Multiple Objective Heuristic for Ring Loading and Logical Wavelength Assignment in OCH-SPRings

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Key words: optical ring networks, network design, OCH-SPRing, routing and wavelength assignment algorithm

Abstract: The dimensioning process of a multi-ring network based on optical channel shared protection is discussed. This dimensioning starts with a multi-ring routing algorithm to decide on the rings traversed by a connection, followed by "Ring Loading"- and "Logical Wavelength Assignment"-algorithms applied to the individual rings. In this paper we focus on this second aspect, for which we introduce an integrated approach. The performance and applicability of this heuristic is evaluated for different objectives.

The original version of this chapter was revised: The copyright line was incorrect. This has been corrected. The Erratum to this chapter is available at DOI: 10.1007/978-0-387-35491-0_28

A. Jukan (ed.), *Towards an Optical Internet*

1. INTRODUCTION

The use of Wavelength Division Multiplexing (WDM) rings has been heralded as the next step in the evolution process from point-to-point WDM links towards optical transport networking (OTN) [1]. Two main types of WDM rings are envisaged: dedicated and shared protection rings. In this paper we focus on the *Optical Channel Shared Protection Rings* (OCH-SPRing).

The design process of an OCH-SPRing network can be divided in multiple consecutive sub-problems, as illustrated in *Figure 1.*

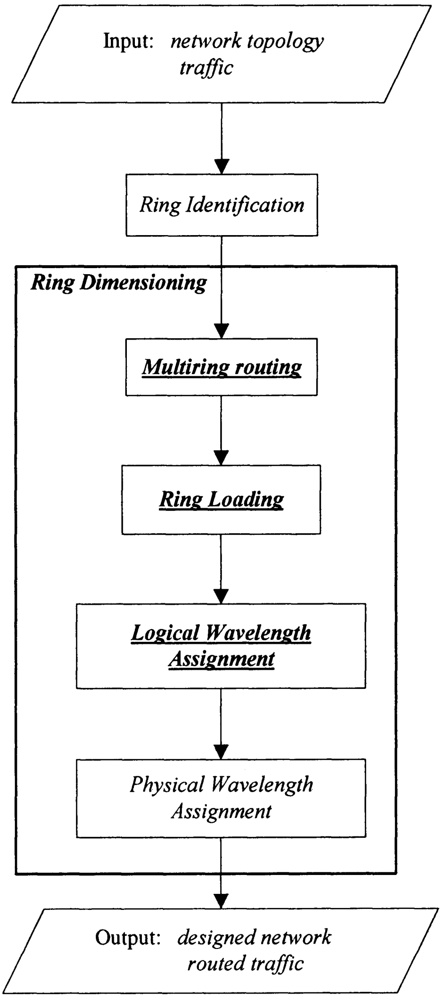


Figure 1. multiple network design steps

In case the rings are not defined up-front, the "***Ring Identification***" *(RI)*-process will try to identify a proper set of rings. Afterwards, these rings have to be dimensioned in order to accommodate the traffic forecast. We propose to split this dimensioning problem in 4 sub-problems. First the traffic is distributed over the different rings, so that the remainder of the dimensioning problem can be solved as a set of independent single-ring problems. This step is called "***Multi-ring Routing***"*(MR)*. Then the so-called "Ring Loading"- and "Logical Wavelength Assignment"-problem [2] are solved on a ring-per-ring base. These problems can be defined as follows:

- ***Ring Loading*** *(RL):* decide for each connection whether to route it clockwise or counter-clockwise on the ring, not taking into account wavelength assignment.
- ***Logical Wavelength Assignment*** *(LWA):* decide which connections to be grouped in a virtual ring (i.e. connections grouped on the same wavelength).

Finally a *"**Physical Wavelength Assignment**"(PWA)* step is executed in order to minimise the cost of the required equipment. This step is especially interesting when the ring has a modular structure, i.e. built-up of stacked fibres (or wavelength bands), and different types of OADM's are available. Suppose for example that there are three types of OADM's, dropping 0, 4 or all wavelengths of a fibre (or a wavelength band). In each node, the packing of logical wavelengths will then influence the choice of OADM for each stacked fibre (or band). For more details about this problem and the solution techniques proposed, we refer to [3].

In the remainder of this paper we focus on the first three sub-problems of the ring dimensioning. Paragraph 2 describes how we deal with the multi-ring routing problem. In paragraph 3 we introduce a new integrated solution method for the RL and LWA problem and finally paragraph 4 discusses the results obtained with this new heuristic.

