Traffic Grooming Algorithms for Reducing Electronic Multiplexing Costs in WDM Ring Networks

EECS 864: Optical Communications Networks

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Grooming

- **The network performance is mainly limited by the processing capability of the network elements, which are mainly electronic.**
- **By efficiently grooming low speed traffic streams on high capacity optical channels, it is possible to minimize electronic processing and eventually increase network performance.**
- **Grooming a term used to describe the optimization of capacity utilization in transport systems.**
- **Traffic grooming is an important part of the WDM network design and implementation.**

SONET

- **SONET ring network is currently the most widely deployed optical network infrastructure**

- **SONET Add/Drop Multiplexer (SADM) can be used to aggregate lower rate stream from different end-users into a single high-rate SONET stream in Time Division Multiplexing (TDM) fashion.**

  EXAMPLE: Four OC-3 circuits can be multiplexed into an OC-12 and 16 OC-3's can be multiplexed into an OC-48.

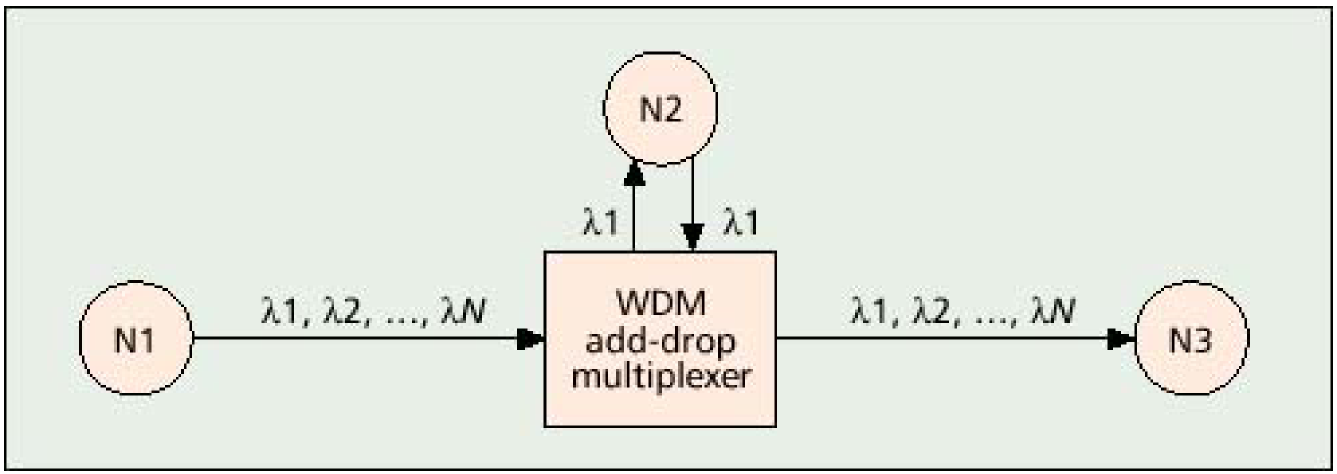
- **With WDM technology, multiple SONET rings can be supported on a single fiber pair by using multiple wavelengths.**

- **Requires more electronic multiplexing equipments .**

- **The cost of electronics, instead of the cost of optics, dominates the cost of optical network**

WADM

A WADM is an integral part of the SONET/WDM architecture



WDM add/drop multiplexers (WADMs) provide the ability to drop (or add) only those wavelengths that carry traffic destined to (or originated from) a given node, optically bypassing other wavelengths.

