Using grooming cross-connects to reduce ADM costs in SONET/WDM ring networks

Eytan Modiano
MIT Laboratory for Information and Decision Systems, Cambridge, MA 02139
modiano@mit.edu

Randall Berry
Northwestern University, Department of Electrical and Computer Engineering, Evanston, IL 60208
rberry@ece.nwu.edu

Abstract: We show that the cost of electronic multiplexing in SONET/WDM rings can be reduced using small SONET cross-connects at multiple nodes. Our architecture uses multiple hub nodes and achieves significant savings over single hub architecture.

1. Introduction

Optical WDM systems have increasingly been deployed to increase network capacity. Typically these networks have a SONET ring architecture; each additional wavelength is used to add an additional SONET ring between the nodes. The nodes in the ring use SONET Add/Drop Multiplexers (ADMs) to electronically combine lower rate streams onto a wavelength, *e.g.* 16 OC-3 circuits can be multiplexed onto one OC-48 stream. The cost of these electronic multiplexers dominates the costs of such a network. The number of electronic ADMs can be reduced by employing WDM Add/Drop Multiplexers (WADMs) which allow a wavelength to either be dropped at a node or to pass through optically. When a wavelength is not dropped at a node an electronic ADM is not required for that wavelength. The required number of SONET ADMs can be further reduced by *grooming* the lower rate traffic so that the minimum number of wavelengths need to be dropped at each node.

The benefits of grooming with WADMs have been looked at in several papers including [1], [2], [3] and [4]. In [1] it was shown that the general grooming problem is NP-complete. However for several special cases, algorithms have been found that significantly reduce the required number of ADMs. For example, for uniform all-to-all traffic, algorithms have been found for both bi-directional rings [4] and unidirectional rings [1]. In [1] it was shown that with a hub node, where low rate traffic can be switched (cross-connected) between different wavelengths, the overall number of ADMs can be reduced by efficiently multiplexing and switching the traffic at the hub.

In this paper we show that additional savings can be obtained by distributing the cross-connect function among multiple nodes in the ring. These savings are significant in three ways. First, the use of multiple cross-connects can reduce the number of SONET ADMs needed. Second, using multiple smaller cross-connects rather than one large cross-connect at the hub reduces the cost of the cross-connects. Finally, the use of cross-connects for grooming adds flexibility to the network over a static solution that does not use a cross-connect. This flexibility allows traffic to be provisioned dynamically thereby reducing the need to know the exact traffic requirements in advance. Another benefit of this flexibility is that the network will be more robust to node failures. Also, we note that a multiple hub solution will often require fewer wavelengths than a single hub solution.

2. SONET/WDM Ring architectures

We compare three ring architectures for the purpose of efficient traffic grooming: static ring without cross-connects, single hub with a cross-connect and multiple-hubs with a cross-connect. With the static architecture no cross-connecting is employed, hence each circuit must be assigned to a single wavelength that must be processed (dropped) at both the source and the destination. The static architecture is the traditional SONET ring architecture that has been used in the studies of [1,2,4]. The single hub architecture uses a large cross-connect at the hub node. The cross-connect is able to switch any low rate circuit from any incoming wavelength to any outgoing wavelength. With this architecture, each node sends all of its traffic to the hub node where the traffic is switched and groomed and sent back to the destination nodes. In the multiple hub architecture, K hub nodes are used on the ring. Each hub node has a small cross-connect that can switch traffic among the wavelengths dropped at that node. Each node on the ring sends a fraction of its traffic to one of the hub nodes, where it is properly groomed and relayed to its destination. These three architectures are depicted in Figure 1. Shown in Figure 1a is the static grooming solution where one wavelength is used to support traffic between nodes 1,2 and 3, another for traffic between 2,3 and 4, and a third wavelength for traffic between 1, 3 and 4. The hub architecture shown in Figure 1b has each node send all of its traffic to the hub located at node 3, where the traffic is groomed and relayed back to its destination. Finally shown in Figure 1c is the multiple hub architecture where each node can send its traffic to one or more of the hubs.

