Traffic Grooming in WDM Networks with Multi-Layer Switches

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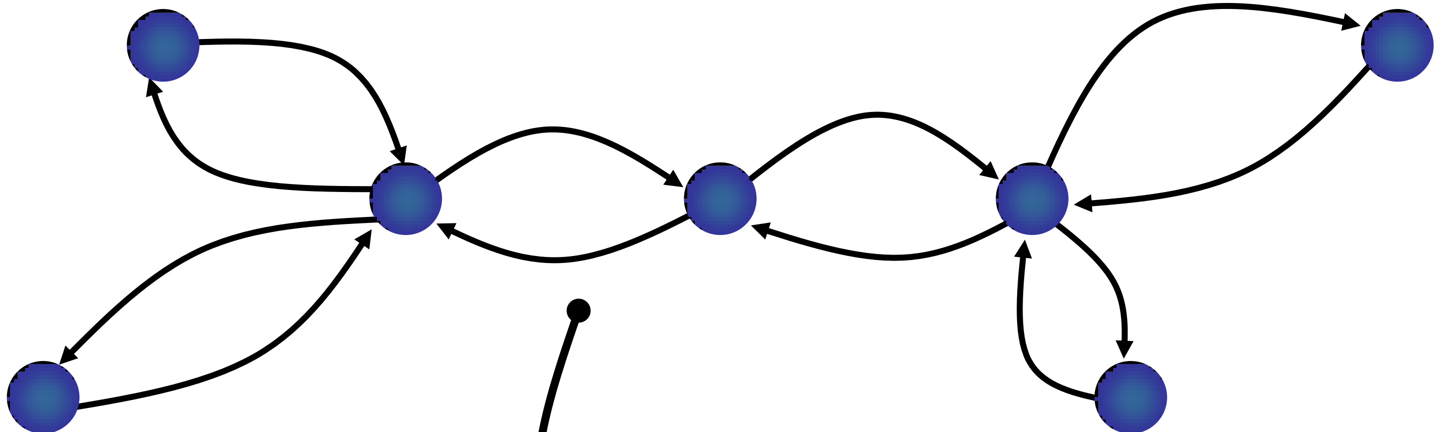
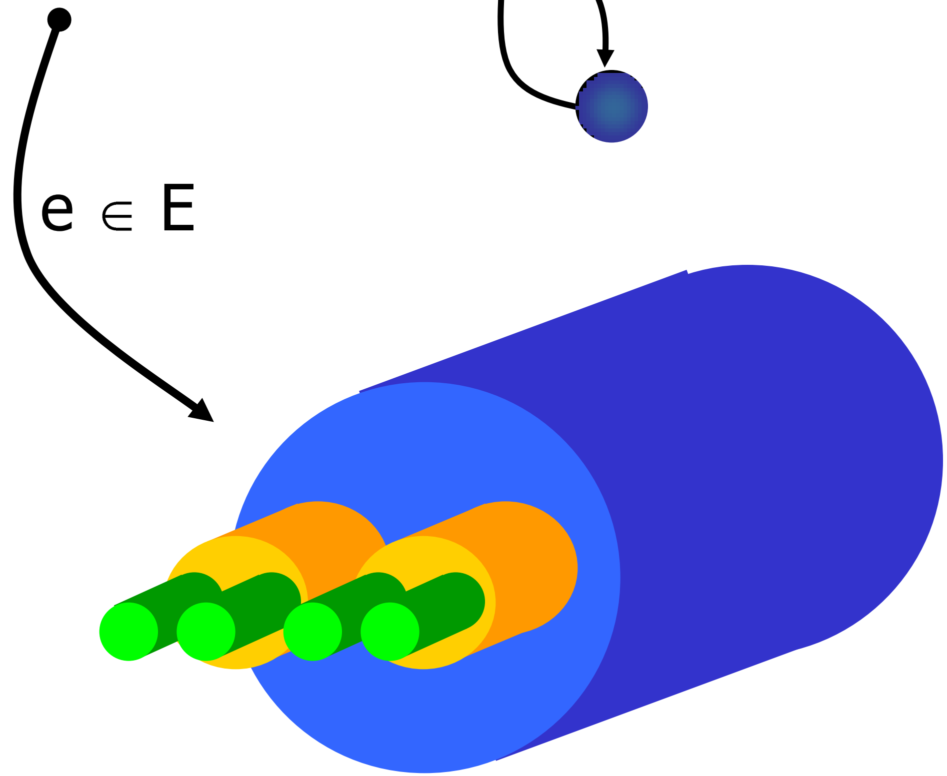
WDM network model

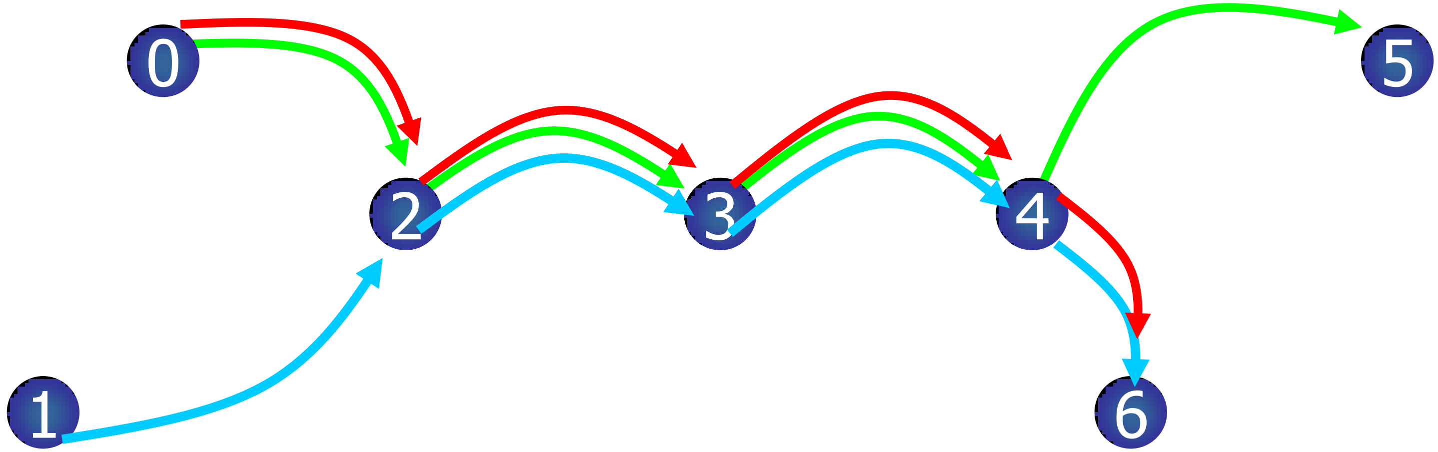


Network G=(V,E)

