Resource Allocation in WDM OMS-SPRing Architectures with Arbitrary Demand Patterns

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Wavelength Division Multiplexing (WDM) optical network design is becoming increasingly important for network planners. As the demand for WDM systems increases in pace with the demand for higher bandwidth in telecommunication transport networks a number of issues need to be examined concerning new design techniques, architecture performance and architecture resilience.

In this paper we concentrate on wavelength routing and wavelength allocation issues in single OMS-SPRing architectures. we examine the effectiveness of wavelength translation. Where wavelength translation is not possible we propose novel algorithms for wavelength allocation. Simulation work using arbitrary traffic demand patterns is carried out and a number of traffic and architectural issues that affect the performance of the architecture and the algorithms are examined. The results obtained can produce an insight into the applicability of wavelength translation and can demonstrate the potential of the proposed algorithms.

Introduction

In this paper we examine wavelength allocation in WDM networks with and without wavelength conversion with a variety of topologies and traffic distributions. While an allocation algorithm for static demands is proposed it does not aim to be optimal rather it aims demonstrate the effect of the changes mentioned.

Optical transmission has been an important issue in deployed telecommunications networks throughout the 1990's. Today's TDM-based transport networks have been designed to provide an assured level of performance and reliability for the predominant voice and leased-line services. Proven technologies, such as SONET/SDH, have been widely deployed in the current transport infrastructure, providing high-capacity transport, scalable to gigabit per second rates, with excellent jitter, wander, and error performance for 64 kbit/s voice connections and leased-line applications. More recently the much wider use of IP has fuelled the need for high capacity data connections. With the advent of QoS schemes at the IP level such as DiffServ data flows can now be managed and provided with a certain level of service. There have been a number of proposals to put IP directly over core transport.

Since WDM is emerging from a research topic to a real alternative for network operators to upgrade their transport network infrastructure, a need arises to progress from optical transmission to optical networking [1, 2]. A first step is upgrading point to point links by using multiple channels in one fibre in order to share the amplifier cost between more channels which lowers the cost per information unit. While WDM line systems alone support little in terms of networking functionality, the elements for WDM Optical Transport Networking are on the horizon. WDM line systems with a fixed wavelength add/drop capability are being deployed, and optical network elements with nodal features, such as optical add/drop multiplexers (OADMs) and optical cross-connects (OXCs) (employing either electrical or optical switching matrices) have been reported in laboratory and field trials. The ability of these WDM nodal elements to add, drop, and in effect construct optical channel routed networks allows for the manipulation of optical channels in WDM networks, just as time-slots are manipulated in TDM networks today. This ability to construct WDM networks with advanced features such as optical channel routing, is the intent of Optical Transport Networking.

In next generation networks, transport functions will migrate from SONET/SDH networks to optical transport networks, and will complement service layer features to satisfy the full range of infrastructure and service-specific requirements. The successful deployment of SDH resilient rings in transport networks to date and the well discussed attractive features of these architectures, pushed for the significant initial research on WDM rings realised by OADMs [3-6].

WDM rings are commonly regarded as a first step towards the all-optical transport network, and are expected to provide network operators with badly needed flexibility and large protected bandwidth capacity. WDM rings are expected to be the first architectures to realise optical transport networking and a WDM ring based transport network architecture is illustrated in figure 1.

In this paper we will examine the requirement of wavelength conversion from OXCs and see how this requirement changes with network topology and traffic distribution. A wavelength conversion network assumes that any node can translate incoming paths from one wavelength to an outgoing path on another wavelength.

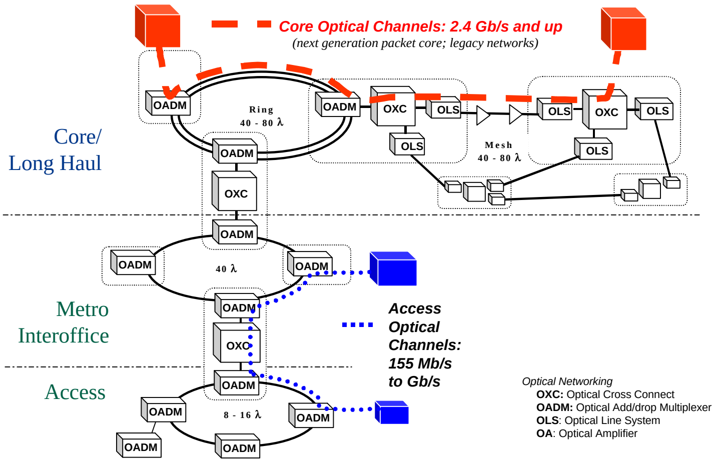

Figure 1 WDM ring based optical transport architecture

WDM Ring architectures.

Here we will be concentrating on a single WDM ring architecture where all demands are bi-directional. By demands we mean a required capacity between two end-point nodes. We examine how much wavelength conversion may decrease the number of wavelengths required as compared to our no wavelength conversion algorithms.