Traffic Grooming in Ring Networks

- **For a node to receive or transmit traffic on a wavelength, the wavelength must be added or dropped at that node using a SONET ADM.**

- **Using the optical bypassing capacity provided by WADMs, the traffic can be groomed in such a way that the total traffic, to and from a node, is carried on minimum number of wavelengths there by reducing the number of SADMs needed**

- **Consider a Unidirectional ring network with four nodes. Between each pair of nodes there are eight OC-3 (r_{ij}=8) circuits and each wavelength on the ring is a OC-48 circuit (g = 16)**

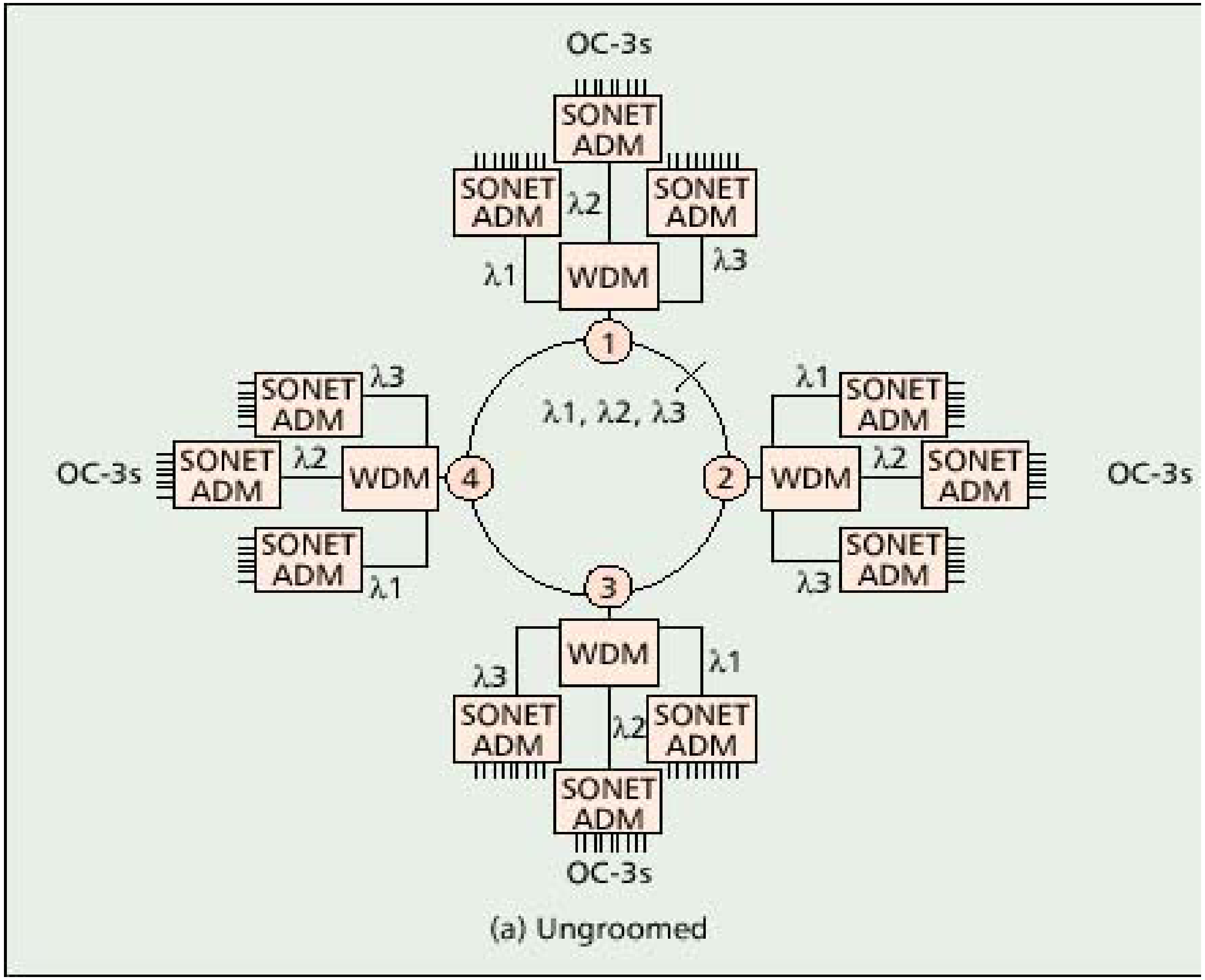
Traffic Grooming -Example

Traffic assignment:

λ1: 1-- 2, 3-- 4

λ2: 1-- 3, 2-- 4

λ3: 1– 4, 2-- 3



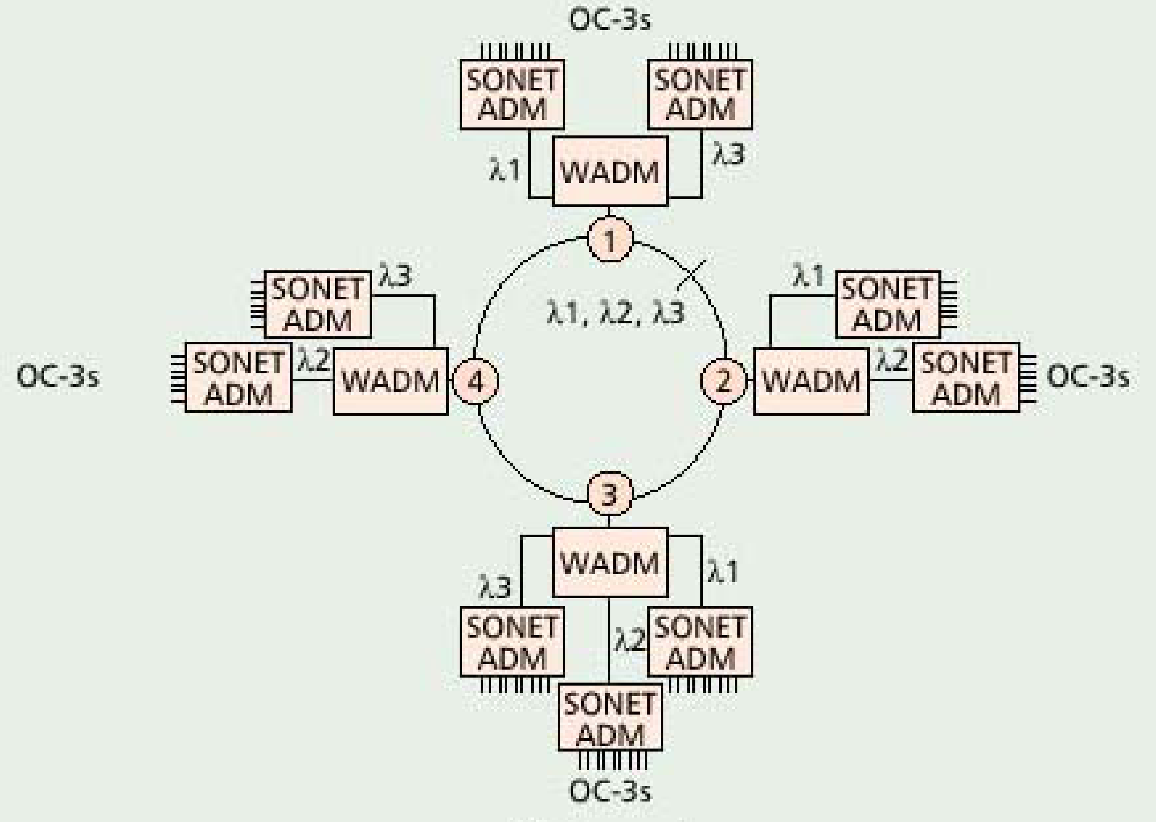
Traffic Grooming -Example

Traffic assignment:

λ1: 1-- 2, 1-- 3

λ2: 2-- 3, 2-- 4

λ3: 1– 4, 3-- 4



(b) Groomed

Algorithms for Unidirectional SONET/WDM Ring Networks

Objective

To assign wavelengths in a way that minimizes the total cost of electronic equipment – SONET ADM's

In general the traffic grooming problem is NP-complete. Hence only for special cases algorithms have been developed that result in significant reduction in the number of ADM's

Traffic from all nodes is destined to a single node, and all traffic rates are the same – Obtain a solution that minimizes the number of ADM's

More general case of all to all traffic – Obtain a lower bound on the number of ADM's and provide heuristic algorithms that perform closely to the bound

Egress Node

All traffic on the ring is destined to a single node.

