Introducing optical transparency into core networks with R-OADMs

Neil Geary†,Georgia Bernidaki†, Andreas Antonopoulos‡, John Mitchell†

† University College London, ‡ RHK Inc.

Abstract: New technologies such as Ultra Long Haul transmission and Reconfigurable Optical Add-Drop Multiplexers (R-OADMs) seem set to transform the economics of optical core network architectures as they become commercially available. Together, they allow an important first step towards optical transparency by allowing transit traffic to pass without regeneration along chains of nodes. This paper looks in detail at how cost savings are achieved through this process, and introduces some of the key network, traffic, and cost parameters influencing the benefits.

1. Introduction

Optical transport networks are now in place carrying many wavelengths of traffic using Wavelength Division Multiplexing. Current deployments are of the 'opaque' variety where all wavelengths undergo 3R regeneration at all nodes. 'Intelligent' optical core networking calls for reconfigurability at all nodes, in opaque optical networking this can be realised via either OEO optical switching or photonic switching via MEMS-based Optical Cross Connects (OXCs).

However, the reach of optical line systems is being extended with Ultra Long Haul (ULH) transmission techniques. Sophisticated dispersion compensation, channel equalisation and Raman amplification allows distances of up to 2000km to be covered without requiring regeneration [1]. Together with Reconfigurable OADMs a first step towards optical transparency can be achieved: 'islands of transparency' -- regions where the optical signals remain transparent without regeneration. A linear chain of degree 2 nodes, utilising R-OADMs at intermediate nodes, represents the simplest form of transparent sub-network. OADMs allow transit traffic to be passed through transparently using passive optics, only traffic that is to be dropped requires any further equipment.

The value proposition for deploying ULH and R-OADMs together is that intermediate nodes in chains do not require regeneration for transit traffic. Since ULH allows long distances to be covered without regeneration, the chains may become long and have many intermediate nodes. Furthermore, R-OADMs are cheaper nodal architectures than OXCs. The goal of this paper is to quantify the potential cost benefits in representative national mesh networks using ULH transmission and R-OADMs at degree 2 nodes. Table 1 below quantitatively summarises the two options for each chain. The optimal network-wide solution is not clear cut since each choice has expensive and cheap elements contributing to the total cost so detailed analysis and optimisation is required.

Table 1 - Summary of choices for each chain in a network

Transmission type and reach	*Transparency*	*Intermediate nodes require:*	*Regenerators needed?*	*Simple guide to their applicability*
Ultra Long Haul *1000-4000km* ***($$$)***	Transparent along length of chain	R-OADMs ($)	No	Long chains with a high proportion of transit traffic
Long Haul *400-600km* ***($)***	Opaque	OXCs ($$)	Yes, at every intermediate node ($$$)	Short chains with most traffic terminating at intermediate nodes

2. Network cost optimisation

This paper extends [2], which considered a single chain in a network, by optimising the topology of entire networks in order to achieve the lowest cost design. The optimal design will be a hybrid of both long haul transmission with OXCs at nodes (opaque networking), and ULH transmission with R-OADMs at intermediate degree 2 nodes (transparent chains). A Simulated Annealing heuristic optimisation method is employed to find a lowest cost solution [3]. 'Modify' operations for the annealing include *adding* and *removing* links from a candidate link set, and *swapping* a removed link with a current link. The idea behind Simulated Annealing is that the optimisation loop will avoid local minima via occasional acceptance of higher-cost solutions. An important observation is that as the network connectivity decreases, there is a greater likelihood of chains forming in the topology [4]. Therefore the *'remove link'* modify operation is given the highest probability in the Simulated Annealing optimisation loop. The goal then becomes to 'remove' enough links to permit long chains with a high proportion of transit traffic to form, thus matching the characteristics of ULH as shown in Table 1 when it becomes cost-optimal to do so.

1. Start with all links lit up with LH and OXCs present at all nodes. Initialise Simulated Annealing optimisation parameters (temperature **T** to 225 ,and cooling rate **R** (0<**R**<1) to 0.95).
2. Route traffic using Dijkstra algorithm, assign either LH or ULH to individual chains. Find total network cost **c**.
3. Modify topology by removing a link at random (or a small chance of adding/swapping a link out)
4. Route traffic again, assign LH or ULH to individual chains. Find new total network cost **m**
5. If (e^((**c-m**)/T) > random number between 0 and 1) *accept new solution* with cost **m**
6. Update **T** parameter by multiplying by **R**
7. Repeat steps 3 to 6 until termination condition reached (**T** < 5)
8. Put back deleted links but with no installed line systems on them. Output total cost of network

3. Architectures, Costs and Engineering Rules

The relevant engineering rules and costs assumed are detailed in Figure 1. There are fixed cost elements such as OXCs, End terminals and amplifiers, as well as variable cost elements such as add/drop transponders and regenerators, which vary with the number of lit wavelengths in the network. This form is part of an optical network design and optimisation tool implemented in Java. Figure 2 illustrates the arrangements of the network elements in a typical chain of nodes, for both the LH and ULH solutions.