2. MULTI-RING ROUTING

In the "multi-ring routing"-phase, we try to determine for each connection which rings are best suited to use and through which nodes the connections enter and leave each of the visited rings. Although these early decisions limit the freedom in the next steps of the design, they are required to split up the global problem into several single-ring problems. Note that this step only decides on the rings and interconnections visited. The routing on the ring – clockwise or counter-clockwise – is left to next steps. As such the decisions made in this phase have only limited impact on the following steps.

Our solution method is based on balanced shortest paths.

We use the shortest path algorithm to determine the shortest path in the network, build up of all rings and the interconnections between them. We associate a cost to each of the links. Note that there can be multiple links between 2 nodes, because each ring has its own links. This cost can be fixed or link-dependent. We have chosen for the first option, but extensions can be made easily. Using the same cost for all the lines in the network implies "least hops"-routing.

The ties that occur when paths having the same hop length are found, is a drawback of using hop count for the shortest path routing. In order to obtain a better spreading of the traffic over the rings in the network, we extended the cost-model to obtain a 'balanced routing'. Initially, all links of the rings have a cost 1000. Each time a link is used by a connection with a capacity C, C is added to the cost of this link. This way, we select the path with the least used links in case there are multiple "least-hop" paths.

The influence of the balanced cost-model on the dispersion of the traffic, depends on the way the connections are routed. We order the connections according to their demand. The ones with the highest demand are routed first. This way, connections with lower capacity can be used to eliminate the relative big difference in cost between the used and the unused links of the first connections.

Although each connection has been routed at the end of this phase, these routes are not yet final, because this would be too restrictive for the logical wavelength assignment. Part of the information will be eliminated to allow more possibilities for the sharing of wavelength resources. *Figure 2* shows a possible representation of a route in a multi-ring network. Each route can be completely described by means of an ordered list of visited rings, with for each ring the nodes in which the connection enters and leaves the ring and the direction of the connection over the ring (clockwise (CW) or counter-clockwise (CCW)).

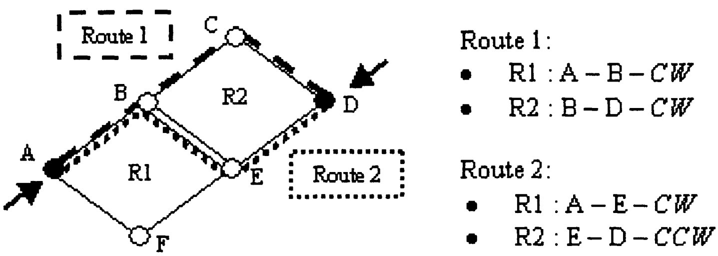


Figure 2. Example of route representation

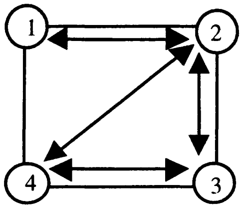
From the routes, only the rings and end-points are retained. Removing all the directions in this representation, means that this decision is postponed. This offers additional freedom to the logical wavelength assignment algorithm. Eliminating the directions, leaves just enough information to split up the multi-ring dimensioning problem into multiple single-ring problems. Indeed, with the remaining information, the global traffic matrix can be split up into traffic matrices per ring. From this point on the dimensioning process is continued ring per ring by the algorithm discussed in the next paragraph.

3. RL+LWA: MULTI-CRITERIA HEURISTIC

The "Ring Loading"- (RL) and "Logical Wavelength Assignment"-problem, have been subject to previous studies in literature. Both problems can be solved independently and consecutively, as in [2][4]. An integrated approach based on linear programming has been presented in [5]. To deal with both problems in an integrated way in a computationally efficient way, we present a heuristic approach. This heuristic iteratively assigns connections to wavelengths in a greedy manner according to a set of different criteria. As such the ring can be optimised according to different objectives. An obvious objective is to minimise the amount of required wavelengths, but it could also be interesting to minimise the number of access points, in order to share a protection card in an OADM for two connections. A possible secondary objective could be to maximise the number of free links in the final configuration, in order to offer some flexibility for future traffic. Even a combination of different objectives could be interesting for the network designer. Our heuristic approach called "Multi-criteria heuristic", is able to take these multiple objectives into account.

In this paragraph we explain this method in detail. In the next paragraph, the results for different objectives are discussed.

This algorithm is based on the construction of "Shared Connection Sets" (SCS's). A SCS is defined as a set of non-crossing routed connections, such that there is no other connection available that can be added to form a new SCS. A simple example (*Figure 3*) will clarify this. The set of connections 1-2 and 2-3 is not a valid SCS since there is still room on the ring to route the connection between node 3 and 4. By adding connection 3-4 we end up with a valid SCS. For this small example there are 3 valid SCS's.



