Impact of Wavelength Route Correlation on the Optimal Placement of Optical Monitors in Transparent Mesh Networks

Alex Ferguson (1,2), Barry O'Sullivan (1,2), Dan Kilper (3)
1 : Cork Constraint Computation Centre, University College, Cork, Ireland, {a.ferguson,b.osullivan}@4c.ucc.ie,
2 : Centre for Telecommunications Value-chain Research, Ireland,
3 : Bell Labs, Alcatel-Lucent, New Jersey, USA dkilper@alcatel-lucent.com

Abstract

Wavelength route correlation is considered for optimal monitor placement in transparent networks. The associated reduction in monitoring requirement is studied as a function of repair cost and traffic loading.

Introduction

Reduced signal regeneration in transparent networks has the consequence of reducing signal performance monitoring and increasing the range over which optical signal impairments can propagate. The cost of isolating faults that do not trigger component alarms, for example due to incorrectly configured dispersion compensation modules, is expected to scale with the size of these transparent regions. This new challenge in transparent networks has brought focus to optical performance monitoring (OPM) in order to recover fault management functionality in the physical layer [1]. For this application, OPM is used to selectively monitor the optical signal quality along the propagation path in order to effectively reduce the size of transparent regions. Recently we studied the optimisation of monitor placement with respect to reducing the transparent path length between monitoring sites [2]. This approach starts with the assumption of perfect monitoring and explores the impact of topology and traffic on the monitor placement strategy. Whereas previous work primarily focuses on the details of the physical layer impairments and their implications on monitor design and application [1,3], here we study the dependence of the monitor placement optimisation on the wavelength filling for regular graphs. We exploit the fact that in transparent networks one has the potential to use knowledge of the wavelength routes to correlate monitor alarms generated along overlapping light paths. We show that the benefit of this method varies with the traffic loading and, under certain conditions, can lead to dramatic reductions in the required number of monitors for a given maximum transparent path length constraint.

Method

As previously [2], the repair cost is given by the effective transparent path length, which is the number of un-monitored links around a fault location along the impacted lightpaths — representing the fault location uncertainty due to transparency. We optimise to avoid the worst case or maximum repair cost. However, rather than taking into consideration only a single alarm on one channel, for wavelength route correlation we assume the availability of information about the presence *or absence* of alarms on *every* channel. Starting from the ideal case, a fault on a link is assumed to generate alarms for all channels propagating through that link. Accordingly, the repair procedure requires inspection only on those network edges in the transparent region for each correlated *set* of channel alarms indicating a given fault. This decreases the number of edges for a given fault involved in the repair operation, and thus the repair cost, and the corresponding size of the transparent region. In order to bound repair cost, monitors are placed to ensure a maximum transparent path length by generating a set of constraints, and optimising these via *integer linear programming*.

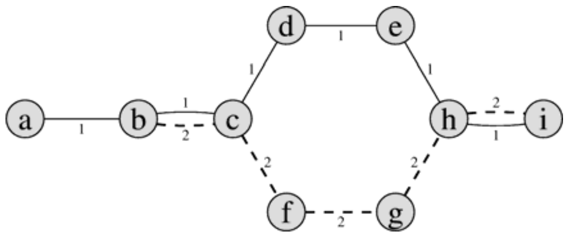

Figure 1. Faults between nodes b and c will generate alarms on channels 1 and 2. Correlating alarms isolates the fault to links (b,c) or (h,i).

Example: In Figure 1, we have two channels, 1, from node *a*, to node *i* via the path *(a, b, c, d, e, h, i)* and 2, from *b* to *i* via *(b, c, f, g, h, i)*. With no correlation, any alarm on channel 1 corresponds to a transparent path of length 6, and will have accordingly a worst-case repair cost of 6, and any alarm on channel 2 will have a worst-case repair cost of 5. The correlated alarm state {1}, that is where an alarm exists on *only* channel 1, corresponds to the transparent region *{(a,b), (c,d), (d,e), (e,h)}*; the state {2} to *{(c,f), (f,g), (g,h)}* and {1,2} to *{(b,c), (h,i)}*. With no optical performance monitors, faults on each of the {1}-state edges have a repair cost of 4, {2} a repair cost of 3, and {1, 2} a repair cost of 2. If a monitor is placed on node *c*, the repair costs for each of the edges between *c* and *h* become 3, while all other costs are reduced to 1.

978-1-4244-2229-6/08/$25.00 ©2008 IEEE

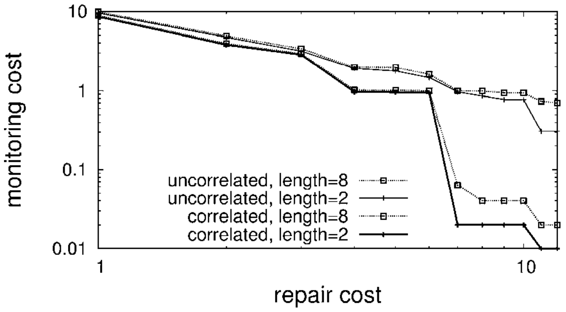

Figure 2. Optimisation curves demonstrating reduced monitoring cost from wavelength route correlation in a regular degree 4 network.

