WDM 링 네트워크의 비용 절감을 위한 트래픽 통합 기법 : 유니폼 트래픽 경우

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Cost-Effective Traffic Grooming in WDM Ring Networks: Uniform-Traffic Case

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요 약

SONET/ADM 망의 용량을 최대한 활용하기 위해선 트래픽 통합(grooming)이 필요하다. 이는 저속의 여러 트래픽들을 한 개의 고속 스트림으로 다중화하거나 그 반대로 함으로서 이루어 진다. SONET 링 네트워크의 용량은 다중 파장상에서 운용됨으로서 증가될 수 있다 하더라도, 이를 위해선 망 설계 시 많은 ADM을 사용하여 높은 비용이 들 수 있다. 비용 측면에서 효과적인 설계를 위해선 제공되는 트래픽을 수용하면서 최대한 ADM 개수를 줄이는 것이므로 본 논문에서는 WDM 링 네트워크를 위해 새롭게 제시된 다중 홉 트래픽 통합 방식의 특성과 성능을 소개하고 평가한다. 다중 홉 방식에서는 트래픽 행렬에서 요구되는 트래픽에 기반을 해서 각 노드에 ADM을 둔 다음, 통합될 수 있는 파장들을 통합한다. 그리고 노드들 중 하나를 각 파장 당 하나씩의 ADM을 가지는 허브 노드로 선택한다. 이렇게 함으로써 허브 노드는 모든 파장 사이에 존재하는 트래픽을 연결할 수 있다. 알고리즘은 간단한 예를 통해서 설명되었다. 본 논문의 결과에 의하면 통합 비율이 낮을 경우에는 단일 홉 접근 방식을 사용하는 것이 유리하지만, 비율이 높고 노드 수가 많을 수록 제안한 다중 홉 방식이 좋은 성능을 보였다.

ABSTRACT

To fully utilize the capabilities of a SONET/ADM network, traffic grooming is needed to multiplex a number of lower-rate traffic streams into a higher-rate stream, and vice versa. Although the capacity of a SONET ring network can be upgraded by operating it over multiple wavelengths, the corresponding network design may be costly if it employs a large number of ADMs. A cost-effective design attempts to minimize the total number of ADMs used in the network while carrying the offered traffic. We introduce and evaluate the performance characteristics of a new traffic-grooming approach for WDM ring networks, called multihop. The multihop implementation places an ADM at each node based on the requested traffic in the traffic-demand matrix; then, it tries to groom the wavelengths which can be groomed. We select one of the nodes to be the "hub" node which has an ADM for each wavelength. The hub node, therefore, can "bridge" traffic between all of the wavelengths. The algorithm is specified and illustrated by a simple example. Our results demonstrate that it is beneficial to use a single-hop approach, but for a large grooming ratio and node number, we advocate the use of the multihop approach.

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I. Introduction

Synchronous Optical Network (SONET) rings are widely used in today's optical network infrastructure due to their large capacity and inherent reliability. Such a network may be operated over multiple wavelengths to support even higher traffic demands. SONET equipment allows high-speed OC-N channels, each running at the line rate of one wavelength, to carry several independent OC-M (M≤N) traffic streams in TDM fashion. A number of SONET Add-Drop Multiplexers (S-ADM, or just ADM) may be used to interconnect the network nodes as shown Figure 1. In the simplest design, the ring is unidirectional, support *W* wavelengths, and each node has *W* ADMs, as shown in Figure 1[3,4].

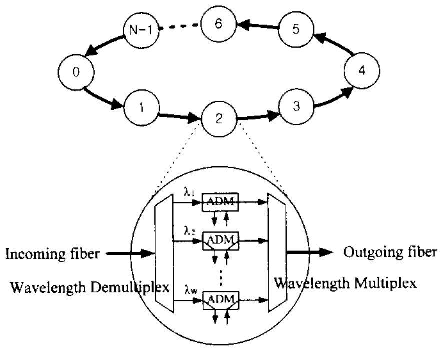

Fig. 1 An unidirectional WDM ring network where each node is equipped with W ADMs, one per wavelength.

