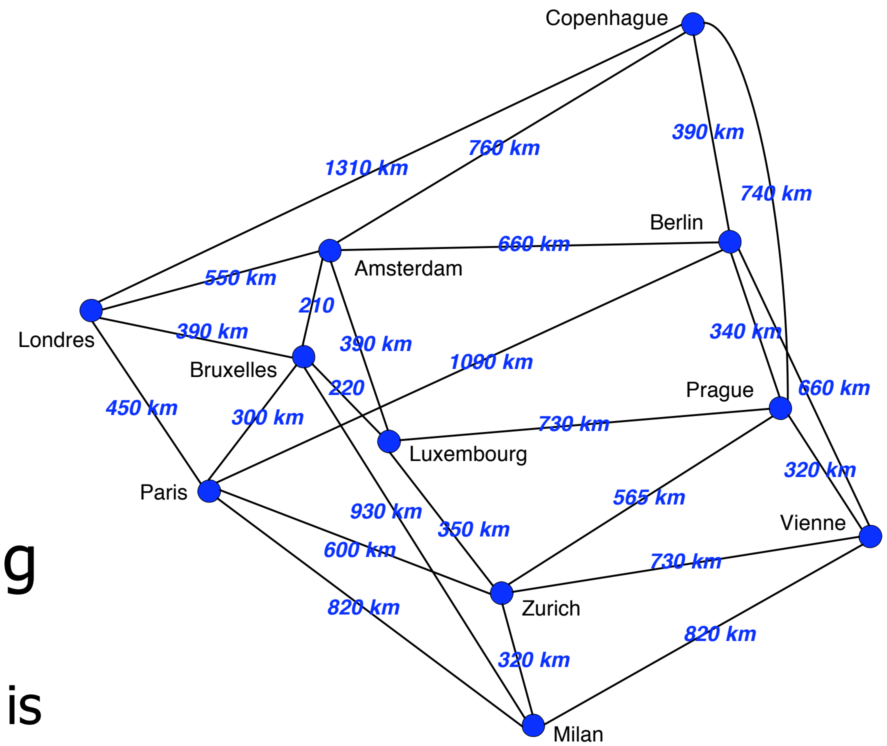
Planning and Design of WDM Networks: PORTO

RNRT PORTO: Alcatel CIT, France Télécom R&D and Mascotte: University of Nice / CNRS / INRIA Sophia Antipolis France

Optical backbone (transport)

- Carrier network
- Transport « pipes » STM-n, STM-16 : 2,5 Gbit/s (OC-192,...)
- Arbitrary topology
  - Mesh networks
- Routing and Grooming of traffic demands:
  - Assume cost of network is node equipment, not fibres (already existing)



Routing problem

- Problem input:
  - Directed Graph $G=(V,E)$

    arcs associated to fibres with capacities (amount of λ multiplexed), length of fibres (km)
  - Traffic: demands matrix $D\ [d_{i,j}]$

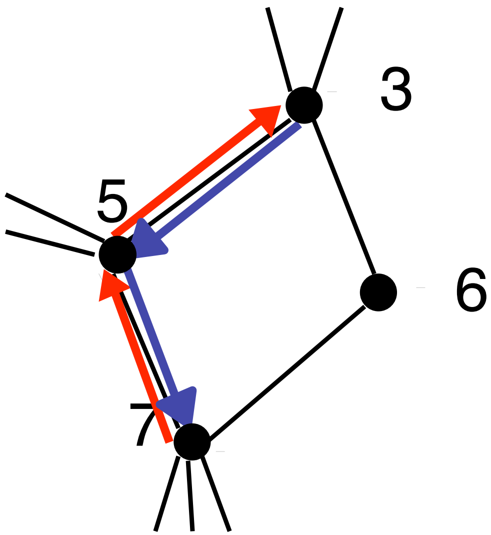
    $d_{i,j}$ is the amount of λ requested from i to j