Empirical Evaluation

A range of uniform demand, regular networks with variable mean degree and traffic loading [2] were used to compare uncorrelated and correlated procedures. Shown in Figure 2 are results for a medium-loaded mesh network (30 biconnected add-node nodes, with 3 and 6 optical amplifiers per A/D hop), showing a maximum repair cost (size of unmonitored transparent region) plotted on a log-log graph, against monitoring cost (number of monitors placed), with hop lengths per wavelength varying across the set {2,4,6,8}, averaging over 10 random loading instances. Repair cost is the maximum size of transparent paths in the network, and monitoring cost is the number of monitors normalized by the network size in add-drop nodes (30 for all cases).

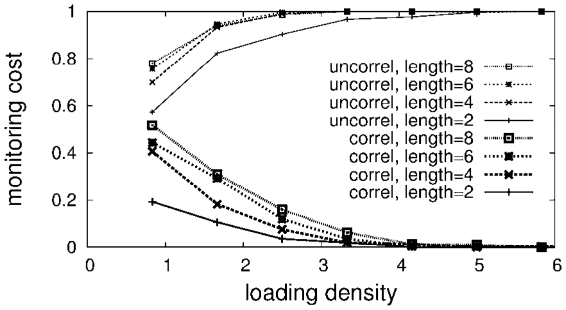

Figure 3: Dependence of monitoring cost on loading density for a maximum repair cost = 7 links.

The route-correlated curves are systematically below their uncorrelated counterparts, indicating a significant reduction in monitoring cost. Furthermore, the correlated cases deviate from the inverse relationship (linear on log-log plot) observed previously for the uncorrelated cases [2].

Different loading parameters bore out the same pattern, but we also observed a variation in the separation between the two sets of curves. To examine this more systematically, we produced a set of plots in which we hold maximum repair cost constant for each graph, and vary demand loading. In Figure 3, the maximum repair cost is 7, and the loadings are varied up to the maximum predicted to be saturated due to wavelength blocking. Network loading is given as the average number of distinct demands on each add-drop node interconnection.

For the uncorrelated alarm cases, increasing the number of channels increases the required monitoring, as expected, until a monitor is placed on every add/drop node and the repair cost of r = 7 is satisfied regardless of loading. With wavelength route correlation, heavier loading enables better fault isolation through greater scope for correlation. For this repair cost, which is equal to the maximum add-drop node separation (including intermediate amplifier nodes), no additional transparent monitoring is needed to adequately isolate faults once the network is sufficiently loaded.

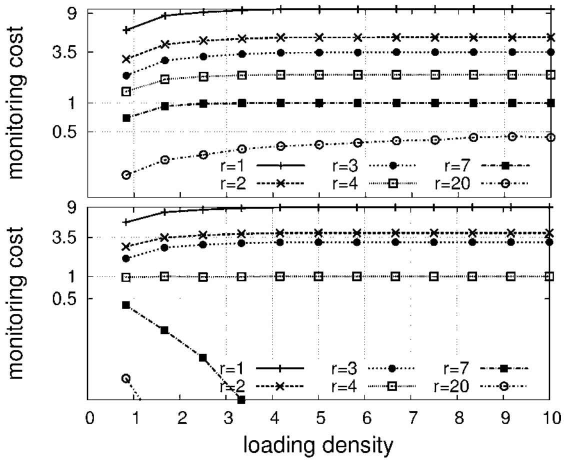

Figure 4. Loading density dependence for a hop length of 4 and different repair costs (a) with no route correlation, (b) using route correlation.

In Figure 4, the hop length is fixed to 4, and loading density and maximum repair cost are varied. For repair costs less than the add-drop node distance, correlation alone cannot isolate faults sufficiently and therefore, the correlated alarm curves tend toward a finite heavy loading asymptote related to the topology, such as multiples of add-drop nodes.

Conclusions

The potential for wavelength route correlation to enable dramatic reductions in the transparent network monitoring requirement for a cost tied to the transparent path length has been demonstrated. This benefit was shown to depend on wavelength filling and the desired maximum repair cost.

Acknowledgement*:* This work was supported in part by Science Foundation Ireland, grant number 03/CE3/I405.

References

1. D. C. Kilper, et al., J. Lightwave Technol. 22, 2004, 294.
2. Alex Ferguson et al., OFC/NFOEC 2008, OThI3.
3. C. Mas et al., IEEE J. Sel. Areas Commun. 23, 2005, 1508.