Our simple network model consists of nodes which are connected in a ring by links. These links are capacities connecting adjacent nodes. Since we are trying to find out the required capacity of these links we do not assign a finite capacity to them. Each link has the same capacity. We also have a set of demands between node pairs. These demands have a required capacity assigned to them, a certain number of required channels. We will map one demand channel to one wavelength. The assignment and arrangement of demands decides our traffic patterns, for example if all demands have a single node in common and are non-nil then the demands could be described as having a hub distribution. All the links are considered to be bi-directional as are the demands. Symmetric routing is assumed i.e. the return path is the same as the forward path. We also assume that our demand matrix is static i.e. demand traffic doesn't change and also that all of it is known in advance.

In the analysis of the no-conversion algorithms the nodes are considered passive and cannot translate incoming routed demands on one wavelength to a different outgoing wavelength. The nodes can only add and drop demands originating or terminating at that node. In the conversion case we assume that translation between wavelengths is possible at every node.

A random traffic generator was used to generate many sets of demands that were to be applied to the network. The traffic generator had a number of parameters: Number of Nodes, Total Traffic, ratio of Hub to Node-to-Adjacent-Node to Uniform distributions and liveness (the fraction of demands in a fully meshed network that are not nil). One parameter can affect the others so their ranges were limited. In all of the analysis the liveness was set to 1.0. Attempts were made to generate traffic flows which would mimic diverse routing considering the shortest-path routing algorithm used – this would allow for OMS-SPRing protection in some of the routes.

Planning Algorithms for WDM Rings

Wavelength Conversion case

The minimum number of required wavelengths can be found by the Seymour-Okamura Theorem [7] assuming the parity condition holds for the network [8]. This involves performing cuts of the network between every link pair like those shown in figure 2. The total capacity cut must be greater than or equal to the total demands cut, for every cut of the network. The Seymour-Okamura condition holds when the network is even. The network is considered even when all the nodes are even. A node is even when the sum of the total capacity to a node and the sum of demands with that node as an end-point is even and odd otherwise. To be able to find the maximum capacity required in a cut for originally non-even networks we must augment the original demand matrix so that it is even – this is described in [8].

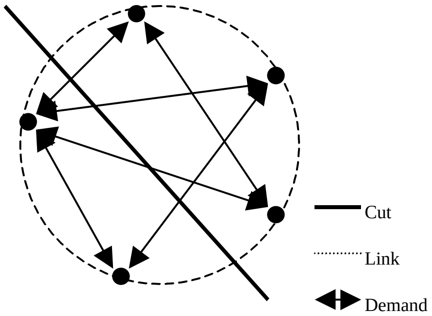

Figure 2. The cut process of the Seymour-Okamura Theorem.

No Wavelength Conversion case

An example algorithm was conceived to test the effectiveness of conversion. The algorithm must be fast and be able to allocate demands to wavelengths so as to minimise the number of wavelengths required. This algorithm would allocate a pre-defined set of demands to wavelengths i.e. the demands were static and known in advance. The wavelengths in the network are numbered as λ_1, λ_2, λ_3, etc. In this algorithm the routing and allocation of demands is in two separate steps and may restrict the applicability because it doesn't allow for load balancing or demand splitting. The basic algorithm was as follows:

1. Route the demands around the ring using the shortest path. No load balancing is attempted. If the demand end-points are diametrically opposite on the ring then one of the routes (clockwise/counter-clockwise) was chosen at random.
2. Allocate each demand to whatever number of wavelengths the demand requires, starting with the first wavelength which is free along the entire path of the route. The demands are allocated in decreasing order of path length i.e. the demands requiring most hops are allocated first. If more than one demand has the same hop distance then they are allocated in a random order until that group is empty.

If there were random choices made such as the route for diametric demands or the order of allocation of demands in a hop distance group then the whole allocation process was repeated a number of times and the network requiring the least wavelengths was the result. Due to the use of shortest path routing the algorithm does not allow for either load balancing or splitting the demand and route it both ways around the ring.

Allocation Algorithm Analysis

A number of networks with a range of parameters were analysed. The parameters ranged in number of nodes, from 5 to 13, total traffic, from 20 to 240 channels and distribution, totally meshed, totally hub and totally node-to-adjacent-node. The efficiency of the algorithm for a fully meshed traffic pattern (uniform distribution) is shown in figure 3. Figures 5 and 6 show the change in efficiency with total traffic. Figure 4 shows the average efficiency for all traffic demands across a range of odd node numbers, for Mesh and Hub distributions.

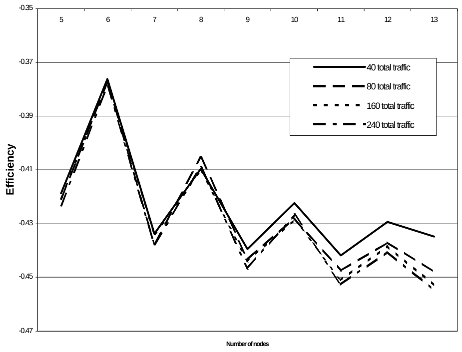

Figure 3. The efficiency of the no-conversion algorithm against the number of nodes in the network with constant total traffic with a uniform distribution.