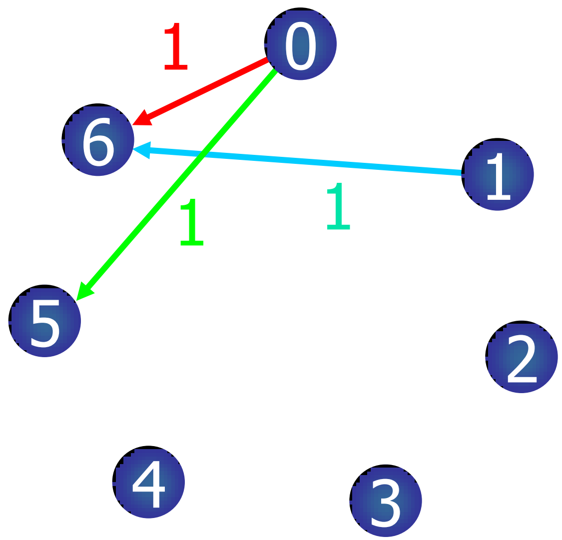


- Fiber
- (Wave)Band
- Wavelength

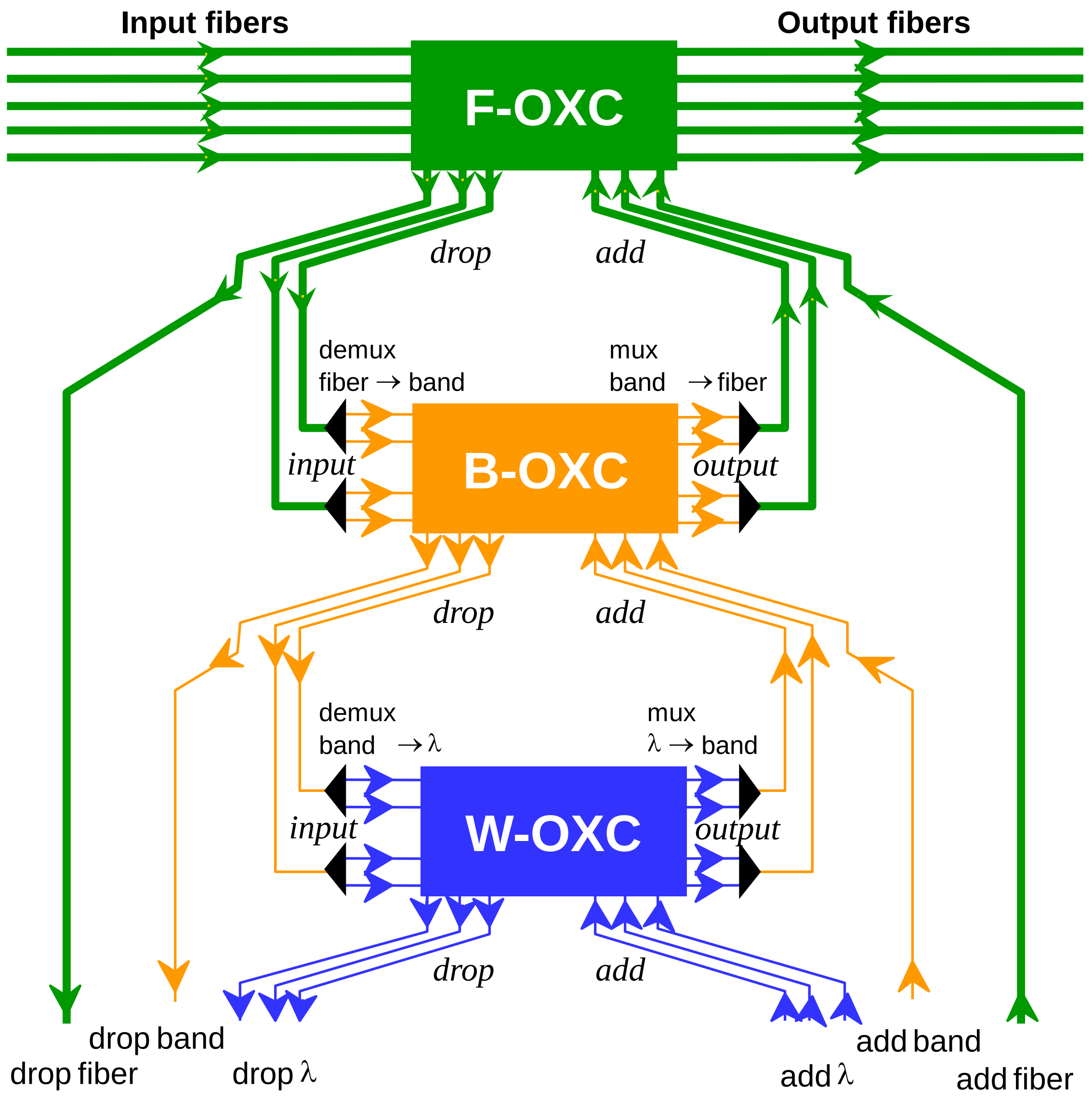
WDM network problem



Traffic demands:



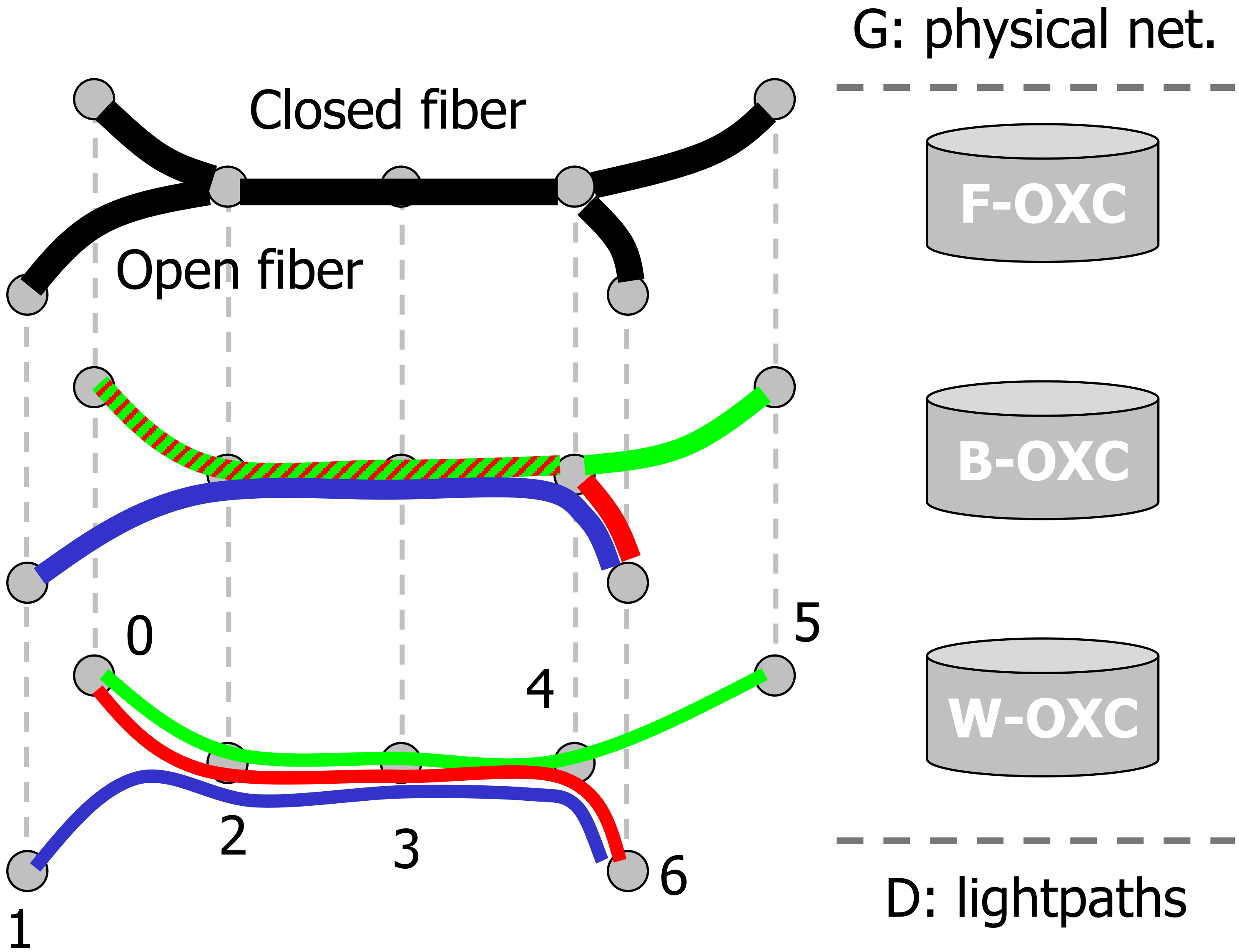
Functional model of nodes



Layered WDM network model

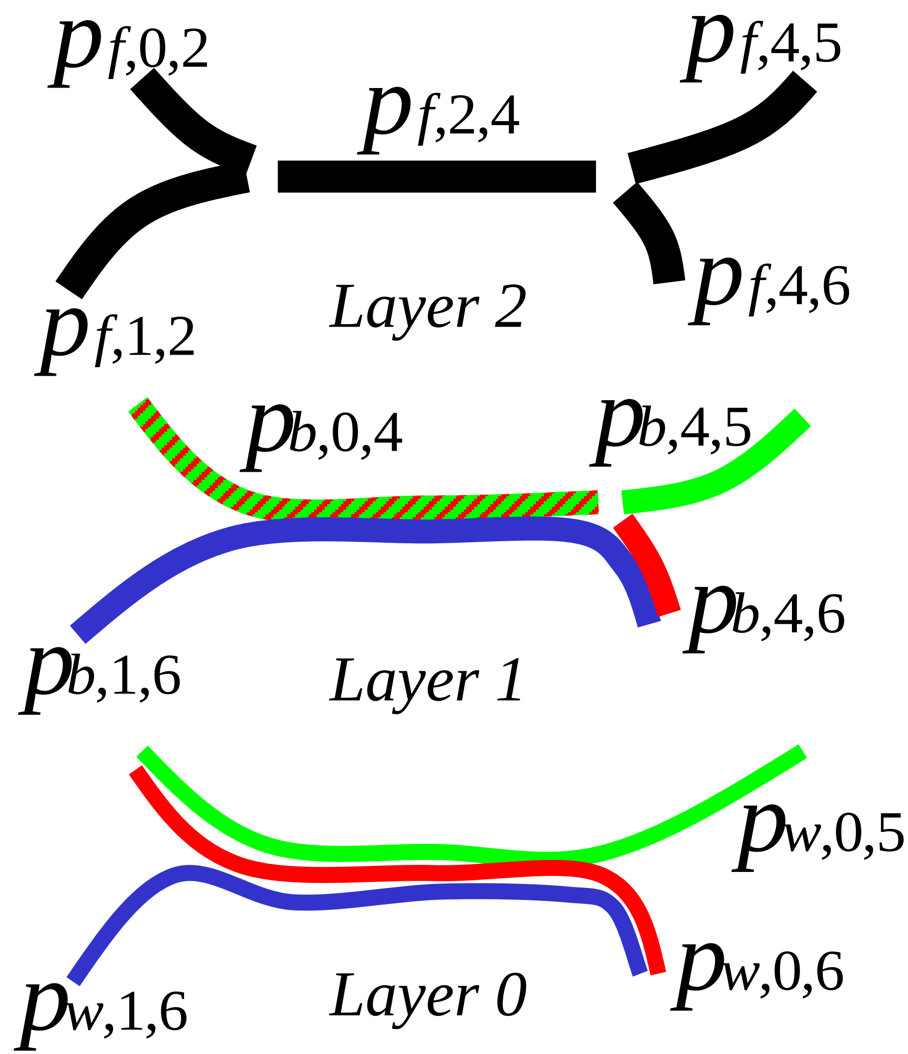
Node cost: function of the OXC's degrees