Consider a multi-wavelength ring network in which each wavelength channel operates at a certain high rate, say OC-48 (2.5 Gbps). The traffic demands between node-pairs, however, may be sub-multiples of this high rate, e.g., the connection demands between node-pairs may be OC-3 (155 Mbps), OC-12 (622 Mbps), OC-48 (2.5 Gbps), etc. The problem of *traffic grooming* is to multiplex a number of lower-rate traffic streams into a higher-rate stream, and vice versa. (The ratio of the wavelength-channel rate to the lowest traffic rate is known as the *grooming ratio G*, i.e., *G*=16 in the above example.) The multiplexing (and demultiplexing) of traffic at a node can be performed by a SONET/ADM (or ADM for short). Given that the cost of an ADM is very high, the objective of the traffic-grooming problem is to minimize the total number of ADMs in the network design while still carrying the traffic demand, which is static and which is known a priori. The solution to the traffic-grooming problem should also specify which wavelength a node's ADM must operate on. Note that a node may have multiple ADMs if it is sourcing, sinking, or serving as an intermediate hop for a large amount of traffic.

Quite a bit of research on the traffic-grooming problem has been reported in the literature [5]~[14]. In general, the ring may be unidirectional or bidirectional. Also, the traffic demands may be uniform or nonuniform. Most previous work assume uniform traffic demands, although nonuniform traffic is receiving more attention now. Also, to the best of our knowledge, almost all previous work assume that traffic demands are static and are known a priori; this is what our current work will also assume. However, dynamic traffic demands can be handled by employing dynamic Wavelength Add-Drop Multiplexers (WADMs) and using appropriate signalling and control protocols. (This problem is a part of our ongoing investigation.)

Our technical contributions in the present paper are to introduce and evaluate the performance characteristics of a new traffic-grooming approach, called *multihop*[1],[2]. Our multihop approach is based on the idea of a hub node[14]. We shall demonstrate that our WDM-ring-network-design algorithms will employ a smaller number of ADMs than previous work[5].

1.1 Previous Work

The work in [5] proposed optimal or near-optimal algorithms for traffic grooming and wavelength assignment to reduce both the number of wavelengths and the number of ADMs. The algorithms proposed are generic in that they can be applied to both unidirectional and bidirectional rings with an arbitrary number of nodes under both uniform and nonuniform traffic with an arbitrary grooming factor. Lower bounds on the number of wavelengths and ADMs required for a given traffic pattern were derived, and they were used to determine the optimality of the proposed algorithms.

The study in [9], which considered an unidirectional ring, showed that the, general traffic-grooming problem is NP-complete. However, when the traffic from all nodes is destined to a single (egress) node, an optimal algorithm is obtained.

In [11], only rings with an odd number of nodes are considered. An excellent analysis on how to combine different channels into wavelength bundle is provided. A very tight bound for minimal number of ADMs is provided.

The study in [14] addressed the problem of designing optical WDM rings (PPWDM, fully-optical, single-hub, double-hub, hierarchical, and incremental) for cost-effective traffic grooming.

1.2 Our Contributions

Let N nodes be connected together by a WDM ring network with W wavelengths. Let some node, say node i, be equipped a static ADM operating on wavelength k. Then, node i can communicate directly with all other nodes which have an ADM operating on wavelength k. In other words, wavelength k forms a logical ring consisting of the subset of the N nodes which have a wavelength-k ADM. Each of the other wavelengths also form a similar logical ring, for a total of W logical rings. Nodes within a logical ring communicate with one another "directly", i.e., in a single-hop.

In a multihop approach, a transmission between two nodes may occur through zero or more intermediate nodes, each of which will shift the information from one wavelength to another; thus, each such intermediate node must be equipped with at least two ADMs operating on distinct wavelengths.

