Planning techniques for Multi-Period Optical Network Designs

Neil Geary[†‡], Andreas Antonopoulos[‡], John O'Reilly[†], Elias Drakopoulos[‡]

[†] Communications Engineering Doctorate Centre, Department of Electronic & Electrical Engineering, University College London, Torrington Place, London WC1E 7JE.

[‡] Lucent Technologies, 101 Wigmore Street, London W1H 9AB.

Abstract: *A typical mid-sized national network is planned using various multi-period optimisation techniques, considering the use of either 1+1 SNCP optical protection or Optical Channel rings (OCh-SPRings) to give a survivable network design. Traffic growth is applied over a five year planning horizon to give a tenfold increase in total traffic volume for the final year. Results are presented in terms of the number of DWDM systems required for each scenario, but since deployment occurs over several years, a Net Present Value for the total network cost is evaluated. As expected, Shared protection rings are shown to reduce the system requirement significantly, yet the best multi-period optimisation technique depends heavily on the discount factor rate chosen.*

1. Introduction

Network operators are currently deploying DWDM-based (Dense Wavelength Division Multiplexing) optical transport networks to meet the tremendous bandwidth requirements caused by the explosive growth in Internet traffic, and corporate Virtual Private Networks spanning the globe. Existing DWDM systems can handle different rate client signals, e.g. 2.5GHz and 10GHz, on the same network, as well as very different service types, e.g. SDH and Gigabit Ethernet. Current commercially available systems can offer up to 80 optical wavelengths on a single fibre. Many DWDM line systems include modular components, allowing an incremental growth of channels, spreading network investment over the lifetime of the network. Therefore careful optimisation of the network design is required in a *Multi-period* planning situation. Inputs to the planning process include the node locations, available duct routes between nodes (links), and the traffic forecast for each period.

2. Optical layer protection techniques

Availability of the network is a key factor to allow the provisioning of service level agreements. Optical layer protection and restoration give an extra option to the traditional client layer protection/restoration protocols such as IP router topology reconfiguration and SDH self-healing rings. Attractive optical layer survivability techniques proposed include: 1+1 Optical Channel layer SNCP path protection, Optical Multiplex Section shared protection rings, and Optical Channel layer Protection rings (with either Shared or Dedicated protection) [1]. As with SDH rings, Shared Protection offers capacity savings for most types of traffic patterns [2]. However, Optical Channel Shared Protection rings (OCh-SPRings), have many extra benefits compared to their SDH counterparts, MS-SPRings:

- Granularity

OCh-SPRings can be built up wavelength by wavelength, not per system as with SDH. Protection wavelengths are added as the traffic grows, whereas with SDH 50% of the capacity is reserved for protection from day 1.

- Easier ring stacking/interworking

A DWDM multiplex section can form part of several rings. So for a 40-channel system, 30 wavelengths might be assigned to one ring, and the remainder allocated to a separate overlapping or stacked ring.

- Mixed capacity systems in a ring

SDH rings require each link to have the same capacity, e.g. STM-64. DWDM rings allow for different capacity systems to be employed based on the optimised load per multiplex section. For example, an 80-channel system could be used for a heavily loaded link, and 40-channel systems deployed elsewhere in the ring.

3. Multi-period planning

Multi-period network planning is planning across several years, with a view to producing incrementally a network capable of carrying all traffic predicted up to the end of the planning horizon, in a cost-effective way.

3.1 Candidate multi-period optimisation techniques

In [3] several different optimisation goals are proposed for multi-period optical network planning, including:

1. An approach to optimise network costs at the same time for all periods in the plan. This technique would seem to be very sensible, yet it is highly complicated since previous years' routings affect later years due to the fact that wavelength reconfiguration is often not allowed for reasons of continuity of service. The network is optimised for the final year with all the cumulative traffic. Assuming a 5-year horizon, we denote this method **O5**.
2. Optimise the network year-by-year, effectively ignoring knowledge about future traffic. However, since demands which have been provisioned in a previous year cannot be re-routed in order to maintain continuous service, only the 'new' incremental traffic is available each year to be routed at minimum cost. New systems are only deployed when absolutely necessary. This technique shall be called **O1+**, for iterative optimisation from year 1 onwards.

These techniques will be complemented with a hybrid approach between that of O1+ and O5. The technique **On+**, where n represents a year between 2 and 4, indicates that for years up to Year n inclusive, the O5 technique is to be used (all traffic for these years to be optimised at the same time). Then, for each year after Year n, the iterative O1+ method shall be applied, optimising the incremental traffic year by year.