1-2 ; 2-3 : 2 connections shared, but no valid SCS.
1-2 ; 2-3 ; 3-4 : 3 connections shared, valid SCS.
1-2 ; 2-4 : 2 connections shared, valid SCS.
2-3 ; 3-4 : 2 connections shared, but no valid SCS.
2-3 ; 3-4 ; 4-2 : 3 connections shared, valid SCS.

Figure 3. Example of ring with all valid SCS's

Figure 4 gives an overview of the different steps of the algorithm, which works in an iterative way.

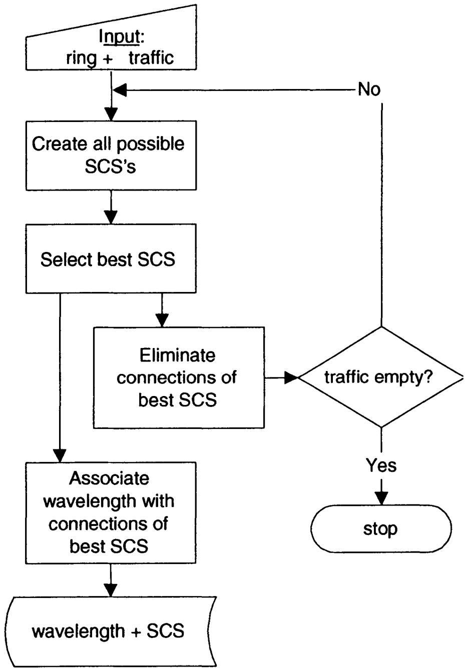


Figure 4. Multi-criteria heuristic

Each iteration starts with the creation of all possible SCS's, given the ring and its (remaining) traffic demand. With each of these SCS's, we can associate some values, reflecting the quality of the SCS, e.g. the number of connections in the set or the number of links occupied on the ring. Based on these values, we can identify one of these sets as the best, according to a certain criterion. The connections of the best SCS are then associated with one virtual ring and we start over with the remaining connections, until they are all assigned to a virtual ring.

The advantage of this solution method is that the selection criterion for the best SCS can be chosen according to the designer's preferences. When trying to minimise the number of wavelengths, good results are generally found when we select in each iteration the set with the maximum number of connections. Often there will be more than one such set. If we favour for instance the set that uses the least number of links, we will end up with a solution that maximises also the number of free links. On the other hand, we could try to minimise the number of shared protection cards by selecting the set with the most adjacent connections. To take into account different possible choices we developed five criteria, having different optimisation objectives. They select the best SCS based on following ideas:

- *Criterion 1*: best SCS contains highest number of connections, and least number used links in case of a tie.
- *Criterion 2*: best SCS occupies most links without using longest path.
- *Criterion 3*: best SCS has minimum weighted sum of number connections and number access points
- *Criterion 4*: best SCS has the least number of access points per connection.
- *Criterion 5*: best SCS has the highest value, obtained by a weighted function of the number of connections, number of used links and the number of access points per connection.

An additional advantage of the multiple criteria, is that the overall performance of the algorithm gets better when we combine more than one criterion, and select for each case the best result according to the preferred objective(s). In the results described in paragraph 4, it is shown that different criteria can complement each other.

4. RL+LWA: PERFORMANCE EVALUATION

4.1. Multi-criteria

To illustrate the use of multiple criteria, we performed the RL+LWA on a set of single ring networks with the amount of nodes varying from 3 to 16. To simulate the traffic of a multi-ring network, we consider a mix of random (intra-ring) and hubbed (inter-ring) traffic in different proportions. The validated objective is the number of required wavelengths. In the first three cases, the result is obtained with a single criterion, respectively 1,3 and 5. In the last case the best result of all three criteria is always selected. *Figure 5* gives an overview of the percentage of the average amount of extra wavelengths required by the four different solutions, compared to the minimum, obtained by means of a de-coupled ILP algorithm [2]. The chart shows that using multiple criteria results in a considerable improvement compared to a single criterion (depending on the traffic, an improvement from 10 to 50%). If we always use all the criteria, obviously the results will be the best that can be generated with the heuristic. Calculation time on the other hand is proportional to the number of used criteria.