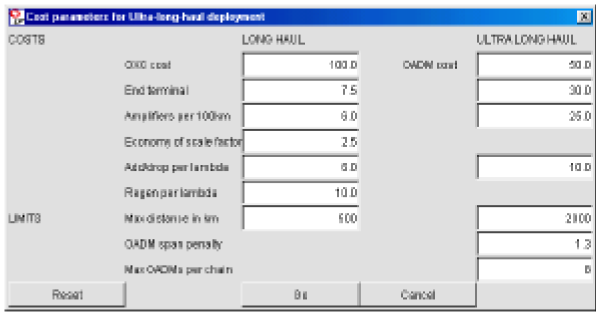

Figure 1 - Equipment costs and engineering rules

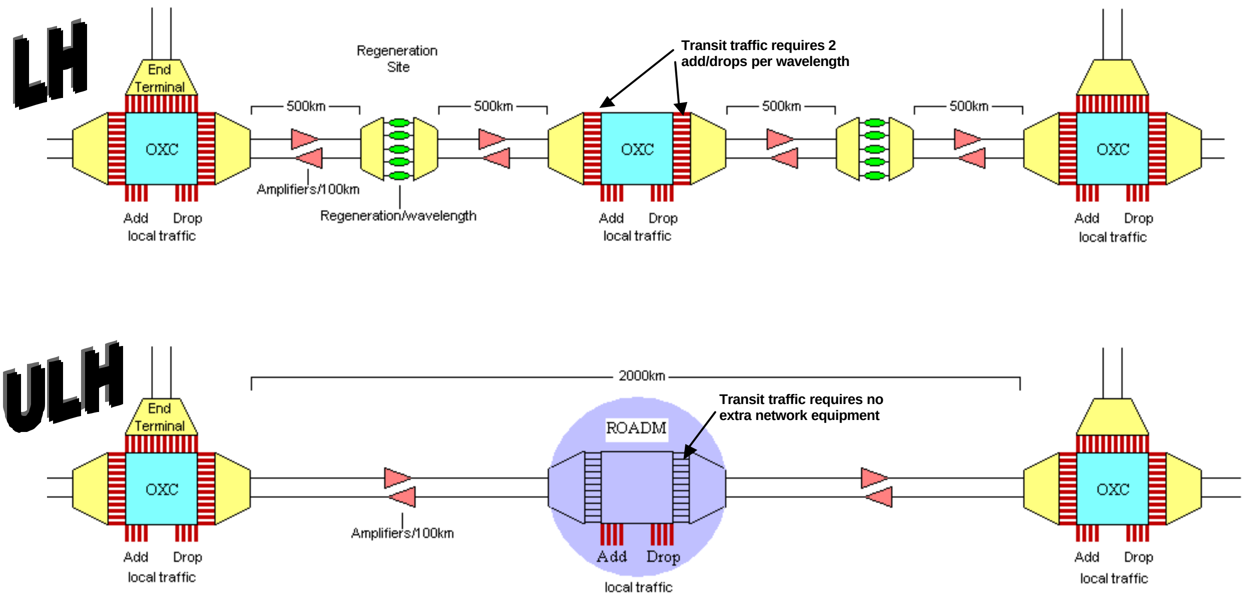

Figure 2 - LH and ULH architectures for a chain of nodes, with one intermediate node shown.

4. Results on two sample networks

The optimisation was performed on two different networks, both representative of national core networks, but of different scale. Figure 3 shows the two networks. One has 15 nodes, the other 45. Both have average node degrees of 2.8 candidate links per node. It is important to note that the process of topology optimisation may well decide not to use some of the candidate links if it is deemed cost-optimal to ignore some. The traffic pattern of wavelength demands is assumed to be a mix of three types of idealised traffic patterns, this results in an approximation to the real traffic patterns seen in circuit-switched core networks:

- 60% of traffic uniformly distributed
- 20% node to adjacent node traffic (between two nodes that share a candidate link)
- 20% hubbed from the topologically central node (representing a capital city) to all other nodes

Half of the traffic is assumed to require 1+1 path protection on a disjoint path, these demands are chosen at random.