Capacity:
W=1
B=2
F=2



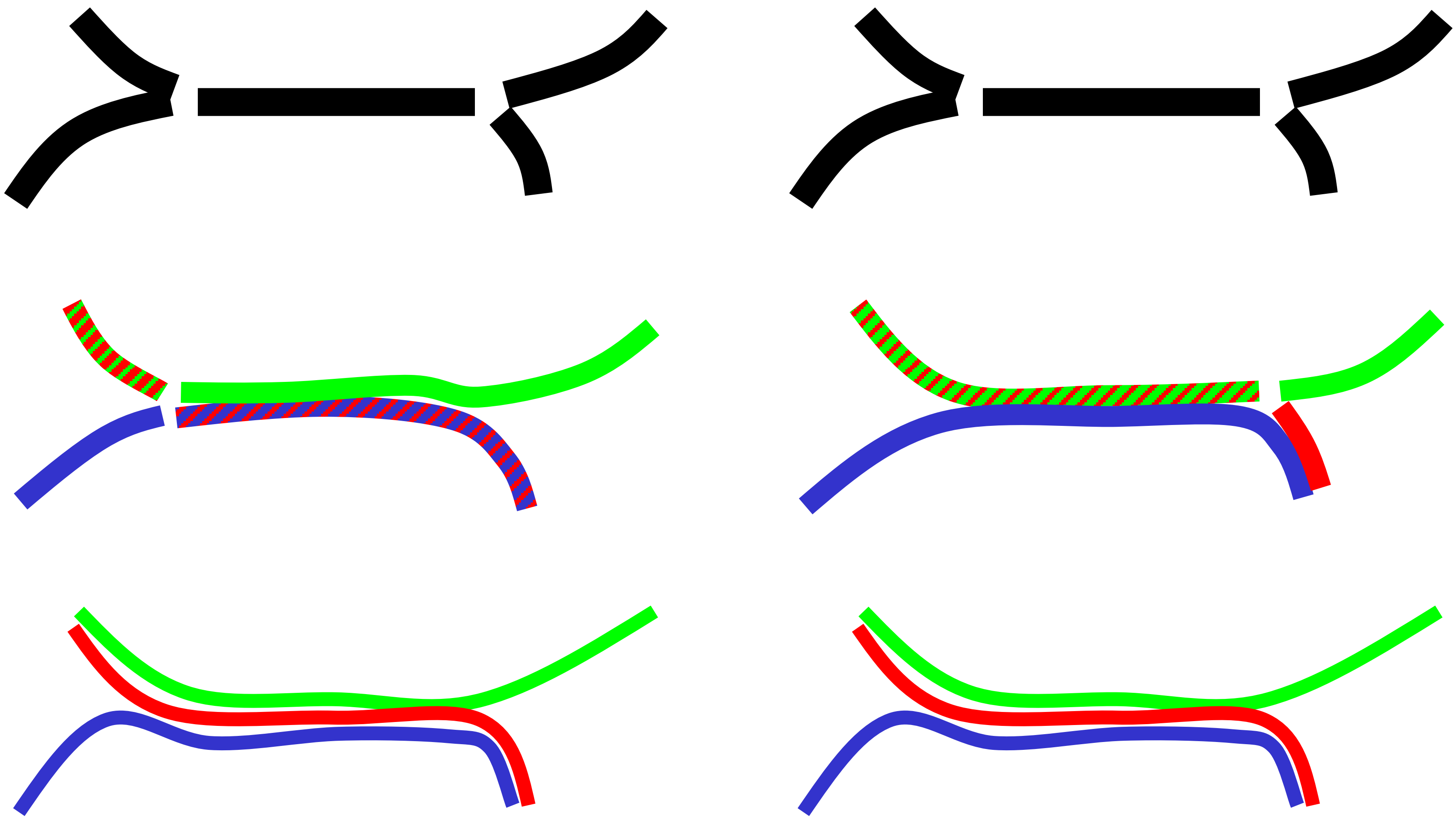
Pipe definition

- 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 example (cont'd)

Grooming (b) Grooming (a)



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

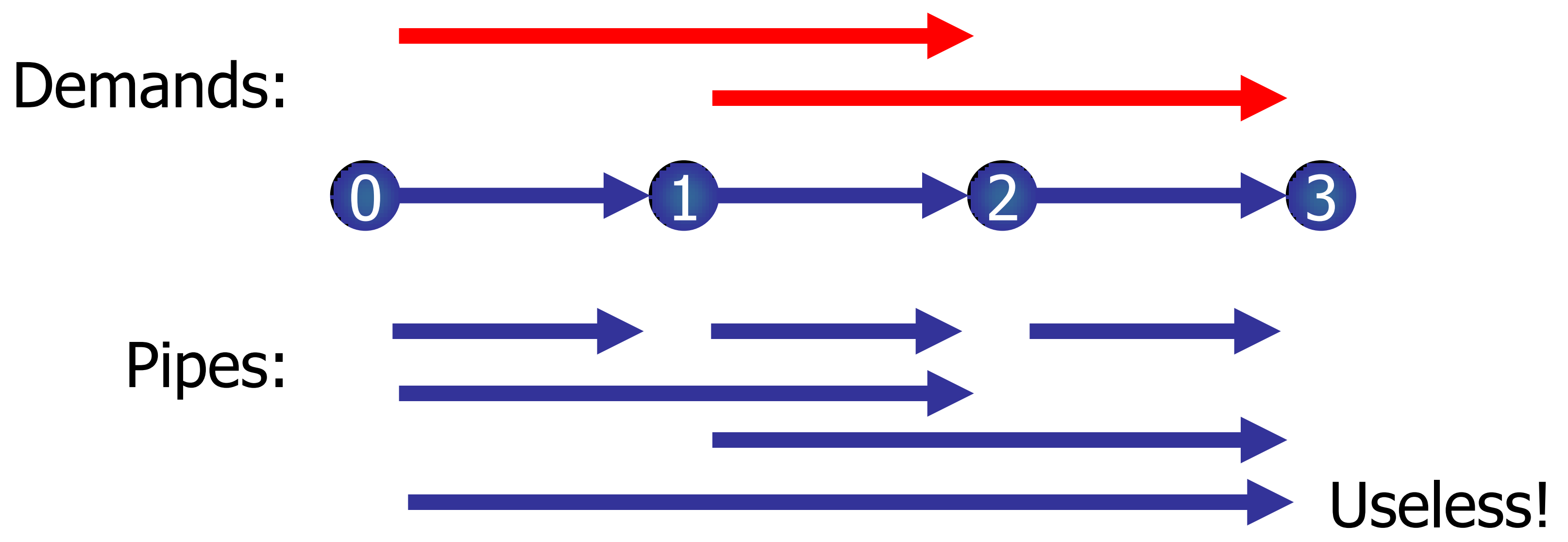
- Defined over two layers only: multi-stage grooming if #layers > 2 (iterate)
- Simple model compare to the complete detailed ILP formulation, but:

  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:



ILP complexity

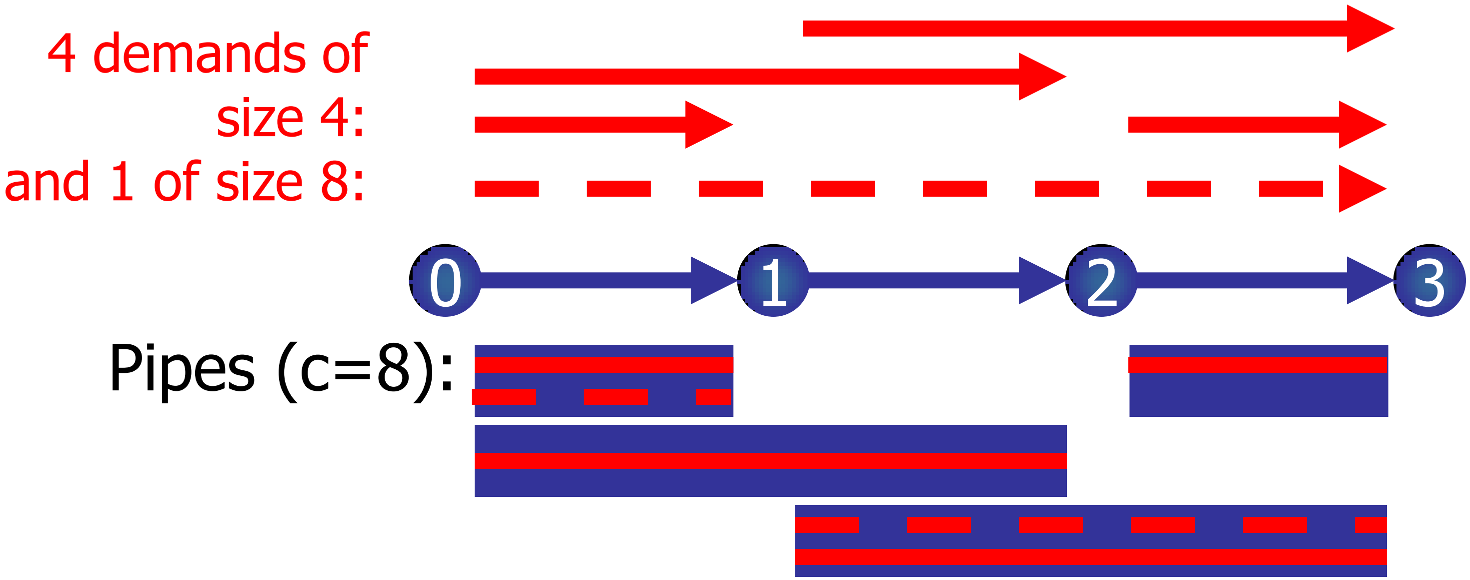
- Notations:
  - L is the maximum length of a path
  - r is the number of demands
  - p is the number of pipes
  - m is the number of edges
- # equations: $O(pL^2)$
- # variables: $O(r(m+p))$

This is polynomial but still large

$\rightarrow$ How can we reduce it?

Large demands & split number

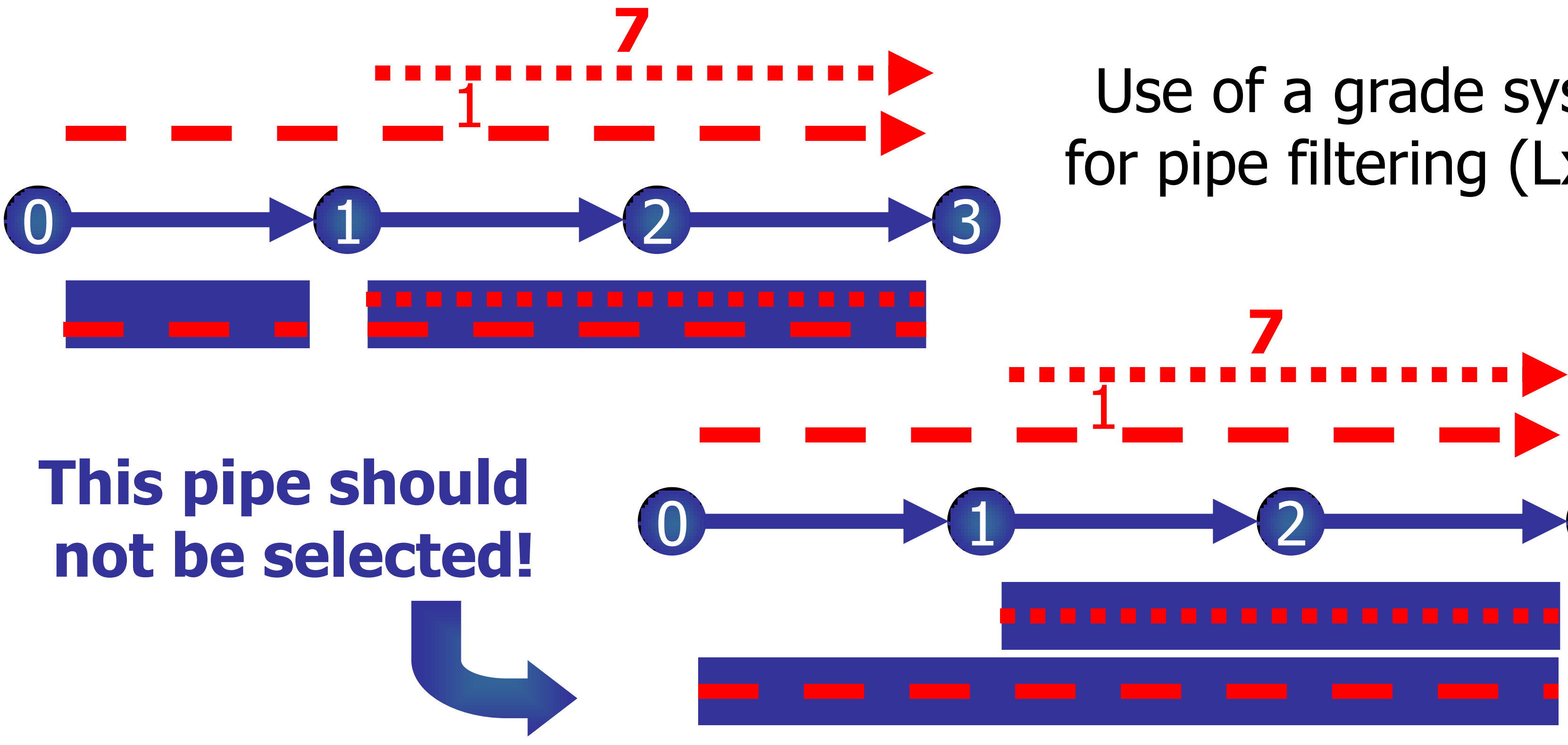
- Use weighted instead of unitary demands
- Allows splitting in a maximum number of parts
- Perform also greedy grooming by respect to the pipe size



Pipes filtering

- Decreases the number of potential pipes:

    suspect long pipes (waste capacities + integer/real numbers issues)