The traffic rate between the nodes i and j takes on positive values only when j =0 and i = 1,2……N.

Link (N,0) carries the heaviest load, which is given by $L_{max} = \sum_{i=1}^{N} r_{i0}$

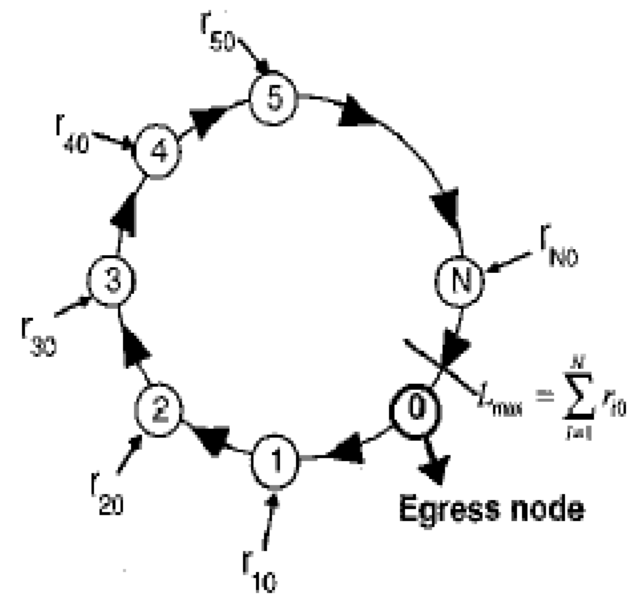


Fig. 3. Unidirectional ring network with an egress node.

Minimum number of wavelengths required to support this load is,

$W_{min} = \lceil L_{max} / g \rceil$

Special case: $r_{i0} = r$

Without loss of generality we assume that $r < g$.

Consider a circuit assignment that has traffic from a node split onto two or more SONET rings. The node will need atleast two ADM's.

But since $r < g$, all of the traffic from that node can be accommodated on a single ring with two ADM's one at that node and the other at the egress node.

Without splitting traffic, traffic can be groomed from at most $\lfloor g / r \rfloor$ nodes on one SONET ring.

Number of SONET rings needed $W = \lceil N / \lfloor g / r \rfloor \rceil$

Minimum number of SONET ADM's required is $N + W$ since one ADM is needed at every node plus at the egress node one ADM is needed for each wavelength

Minimizing ADM's Subject to the Minimum Number of Wavelengths

The resulting number of SONET rings in the above case may be larger than the minimum number of rings required.

Example N=4, g =7 and r =5.

A solution is required that uses minimum number of wavelengths – W_{min}

Since we are restricted to use minimum number of wavelengths, traffic from a node may have to be split onto multiple rings and each node will have one ADM for each SONET ring.

Hence the total number of ADM's needed is $W_{min} + N + S$ where S is the total number of traffic splits over all the nodes.

Minimum number of SONET ADM's subject to minimum number of SONET rings is achieved by minimizing the total number of traffic splits.

Algorithm

The algorithm assigns circuits to wavelengths in a way that minimizes the number of traffic splits and hence the number of ADM's.

The algorithm is iterative with the following three steps:

Step1

Fill each of the $W = W_{min}$ rings with the unsplit traffic from $\lfloor g / r \rfloor$ nodes. The remaining capacity for each of the W rings is $g_1 = g - \lfloor g / r \rfloor\ r < r$ and traffic from $N_1 = N - \lfloor g / r \rfloor W$ nodes still needs to be assigned. The remaining $N_1 r$ needs to fit on the total remaining capacity, $g_1 W$.