Our multihop implementation places an ADM at each node based on the requested traffic in the traffic-demand matrix; then, we try to groom the wavelengths which can be groomed. We select one of the nodes to be the "hub" node which has an ADM for each wavelength, as in [14]. The hub node, therefore, can "bridge" traffic between all of the wavelengths.

This paper is organized as follows. In Section II, we describe our multihop (hub-based communication) approach for traffic grooming. Our algorithm reduces the number of ADMs and wavelengths; our approach is illustrated using numerical examples in Section III. Finally, we conclude the paper in Section IV.

Ⅱ. Multihop (Hub-Based Communication) Approach

If nodes i and j are on different logical rings, then how can they communicate? One approach would be to employ an optical crossconnect (OXC) at one of the network nodes, so that the OXC can "bridge" the communication over all of the wavelengths. In this case, inter-wavelength traffic would take two hops. The technology for OXCs is still maturing and is costly today; thus, an alternative approach is to employ more than one ADM (to provide bridging between wavelengths) at some of the nodes. Now, on the one hand, the system cost is significantly reduced since an ADM is relatively inexpensive compared to an OXC. On the other hand, traffic flowing from a source to a destination may need to travel through several intermediate ADMs, thereby encountering more delay and resulting in a reduced overall network throughput, as well as requiring more elaborate network control and management procedures. This price-vs.-performance tradeoff is an important problem that needs to be examined. It gives rise to the optimal multihop network design problem, i.e., given a traffic matrix, which nodes should be equipped with how many ADMs and on which wavelengths should these ADMs operate in order to minimize system cost? To achieve the functionality of an OXC, we introduce the hub node with an ADM for each wavelength; this hub node is located at node 0. By increasing the grooming ratio G, we can obtain a ring network with a small number of wavelengths such that the total number of ADMs is reduced.

2.1 Ring and Node Configuration (Unidirectional Ring with Uniform Traffic)

In order to explain our idea, we consider an unidirectional multihop WDM ring network with N nodes numbered 0, 1, 2, ⋯ , N-1 distributed on the ring in the counterclockwise direction and W wavelengths. Each node has one WADM and D_i ADMs (see Figure 1). Each ADM is used to aggregate up to G low-rate circuits onto a single high-rate circuit that is carried on a wavelength. The traffic requirement is for t_{ij} low-rate circuits between each pair of nodes (i,j), for any $i \neq j$. Since we only consider an unidirectional ring with uniform traffic, t_{ij} = 1 for all $i \neq j$ and t_{ij} = 0 for all $i=j$.

For designing a simple multihop WDM ring network, first, let us consider a central node for switching called the *ADM hub node* as shown in Figure 2. Each node has to have one or more ADMs to support its input and output traffic. For simplicity, after computing the number of ADMs needed at each node, let us assign the ADMs sequentially as shown in Figure 3. After assigning all of the traffic on each wavelength from source node to destination node, if grooming is possible, the traffic is groomed to minimize the number of ADMs and wavelengths.

As an initial value to run the program, the number of ADMs needed at each node (except the hub node) is computed as follow. If traffic from node i to node j is t_{ij} for all $i \neq j$ and the grooming ratio is G, then

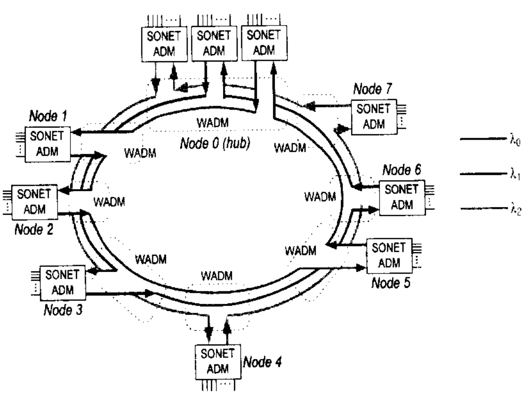

Fig. 2 Unidirectional multihop WDM ring network. (Note that node 0 is the hub node; nodes 0, 1, 2, and 5 operate on λ_0; nodes 0, 3, and 6 operate on λ_1; nodes 0, 4, and 7 operate on λ_2.)

