Planning issues of linear 'chains' in optical networks

Neil Geary §‡, Andreas Antonopoulos§, John O'Reilly‡, John Mitchell‡

§ Lucent Technologies, 103 Wigmore Street, London, W1Q 1QS.

‡ Communications Engineering Doctorate Centre, UCL, Torrington Place, London WC1E 7JE.

Abstract: The reasons why linear chains of nodes are becoming common in optical networks are outlined. Several equipment cost saving measures are introduced along with their associated planning rules and a guide to their applicability. These include 'express' routing of through traffic and the dis-association of WADM nodes.

1. Introduction.

Current optical backbone communications networks generally use SDH rings carried over a WDM transmission layer. The legacy of this ring-based transport has resulted in fibre topologies which are often quite sparse (average nodal degree less than 2.5). The economic realities of WDM transmission are that there are high economies of scale for optical line systems as the channel count grows, favouring topologies with fewer 'higher capacity' systems rather than many of 'lower capacity' [1]. Furthermore, Optical-Cross-Connect (OXC) based architectures utilising mesh restoration have been shown to be efficient even on low connectivity topologies [2, 3]. These factors indicate that many optical transport networks in the near to mid-term will still be based on sparse fibre topologies even though the survivability mechanisms employed are likely to be mesh-aware.

This is particularly evident in transcontinental networks where the cost of installing fibre over large distances is prohibitive, and for new-entrant national network operators for whom time to market is critical.

These low connectivity topologies often contain linear chains of nodes of degree 2. These chains can often reach a 'depth' of 5 intermediate nodes before meeting a node of degree 3 or more. Figure 1 illustrates an example. The equipment cost of carrying optical channels through multiple hops in the chain can be high. This paper will identify and analyse some of the practical network planning issues relating to these linear chains, with the goal of reducing the terminal and regenerator costs.

2. Linear chains of nodes

Each linear segment can be considered a separate sub-network with two egress nodes (IN and OUT) and therefore can be analysed independently of any others in a network. Therefore the optimisation of the chains can be carried out as a post-processing stage in the network planning process.

As networks are required to be survivable, it is normal that there are at least 2 node & link disjoint routes between IN and OUT, one of which being the chain itself. We define N as the depth of the chain, the number of intermediate nodes between IN and OUT.

It is assumed that the following information is available about the linear segment following the network planning process (routing, spare capacity allocation, optimisation etc.) See Figure 1.

- N = Depth of chain (no. of nodes)
- T*x* = Traffic terminating at the intermediate node 'N*x*' (channels)
- U*x* = Load on link 'L*x*' (channels)
- D = Distance between end nodes (km)
- P = traffic passing directly from IN to OUT (channels)

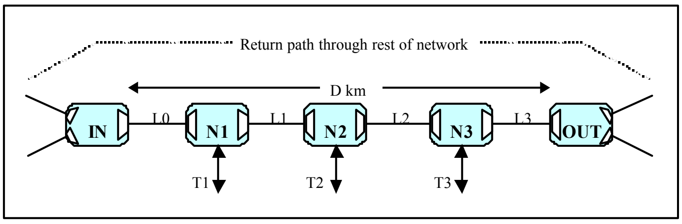


Figure 1 - Linear chain where N=3.

The internal wavelength switching architectures may be either fixed (using an Optical Distribution Frame), or reconfigurable via an OXC.

3. Full access nodes – express traffic

In this case we assume that each intermediate node contains 2 DWDM de-multiplexers and 2 multiplexers in order to carry bi-directional wavelength traffic on the 2 incoming fibres. These nodes can access any or all of the wavelength channels on the fibres and are called 'Ring terminals'. Wavelengths simply passing through the node along the chain require 3R regeneration, mainly due to the insertion loss of the demultiplexers.

Fig. 2 indicates the model used in this analysis for traffic flows.

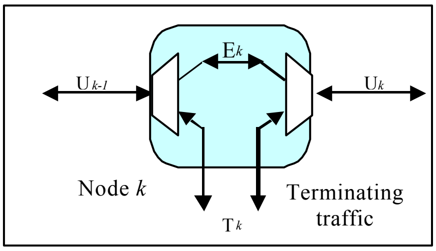


Figure 2 - Model of bi-directional channel flows at an intermediate node in a chain.

From Kirchoff's first law:

$$E_k = \tfrac{1}{2}\left|T_k - \left(U_{k-1} + U_k\right)\right|$$

The sum of the traffic passing through all intermediate nodes:

$$TOTAL = \sum_{k=1}^{N} E_k$$

represents the total number of regenerators required.

