Dimensioning of Non-hierarchical Interconnected WDM Ring Networks

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Abstract: In this paper we consider the routing of wavelengths in an interconnected WDM ring network, based on Optical Channel Dedicated Protection Rings (OCh-DPRing). We developed an integer linear programming and an efficient heuristic solution method and compare both methods. Furthermore we present results on network cost and availability for different network and ring sizes.

1. INTRODUCTION

The Wavelength Division Multiplexing (WDM) technology enables to multiplex several optical signals together on one single fiber. Due to the increase in the amount of backbone traffic in recent years, public network operators have adopted WDM as an economic alternative to upgrade the capacity of the point-to-point fiber links in their long haul network [1]. As WDM technology further matures, all-optical networking will become possible through the use of optical add-drop multiplexers (OADM) and cross-connects (OXC), leading to a (re)configurable optical layer [2]. In such

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a configurable optical layer, data can be routed on a wavelength basis (along so-called lightpaths), and different client layer signals can be supported on separate wavelengths, such as SDH, PDH, ATM and IP traffic. Wavelength routing allows to lower the transmission costs by reducing the amount of optical-to-electrical conversions as well as the required amount of electrical processing capacity. As all-optical networking becomes a reality, also survivability in the optical layer will gain importance [2]. Due to the increase of traffic by the deployment of WDM, a single fiber cut potentially affects hundreds or thousands of client layer connections simultaneously. By using WDM recovery, all these failures can be tackled at once and no protection resources need to be allocated in the client layers. In addition, optical recovery also offers transparent survivable support for services which do not have their own recovery mechanisms.

A first step towards a survivable optical layer is seen through the use of WDM rings [3]. Since components and management for rings are simpler than for meshed networks, OADM's for ring architectures are expected to be earlier available at the market than OXC's. Indeed, fixed OADM's (capable of adding/dropping a limited set of fixed wavelengths) are already available from some vendors today, while reconfigurable OADM's - also capable of performing protection switching - are expected in the forthcoming years. First generation WDM ring architectures will be based on so-called optical channel dedicated protection rings (OCh-DPRing), protecting traffic on a wavelength basis. An OCh-DPRing consists of two counter-rotating fibers, with WDM deployed on each fiber. Each wavelength demand is protected using a main path along one side of the ring and a dedicated backup path along the other side of the ring. When a link or node failure occurs within the ring, the traffic can be switched over to the protection path, as illustrated in *Figure 1*.

Figure 1a: OCh-DPRing

Figure 1b: OCh-DPRing after failure

In the OCh-DPRing based on 1+1 protection, traffic is duplicated at the transmitter side (e.g. using an optical splitter) and the best of both signals is selected at the receiver side (e.g. using a 2x1 switch). Single ended protection switching occurs based on the monitoring information of the

optical channel (hence no signaling protocol is required), which makes the implementation conceptually simple and allows fast protection switching.

The routing of bi-directional protected traffic on an OCh-DPRing is trivial since the main and protection paths of each demand, use both sides of the ring. As such, every demand is carried over every section of the optical ring. The utilization of every section - and the required ring capacity - is thus equal to the total demand. While single OCh-DPRings are straightforward to plan and operate, backbone networks based on OCh-DPRings typically consist of a multitude of interconnected rings. Building a network based on such a set of interconnected rings is a complex task, which consists of finding a minimum cost combination of interconnected rings, such that all demands in the network can be supported. While initially overlapping rings can be created such that no interconnection between rings is required, ring interconnection is a long-term requirement for an economical, reliable and manageable large-scale ring network. The rings can be interconnected logically in two ways, either by defining a hierarchy as in [4], or in a flat way without defining a hierarchy. In this paper we study the design of a flat interconnected ring network within an existing fiber topology.