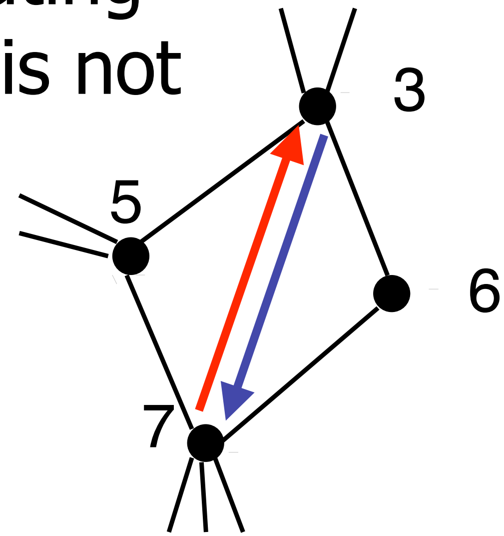
    Almost static – May change dayly
- Problem output: routing of D

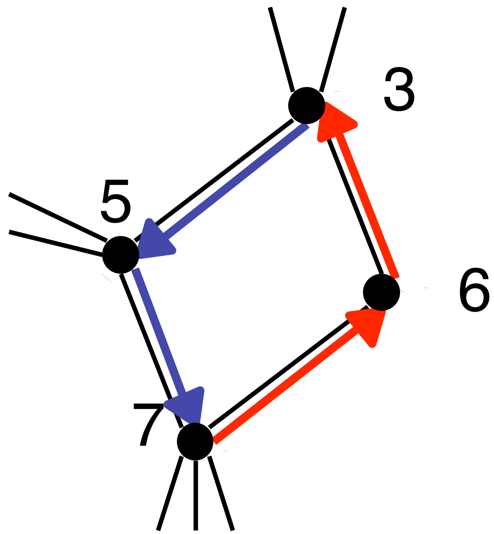
  Each $d_{i,j}$ is assigned to some wavelength paths in G subject to capacity constraints: **routing of $d_{i,j}$**

Routing of demands

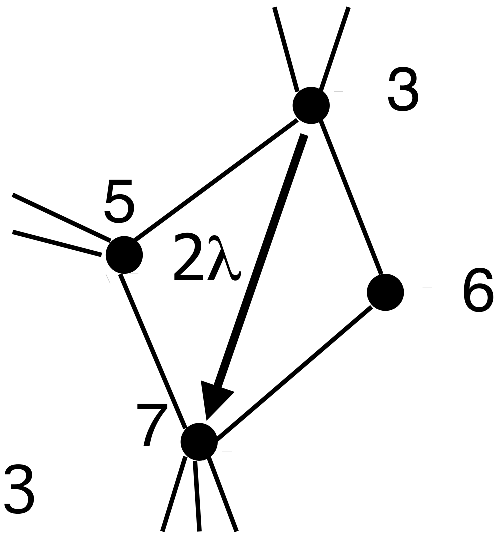
- *Symmetric* routing or not: traffic is not symmetric