If the traffic which passes from IN to OUT directly is significant, then the cost of regenerating these channels at all of the intermediate nodes becomes prohibitive. The applicability of 'expressing' this traffic on a parallel line system must be investigated.

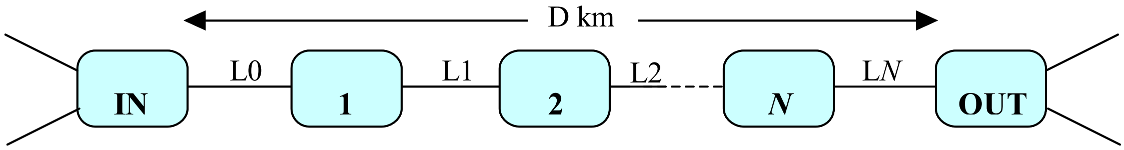
The number of regenerators required for the express traffic is $P.N$. If the ratio $P.N/TOTAL$ is close to 1, then the express traffic dominates and we would expect to save the majority of regenerators. Expressing this traffic would require an additional DWDM end-terminal at both IN and OUT nodes, amplification of the WDM signal along the path, and possibly the cost of laying the additional fibre if not already present.

Let D represent the distance between the IN and OUT nodes, and DMAX represent the maximum reach of the optical line system before regeneration is required (typically several hundred km).

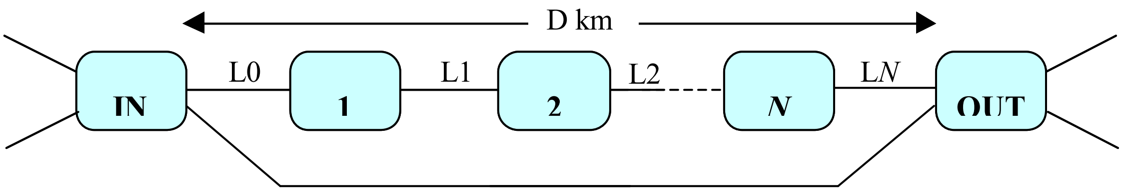
If $D < DMAX$:

If $\left(P.N.COST_{regen}\right) < \left(2.COST_{endterm} + COST_{laynewfibre} + COST_{amplifiers}\right)$

Then it is more cost-effective to use one fibre:



Else it is more cost-effective to use an express line system on a second fibre:

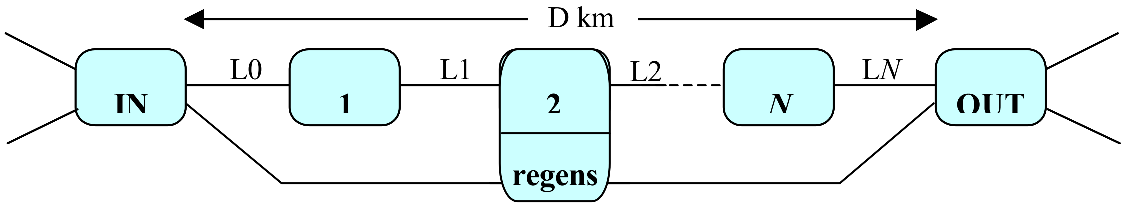


If $DMAX < D < 2DMAX$:

Now regeneration is required at a mid-point node since the single hop reach has been exceeded. This reduces the number of regenerators that might be saved by running an express line system, as well as the extra node equipment (a ring terminal) required:

$$\textbf{If } \left(P(N-1).COST_{regen}\right) > \left(2.COST_{endterm} + COST_{ringterm} + COST_{laynewfibre} + COST_{amplifiers}\right)$$

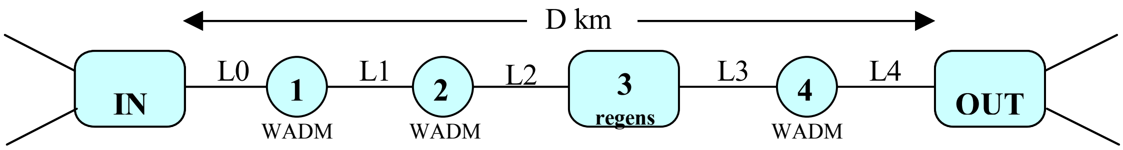
Then it is more cost-effective to use an express line system on a second fibre:



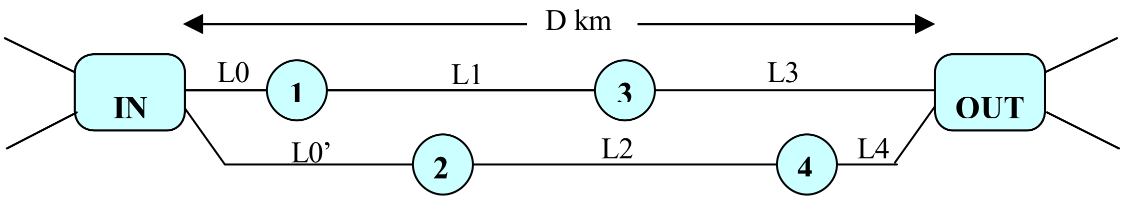
4. Partial access nodes – dis-association

Nodes in chains, that are not expected to terminate a large amount of traffic, may be considered for the use of Wavelength Add-Drop Multiplexers (WADMs). Access to a subset of the wavelengths is permitted with these devices which are cheaper than a full ring terminal. Regeneration is not performed in WADMs, as the non-terminating wavelengths are passively passed through. This means that there are distance-related constraints in the introduction of WADMs, yet they offer the ability to save regenerators compared to a full-access node. There are also limitations on the number of WADMs allowed in cascade due to the insertion loss.

In this example we assume $D < DMAX$, and that the number of WADMs permitted in cascade before regeneration is needed, MAXWAD=2. The number of nodes in the chain, N = 4.



A full-access node with regenerators is required at node 3 since preceding it there are two WADMs in cascade. If the through traffic is heavy at node 3, a large number of regenerators may be required. An express line system as in section 3 may be considered if the through traffic is in the main passing from IN to OUT directly. However, if the through traffic at 3 is caused by demands terminating at other nodes in the chain the dis-association of the chain nodes may be considered:



Now all of the nodes are partial-access and no regenerators are required, significantly reducing the node costs. However, an extra fibre is required with the associated amplifier costs. End terminals at IN and OUT are also needed.

For an N node chain where $D < DMAX$, the number of equally spaced full access nodes required for the single fibre solution, R, is: $R = \left\lfloor \frac{N}{MAXWAD+1} \right\rfloor$

The number of regenerators required is the sum of the number of channels passing through these R full access nodes:

$$TOTAL = \sum E_k \quad \text{for } k \text{ when node } k \text{ is a full access node}$$

The number of fibres, F, required for the disassociated solution is: $F = \left\lceil \frac{N}{MAXWAD} \right\rceil$

Therefore the dis-association method becomes cost-effective when:

$$\left(TOTAL.COST_{regen} + R.COST_{ringterm}\right) >$$
$$\left(2(F-1).COST_{endterm} + R.COST_{wadm} + (F-1).COST_{laynewfibre} + (F-1).COST_{amplifiers}\right)$$

However, this method will only be attractive when there is no traffic *between* the nodes on the different fibres, e.g. between nodes 1 and 2 above. If such local traffic is requested, the solution would be costly since these demands would have to be routed via IN or OUT.

If such localised traffic is expected, yet the express traffic is also high from IN to OUT, an express line system approach as in section 3 is recommended, especially for large N and when MAXWAD is low. For distance $D < DMAX$, this results in a line system for express traffic with no regenerators, and a line system for local traffic using WADMs and fewer regenerators (the latter tends to zero as MAXWAD equals or exceeds N).

5. Conclusions.

Equations have been developed that can be used when analysing linear chains in low connectivity networks. The applicability of express line systems and the dis-association of partial access nodes can be assessed.

While optical layer traffic levels are low, network operators will consider the use of partial access nodes in chains to save on equipment cost. Careful traffic analysis is required to determine the most cost-effective solution including the possibility of uncertainty in future traffic, and the minimisation of the perceived risks.

When express traffic levels are high, it is important to reduce as far as possible the regeneration costs incurred at intermediate nodes, since wavelength channels must be regenerated separately. As the traffic volume increases in optical networks it is expected that ‘expressing’ of traffic will become more commonplace, either through WADMs or by dedicated line systems. This is compatible with the trend for ‘managed reach’ network engineering -- on a per-demand rather than per-span basis. The continued development of Ultra Long Reach transmission technologies will benefit greatly these chains of nodes by increasing the maximum distance before regeneration is required.

Acknowledgments.

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