Dimensioning of Multi-Granular Optical Networks

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Abstract

We present an ILP model for dimensioning optical networks that support wavelength and sub-wavelength switching. Results indicate significant reductions in cost and node-complexity with such multi-granular networks.

Introduction

Future networks will likely consist of some form of all-optical networking, implying data remains in optical form end-to-end. An apparent difficulty is that a single infrastructure must support a wide range of application requirements and their associated connection constraints. It is however well known that performance can become unacceptable when the switching granularity is insufficiently adapted to the traffic demands. An example is sending burst or packet-sized data on wavelength-granular switches. We therefore propose to offer switching at wavelength (circuit) and sub-wavelength (burst or even packet) level, a concept generally referred to as multi-granular switching.

Previous work has demonstrated that multi-granular optical switching can improve bandwidth utilization. In this paper, we explore the possible cost and complexity savings when multiple switching technologies are incorporated, and compare them to more traditional, single-technology solutions. To this end, we propose a dimensioning algorithm to optimally install switching ports in the network. Results are presented to investigate total installation cost and node complexity of the network infrastructure.

Multi-Granular OXC

An essential device is the multi-granular optical cross-connect (MG-OXC). This device is in general composed of several different switching fabrics to support a wide range of switching speeds. In [1], the authors describe the design and architecture of an MG-OXC based on the combination of a slow and cheap MEMS-based switching block, and a fast but expensive SOA-based switching fabric. A number of key design choices are identified, and their effect on scalability and reconfigurability are studied. Of special importance for the study presented in this paper, is the distinction between a sequential and a parallel MG-OXC design. In brief, in the parallel approach, switching blocks are placed in parallel, which offers good performance with respect to scalability. The sequential approach, on the other hand, connects the output of slow switching fabric to the input of the fast switching block. In this way it becomes possible to reconfigure which wavelengths have access to the fast switching block, at an increase in number of slow switching ports.

Furthermore, in [2] we have studied the performance behaviour of a single OXC through simulation, and showed that even a small number of fast and expensive wavelength ports are sufficient to provide significant performance improvements.

In this paper, we present an ILP-based algorithm to dimension a network composed of MG-OXC, by incorporating the price ratio of fast over slow switching fabrics.

Network Design Model

Suppose the network is defined by the directed graph G(V,E), V the set of nodes, and E the set of directed links. Each wavelength has a fixed bandwidth B, identical for all links and wavelengths. Traffic between source s and destination d is represented by Δ_{sd}, and C is the cost ratio of fast over slow switches. Finally, the possible paths between source s and destination d are determined in advance, and captured by the boolean parameters $\pi_{pl}^{sd} = 1$ iff link l is part of path p between source s and destination d, 0 otherwise.

Furthermore, the following variables are introduced:

- $\delta_p^{sd} = 1$ iff demand (s,d) uses path p, 0 otherwise

- $\varepsilon^{sd} = 1$ iff demand (s,d) is switched fast, 0 if slow

- integer variables x_l and y_l, representing the number of slow and fast wavelengths on link l

We now state the problem as a non-linear model, in which the last constraint ensures that only single-path routing is used between source and destination.

$$\forall (s,d), p : x_p^{sd} \geq \Delta^{sd} \delta_p^{sd} (1 - \varepsilon^{sd})$$

$$\forall l : x_l = \sum_{sd} \sum_p \pi_{pl}^{sd} x_p^{sd}$$

$$\forall l : y_l \geq \sum_{sd} \sum_p \pi_{pl}^{sd} \Delta^{sd} \delta_p^{sd} \varepsilon^{sd}$$

$$\forall (s,d) : \sum_p \delta_p^{sd} = 1$$

It follows from variables x_l that the number of slow ports on node n are $x_n = \sum_m x_{(m,n)} + x_{(n,m)}$ (and similar for y_n). Finally, the objective is to minimize the total installation cost of the network: $\min \sum_l (x_n + C \cdot y_n)$. An alternative objective is to minimize the cost (and thus complexity) of the individual nodes: $\min z$ where $z \geq x_n + y_n, \forall n$.

