Static Lightpath Routing in IP over WDM Networks

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Overview

- Motivation and Introduction
- Node and Network Models
- Solution Approach
- Finding the Virtual Topology
- Wavelength Assignment
- Graph Coloring
- Case Study
- Results
- Conclusions
Exponential growth of IP backbones

log traffic

data

voice

2000

time

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Motivation

- IP fiber backbones - usage of WDM:

  - Optical crossconnects (OXC)s interconnect IP routers by lightpaths
  - No intermediate multiplexing layers (e.g., SDH, ATM) ⇒ less administration, fixed capacities per lightpath
  - Aim: determine efficient (static) configuration of the lightpaths for IP router demands, i.e. find an optimal
    - virtual topology for IP and
    - a routing and wavelength assignment (RWA)
{N,F,P}-WC = {Non, Full, Partial}-Wavelength Converting
The Entire Problem

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<th>Main Characteristics</th>
<th>Flow Formulation</th>
<th>Route Formulation</th>
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<td><strong>IP Layer</strong></td>
<td>+ Unknown virtual topology</td>
<td>+ Path constraints</td>
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<td></td>
<td>− Metric assignment</td>
<td>− Path pre-selection</td>
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<td><strong>WDM Layer</strong></td>
<td>+ Partial conversion</td>
<td>+ Path constraints</td>
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<td></td>
<td>− Long computation time</td>
<td>− Wavelength constraint</td>
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Large problem $\Rightarrow$ approach: consider subproblems

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Network Model IP over N-WC WDM

- OXCs are interconnected by fiber pairs (wavelength constraint)
- OXC are connected to at most one IP router (source and sink for least one lightpath)
- Transponders or colored interfaces
- No wavelength converters present (wavelength continuity constraint)
- Shortest path based IP routing protocols (e.g., OSPF)
- Equal IP routing metrics (e.g., all 1)
Whole problem becomes too complex (let alone RWA)
⇒ subproblems solved each by heuristic algorithms:
- Objective: minimize laser sources (significant cost factor)
- Virtual topology: minimize virtual links (and thus laser sources)
- Routing of lightpath demands: shortest path (keeps fiber usage and lightpath lengths low)
- Assignment of wavelengths: graph coloring problem (even minimization of number of wavelengths)
Finding the Virtual Topology

Bandwidth Demands  \( G_v = G_d \)

Calculate used Link-Bandwidth using Shortest Path Routing

Find (next) Link \( L \) with min. used Bandwidth

By deleting Link \( L \), Constraints violated?

\[ G_v = G_v \setminus L \]

\[ G_v = G_v \]

Aim:
find virtual topology with minimum number of links such that bandwidth demand is carried

Further constraints:
- link capacity
- maximum number of hops (keeps IP packet delay low)
- maximum amount of transit traffic through an IP router (avoids overwhelming of routers and reduces IP packet delay)
Wavelength Assignment and Graph Coloring

Network example:

Corresponding path graph:
Graph Coloring Algorithm

Aim: assign colors to the path graph nodes such that
   • adjacent nodes do not have the same color
   • the number of used colors is minimized

Algorithm:
Degree of Saturation (DSATUR) heuristic

“Degree of saturation:” the number of colors that are not allowed for a node (adjacent nodes have already obtained these colors)
Case Study

NSF network with 14 nodes (node: IP router plus OXC) and 21 links (fiber pairs)

Bit rate capacity of a wavelength: 10 Gb/s

Traffic matrix: scaled such that entry with maximum value equals 10 Gb/s (total network load: 120 Gb/s)
Results: Dependence of Allowed IP Hops

⇒ 2-3 hops: already reasonable results

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Results: Dependence of Allowed Transit Traffic

Traffic matrix: full mesh demand with demand-pairs of 1 Gb/s

⇒ heuristic nature of the virtual topology algorithm
Restrictions can be used to obtain result alternatives.
Conclusions

Static lightpath routing in IP over WDM networks:

- Finding a virtual topology for the IP layer
- Routing and wavelength assignment on the WDM layer

The results of the heuristic algorithm approach show:

- The simple heuristic for virtual topology produced already reasonable results
- DSATUR algorithm for the graph coloring performed well
- Due to heuristic approach: short execution time

Further information: http://www.transinet.de/