Effects of Modularity and Connectivity on OADM Deployment in Ring Networks

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For a class of Optical Add/Drop Multiplexers, we empirically study the effects of port modularity and connectivity on device deployment. Designs with greater connectivity and smaller modules allow fewer devices to be deployed.

I. Introduction

Although WDM transmission in metropolitan area networks is an established technology, the design of economical and flexible Optical Add/Drop Multiplexers (OADMs) to access the WDM channels is a problem of current interest. In recent years, many different OADM designs have been proposed and implemented. Underlying technologies for these OADMs include waveguides, MEMS, liquid crystals, and others. The designs based on these technologies differ greatly in the connectivity provided, in optical characteristics, and in cost [1,2,3]. Although OADMs can be compared directly in terms of these and other metrics, for a system designer it is more appropriate to evaluate them based on the effect the devices have in a network scenario. This comparison is difficult for a number of reasons, including the problem of specifying realistic traffic scenarios and operating conditions.

In this paper, we study a particular class of OADM devices that covers a range of connectivity levels from sparse to complete. The devices also have various degrees of modularity; that is, add/drop ports can be deployed in modules until the required number of ports is obtained. The metric used to compare different designs is the number of devices required as a function of growing network load. In our simulations, bandwidth demands arrive sequentially and permanently in the network. When currently deployed devices are unable to meet the demands, new devices are deployed where possible. For a given OADM design, it is desirable to be able to handle a given load with the smallest number of devices. The final goal is to multiply device counts by device cost estimates, in order to directly compare different architectures on a cost vs. load basis.

II. OADM Model

We use an abstract model for the OADM devices. Although the model was motivated by the planar waveguide based OADMs described in [3], the results in following sections are independent of the implementing technology. The physical implementation, of course, drives the direct device costs and determines the optical characteristics of the device, which in turn affect the costs of other network elements such as amplifiers.

The OADM architecture is depicted schematically in Figure 1. The ring consists of a pair of fibers, with one fiber carrying traffic clockwise (East) and the other carrying traffic counterclockwise (West). At a node, an OADM device containing P add ports and P drop ports may be deployed in either an East or West configuration. An East device can drop West-going signals and add East-going signals, while a West device has the opposite connectivity. Up to W/P devices may be deployed in each direction at a node. Each drop port can choose to drop any one of a fixed band of D wavelengths, and each add port can add any one of a fixed band of A wavelengths. For simplicity we assume that P, A, and D divide W evenly, so that there are W/A disjoint addbands and W/D disjoint drop bands. The modularity of the device is determined by the port count P, and the connectivity is determined by the band sizes A and D. When A and D are both less than W, the ring effectively consists of W/max(A,D) completely independent subrings. Each architecture is described by the notation W:D:P/A. Large values of D and A are desirable in order to allow each port to access more channels, while small values of P are desirable to customize each node as closely as possible to its traffic level. Typically these desirable qualities must be traded off against increased per port device costs.

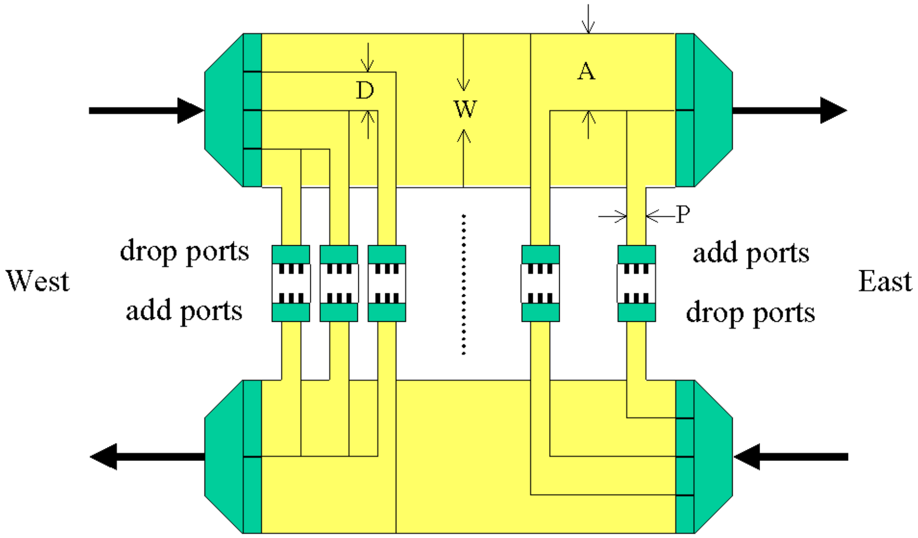

Figure 1: Schematic diagram of a node with modular OADM devices deployed. Three devices are deployed on the West side, and two are deployed on the East.