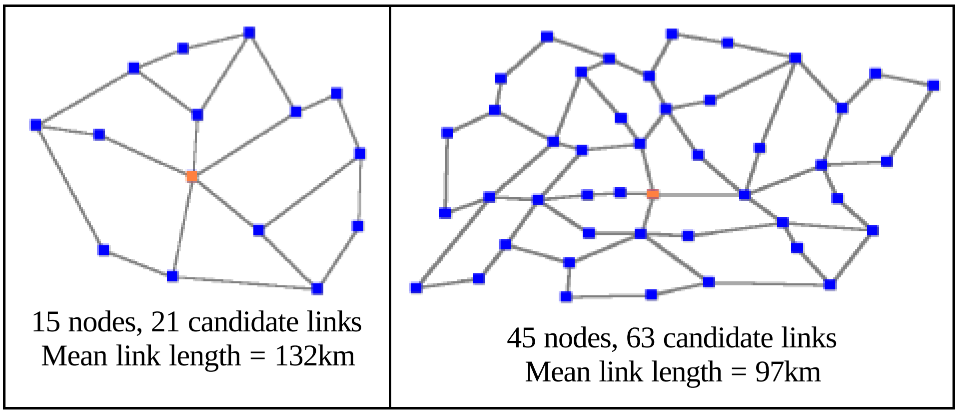

Figure 3 - Network topologies analysed

These networks have been analysed with variations in many different parameters of traffic, costs and engineering rules in [5] and [6]. In this paper the effect of one engineering rule parameter, the limit on the number of R-OADMs permitted in a chain, is assessed. This parameter shall be known as **MaxOADM** in the remainder of this paper.

Figure 4 shows the effect of varying the **MaxOADM** parameter on the lowest cost network solution found via optimisation on the 15-node network. For comparison, the total network cost is shown when only LH transmission and OXCs are considered available. The traffic was increased from 0 to 260 wavelengths networkwide. It can be seen that the higher the **MaxOADM**, the lower the cost of the optimal network design. This is because longer chains of nodes are allowed to form through the optimisation process, and these chains can take advantage of deploying R-OADMs at intermediate nodes. If **MaxOADM** = 2, this does not allow sufficient chains to form and the cost is the same as for a solely LH & OXC architecture, except at low traffic volumes of less than 60 wavelengths.

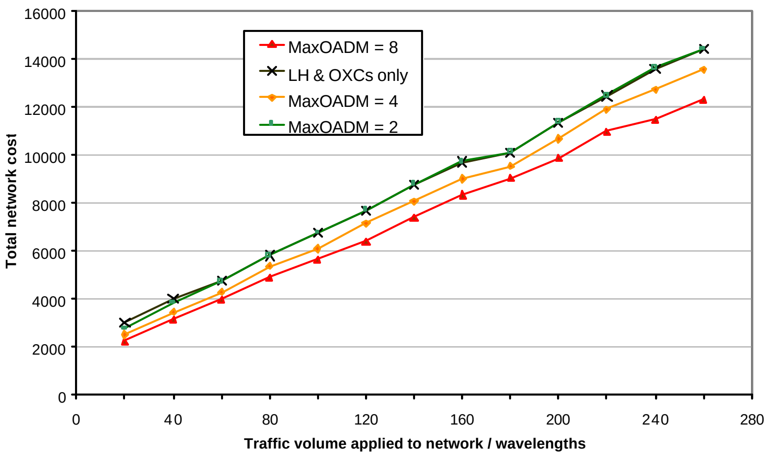

Figure 4 - Cost evolution for the 15-node network as the traffic volume increases. The parameter MaxOADM is varied from 2 to 8.

Figure 5 shows two key outputs from the optimisation process on the 45-node network as the traffic is increased, the resulting connectivity of the network design (**C**), and the proportion of OADMs in the network (**%OADM**). The highest **C** value possible is 2.8 when all links are used. If the optimisation process removes links to form chains with R-OADMs, then **C** will be lower than 2.8. The **C** value is much lower when long chains are permitted (**MaxOADM** = 8), with over ¾ of the nodes in the network being R-OADMs (the rest being OXCs).