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

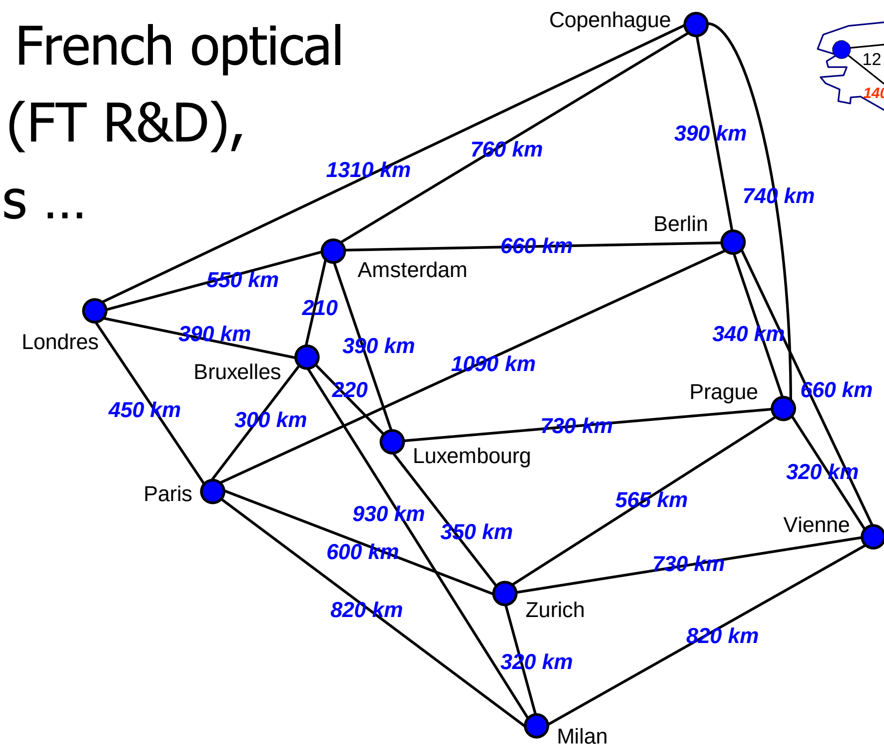
We also propose a fast greedy algorithm based on the grade of pipes (a feasible solution should exists with all pipes lengthen to 1, i.e. no grooming at all)

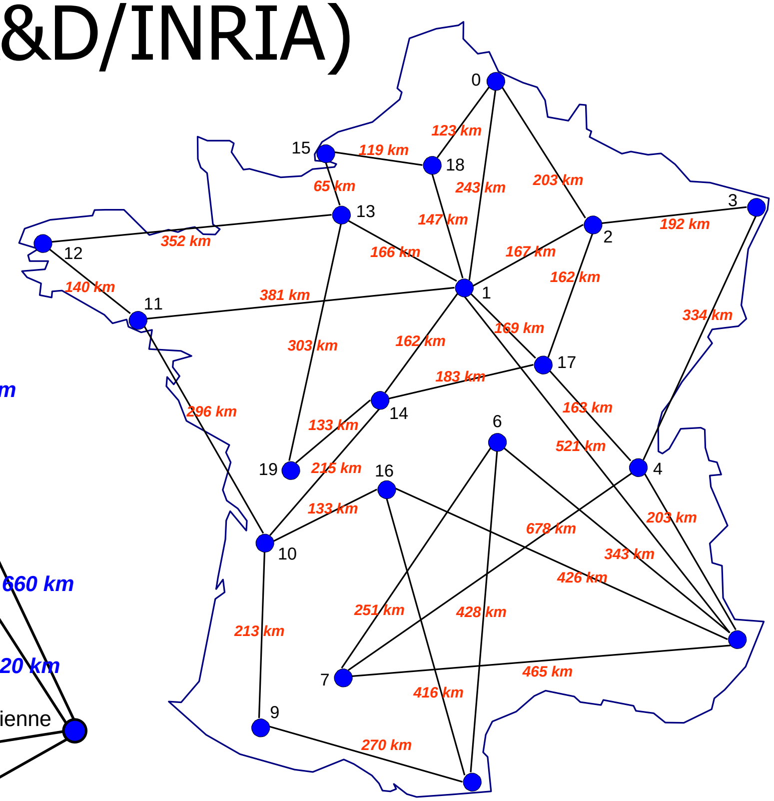
Numerical results

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

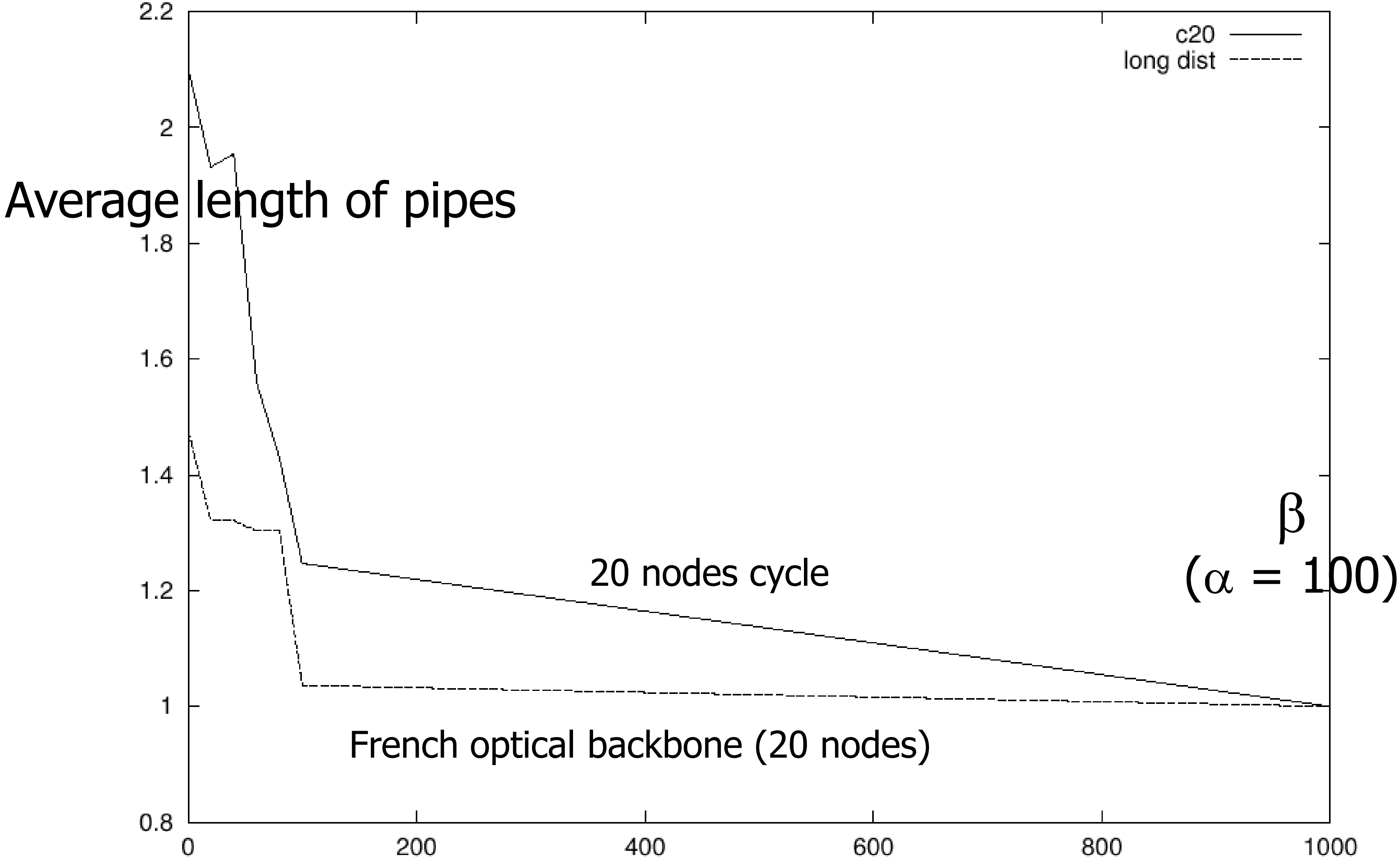
- Each pipe has a capacity and a cost:

  $\mathrm{Cost}(p_i) = \alpha_l + \beta_l\, n$ in our tests

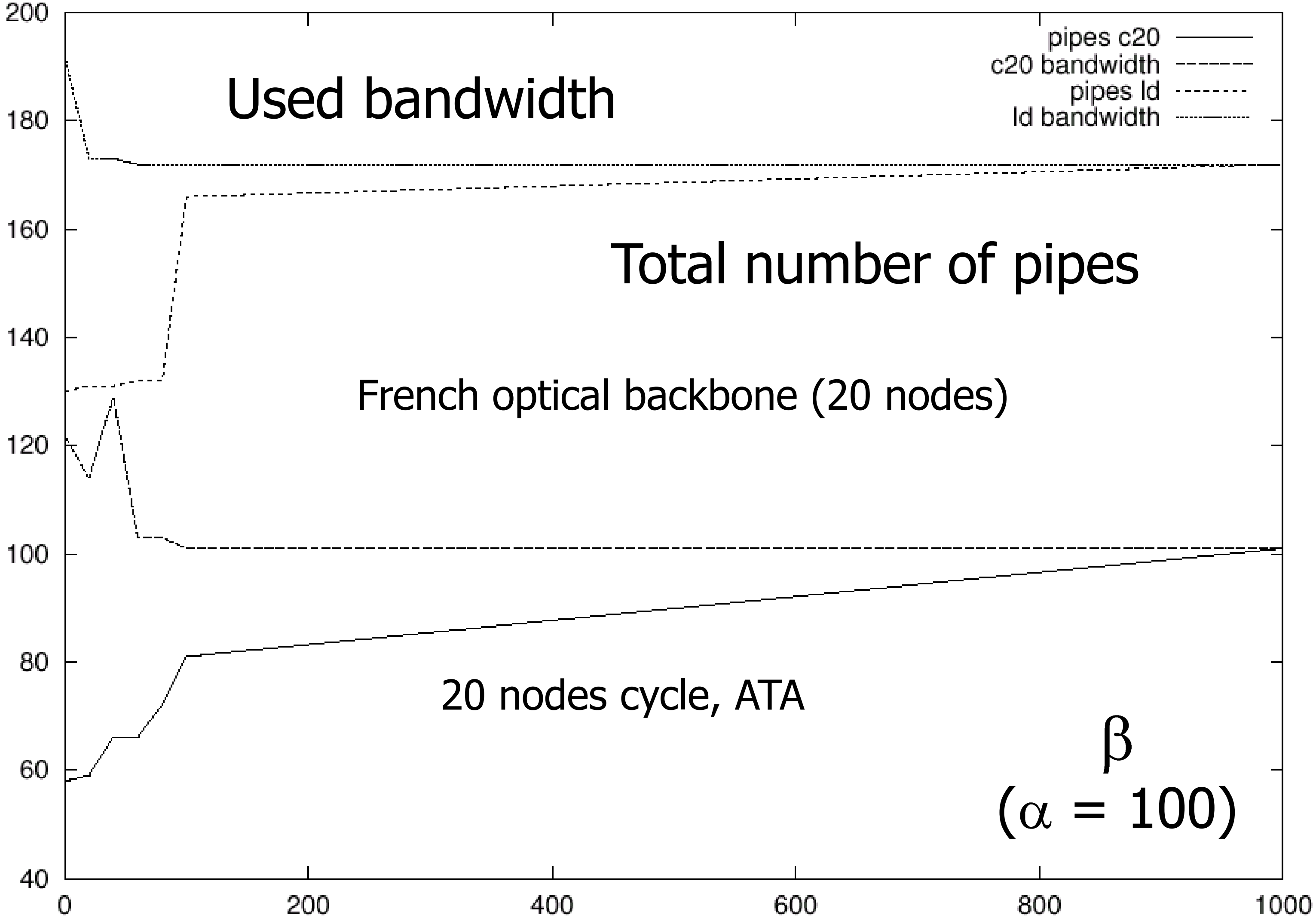
  Special case : $\beta_l \ll \alpha_l$

  (minimize # pipes)