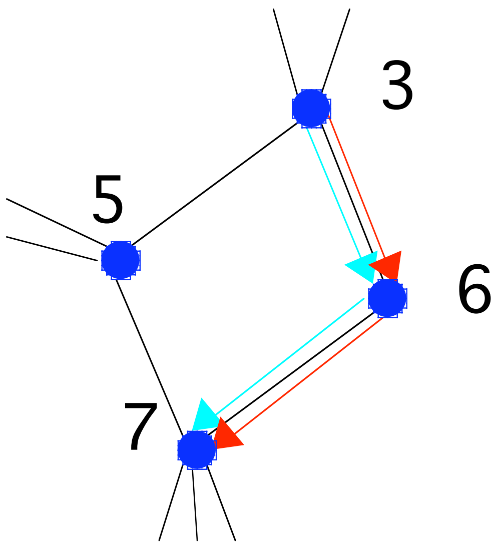


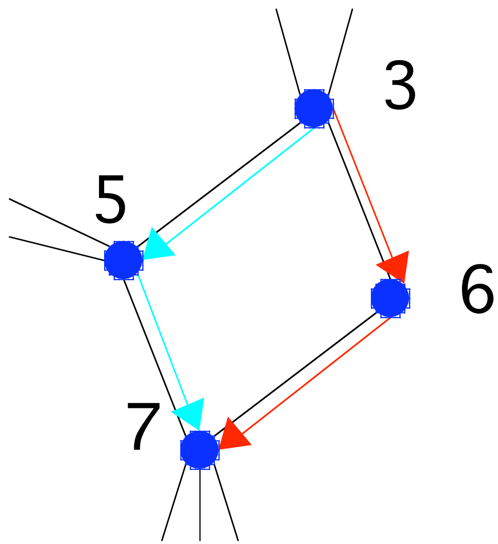


Routing of demands



- *Unsplitable routing*
- *Splitable*





Multicommodity flow ILP

$$\forall d \in D, \forall e \in E, \lambda(e,d) \leq e_{size}$$

$$\forall d \in D, \forall v \in V$$

$$\sum_{e \in E, e \in v^-} \lambda(e,d) - \sum_{e \in E, e \in v^+} \lambda(e,d) = AddDrop(v,d)$$

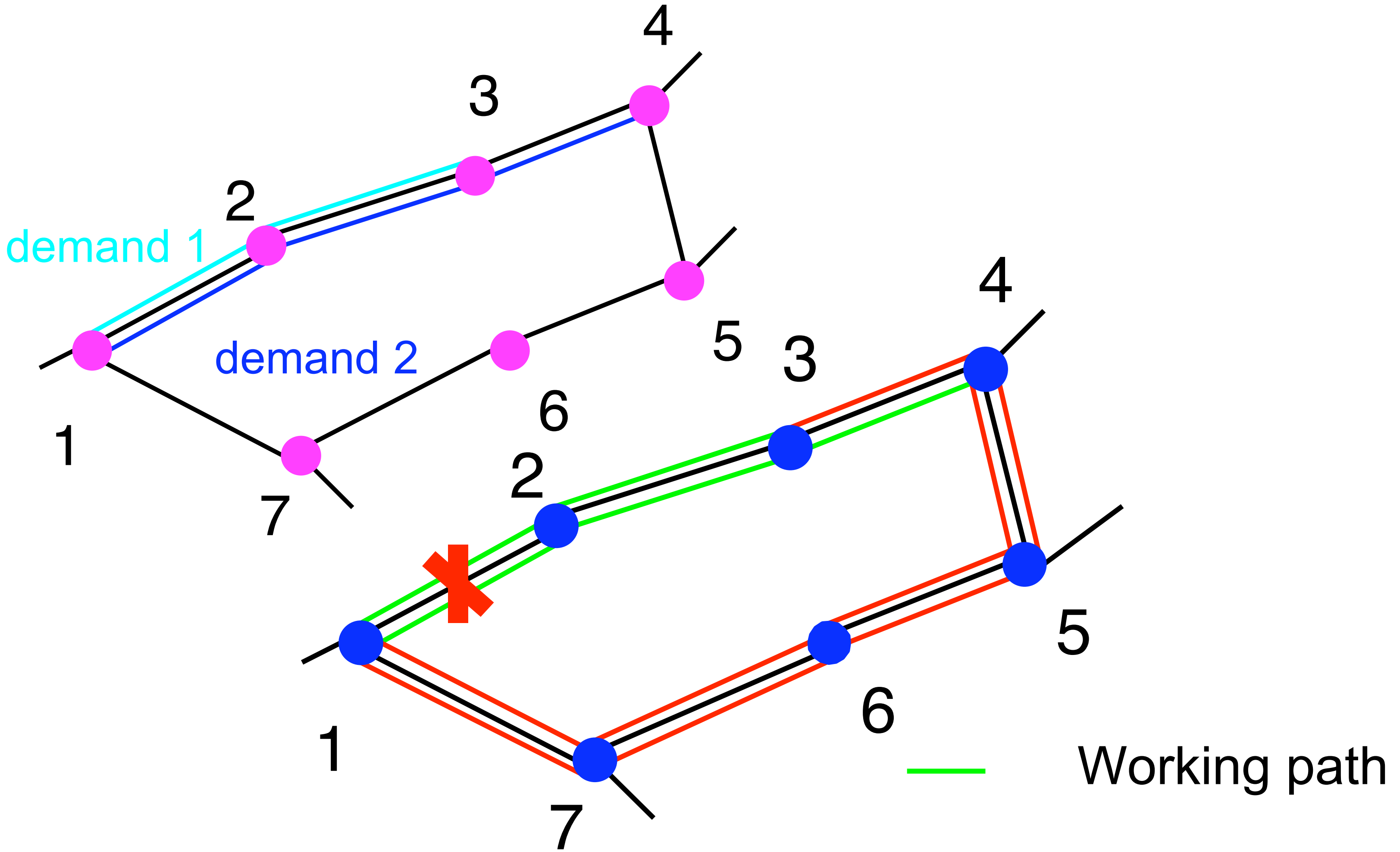
$$\forall d \in D, \forall e \in E, \lambda(e,d) \in N$$

