

On The Value of Wavelength-Add/Drop in WDM Rings With Uniform Traffic

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Abstract

In WDM rings, the value of wavelength-add/drop rises steeply with ring size and/or node-to-node demand. We present a bound on attainable equipment savings, and present a methodology for performing the bundling for rings carrying uniform traffic.

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There is a great deal of interest in designing networks comprised of WDM SONET rings, due to their large capacity and inherent reliability. However, the value of wavelength-add/drop in such rings has not been quantified. We have addressed this issue for rings carrying uniform traffic.

The first steps in designing rings are laying out the topology, and routing the demands. Once the demands have been routed, they are assigned to OC-M time slots, with $M \geq 1$, which are then bundled together in units of the OC-L line rate. For illustration, we here assume $L = 48$ and $M \leq 48$, however, our results are general. In Wavelength Division Multiplexing (WDM) rings, multiple OC-48s are multiplexed onto a single fiber around the ring. Thus, in general, there are a very large number of ways to group OC-M time slots together to form the OC-48s, assuming $M < 48$.

Typically, at each office in a ring, the OC-48 signal is terminated at a SONET Add/Drop Multiplexer (ADM). If no portion of the OC-48 needs to be dropped at an office, then it is possible to remove the ADM from the office and, via wavelength-add/drop, allow the OC-48 to express through. The goal of ring bundling is to group together time slots that pass through a common set of offices, thereby reducing the number of required ADMs. This paper presents a bound on the number of ADMs that can be removed from a ring supporting uniform traffic between each pair of offices.

Assume there are N offices on a bidirectional ring, and assume each office sends one OC-M worth of traffic to every other office, where the traffic is always routed over the shortest path. The ADMs are assumed to be of the Time Slot Assignment type, and operate on bidirectional OC-48 lines.[1] In general, for uniform traffic and N odd, the number of required time slots is $\frac{N^2 - 1}{8}$. In Figure 1, one particular time slot assignment is shown for a ring with N

equal to 7. Note that the add/drop locations in the six OC-M time slots allow each office to transmit one OC-M to every other office.

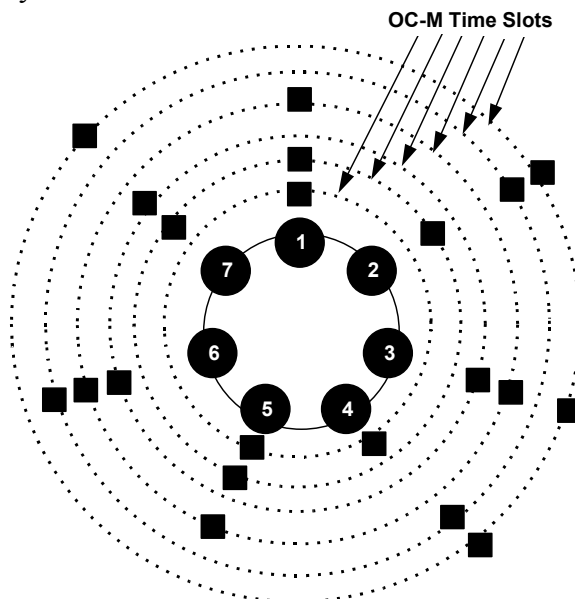


Figure 1. Schematic illustration of a time-slot assignment for a 7-node SONET ring. Time slots are added and dropped at locations marked by a square.

If each office transmits a full wavelength to each other office (i.e., $M=48$), the minimum number of required ADMs is $\frac{N(N-1)}{2}$, one for each source/destination pair. By contrast, in the absence of wavelength-add/drop (i.e., an ADM in every office for every OC-48), one requires a total of $\frac{N(N^2-1)}{8}$ ADMs. Thus, wavelength-add/drop would allow one to save a fraction $\frac{N-3}{N+1}$ of the ADMs.

