Grooming dynamic traffic in unidirectional SONET ring networks

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The initial deployment of WDM systems has been primarily to increase the number of wavelengths in point to point links between SONET elements. The dominate cost of such a deployment is the electronic Add Drop Multiplexers (ADMs) required at each node for each additional wavelength. This cost can be reduced by employing Wavelength Add Drop Multiplexers (WADMs) which allow one to either drop a wavelength at a node or allow it to pass through optically. When a wavelength is not dropped at a node, an electronic ADM is not required for that wavelength. By assigning the offered traffic to wavelengths in an intelligent manner, certain wavelengths will often not need to be dropped at certain nodes, allowing one to save on the required number of ADMs. Such an assignment of the offered traffic is referred to as *traffic grooming.* The benefits of grooming with WADMs has been looked at in several papers including [2], [3] and [4]. Most of the previous work on grooming in SONET rings has considered developing algorithms to reduce the required number of ADMs for a particular traffic matrix, such as uniform all-to-all traffic. In this work, instead of focusing on a single traffic matrix, our goal is to allocate ADMs so that the resulting network can handle any traffic pattern out of a given class which is defined below. Such an allocation enables one to support traffic which dynamically changes in this class. We provide an algorithm which allows one to significantly reduce the required number of ADMs in this setting. We will also discuss the use of a hubbed architecture or tunable lasers to further reduce the required number of ADMs. The only other work we are aware of that considers grooming for dynamic traffic is [5]; the emphasis and assumptions of this work are quite different from those here.

The network model we use is similar to that in [4]. We consider a unidirectional ring network with N nodes. Each node has one static WADM, that is the set of wavelengths dropped at the node is fixed. For each dropped wavelength a node requires a SONET ADM which multiplexes g low rate streams onto that wavelength, *e.g.* if each wavelength carries one OC-48 stream and the low rate circuits are OC-3, then $g = 16$. A set of requested circuits will be represented by a traffic matrix, $[R_{i,j}]$, where $R_{i,j}$ is the number of desired low rate circuits between nodes i and j. Each circuit is considered to be bi-directional so that $R_{i,j} = R_{j,i}$. We assume that each node can source at most t bi-directional circuits at a given time, *i.e.*

$$\sum_j R_{i,j} \leq t \text{ for all } i \tag{1}$$

We will call a traffic matrix which satisfies (1) *t-allowable.* The class of traffic patterns which we want to be able to accommodate is the set of all t-allowable traffic matrices for a given choice of t.

The minimum number of wavelengths, W_{min}, required to support every t-allowable traffic set is given by

$$W_{min} = \left\lceil \frac{1}{g} \left\lfloor \frac{Nt}{2} \right\rfloor \right\rceil \tag{2}$$

If we use W_{min} wavelengths and drop each wavelength at each node then the resulting network can clearly support any t-allowable traffic matrix. Thus NW_{min} gives an upper bound on the required number of ADMs. We will focus on reducing this number of ADMs while still supporting any t-allowable traffic matrix with W_{min} wavelengths.

The solution to this problem requires us to specify two things: the topology, *i.e.* which nodes have ADMs on which wavelengths, and the routing, *i.e.* for a given traffic matrix the assignment of the circuits

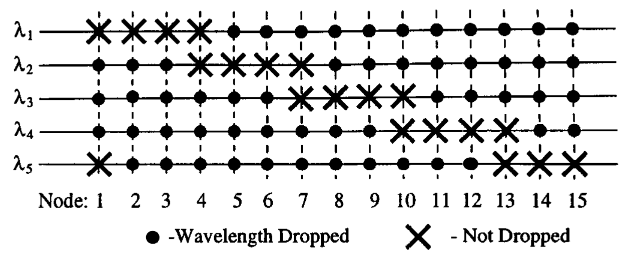

Figure 1: An allocation of ADMs for a network with 15 nodes,$g = 16$ and $t = 10$.

to these ADMs. We address the latter of these first. Given an assignment of of ADMs which can support all t-allowable traffic, and a t-allowable traffic matrix, we can find an assignment for these circuits by solving a bipartite matching problem. Polynomial algorithms for solving such problems are well-known[1].

Finding a good topology is the more difficult problem, for we must show that a topology can accommodate every t-allowable traffic set, and it is not feasible to consider each set individually. By again using ideas from bipartite matching, one can show that if a topology satisfies the following two conditions then this is equivalent to being able to support every t-allowable set. These two conditions are:

1. For every pair of nodes i and j there exists a wavelength on which both i and j have an ADM.
2. For any group of m wavelengths, there exists at most gm circuits, out of any t-allowable set, which must be routed on this group. We say a circuit between nodes i and j must be routed on a set of wavelengths if for any wavelength not in this set, either i or j does not have an ADM on that wavelength.