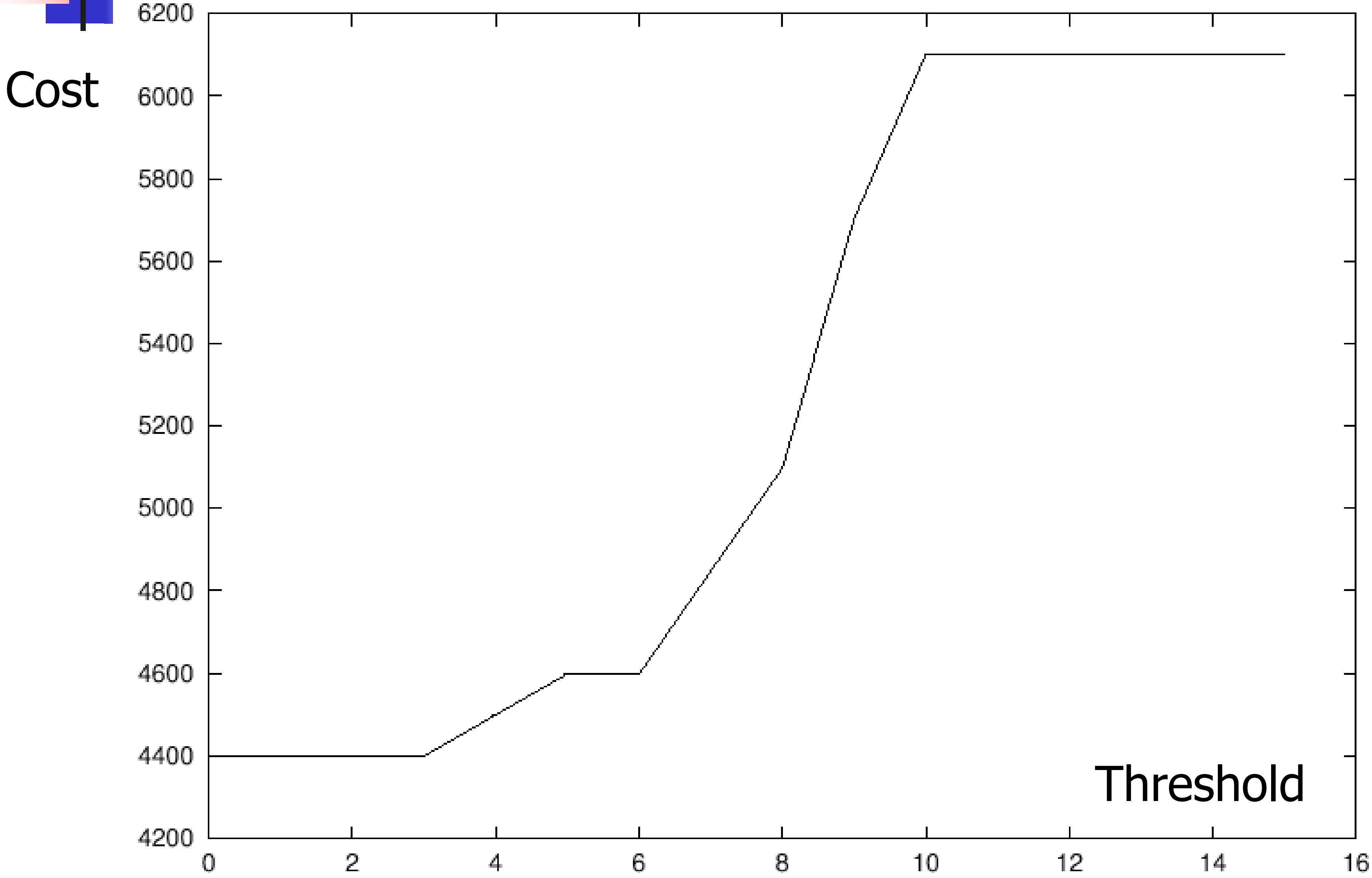
α/β tradeoff



α/β tradeoff

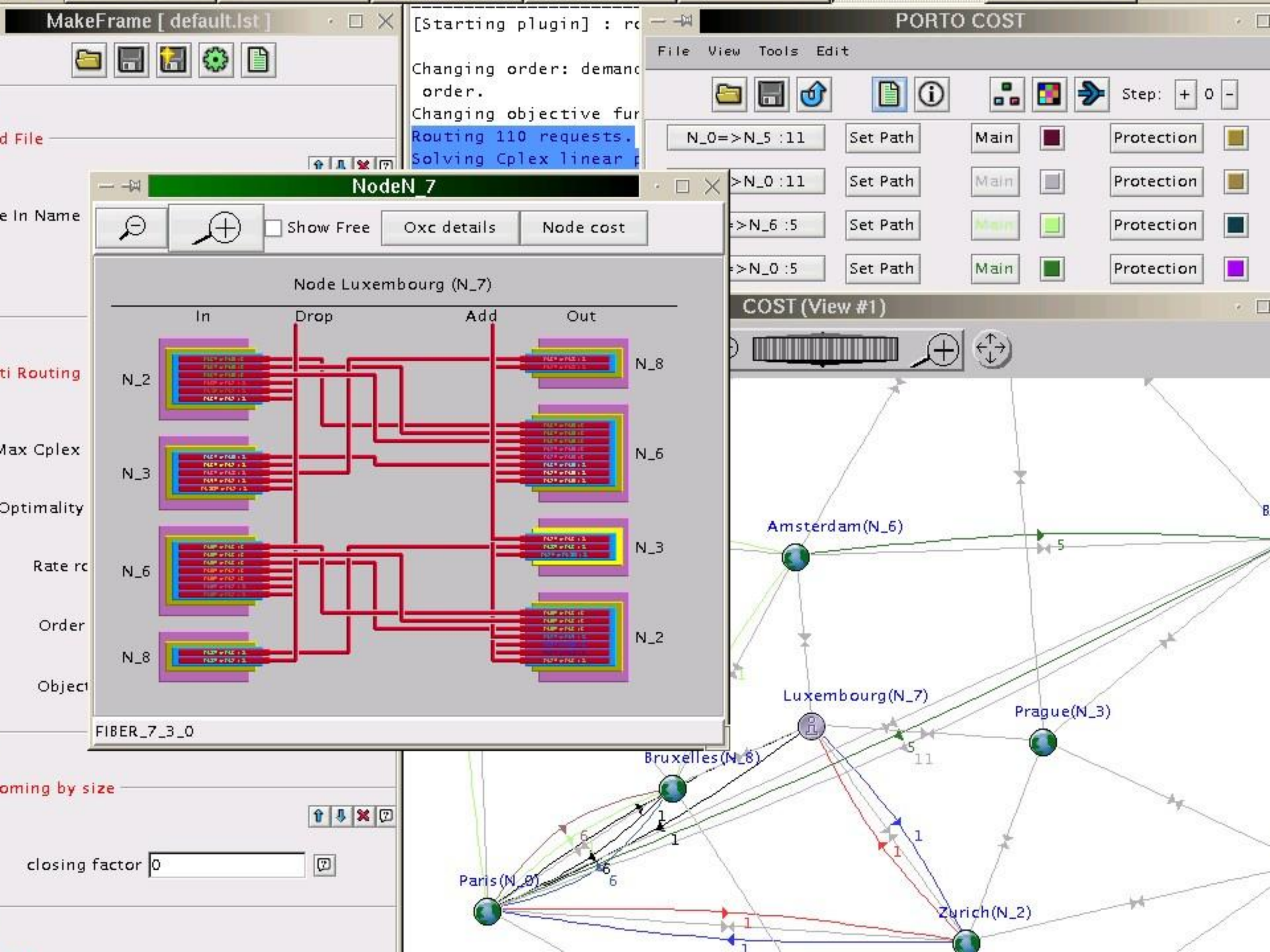

200
180
160
140
120
100
80
60
40
0
200
400
600
800
1000
pipes c20
c20 bandwidth
pipes ld
ld bandwidth
Used bandwidth
Total number of pipes
French optical backbone (20 nodes)
20 nodes cycle, ATA
β
(α = 100)

Filtering


Cost
6200
6000
5800
5600
5400
5200
5000
4800
4600
4400
4200
0
2
4
6
8
10
12
14
16
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


MakeFrame [default.lst]
d File
e In Name
ti Routing
Max Cplex
Optimality
Rate rc
Order
Object
oming by size
closing factor
0
[Starting plugin] : rc
Changing order: demanc
order.
Changing objective fur
Routing 110 requests.
Solving Cplex linear p
PORTO COST
File
View
Tools
Edit
Step:
+
0
-
N_0=>N_5 :11
Set Path
Main
Protection
>N_0 :11
Set Path
Main
Protection
>N_6 :5
Set Path
Main
Protection
>N_0 :5
Set Path
Main
Protection
COST (View #1)
NodeN_7
Show Free
Oxc details
Node cost
Node Luxembourg (N_7)
In
Drop
Add
Out
N_2
N_3
N_6
N_8
N_8
N_6
N_3
N_2
FIBER_7_3_0
Amsterdam(N_6)
Luxembourg(N_7)
Prague(N_3)
Bruxelles(N_8)
Paris(N_0)
Zurich(N_2)
5
11
1
6