Step 2

Fill the remaining capacity g of each of N_1 rings by traffic from each of the remaining N_1 nodes. The remaining traffic of each of the N_1 nodes becomes $r_1 = r - g_1$.

Algorithm - Contd ..

Step 3

Now, there are $W_1 = W - N_1$ rings that each has a capacity g_1 left, and N_1 nodes that each has traffic r_1 left. Update $W := W_1$, $g = g_1$, $N = N_1$ and $r = r_1$ and repeat Steps 1-3 until the traffic from all the nodes has been assigned ($r = 0$).

Example $N = 5$, $r = 5$, $g = 9$, $W = 3$

Step 1:

Fill each of the rings with g/r = 9/5 = 1 node's traffic.

The remaining capacity on each wavelength is 9 – 1*5 = 4 (g_1)

Traffic from 5-1*3 = 2 (N_1)Nodes still needs to be assigned.

Total remaining traffic = $N_1 r$ = 2*5 = 10.

Total remaining capacity = $g_1 W$ = 4* 3 = 12

Example - Contd…

Step 2:

Fill the remaining capacity of 2 (N_1) rings with traffic from each of the nodes that are left over.

Remaining traffic of each of the nodes is 5 – 4 = 1 (r_1).

Step 3:

There is only one ($W_1 = W - N_1$) ring left with a capacity of 4. Assign the two remaining circuits to this ring. The total number of traffic splits is two.

1 – 0 r = 5 w1

2 – 0 r = 5 w2

3 – 0 r = 5 w3

4 – 0 r = 5 4 on w1

5 – 0 r = 5 4 on w2

4 – 0 r_1 = 1 1 on w3

5 – 0 r_1 = 1 1 on w3

All To All Uniform Traffic

The node load is the number of low rate circuits originating or terminating at that node $L_d = (N - 1) r$.

The total link load is the number of low rate circuits traversing the link -
$L = N(N-1)r / 2$, since there are $N(N-1)/2$ node pairs each with r circuits between them.

The lower bound on the number of wavelengths is given by the minimum number of wavelengths required to carry the traffic to and from a node multiplied by the number of nodes. $M \geq \lceil L_d / g \rceil N$.

The minimum number of wavelengths required to carry all of the traffic in the network is equal to the link load divided by g, $W_{min} = L / g$.

The upper bound on the ADM's can be achieved by dropping of each W_{min} wavelengths at each of the nodes hence $M \leq W_{min} * n$

An upper bound on the number of wavelengths used can be obtained by using dedicated wavelengths between each pair of nodes. With this approach $\lceil r / g \rceil$ wavelengths will be needed for each pair of nodes and the total number of wavelengths would be $W_{max} = \lceil r / g \rceil N (N - 1) 2$ and the corresponding number of ADM's, $M = 2 W_{max}$.

Note: When g =1 both the upper and lower bounds on the number of ADM's are equal to N (N –1)r and the solution is optimal.

Heuristic Algorithm

The algorithm attempts to assign nodes to a wavelength by efficiently packing the wavelength assuming r = 1.

Let n = $\lfloor \sqrt{g} \rfloor$ and divide N into G = N / n groups of n nodes, where the last group has only (N mod n)

Assign different pairs of groups to each wavelength with cross traffic between the two groups. By design the cross traffic between two groups of size n = $\sqrt{g}$ is less than g circuits and can fit on a wavelength.

In order to accommodate all cross traffic between G groups a total of G(G-1) / 2 wavelengths are needed.

The remaining traffic is the all to all traffic within each group and is fit on the existing wavelengths if possible, otherwise on additional wavelengths.

Example

Assume OC –12's on a OC-48 ring . Since g = 4 divide N nodes into G groups with 2 (n) nodes each.