To summarise, we will test methods O1+, O2+, O3+, O4+ and O5, but also using a Net Present Value calculation in all cases since equipment is deployed over several years. This will give a fairer representation of total network cost, and these costs will be compared for both 1+1 Optical Path protection and OCh-SPRing architectures.

3.2 Single period optimisation step

Optimising the network involves re-routing traffic away from shortest paths in order to avoid deploying certain optical line systems on a link (load balancing). For the ring protection scenario, optimising the network involves the determination of an effective ring layout which results in good capacity savings. However, to avoid over-long working paths, a constraint is placed on ring-based routing that the shortest path between source and destination has to be used for the working wavelengths. Therefore, the ring optimisation involves the effective routing of the protection paths onto a ring topology.

4. Case study network

A case study network was determined using a random placement of 16 nodes, and a sensible manual placement of links to give a survivable network. The nodes decrease in order of importance (and traffic volumes generated) down to node P, in alphabetical order. A traffic growth of x10 over 5 years is assumed, taking the total traffic volume to 600 wavelengths in Year 5. All traffic is assumed to require protection.

5. Algorithms employed

The planning and analysis of the network was performed using a Java-based optical network design tool.

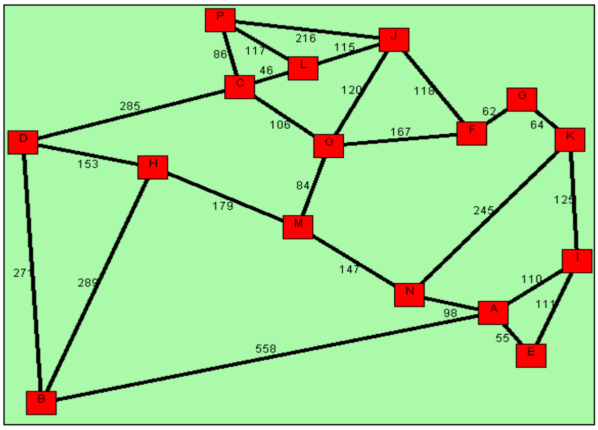

Figure 1 – Case study network with distances (km)

5.1 Routing

- 1+1 Path protected traffic is routed using a minimum-cycle algorithm.
- Ring traffic is routed shortest path for the working path, and the protection paths are allocated to rings in order to create rings with a high number of demands routed on them. Thus the traffic itself defines the rings using a heuristic algorithm. Demands with a high volume of wavelengths are weighted such that popular rings are more likely to be formed around them. Another advantage of this optimisation technique is that it favours single ring demands, avoiding the need for complicated inter-ring issues.

5.2 System allocation

Based upon the routings, DWDM systems are allocated to the links using a simple look-up table approach. Systems can also be stacked using different fibres on the link. Three types of system are assumed, of different capacities: 40, 80, and 160 wavelengths. Following a simple transmission system rule of thumb, the 'costs' of these systems are taken as 1, 1.6, and 2.5 respectively. An in-service upgrade is also permitted to migrate from 40 to 80 channel systems, at an incremental cost of the difference between the two systems.

5.3 Load balancing for path protected traffic

The optimisation step for 1+1 path protected traffic occurs after the system allocation, as explained in section 3.2. Systems are considered for removal if their utilisation is under 30%, or for downgrading, (e.g. from an 80 to a 40 channel system) if they are within 30% of a possibility to downgrade.

6. Results

Results for the O2+ and O3+ technique are very similar to those for O1+, since the total traffic levels are similar, and are thus omitted for clarity. Figure 2 shows the results of the planning for OCh-SPRing protected traffic. The number of rings in the architecture increases over the years of the plan as the demand diversity increases, but the O5 technique produces the lowest number of rings (19) at Year 5 since all traffic is considered at the same time for ring building optimisation. The ring efficiency increases over the years, as more and more traffic demands can be fitted optimally to share the protection wavelengths. Ring efficiency is defined as the percentage saving of wavelengths required on the ring compared to a Dedicated Protection scenario. The O5 technique produces the most efficient topology since the ring count is lower, and more demands are fitted to these rings.