The main tasks in the ring design process consist of finding communities of interest between which to deploy the rings (i.e. ring selection), and routing inter- and intra-ring traffic on the selected interconnected rings. In a hierarchical network, the second phase of this design process is trivial because the routing possibilities are constrained by the hierarchy. In this paper we consider this routing process for a flat ring network, which is a more difficult problem. The routing algorithms we developed can then be used as a phase in the ring selection process, or they can be used as a stand-alone process for dimensioning an existing network with already determined rings. When the routing algorithm is used as a phase in the ring selection process, it has to be executed a large number of times, in order to evaluate a large set of possible ring combinations. Therefore, it is of paramount importance that the routing algorithm is sufficiently fast. In this paper we present a fast and simple heuristic, that has shown to yield close to optimal results, and can thus be used for this purpose.

In section 2 of the paper, we discuss the givens and assumptions of the problem formulation. In section 3, solution methods are presented, both using integer linear programming and heuristic techniques. In section 4 we present some obtained results, by comparing the different algorithms and describing the effects of different network and ring sizes on network cost and availability. Finally, section 5 concludes the paper.

2. PROBLEM FORMULATION

We consider the physical network topology to be given as a set of cables (or links) L and a set of offices (or nodes) N . We also know the ring-sites R , i.e. the positions where OCh-DPRings can be deployed. If a site $r \in R$, passes through office $n \in N$, then $s(r,n) = 1$ (otherwise 0).

In a ring-site, an OCh-DPRing can be deployed by using one fiber pair in the cables, and one OADM in the offices along which it is routed. This can be seen in *Figure 2*, in which a simple 9-node network with 4 rings is shown. In the optical transmission section (OTS) layer, the physical network topology is represented, while in the optical channel (OCH) layer, the OCh-DPRings are represented.

Figure 2: Physical network topology (OTS layer) and rings (OCH layer)

The demand d_{ij} expresses the amount of bi-directional wavelengths that have to be routed and protected between each two different offices $i \in N$ and $j \in N$ ($j > i$). Each demand is protected in each ring in which it is routed (which allows to independently recover from multiple failures occurring in different rings) and traffic exchanged between 2 rings is protected using drop & continue as in SDH rings [5], which results in a very secure architecture.

We assume that at least one ring-site passes in each office, and the ring-sites are connected, such that all demands can be routed. The interconnection between two different rings is assumed to be hard-wired (i.e. without the use of cross-connects) and is performed in at least 2 different offices (to allow drop & continue).

We consider a network design based on a homogenous set of rings, i.e. all rings in the network are of the same type. In our case this means all rings are OCh-DPRings with the same amount of wavelengths W .

We consider the following generic cost model:

- A ring cost C_r^{ring} for each ring to be deployed on ring-site $r \in R$: this cost includes the fixed installation costs of the ring, fiber costs, amplifier costs, OADM costs, ...
- A routing cost C_r^{route} for routing one wavelength on a ring on ring-site $r \in R$: this costs accounts for the modular components of the ring that can be installed on a wavelength basis (e.g. tributary cards, transponders).
- An interconnection cost C^{inter} : the cost for interconnecting a wavelength between 2 rings (e.g. transponder cost).

The integer variable $x(r)$ represents the amount of OCh-PRings to be deployed in each ring-site $r \in R$. When multiple rings are deployed in the same ring-site r (i.e. when $x(r) > 1$), these rings are referred to as *stacked* rings.

Each demand d_{ij} can be routed along a number of possible paths $p_{ij} \in P_{ij}$. Such a path consists of a number of interconnected ring-sites (in section 3 we will discuss how these paths are obtained). If ring-site $r \in R$ is contained in path $p_{ij} \in P_{ij}$, then $q(p_{ij}, r) = 1$ (otherwise 0). The integer variable $y(p_{ij})$ represents the amount of traffic that is routed on path $p_{ij} \in P_{ij}$.