Case 1: N is even

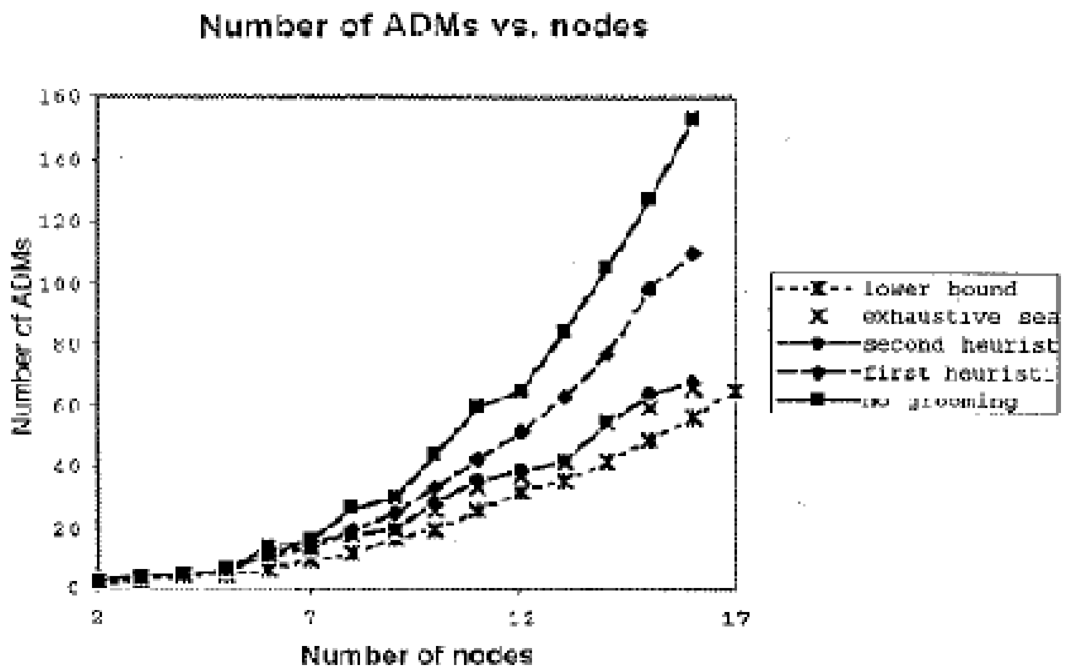
G = N / 2 - G (G – 1)/2 wavelengths can be filled with cross traffic between different pairs of nodes. The all-to-all traffic would require additional $\lceil G/4 \rceil$ with four groups on each wavelength. Hence each node requires G = N/2 ADM's For a total of N^2 / 2 ADM's

Case 2: N is odd.

G =(N+1) / 2. The first G-1 groups have two nodes each and the last group has one node. For cross traffic between the first (G-1) groups (G-1)(G-2)/2 Wavelengths are required . An additional $\lceil (G-1)/2 \rceil$ wavelengths are required for cross traffic with the node from the last group, where each wavelength has two Groups (4 nodes) from the first (G-1) groups. The remaining all-to-all traffic can be handled by assigning four groups to each wavelength.

So the number of ADM's at each node is G = N+1 / 2 except for the last node which uses $\lceil (G-1) / 2 \rceil = \lceil (N-1) / 4 \rceil$ ADM's. Hence total number of ADM's used N is odd is $(N-1)(N+1) / 2 + \lceil (N-1) / 4 \rceil$

Performance comparison



Comparison of heuristic algorithms ($g = 16$, $r = 1$).

References

E. Modiano and A. Chiu, “ Traffic grooming algorithms for minimizing electronic Multiplexing costs in Unidirectional SONET/WDM ring networks”,CISS ’98, Princeton, NJ, Feb., 1998.

E.Modiano and J. Lin “Traffic grooming in WDM Networks” IEEE Communications magazine July 2001.

http://networks.cs.ucdavis.edu/~mukherje/links/kz_onm03_traf_gr.pdf

Homework

What is the difference between a SONET ADM and a WADM?

For a ring network with 5 nodes (N = 5), three circuits between every pair of nodes (r = 3) and a granularity of four (g = 4) a solution does not exists that uses both minimum number of wavelengths and ADM's.