$$Obj : Min\left(\sum_{e \in E, d \in D} \lambda(e,d) \right)$$

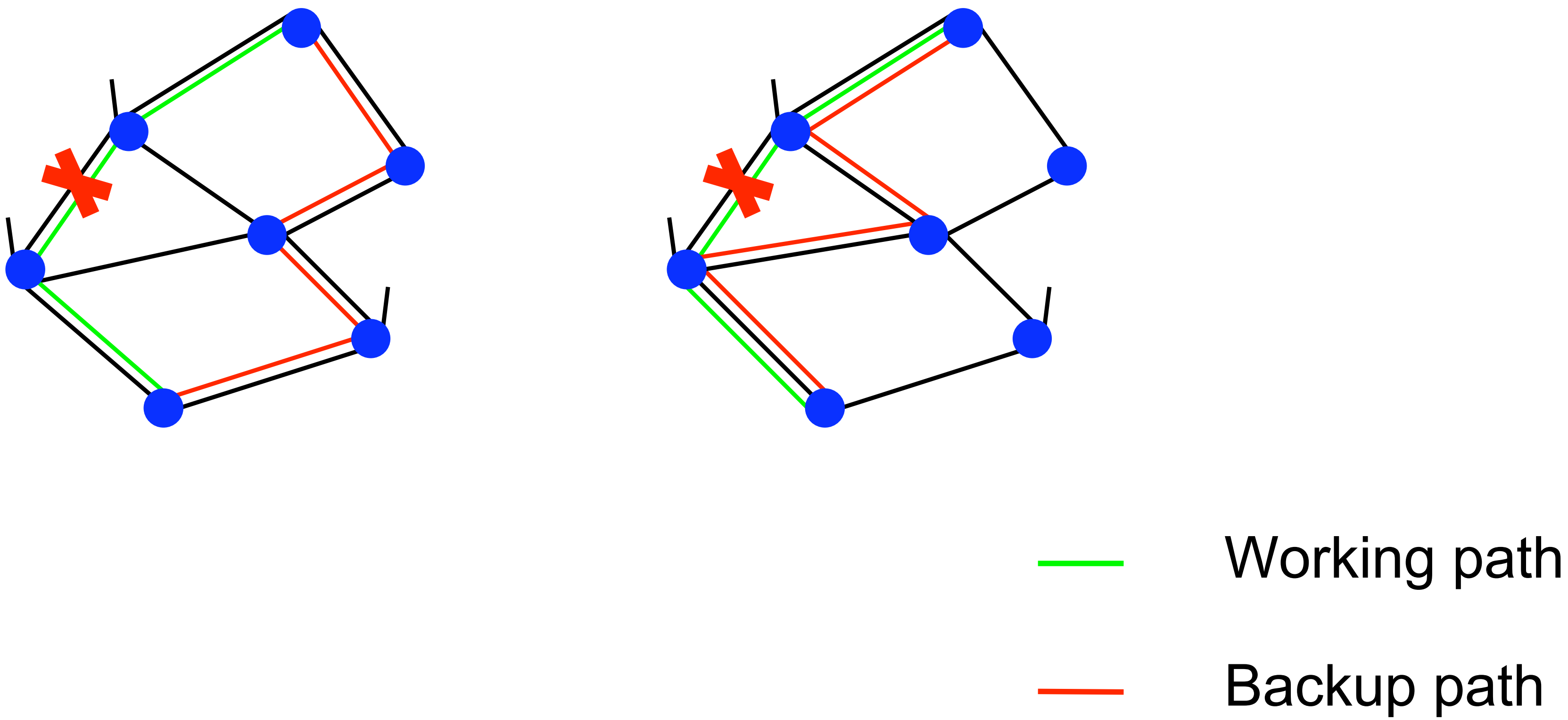
Survivability

- Protection
  - **`1+1`** 1 working path +1 backup path
  - **`1:1`** 1 working path :1 backup path
  - **`M:N`** M working paths :N backup paths
- Restoration
  - Path Restoration
  - Link Restoration