The aim is to minimize the total cost of the interconnected ring network, such that all demands can be routed and protected. This can be formulated as follows:

$$\text{Minimize: } \begin{cases} \sum_{r \in R} C_r^{ring} x(r) + \sum_{r \in R} C_r^{route} \cdot \sum_{i \in N} \sum_{\substack{j \in N \\ j > i}} \sum_{p_{ij} \in P_{ij}} q(p_{ij}, r) \cdot y(p_{ij}) \\ + 2 \cdot C^{inter} \cdot \sum_{i \in N} \sum_{\substack{j \in N \\ j > i}} \sum_{p_{ij} \in P_{ij}} \left(\sum_{r \in R} q(p_{ij}, r) - 1 \right) \cdot y(p_{ij}) \end{cases}$$

Subject to:

$$\sum_{p_{ij} \in P_{ij}} y(p_{ij}) = d_{ij} \quad \forall i \in N, j \in N \mid j > i$$

$$\sum_{i \in N} \sum_{\substack{j \in N \\ j > i}} \sum_{p_{ij} \in P_{ij}} q(p_{ij}, r) \cdot y(p_{ij}) \leq W \cdot x(r) \quad \forall r \in R$$

$$y(p_{ij}) \text{ integer and } \geq 0 \quad \forall i \in N, j \in N \mid j > i$$

$$x(r) \text{ integer and } \geq 0 \quad \forall r \in R$$

The objective function consists of 3 terms. The first term accounts for the fixed ring cost contribution. The second term represents the cost of routing wavelengths on the rings. The third term adds the cost of interconnecting wavelengths between two rings. The factor 2 in this third term expresses the fact that interconnection between two rings takes place in two nodes (to allow drop & continue).

3. SOLUTION METHOD

3.1 Equivalent network

The *equivalent network* represents the topological relationship between the different ring-sites and can be used to assist in the routing decisions within the rings. In the equivalent network, each office is represented by a separate node. In addition, each ring-site is also represented by a node. Two types of links exist in the equivalent network. A link between a node representing an office n and a node representing a ring-site r is present if $s(r,n) = 1$. Such a link is called an *access link* and represents the fact that the ring-site passes through this office (and thus traffic injected at this office has access to the rings of the ring-site). A link between two nodes representing a ring-site is called an *interconnection link* and represents the fact that both ring-sites are interconnected in at least two offices (and thus traffic can be exchanged between rings of both ring-sites, using drop & continue). An example of a ring network and the corresponding equivalent network is given in *Figure 3*.

Figure 3: Ring network and equivalent network

Traffic between two offices in the ring network can be routed by finding a path between the corresponding nodes in the equivalent network. A path in the equivalent network should always start and end with an access link, while all intermediate links should be interconnection links. Afterwards, the obtained path in the equivalent network can be translated again to a sequence of interconnected rings in the original network.

We assign weights w_l and capacities c_l to links l in the equivalent network in the following way:

If l is an access link between nodes representing office n and ring-site r :

$$w_l = \frac{C_r^{ring}}{2.W} + \frac{C_r^{route}}{2}$$

$$c_l = W.x(r)$$

If l is an interconnection link between nodes representing ring-site r_1 and r_2 :

$$w_l = \frac{C_{r1}^{ring}}{2.W} + \frac{C_{r1}^{route}}{2} + \frac{C_{r2}^{ring}}{2.W} + \frac{C_{r2}^{route}}{2} + 2.C^{inter}$$

$$c_l = W.\min\{x(r_1), x(r_2)\}$$

As such, the cost of a ring is divided over the links which are adjacent to the corresponding node in the equivalent network. The fixed cost is divided by the amount of wavelengths on the ring, distributing this cost equally among all channels on the ring. The interconnection costs are in turn accredited to the interconnection links.

3.2 Integer linear programming (ILP) solution

A first way of solving the problem under study is to implement the model presented in section 2 in an integer linear programming solver such as CPLEX [6]. The set of paths P_{ij} we use for each pair of offices is determined by searching for the K-shortest paths between the corresponding nodes in the equivalent network. The 'optimal' solution can only be found by considering all possible paths (i.e. K very large), however this tends to increase the computational complexity of the problem considerably. In practice, only modest values of K will be considered, which can still result in very good results, as will be shown. The ILP solution method is suitable for optimizing medium sized problems and to benchmark the heuristic solution method.