Figure 3 compares the total discounted network cost for the 1+1 path protection option compared to the ring-based solution. The ring-based solution consistently requires less DWDM systems due to the shared protection, but the lowest cost multi-period optimisation technique depends strongly on the discount rate percentage used. For 10%, the O5 technique provides the lowest total network cost, as shown in Figure 3. This is because higher capacity systems are deployed earlier on in anticipation of high future demand, and

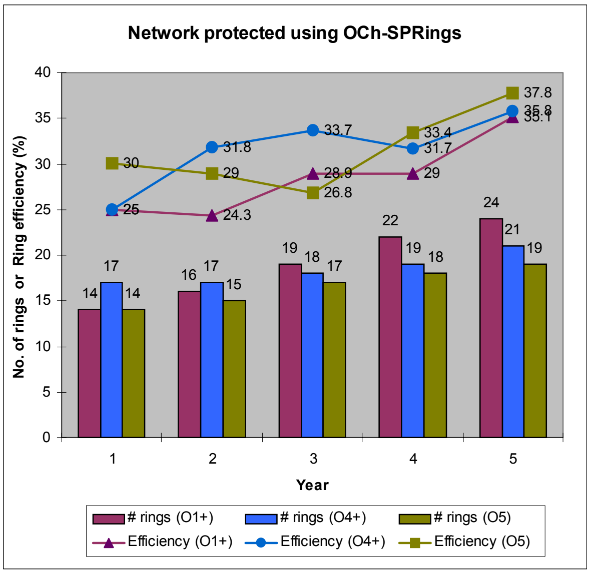

Figure 2 - Results for ring protected traffic.

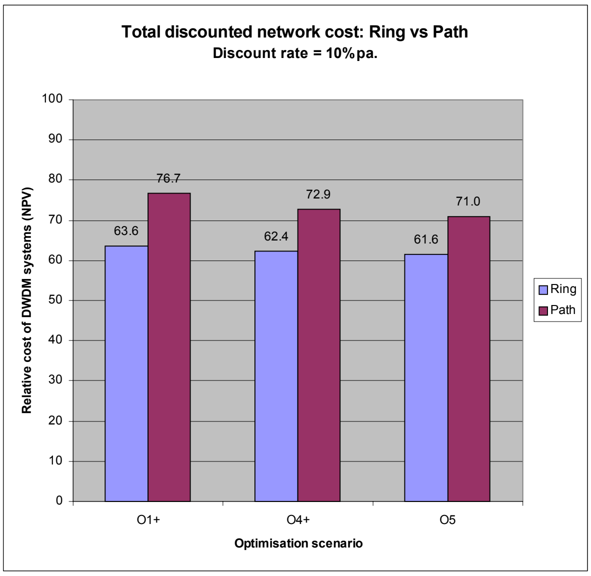

Figure 3 - Comparison between path and ring protected solutions.

these higher capacity systems have a lower cost per channel. For a discount rate of over 13%, the O1+ technique provides the lowest total system cost, since although more systems are required (and stacked), they are deployed in later years and are therefore subject to more of a discount.

Other factors to investigate

For a more complete analysis the contribution to network cost of the optical transponders needs to be considered. The more demands are routed away from the shortest paths, the greater the number of transponders required.

The Optical Amplifier (repeater) count is also vital since the number of optical amplifiers on a link depends on the number of systems deployed, and the distance between the two end nodes. The O1+ method is expected to require more amplifiers since systems are stacked to a greater extent, whereas with O5 the higher capacity systems are installed earlier on in the plan.

Another factor necessary to investigate when comparing the protection architectures is the relative costs of Optical Ring Switches and the 1+1 protection OTUs (containing the splitting and switching functions).

7. Summary

We have shown how planning over several years is affected by the traffic protection method and the optimisation strategies. It will be possible to optimise networks according to aimed investment targets. Real networks contain a mix of protected and unprotected traffic, the proportions of which will have a marked effect on the results. Some traffic may be protected in other layers, e.g. SDH traffic. A complete multi-layer and multi-period network optimisation has to be considered to yield practical network solutions.

8. References

[1] O. Gerstel, R. Ramaswami, 'Optical Layer Survivability: A Services Perspective', IEEE Communications Magazine, March 2000.

[2] P. Arijs, M. Gryseels, P. Demeester 'Planning of WDM Ring Networks', Photonic Network Communications, vol. 2 no. 1, March 2000

[3] 'Planning of Optical Networks', EURESCOM Project P709 Deliverable 3, March 2000. http://www.eurescom.de/P709