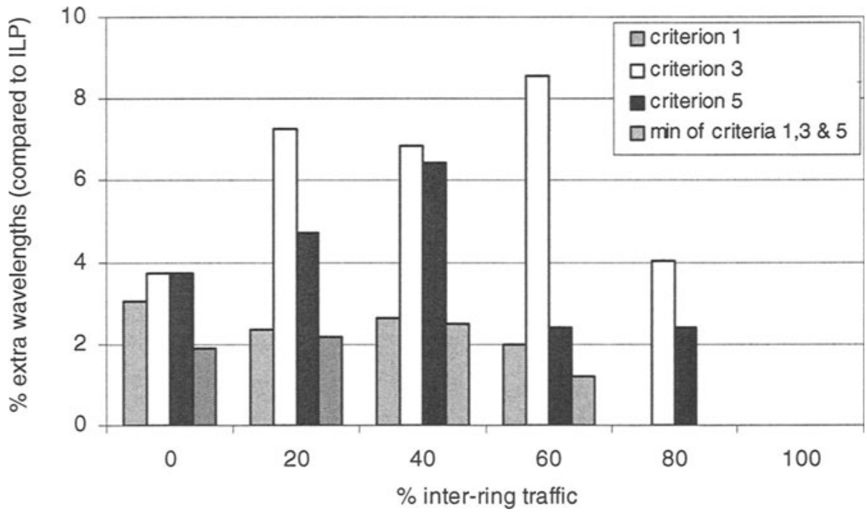


Figure 5. Comparison single criterion / combined approach

4.2. Multi-objective

With the 5 presented criteria, we can find good solutions for the three objectives we considered: minimum number of wavelengths, minimum amount of access points, maximum number of free links. Even combinations of objectives can be considered. In *Figure 6* we give an overview of the average results that were obtained with the different criteria for the different objectives in a series of experiments (each bar is average for rings with the number of nodes from 3 to 16, with five different traffic matrices per ring). Based on this chart, we can choose the best criterion corresponding with our (multi-) objective(s). E.g. if the amount of wavelengths is the most important objective, criterion 1 performs well, but if also "% free links" is important, criterion 3 is better. Considering only free links and access points favours criterion 4, etc...

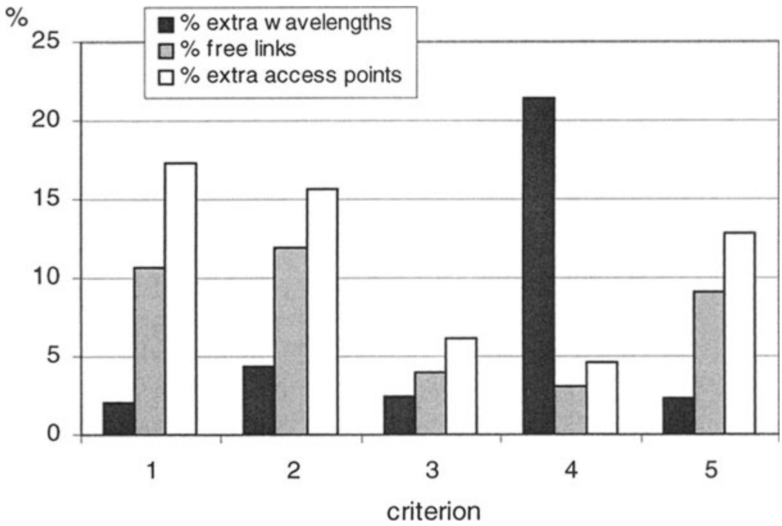


Figure 6. Performance multiple criteria for multiple objectives

4. CONCLUSIONS

In this paper we present a modular design approach for multi-ring networks based on optical channel shared protection. We discuss in detail the approach to split up the global problem into independent single-ring problems. A multi-objective heuristic, based on multiple selection criteria is introduced. This approach offers a fast way to solve the 'Ring Loading'- and 'Logical Wavelength Assignment' problem in a proper way. In addition, upon the designer's preferences, multiple objectives can be selected, which is less obvious with optimised algorithms based on e.g. integer linear programming techniques. Furthermore, this method can be easily extended for new objectives, simply by designing other criteria.

5. REFERENCES

[1] J. Manchester, P. Bonenfant, C. Newton, "The Evolution of Transport Network Survivability", IEEE Comm. Mag. **37** (8), 44-51 (1999).

[2] P. Arijs, M. Gryseels, P. Demeester, "Planning of WDM Ring Networks", Photonic Network Communications **2** (1), 33-51 (2000).

[3] P. Arijs et al., "Architecture and Design of Optical Channel Protected Ring Networks", Journal of LightWave Technology **19** (1), to appear January 2001.

[4] D. Marcenac, "Benefits of Wavelength Conversion in Optical Ring-Based Networks", Optical Networks Magazine **1** (2), 29-35 (2000).

[5] T. Carpenter, S. Cosares, I. Saniee, "Demand Routing and Slotting on Ring Networks", DIMACS Technical Report 97-02, January 1997.