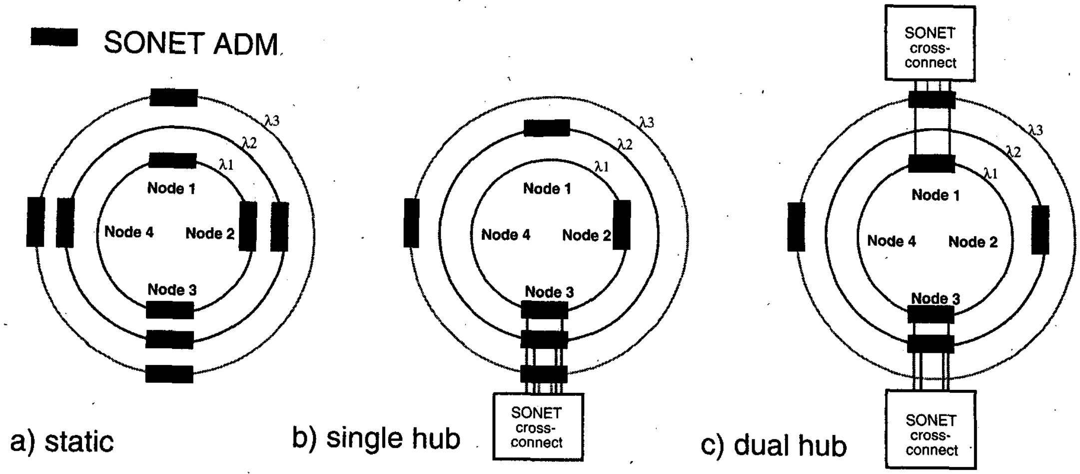

Figure 1: Grooming Architectures.

To illustrate the potential benefit of the multiple hub architecture, consider a ring with N=9 nodes where each wavelength supports an OC-48 and traffic demand is uniform with two OC-12 s between each pair. In this case each node generates 16 OC-12 s or four wavelengths of traffic. With the single hub solution, each node can send all four wavelengths worth of traffic to be groomed at the hub at say node 1. In this case, each node would use 4 ADMs, and the hub would use 8x4=32 ADMs for a total of 64 ADMs. In a two hub architecture each node would send two wavelength worth of traffic to each hub (at nodes 1 and 5) using 58 ADMs. Finally a four hub architecture can be used where each node send one wavelength to each of four hubs. Each of the hubs can combine the traffic from two nodes and relay it back. The four hub architecture would require only 52 ADMs.

3. ADM requirement

We start by presenting a lower bound on the number of ADMs needed with K hubs where each of the K hubs has a cross-connect capable of switching any circuit from any input wavelength to any output wavelength. First consider a unidirectional ring with N nodes, a traffic granularity of g and uniform traffic with r circuits between each pair. In this case the number of ADMs is bounded by:

$$ADMs \geq \max\left\{\frac{2(N-K)(N-1)r}{g} + \frac{K(K-1)r}{g}, \frac{2N(N-1)r}{g+r}\right\}. \quad (1)$$

The second term in the maximum in (1) is a general lower bound from [5] that applies to a ring with cross-connect capability at each node. The first term in (1) accounts for the restriction to K hubs. We can similarly lower bound the number of ADMs required in a bi-directional ring or an arbitrary mesh, without wavelength restrictions. Also we can generalize this bound to the case where traffic is not uniform. In the non-uniform case, this bound is given as the solution to a simple optimization problem. Table 1 shows the lower bound in (1) required for a ring with uniform traffic with one OC-12 worth of traffic between each node. The second column of the table shows the number of wavelength of traffic generated at each node ($W = \lceil (n-1)r/g \rceil$). The next four columns give the lower bound on ADMs when using one, two, three, and four hubs respectively. As can be seen from the table, the lower bound is higher with fewer hubs and it decreases as the number of hubs is increased. This is because increasing the number of hubs also increases the flexibility with which traffic can be groomed.