3.3 Heuristic solution method

For large-scale problem instances (large networks with a lot of ring-sites) the ILP solution method does not scale very well. For this purpose a fast heuristic solution method has been implemented. A schematic overview of the different phases of the heuristic can be found in *Figure 4*.

Figure 4: Heuristic optimization method

The heuristic starts by routing the connections d_{ij} along their shortest path in the equivalent network. After all connections have been routed we can determine the amount of traffic routed on each ring-site. From this we can deduct the amount of stacked rings required at each ring-site, as well as the utilization of each ring. In case multiple stacked rings are present at a ring-site, all rings have a utilization of 100%, except for the last ring in the stack, which might have a lower utilization. The heuristic now attempts to eliminate some of the rings with low utilization ratios, by trying to reroute connections on this ring (or on any other ring of the stack) on a different route, not containing this ring-site. On the ring with the *lowest utilization* ratio, we start with the connection that can be rerouted on an alternative route, with the *least additional cost* compared to the cost of its original route. The new route is calculated in the equivalent network (along the shortest path), in which we first tear down the original route (and adapt the capacities), and from which we exclude the current ring and all other rings that have no free capacity left. This process of rerouting connections is

repeated until no more traffic is present on the last ring of the stack, or until no more connections can be rerouted. In the first case the ring is removed if the elimination of the ring leads to a cheaper overall solution. If the removal does not lead to a cheaper solution, or in the second case, we restore the rerouted connections on the current ring and do not remove the ring. In both cases the algorithm is continued by searching for the ring with the next lowest utilization, and again we try to reroute connections on this ring in the same way. This process is repeated until all rings are evaluated. Note that the utilization ratios are recalculated in each iteration, because the rerouting of traffic of removed rings also affects the traffic on the other rings.

4. RESULTS

In this section, we present results for 2 sample networks:

- a network with 16 nodes, 21 links and a traffic matrix containing 116 wavelengths
- a network with 32 nodes, 41 links and a traffic matrix containing 256 wavelengths

We consider 16 wavelength OCh-DPRings to be used throughout the network. For the 16-node network, we considered a design based on 3 large ring-sites or on 7 smaller ring-sites. For the 32-node network, we considered a design based on 7 large ring-sites or on 13 smaller ring-sites.

We used a generic cost model, with the cost of a ring r passing through N_r offices and having A_r amplification sites:

$$C_r^{ring} = N_r \cdot (C^{link} + C^{OADM}) + A_r \cdot C^{AMP} \quad \text{and} \quad C_r^{route} = N_r \cdot C^{route}$$

The used cost values for this case study are: $C^{link} = 200$, $C^{OADM} = 50$, $C^{AMP} = 40$, $C^{route} = 20$ and $C^{inter} = 10$.

In *Figure 5*, we present a cost comparison of the different designs, using both the heuristic and the ILP algorithm based on the K-shortest path algorithm (using $K=2$ and $K=4$). The graph also shows the utilization ratios¹ of the different networks. A first observation is that the heuristic yields results, which are very close or equal to the results yielded by the ILP algorithm. While the heuristic typically takes a couple of seconds or less on a 166 MHz Pentium PC, the ILP algorithm takes some more time, but never more than a couple of minutes for the considered networks. A second observation is that the ILP algorithm with $K = 2$ (thus only considering the shortest and second shortest path in the equivalent network) gives in most

¹ Utilization = total used capacity / total installed capacity

cases the same result than for higher values of K (although higher values of K require longer calculation times).

When comparing the network designs based on different ring sets, we can conclude that a network composed of a larger amount of relatively small rings results in a lower overall cost, than a network composed of a small number of larger rings. Although in a network with larger rings, less inter-ring traffic is present, and thus a lot of traffic can be carried on a single ring, the total cost is higher. This is because connections typically have long protection paths on the rings, thus making inefficient use of the network capacity. Even in a single ring, a connection between neighbouring nodes takes up capacity on the entire long ring. In addition the connections that do require to be routed on multiple rings, consume capacity on almost the entire network. In a network with smaller rings, the protection paths on each ring are relatively short, and even if a connection is transported on multiple rings, the total amount of protection capacity remains reasonable. However, it could be noted that one or two large 'overlay' rings might be beneficial for transporting connections from one end of the network towards the other end in a network composed of smaller rings.