$$D_{i,i\neq 0,INIT} = \max\left(\left\lceil \sum_{i,i\neq j} \frac{t_{ij}}{G} \right\rceil, \left\lceil \sum_{j,i\neq j} \frac{t_{ij}}{G} \right\rceil\right). \quad (1)$$

The initial number of wavelengths can be easily calculated by:

$$W_{INIT} = \sum_i D_{i,i\neq 0,INIT}\ . \quad (2)$$

Finally, we can get the total number of ADMs as an initial value to be $2*W_{INIT}$.

2.2 Algorithm

1) ADM Placement Algorithm

Our basic idea is to design a multihop ring network easily, simply, and fast with good performance. If the parameters (i.e., the number of nodes N, traffic matrix T, and grooming ratio G) for an unidirectional multihop WDM ring network are given, we can compute the minimum number of wavelengths and ADMs to configure a multihop WDM ring network first. The number of ADMs needed at the hub node is equal to the number of wavelengths computed. After placing an ADM(s) at each node, we can compute the capacity between nodes by a traffic matrix. After finishing the traffic assignment, we use the grooming algorithms to minimize the number of ADMs and wavelengths. After grooming, we must re-assign the traffic in the new configuration with smaller number of ADMs

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Algorithm: An unidirectional multihop ring network
           with minimum number of ADMs
  Input N, G, and T;
  Compute the number of ADMs needed at each
     node by Equation (1);
  Compute the number of wavelengths by Equation
     (2);
  Make an ADM hub node;
  Place the ADMs needed at each node sequentially;
  while (the number of ADMs and wavelengths can
     be reduced)
       {
       Assign traffic on each wavelengths using the
          shortest path;
       Traffic grooming (wavelength combining and
          segment swapping);
       }
  Print results;
```

and wavelengths. And then the grooming and re-assigning is repeated until there is no more enhancement in performance. Finally, we can get the multihop ring network with the minimum number of ADMs and wavelengths. We specify the algorithm to construct an unidirectional multihop ring network with the minimum number of ADMs as follows. This algorithm can also to applied to the non-uniform traffic case.

2) Grooming Algorithm

After finishing to assign traffic from node to node into wavelengths, if there are wavelengths to be assigned, the grooming is possible. We considered two grooming methods, wavelength combining and segment swapping. By grooming, if we could reduce the number of ADMs and wavelengths, a new ring configuration is made and the traffic assignment is repeated on the new one.

Wavelength combining:

If all links on a wavelength λ_i and λ_j have capacities less than G and the sum of both links are equal to or less than G, the two wavelengths, λ_i and λ_j, can be combined. Naturally, by this procedure we can reduce the number of ADMs and wavelengths.

Segment swapping:

If the links from node s to node d on wavelength λ_i and the links from node d to node s on wavelength λ_j have capacities less than G, and other links' capacities except that parts are G, two segments can be swapped. This procedure is not for reducing the number of ADMs and wavelengths but for wavelength combining. By this step, we can get the wavelength on which all links capacities are less than G for wavelength combining.