For more moderate demand ($M < 48$), time slots need to be bundled together to form OC-48s. We use the notation $[i, j, \dots k]$ to indicate that a given time slot add/drops at offices $i, j, \dots k$. Suppose that each office has a half-wavelength for each other office, so that two time slots must be combined to form an OC-48. For N odd and uniform traffic, each OC-48 then requires a minimum of 5 add/drops. Furthermore, it can be shown that the most 'efficient' union that yields 5 add/drops is obtained by combining a 3-add/drop slot with a 4-add/drop slot (not all such combinations yield 5 add/drops). Thus, the optimal ring bundling arises by forming all OC-48s from such combinations, if possible. As an example, for $N = 7$, one optimal bundling is:

$$\text{OC48 \#1} = \text{Union of } [1, 4, 5] \ \& \ [1, 2, 5, 7] = [1, 2, 4, 5, 7]$$

$$\text{OC48 \#2} = \text{Union of } [3, 6, 7] \ \& \ [1, 3, 5, 6] = [1, 3, 5, 6, 7]$$

$$\text{OC48 \#3} = \text{Union of } [2, 4, 6] \ \& \ [2, 3, 4, 7] = [2, 3, 4, 6, 7]$$

This requires a total of 15 ADMs out of a possible $7 \cdot 3 = 21$. Wavelength-add/drop thus permits a terminal-equipment savings of $6/21$. This is optimal, but it is less than the $\frac{N-3}{N+1} = \frac{1}{2}$ attainable with $M = 48$, illustrating that smaller routing granularity undermines the value of wavelength-add/drop.

As N increases, it may not be possible to form OC-48s solely from such combinations, since the average number of add/drops per time slot tends toward 4. Thus, it becomes necessary to form OC-48s with 6 add/drops; the most efficient way to do this is to combine a 4-add/drop slot and a 5-add/drop slot. This same technique can be extended as N increases, and as M/L , the routing granularity, varies.

By extending the above approach using optimal bundlings, one can obtain bounds on the fractional terminal-equipment savings obtainable from wavelength-add/drop. These are shown in Figure 2. The savings are seen to rise steadily as both the size of the network and the internode demand increase.

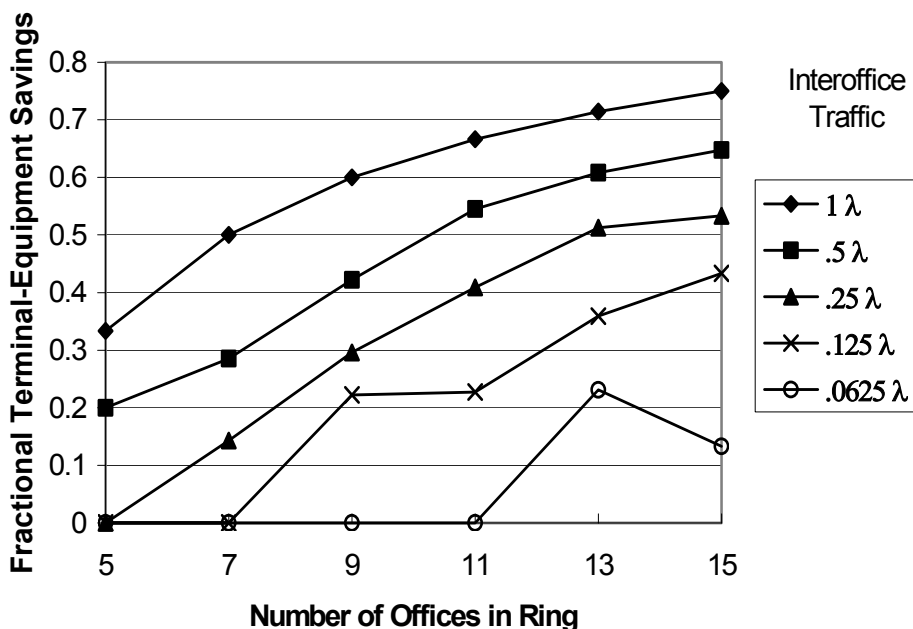


Figure 2. Maximum fractional terminal-equipment savings achievable via wavelength-add/drop in a WDM SONET ring. The parameter represents the fraction of a wavelength from each node to each other node. Terminal equipment savings rise with node-to-node demand and ring size.

Summary

For WDM SONET ring networks transporting uniform traffic, we have devised a traffic-bundling methodology that enables one to both quantify the maximum terminal-equipment savings attainable using wavelength-add/drop, and to produce constructions that achieve these optima. Maximum terminal-equipment savings are seen to increase swiftly, over the region of interest, with both network size and inter-node demand.

References

[1] Wu, T-H., *Fiber Network Service Survivability*, Artech House, Inc., MA, 1992.