These conditions often provide a much easier test of whether an allocation of ADMs can support every t-allowable traffic set. In particular if the network topology has some symmetry, then the second condition need only be checked for a small number of cases. Using these conditions as a guide we have developed algorithms for specifying network topologies. With these algorithms, we can come up with topologies which reduce the required number of ADMs by up to 33 % and are still able to support every t allowable traffic pattern. For example suppose we have a ring with 15 nodes, $g = 16$ (OC-3 's over OC-48) and $t = 10$. For this ring, W_{min} is 5 and therefore without any grooming we need 75 ADMs. Figure 1 shows a topology for this ring which only requires 55 ADMs, a savings of 27 %. This allocation satisfies the two conditions above and therefore can support any t-allowable traffic pattern.

Figure 2 shows a plot of the number of ADMs needed in this network as t ranges from 5 to 30. The number of ADMs needed without grooming is also shown as well as a lower bound on the number of ADMs required.

By investing in more sophisticated components elsewhere in the network one can gain further reductions on the cost of electronic multiplexing. Two examples of this which we will consider is the use of a hub node and the use of tunable lasers. First we consider a hub node. By a hub node we mean a node which has ADMs on every wavelength and has a SONET cross-connect. By similar arguments to those used in [2] we can show that making one node such a hub node will not require any more ADMs than were required without the hub. Assuming that $t \leq g$ we can show that the minimum number of ADMs needed to support all t-allowable traffic with a single hub is given by:

$$\left\lceil \frac{N}{\lceil g/t \rceil} \right\rceil \tag{3}$$

We can also reduce the required number of ADMs if instead of having fixed tuned lasers, each node is equipped with tunable lasers. With tunable lasers the wavelengths dropped at a node are no longer fixed. Clearly with tunability a node needs no more than t ADMs, and thus with small t there is a advantage to tunability. For larger values of t the gain due to tunability is an open question.

To give an example of these approaches we consider a network with 7 nodes, $g = 2$ and $t = 1$. The following table shows the number of ADMs required for this network in each of the cases that we have discussed.

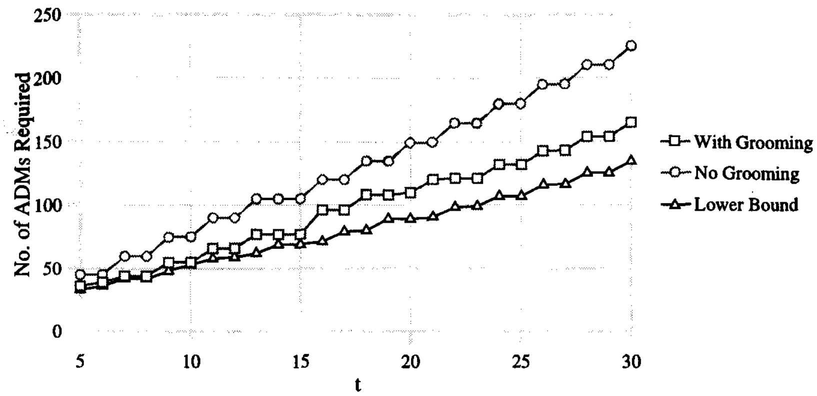

Figure 2: Number of ADMs needed for various values of t.

	Number of ADMs
No grooming	14
Grooming	12
Hub node	10
Tunable lasers	7

To summarize we have shown that one can significantly reduce the electronic multiplexing costs by grooming the offered traffic, even when this traffic can dynamically change within a given set. Further reductions in ADMs are possible by employing other components such as hub nodes or tunable lasers.

References

[1] D. Bertsimas and J. Tsitsiklis. *Introduction to Linear Optimization.* Athena Scientific, Belmont, Massachusetts, 1997.

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

[3] E. Goldstein J. Simmons and A. Saleh. On the Value of Wavelength Add/Drop in WDM Rings with Uniform Traffic. *OFC '98*, February 1998.

[4] E. Modiano and A. Chiu. Traffic Grooming Algorithms for Minimizing Electronic Multiplexing Costs in Unidirectional SONET/WDM Ring Networks. *CISS 98*, February 1998.

[5] R. Ramaswami O. Gerstel and G. Sasaki. Cost Effective Traffic Grooming in WDM Rings. *Infocom 98*, April 1998.