This lower bound, however, does not tell us anything about how traffic should be groomed or even whether it can be achieved. We use a simple algorithm for grooming the traffic using the multiple hub architecture, where each node sends a fraction of its traffic to each of the hubs. The results from using our algorithm are also shown in table 1 on the right hand side. The four columns on the right show the number of ADMs required when using one, two, three, and four hubs respectively. For example, in the case of a 17 node ring, the minimum ADM solution is achieved with 4 hubs. Highlighted in the table is the solution that achieves the minimum number of ADMs. It is interesting to observe that the number of hubs used in the minimum ADMs solution corresponds closely to the number of wavelengths of traffic generated at each node (column 2). This is reasonable because when each node generates K wavelengths of traffic, it can send one wavelength to each of K hubs without needing to use any additional wavelengths. We analyzed this approach for various traffic loads on a ring to find that, in general, the minimum ADM solution is achieved when the number of hubs used is equal to the number of wavelengths needed at each node. Another benefit of the distributed hub architecture is that the size of the cross-connect used is reduced when compared to a single hub architecture. With only a single hub, each node would send $W = \lceil (n-1)r/g \rceil$ wavelengths to the hub and the hub would need a cross-connect of size (n-1)W x (n-1)W. However, when multiple hubs are used each node would only send a single wavelength to each hub and hence each hub would only need a cross-connect of size (n-1) x (n-1). This reduction in cross-connect size is significant because the size of the cross-connect has a dramatic impact on its cost.

Table 1. The number of ADMs needed with multiple hubs.

	a) Lower bound						b) Algorithm			
N	W	K=1	K=2	K=3	K=4		K=1	K=2	K=3	K=4
5	1	8	8	8	8		**8**	14	16	14
6	1.25	13	12	12	12		20	**18**	22	22
7	1.5	18	17	17	17		24	**22**	28	30
8	1.75	25	23	23	23		28	**26**	34	38
9	2	32	29	29	29		32	**30**	40	46
10	2.25	41	37	36	36		54	66	**46**	54
11	2.5	50	46	44	44		60	74	**52**	62
12	2.75	61	56	53	53		66	82	**58**	70
13	3	72	67	63	63		72	90	**64**	78
14	3.25	85	79	73	73		104	98	136	**86**
15	3.5	98	92	86	84		112	106	148	**94**
16	3.75	113	106	99	96		120	114	160	**102**
17	4	128	121	114	109		128	122	172	**110**

3. Generalizations

The architectures discussed above require each node to send a portion of its traffic to one of the hub nodes and that all traffic goes through some hub. Both of these assumptions can be relaxed. Relaxing these assumptions can reduce the required number of ADMs but results in more complicated architectures. We will present a greedy algorithm for designing architectures under these relaxed assumptions. Recall the above example with N= 9 nodes and all-to-all traffic; in this case we can find an architecture with 5 hubs that requires 48 ADMs, however each node only sends traffic to 4 of the hubs. For this example, the architecture exactly meets the lower bound on the required number of ADMs. Another generalization of the above model is to consider the case where a node only cross-connects a subset of a wavelengths that are dropped at that node. This generalization allows us to examine further trade-offs regarding where and how much cross-connect functionality is needed in the network.

4. Conclusion

We show that using multiple hubs with cross-connects can reduce the number of ADMs needed in a SONET/WDM ring network. This architecture also reduces the size of the cross-connects used. Perhaps the greatest benefit of using this cross-connect approach is that it allows for the bandwidth to be provisioned dynamically. In the presentation, we will describe our multiple hub architecture and algorithms for efficiently grooming the traffic.

Referemces

[1] E. Modiano and A. Chiu, "Traffic Grooming Algorithms for Minimizing Electronic Multiplexing Costs in Unidirectional SONET/WDM Ring Networks," CISS 98, Princeton, NJ, February, 1998. Extended version appeared in IEEE Journal of Lightwave Technology, January, 2000.

[2] A. Chiu and E. Modiano,"Reducing electronic multiplexing costs in unidirectional SONET/WDM ring networks via efficient traffic grooming," Globecom 98, Sydney, Australia, Nov. 1998.

[3] O Gerstel and R. Ramaswami, "Cost effective Grooming in WDM Rings," Infocom 98, San Francisco, CA, April, 1998.

[4] J. Simmons, E Goldstein, and A. Saleh, "On the value of Wavelength Add/Drop in WDM Rings With Uniform Traffic," OFC '98, San Jose, CA, February, 1998.

[5] O. Gerstel, P. Lin and G. Sasaki, "Wavelength Assignment in a WDM Ring to Minimize the Cost of Embedded Sonet Rings," Infocom 98, San Francisco, CA, April, 1998.