A linearization of the model can be obtained by the following observation: $\delta_p^{sd} \varepsilon^{sd} = \delta_p^{sd} + \varepsilon_p^{sd} - 1$, enforcing that $\delta_p^{sd} + \varepsilon_p^{sd} \geq 1$, and substitution of variables ε^{sd} by ε_p^{sd}.

Note that this model captures two related scenarios in which either only slow or fast only switching is used. Indeed, in case $\varepsilon^{sd} = 0$, all demands will be served by a slow only connection (i.e $y_l = 0$). Likewise, in case $\varepsilon^{sd} = 1$, only fast ports will be used ($x_l = 0$). In both cases, the problem is reduced to an ILP model.

Furthermore, in its current form, only the parallel MG-OXC design is modelled. To differentiate between the parallel and sequential MG-OXC approaches, the number of slow ports in the latter case is given by $x_n^* = x_n + 2\sum_m y_{(m,n)}$, which corresponds to the allocation of an additional slow port for each fast port that is introduced in a cross-connect.
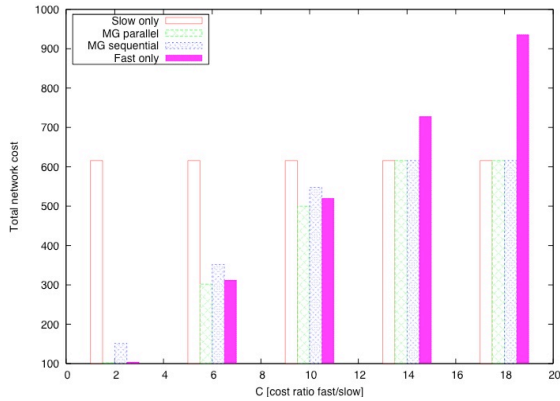

Figure 1 : Optimized total network cost

Results

The ILP model was implemented and solved using the ILOG CPLEX library. The Phosphorus topology, consisting of 13 nodes 42 bidirectional links, was used. Traffic was generated uniformly between all node-pairs, and used on average 5% of the bandwidth offered by a single wavelength.

The first experiment shows the total network cost for varying values of fast/slow cost ratio C (Figure 1). An initial observation is that for low values of C, both fast only and the multi-granular approaches achieve much lower installation costs than slow only. At a value of C = 14 however, the multi-granular design returns identical solutions to the slow only approach. At the same time, networks consisting of fast only OXCs see dramatic increases in installation cost. Also note that the MG sequential approach only slightly increases network cost when compared to MG parallel.

The following result (Figure 2) shows the network installation cost for different C values, optimized for minimal node cost. Now, the multi-granular approaches can have a higher network cost than slow only to obtain reduced complexity of individual nodes. For the same reason, MG sequential can now achieve lower network cost compared to MG parallel.
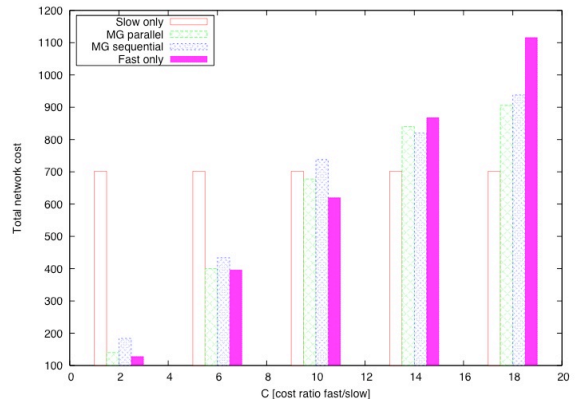

Figure 2: Total network cost optimized for minimal node complexity

Conclusions

Multi-granular optical switching is a promising technique to support end-to-end optical data transfers for a wide range of application requirements. In this paper, we presented an ILP model for network design with either optimal total cost or node complexity. Results indicate the potential cost savings possible when using multi-granular switching when compared to slow or fast only switching.

References

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