III. Simulation Scenario

For various OADM architectures, we simulate the required number of devices on a ring as a function of the number of offered demands. Demands are bi-directional and unprotected, requiring one channel in each direction between a given pair of nodes. The node pair for each demand is chosen at random from some distribution (e.g. uniform or hub-biased). As each demand arrives, an attempt is made to carry it using existing OADM ports. If this is impossible, additional OADMs are deployed if they will allow the demand to succeed. Otherwise, if link resources are insufficient or a full set of OADMs have already been deployed, the demand is blocked. Demands were routed on shortest-paths using first fit wavelength assignment. This simple assignment scheme is often as effective as more complex schemes [4,5], particularly on uniformly loaded, non-banded rings [6]. This algorithm performs reasonably well in our study, although algorithms designed specifically for OADMs with limited connectivity may be worth investigating. In some simulation scenarios, we began with no OADM devices deployed and added them one at a time as needed. In other cases, we deployed the devices in discrete stages.

IV. Results

In the growth deployment scenario described, all architectures have the same blocking performance when first-fit routing is used. Hence the differences between the designs are summarized in plots showing the required number of devices as a function of load. Figures 2 and 3 show typical plots for an eight node ring with W=32 wavelengths, under uniform traffic and completely hub-centric traffic, respectively. The first blocking events occur at around 75 demands in the uniform case and 55 demands in the hub case. In the left side of Figure 2, all designs are rapidly required to deploy a pair of devices at each node, in order to establish connectivity. For the fully connected, unimodular 32:32:32:/32 design, this represents the final deployment. For a banded 32:8:8/8 design on the other hand, devices must be added in a nearly linear fashion, until a full 8 devices are deployed at almost every node. As expected, fewer devices are required for designs with greater connectivity. The more modular the design, the more gradual the increase in cost with increasing load. To compare two designs in the final analysis, one may multiply the number of devices by the cost per device to determine a cost vs. load characteristic. For example, the number of devices is identical for the unimodular 32:32:32/32 and bimodular 32:32:16/32, except under very high loads. Since a device with 16 ports is likely to be cheaper than one with 32, the bimodular design will comes out ahead. This reflects the fact that on an eight node ring with 32 wavelengths, link capacity will run out before a typical node has experienced 16 demands. The advantages of modularity are reduced on smaller rings, where the percentage of pass-through traffic is smaller.

