Quantifying the benefits of Selective Wavelength Regeneration in ultra long-haul WDM networks", in OFC 2001 Technical Digest, Paper TuT4-1, Anaheim, March 2001.
- [2] Y. Agarwal, P. Harshavardhana, M. Kumar, A. Mittal, J. Strand, "Wavelength Routing with Limited Range Tunability", in NFOEC 2001 Technical Proceedings, Baltimore, August 2001.
- [3] R. Ramaswami, K. N. Sivarajan, "Optical Networks: A Practical Perspective", Morgan Kaufmann Publishers, Inc., 1998.
- [4] D. Fletcher, A. DiClemente, "Bandwidth Explosion: Working Through Excess in the Backbone, Spoils to the Survivors", Global Equity Research, Lehman Brothers, February 2001.
- [5] S. Baroni, R. Gibbens, S. Korotky, "Analysis and Design of Resilient Multifiber Wavelength-Routed Optical Transport Networks", in Journal of Lightwave Technology, Vol. 17, No. 5, May 1999
- [6] A. Dwivedi, R. E. Wagner, "Traffic Model for USA Long-distance Optical Network", OFC2000, Paper TuK1, Baltimore, March 2000.
- [7] WDMNetDesign tool, <http://www.comsof.com>, copyright Comsof Communication Software 1999-2001.
- [8] A. Radin, "Graph Coloring Heuristics from Investigation of Smallest Hard to Color Graphs", Rochester Institute of Technology, Computer Science Department, May 2000.