Ⅲ. Illustrative Numerical Example and Performance Comparison

Let us illustrate the multihop algorithm by a simple example. Consider the case where N = 5, uniform traffic, and node 0 is the hub node.

Since every node except node 0 has to manage four units of input and output traffic, if the grooming ratio G is 3, every node except node 0 will need at least 2 ADMs. So, as an initial estimate, the total number of ADMs needed is 16 and the number of wavelengths is 8 as shown in Figure 3. After assigning the traffic on each link between nodes, we get the result shown in Figure 4.

Next, we start the grooming process because wavelengths λ_4, λ_5, λ_6 and λ_7 in Figure 4 have much available capacity. The grooming process can reduce the number of ADMs and the wavelengths as shown in Figure 5. Finally, the number of ADMs needed is only 12 and the number of wavelengths is only 4. The hub node needs 4 ADMs and each of other nodes has 2 ADMs.

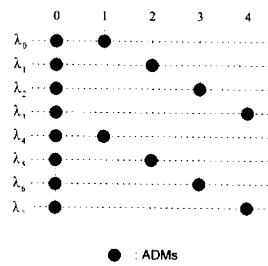


Fig. 3 Multihop example.

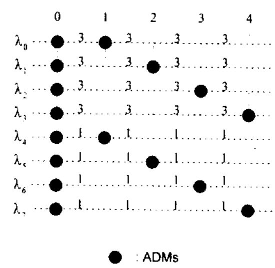


Fig. 4 Multihop example (continued).

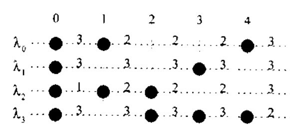
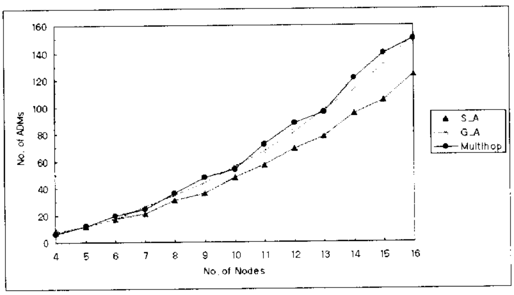


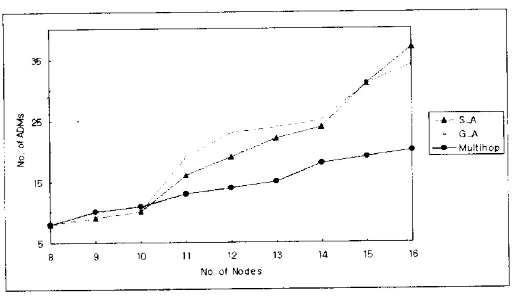
Fig. 5 Multihop example: final result.

We compare the single-hop from [15] and multihop approaches now. Figure 6(a) shows the case of a small grooming ratio (G=3) when the number of nodes is varied from 4 to 16. Results on the minimum number of ADMs required are compared for the single-hop approach (based on simulated annealing, referred to as S_A in the figure), a greedy approach (referred to as G_A in the figure), and our multihop proposal. Observe that the simulated-annealing method for a single-hop ring network employs the fewest number of ADMs relative to the other approaches.

However, when the grooming ratio G is large, e.g., G=48, the results are different, as shown in Figure 6(b). As the number of nodes is increased, the multihop method shows the best result compared with the single-hop methods S_A or G_A. This is because, when G is small, the multihop method needs more ADMs at the hub node; however, when G is increased, the number of wavelengths is decreased resulting in fewer ADMs at the hub node.



(a) G = 3



(b) G = 48

Fig. 6 Comparison of single-hop and multihop approaches.

Ⅳ. Conclusion

For solving the problem of traffic grooming and for minimizing the networkwide total number of ADMs used, we proposed the ring network architecture: multihop. Although the single-hop case uses fewer ADMs when the grooming ratio is small, when the grooming ratio and the number of nodes is high, the multihop approach required the fewest number of ADMs. Thus, we conclude with the following main result for traffic grooming in a WDM ring network. For a small grooming ratio, use a single-hop approach based on simulated annealing, but for a large grooming ratio, we advocate the use of a multihop approach.

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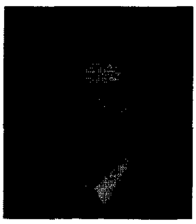

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