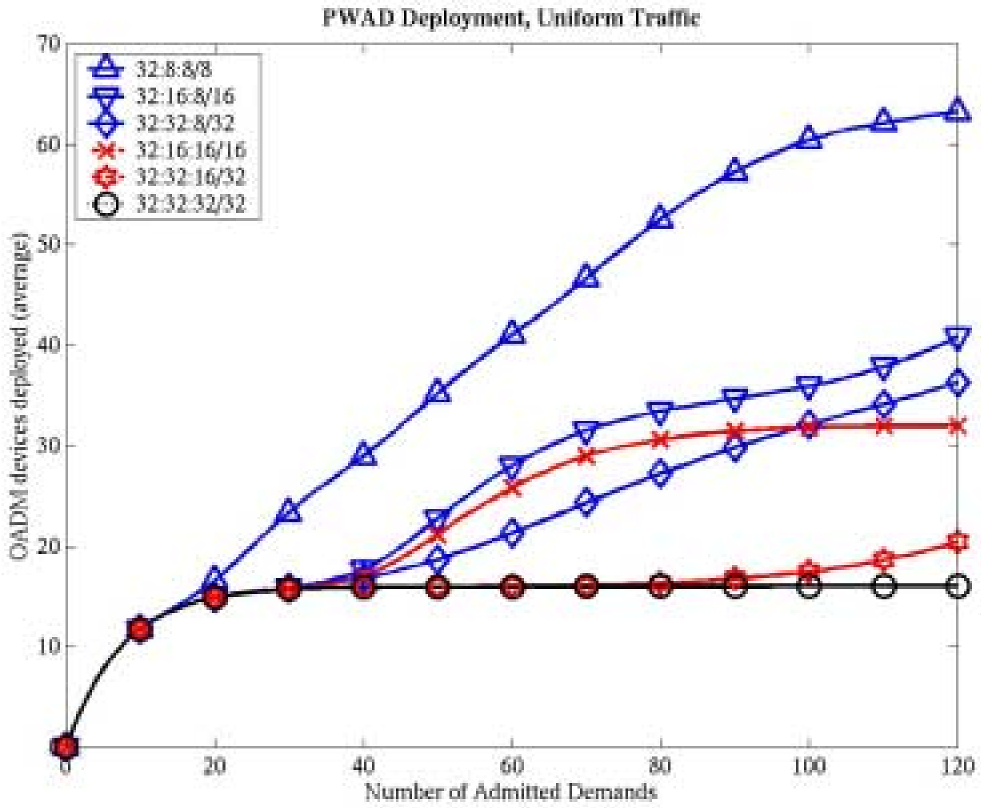

Figure 2: OADM deployment curves for an eight node ring with uniform traffic, averaged over 1000 random demand sequences.

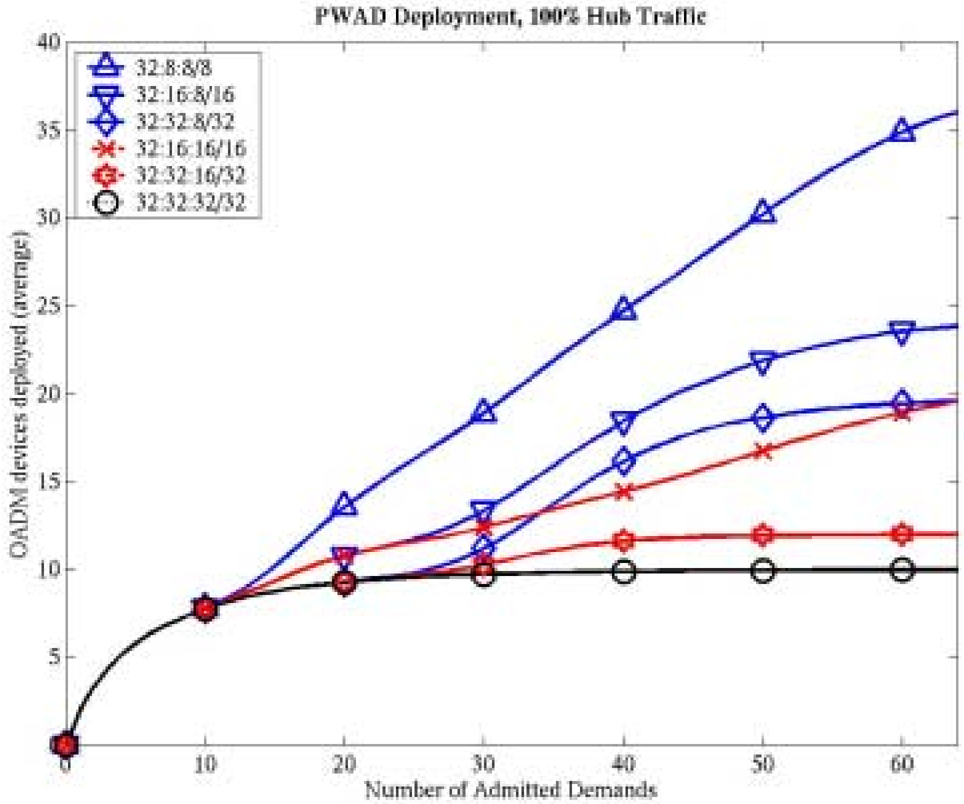

Figure 3: OADM deployment curves for an eight node ring with all traffic connecting to a single hub node. Results are averaged over 1000 random demand sequences