Figure 5: Cost comparison

Smaller rings do not only result in a lower overall network cost, they also help in increasing the availability of the network. This is reflected in Figure 6, which represents the expected loss of traffic (ELT), which is the amount of traffic that the network is expected to lose per year due to failures [7]. We express ELT in STM-16 hours per year, assuming each wavelength transports one STM-16 signal (≈ 2.5 Gb/s). We have calculated the ELT both

for link failures only, and for link and node failures, while considering ring interconnection with and without drop & continue. The availability of a network element is reflected by its mean time between failures (MTBF) and mean time to repair (MTTR):

- Links: MTBF: 1 failure every 300 km per year; MTTR: 24 hours
- OADM: MTBF: 100000 hours; MTTR: 6 hours
- Optical amplifier: 500000 hours; MTTR: 24 hours

Figure 6: Availability comparison

From *Figure 6* we can indeed conclude that a network composed of a large amount of small rings results in a lower ELT, and thus a higher network availability. This is particularly evident when only considering link failures, as multiple small rings can better survive from multiple link failures in the network, because the chance is higher that the different link failures occur in different rings. When considering both link and node failures, the effect is less strong because a node failure involves the loss of all traffic originating/terminating in that node, which is traffic that can not be recovered any way. This explains the much higher ELT values for the node failures and the small differences between the networks with different ring sizes. In fact the difference in ELT for link and node failures between large rings and small rings is very small when not considering drop & continue. Indeed, larger rings can survive from less multiple failures, but on the other hand, they involve less ring interconnections (single point of failure in case no drop & continue is used). When drop & continue is used the difference between small and large rings is more apparent. The overall effect of drop & continue on the ELT values is remarkable, and increases for the larger

network. When considering both link and node failures, the ELT almost doubles when not using drop & continue. As drop & continue does not require any additional ring capacity for OCh-DPRings, it can thus provide a substantial increase in availability at a relatively low cost.

5. CONCLUSION

We discussed the routing problem in interconnected OCh-DPRing networks. We have developed an ILP solution method based on the K shortest paths, that gives good results for low values of K. Furthermore, a simple and fast heuristic optimization method was developed that performs in close range with the optimal result yielded by the ILP algorithm. The heuristic is sufficiently fast to be used as a phase in the more complicated ring identification process, during which it has to be executed a large number of times.

When comparing routing in a network with a limited set of large rings or a large set of smaller rings, the latter architecture is preferred both from a cost and availability point of view. Also the impact of drop & continue on the overall network availability is substantial and increases as the size of the network grows.

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REFERENCES

- [1] E. Lowe, "Current European WDM deployment trends", *IEEE Communications Magazine*, vol. 36, no. 2, Feb. 1998, pp. 46-50.
- [2] P. Demeester, T.-H. Wu, N.Yoshikai (eds.), "Survivable communication networks", *Special issue of IEEE Communications Magazine*, Vol. 37, No. 8, Aug. 1999.
- [3] P. Bonenfant, "Protection and restoration in optical networks", *Proc. of OFC'99* (San Diego, CA, Feb. 1999), Tutorial Sessions, pp. 199-214.
- [4] B. Van Caenegem, P. Demeester, "Design of interconnected WDM ring networks", *Proc. of ONDM'99* (Paris, France, Feb. 1999), pp.61-68.
- [5] M. Sexton and A. Reid, "Broadband networking: ATM, SDH and SONET", *Artech House*, London, ISBN: 0890065780.
- [6] ILOG Inc., CPLEX Division, "Using the CPLEX callable library", 1997.
- [7] D. Vercauteren et al. "Evaluation environment for telecommunications networks", *Proc. of Networks'96* (Sydney, Australia, Nov. 1996), pp. 671-676.