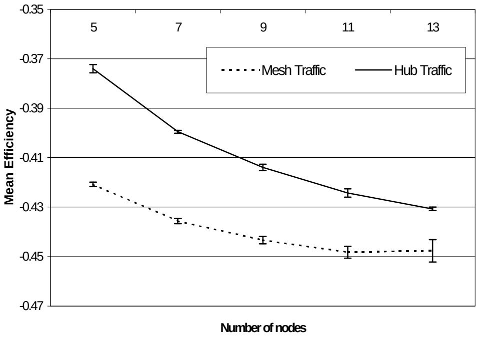

Figure 4. The average efficiency of hub and uniform distributions over a range of nodes.

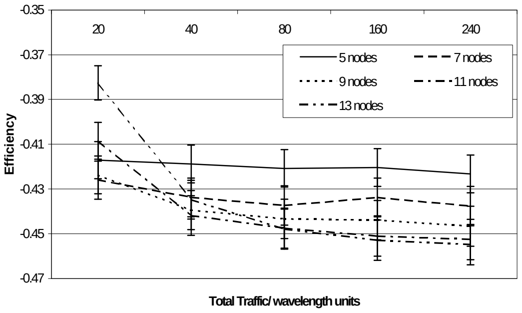

Figure 5. Efficiency against the total traffic in the network with constant numbers of odd nodes and a uniform traffic distribution.

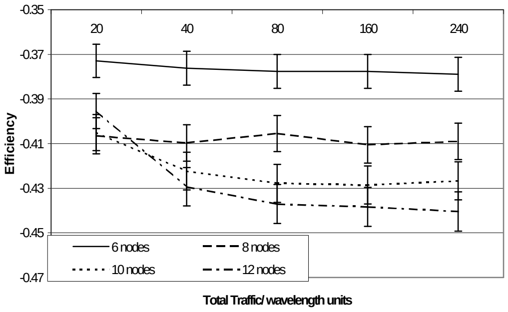

Figure 6. Efficiency against the total traffic in the network with constant numbers of even nodes and a uniform traffic distribution.

Analysis results

The efficiency of the algorithm was calculated thus: $\varepsilon = (N_{algo} - N_{conv})/N_{conv}$; where N_{algo} is the number of wavelengths required by the no-conversion algorithm and N_{conv} is the maximal number of demands cut from the Seymour-Okamura theorem in the augmented network. The actual number of wavelengths required *per link* is between this value and half of this value. N_{conv} is not calculated as $\lceil \mathtt{maximal\_cut/2} \rceil$ because this cannot then be compared against the algorithmic result since it requires the demands to be split, load balanced and routed in a non-shortest path way. This function returns negative values for the efficiency but this was acceptable since we wanted to see the effect of changing the number of nodes and total traffic. We consider the relative efficiency. The more negative the result the better the algorithm performs.

The results showed that the number of nodes affected the efficiency significantly - the results for the no-conversion case with increasing numbers of nodes showed an increase in efficiency. This may be expected since the total traffic, being constant, is being spread across the network and hence there is less overlap and the need for conversion is lower. Networks with an even number of nodes produced worse results because of the random element in the routing of the diametric routes – this is also seen in SDH planning [9]. The situation is worsened because the diametric routes cannot share wavelengths with other demands along that half section of the network. The difference becomes less significant as we have more nodes because the diametric routes represent a smaller proportion of the overall traffic. The fact that demand splitting was not done meant that the longer demands made the network heavier on one side and therefore increased the required wavelengths. The Seymour-Okamura algorithm spread the load across the whole ring and therefore required fewer wavelengths. This can also be seen in the figure 4: the hub traffic should not gain much with conversion but here we can see that load balancing in the conversion case decreases it’s wavelength requirement greatly.

Conclusion

When designing for the layers above WDM we must consider the grooming of the demands required of the WDM layer, for example the design and route of DiffServ flows between nodes. This must be done to minimise wavelength usage but at the same time to maximise manageability in the upper layers. We have looked at the effect of network size on hub and uniform distributions. We have seen that the networks scale well in terms of need for conversion – the larger the networks are, the less the need for conversion for fixed demand patterns. We have also seen that we may have fully meshed interconnect networks and achieve good efficiency without the need for wavelength conversion.

Now we have to consider whether we opt for hub for restorable networks and cached architectures in data networks or a mesh distribution to have a simple and versatile configuration. The results showed that the requirement for conversion between the two distributions decreased as the network had more nodes.

Other distributions such as node-to-adjacent-node wouldn't require wavelength conversion and would also give good manageability but would mean that all demands would be dropped at each node effectively doing wavelength translation through the layer above. If the nodes where switched by IP routers then these may not be fast enough and make the equipment expensive.

Acknowledgements

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