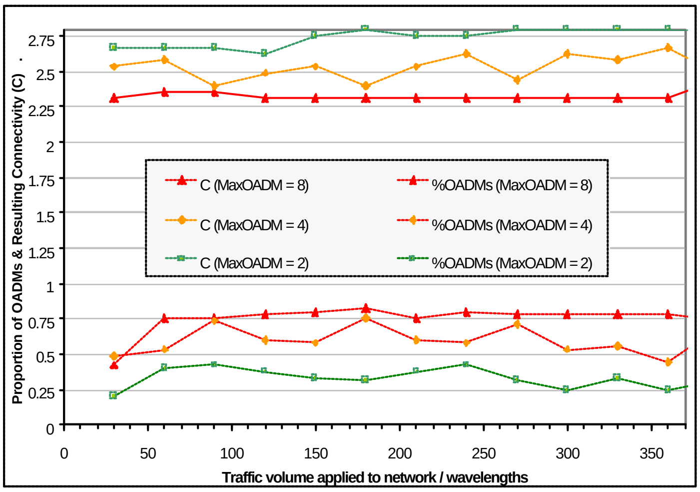

Figure 5 - Resulting connectivity (C), and proportion of OADMs in the 45-node network, against traffic volume as MaxOADM is varied from 2 to 8.

The results from Figure 4 and 5 suggest that lower connectivity topologies give lower cost networks using R-OADMs, given the cost assumptions indicated in section 3. However, there is a penalty for this cost benefit -- the average path distances for the traffic in the network increase since the demands are routed on more circuitous routes. Figure 6 indicates this tradeoff for the 45-node network, showing the path lengths as a scatter plot against connectivity **C**. The mean protection path distances are also shown for those demands requiring 1+1 protection. The protection path distances are especially sensitive to the connectivity, since these are usually the 2nd shortest path between the source and destination nodes. There are a number of implications of these increased distances, notably the increased propagation delay (relevant to both protection switching and TCP/IP throughput), and decreased demand availability.

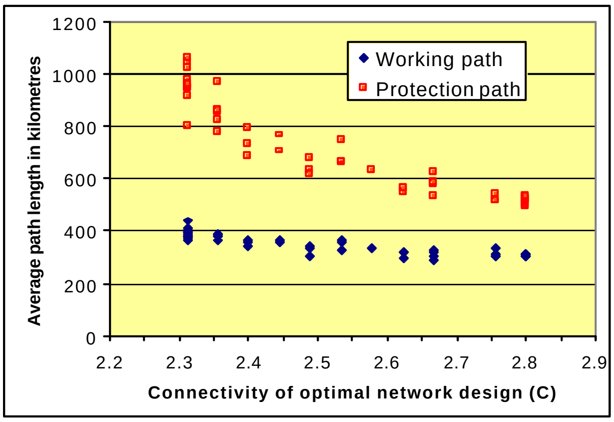

Figure 6 - Mean working and protection path distances increase as the resulting connectivity (C) decreases, for the 45- node network

5. Conclusions

This paper has introduced the new architectures made possible by Ultra Long Haul transmission and Reconfigurable OADMs. Optical transparency can be introduced along chains of degree 2 nodes in a national core network. The network economics determined through heuristic optimisation suggest that lower connectivity networks are more suited to this architecture. The engineering rules of the ULH transmission play an important role -- if the insertion loss of the R-OADMs is low enough to allow up to 8 R-OADMs in a single span (chain), then up to 80% of the network nodes can be R-OADMs. However, there is a tradeoff against the mean path distances for individual wavelength demands.

Acknowledgements

This work has been funded by EPSRC and Lucent Technologies through the Communications Engineering Doctorate centre at UCL.

References

[1] B. Doshi et al, 'OADMs in Optical Networks: Architecture and Algorithms', Proc. Networks 2002, June 23-27 2002, Munich, Germany.
[2] N. Geary, A. Antonopoulos, J. O'Reilly, J. Mitchell, 'Planning issues of linear chains in optical networks', Proc. LCS 2001.
[3] D. Corne, M. Oates, G. Smith (editors), *Telecommunications Optimization: Heuristics and Adaptive Techniques*, Wiley, 2000.
[4] W. Grover, J. Doucette, 'Design of a Meta-Mesh of Chain Subnetworks: Enhancing the Attractiveness of Mesh-Restorable WDM Networking on Low Connectivity Graphs', IEEE Journal On Selected Areas In Communications, Vol. 20, No. 1, January 2002.
[5] G. Bernidaki, forthcoming MSc in Telecommunications dissertation, UCL, September 2002.
[6] N. Geary, EngD thesis on Optical Network Planning, UCL, in preparation.