Optical Network Monitoring Cost Optimisation
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1 Introduction
We are interested in the diagnosis of faults in optical networks. Given observations of faulty behaviour in a network of fibre optic links and optical amplifiers, we seek to explain possible location(s) and type(s) of underlying causes.

Our initial focus has been on the optimisation of the placement of network monitors. Given a repair strategy for a particular diagnosis, a certain repair cost is incurred, related to its remaining uncertainty. Placement of optical network monitors can reduce this uncertainty: how best to place these, to minimise cost (number of monitors), and maximise performance (reduction in repair cost)?

2 The Problem
The optical network is represented as a graph (see below). The graph is loaded with bi-directional channel paths similar to those shown. There are two fibre links between each node and all channels travel in the same direction within a single fibre link.

- The network contains two node types:
  - Add-drop nodes \( \{N_1, N_2, \ldots \} \) of degree 2 or higher.
  - Regen nodes \( \{R_1, R_2, \ldots \} \) of degree 2.
- Nodes are connected by (acyclic) channel paths that begin and end at any two add-drop nodes.
- For every path there is an identical path following the exact opposite route, i.e. Path \( P_1 = \{N_1, N_2, R_1, R_2, N_3, N_4, N_5\} \) implies Path \( P_2 = \{N_1, N_2, R_2, R_1, N_4, N_3, N_5\} \).
- Any node of either type can be assigned a monitor.
- Each monitor has a device cost and an impairment coverage.

3 Terms and Relationships
- An impairment event is a failure occurring at a point along a link in a channel path.
- All channel paths in the link for which the impairment event point is located and going in the same direction will experience the impairment event.
- Impairments are always detected at the channel end points of any affected paths.
- Impairments only occur for one direction of a bi-directional path.
- The impairment will be present along the entire path downstream from the point at which the impairment first occurs, but not upstream from the event location.
- Impairment coverage of a monitor is the probability that if a channel path passing the monitor node has an impairment, then the monitor will detect the impairment.
- Each impairment has associated with it a repair cost, proportional to the distance between the first monitor site at which the impairment is detected at the last monitor site along the path before the impairment event location.
- The device cost is proportional to the impairment coverage.

4 Objectives
- In general the goal is to obtain the largest reduction in the average cost per impairment event for the smallest increase in monitoring device cost.
- An alternative approach, which we have implemented, is to hold either worst-case repair cost or total monitoring device cost fixed, while we optimise the other.

5 Implementation and Experiments
We have implemented a generic approach to optimise either monitor placement a given worst-case repair cost, or vice versa. Our solution is implemented in ILOG OPL Studio, with real-world network data supplied by Bell Labs.

In the following figure we show an example real-world network topology showing the optimal placement of a pair of monitors, with 100% impairment coverage, to achieve minimum worst-case repair cost. In this figure coloured lines represent bi-directional channels and the red nodes represent monitoring nodes.

Based on this, and other networks we have run experiments based on optimising monitor placement and the number of monitors, depending on the problem we wish to study (a demo is available). Below we present results for two network topologies.

6 Conclusions
1. Our approach is novel in the area of optical network monitoring and repair cost optimisation - we perform a complete optimisation.
2. Our approach is a clear example of the utility of combinatorial optimisation methods in the area of optical networks.
3. We will study the more general problem in which we reason about probabilistic faults, monitor coverage, fault types, monitor types, etc.
4. An interesting direction for future work will be to study how the evolution of the network affects monitoring and repair costs.
5. The work we have done here forms the basis of an intelligent network design solution for optical networks.