We also considered scenarios in which OADMs were deployed in discrete stages. In particular, Figure 4 shows discrete results for the uniformly loaded eight-node ring of Figure 2. For designs with port count P, deployment occurred in W/P distinct stages, where one additional East/West pair of devices was deployed at each node in each stage. Hence there are four stages for the solid curves, two stages for the dashed curves, and one stage for the dotted curve. For each design, the next stage deployment stage is triggered at the point at which significant blocking would begin if the deployment did not occur. (Some horizontal jitter has been added to the plot in order to distinguish transitions taking place at the same point). Note that for a given port modularity P, increasing the add/drop connectivity allows the load to increase farther before the next stage is triggered. This plot includes asymmetric demands, for which the add connectivity A does not equal the drop connectivity D. It is interesting to compare the banded 32:8:8/8 design with the asymmetric 32:8:8/32 and the fully connected 32:32:8/32. In the first stages the asymmetric design is just as effective as the fully connected one, while the improvement over the banded design decreases in later transitions.

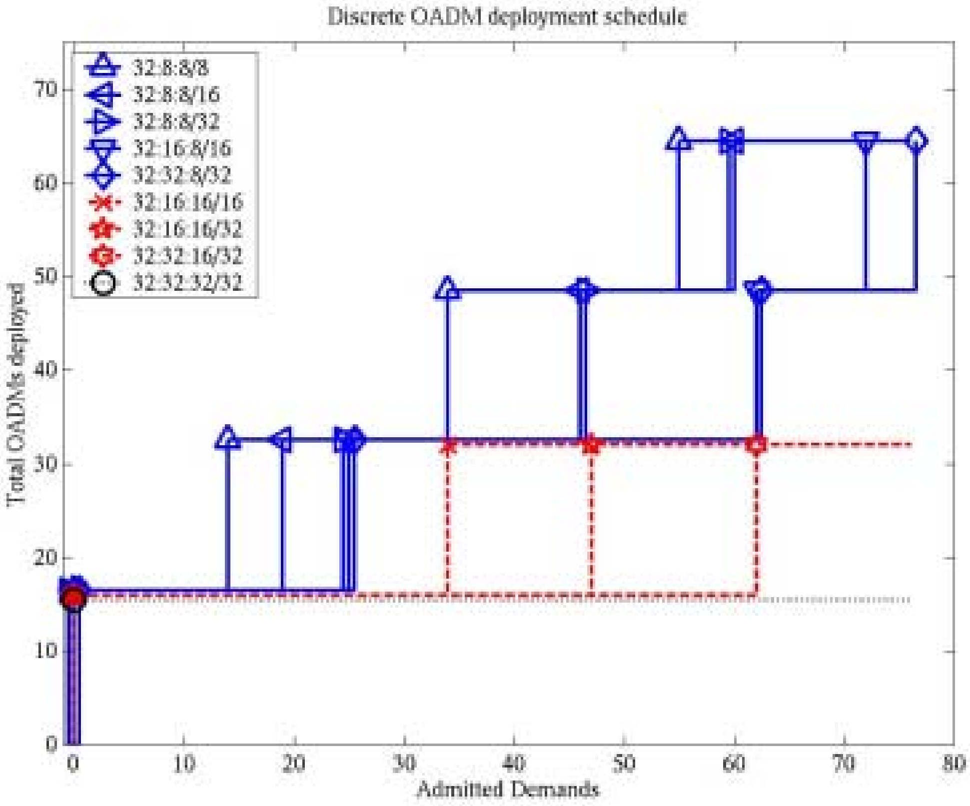

Figure 4. OADM deployment curves for an eight node ring with uniform traffic. Discrete deployment events are scheduled to keep the probability of blocking below 5%.

V. Discussion

Deployment under increasing load is one useful metric for choosing appropriate OADM architecture for metro rings. Under this metric, devices which can be deployed in a modular fashion are desirable, particularly on larger rings. Increased add and drop connectivity is always beneficial, but care must be taken to ensure that the benefit is commensurate with the costs incurred.

Depending on the services which are to be provided on the ring, other metrics will also be important. Blocking performance under dynamic load models will be given higher weight on networks offering dynamic wavelength services. Such a metric will likely emphasize the benefits of connectivity, relative to the metric studied here. Another important factor in OADM evaluation may be the degree to which demand levels can be estimated ahead of time, with greater predictability reducing the level of connectivity required at each OADM.

References

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