Traffic Grooming in WDM Networks with Multi-Layer Switches

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WDM network model

Network \( G=(V,E) \)

- Fiber
- (Wave)Band
- Wavelength
WDM network problem

Traffic demands:
Functional model of nodes

Input fibers

F-OXC

Output fibers

B-OXC

W-OXC

drop | add

demux fiber → band

mux band → fiber

input | output

drop | add

demux band → λ

mux λ → band

input | output

drop band | drop λ

add band | add λ

drop fiber

add fiber
Layered WDM network model

Node cost: function of the OXC’s degrees

Capacity: $W=1$, $B=2$, $F=2$

Closed fiber

Open fiber

G: physical net.

D: lightpaths
Pipe definition

- A continuous path within the same optical layer
- Recursive definition
  - A pipe in layer $i$ is a sequence of pipes in layer $i+1$
- Example
Grooming problem

- **Input:**
  - set of potential priced pipes candidates for being used at layer $i+1$
  - set of unitary demands: pipes in layer $i$

- **Output:**
  - A *min-cost* pipes set of layer $i+1$ that can transport pipes of layer $i$ subject to capacities constraints

- Defined over two layers only: multi-stage grooming if \#layers > 2 (iterate)

- Simple model compare to the complete detailed ILP formulation, but:
  - Flexible cost objective function and cost for pipes that could be adapted to real cases
Grooming problem complexity

- The set of elementary dipaths in the network may have exponential size, but a lot of these are useless:
  - Use sub paths of demands routes only
    (A dipath of size $d$ has at most $(d(d+1))/2$ subdipaths)

- Example:

**Demands:**

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
</table>

**Pipes:**

Useless!
ILP complexity

- Notations:
  - $L$ is the maximum length of a path
  - $r$ is the number of demands
  - $p$ is the number of pipes
  - $m$ is the number of edges

- # equations: $O(pL^2)$
- # variables: $O(r(m+p))$

This is polynomial but still large

$\rightarrow$ How can we reduce it?
Large demands & split number

- Use weighted instead of unitary demands
- Allows splitting in a maximum number of parts
- Perform also greedy grooming by respect to the pipe size

4 demands of size 4:
and 1 of size 8:

Pipes (c=8):
Pipes filtering

- Decreases the number of potential pipes: suspect long pipes (waste capacities + integer/real numbers issues)

This pipe should not be selected!

Use of a grade system for pipe filtering (LxSize)
ILP performances

The improved ILP program raise good and quite fast solutions on our test bed

We also propose a fast greedy algorithm based on the grade of pipes (a feasible solution should exists with all pipes lengthen to 1, i.e. no grooming at all)
Numerical results

Implementation: CPLEX/C++ within the cadre of RNRT PORTO (French funding ALCATEL/France Telecom R&D/INRIA)

Experimentation:
COST239, French optical backbone (FT R&D), rings, grids ...
Cost function for pipes

- Each pipe has a capacity and a cost:
  \[ \text{Cost}(p_i) = \alpha_i + \beta_i n \]  in our tests

Special case: \( \beta_i << \alpha_i \)

(minimize \# pipes)
\[ \alpha / \beta \text{ tradeoff} \]

Average length of pipes

20 nodes cycle

French optical backbone (20 nodes)

\[ \beta \quad (\alpha = 100) \]
$\alpha / \beta$ tradeoff

- Total number of pipes
- Used bandwidth

- French optical backbone (20 nodes)
- 20 nodes cycle, ATA

$\beta$

$(\alpha = 100)$
Filtering

Cost

Threshold
Conclusion

- Accurate and general model for grooming in layered networks
- Efficient solutions with ILP or heuristics for real case studies
- Perspectives:
  - Mixing routing AND grooming
  - Approximation algorithms for specific instances
  - Experimental studies of the grading technique
  - Pipe selection and generating columns in the LP