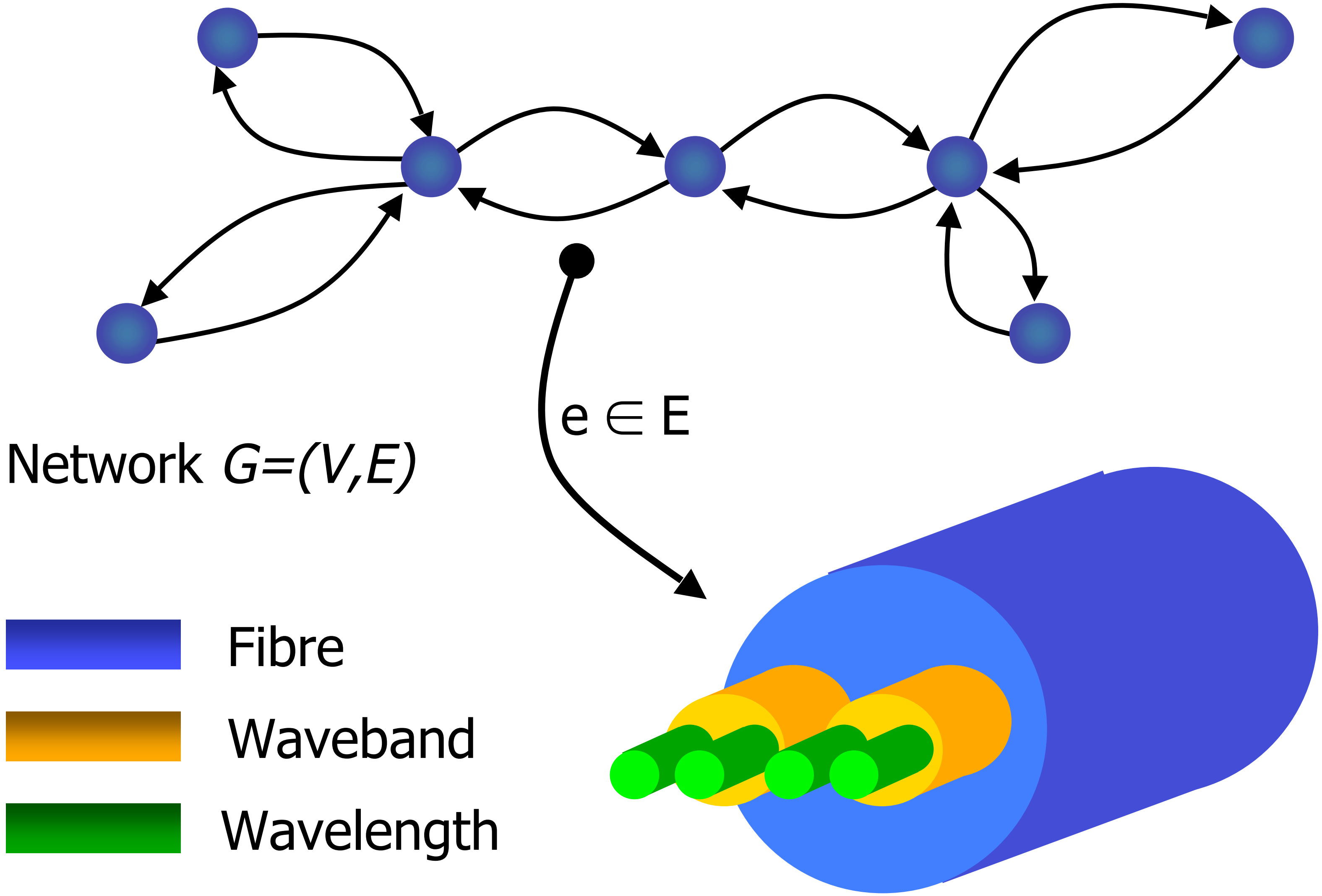
Path restoration



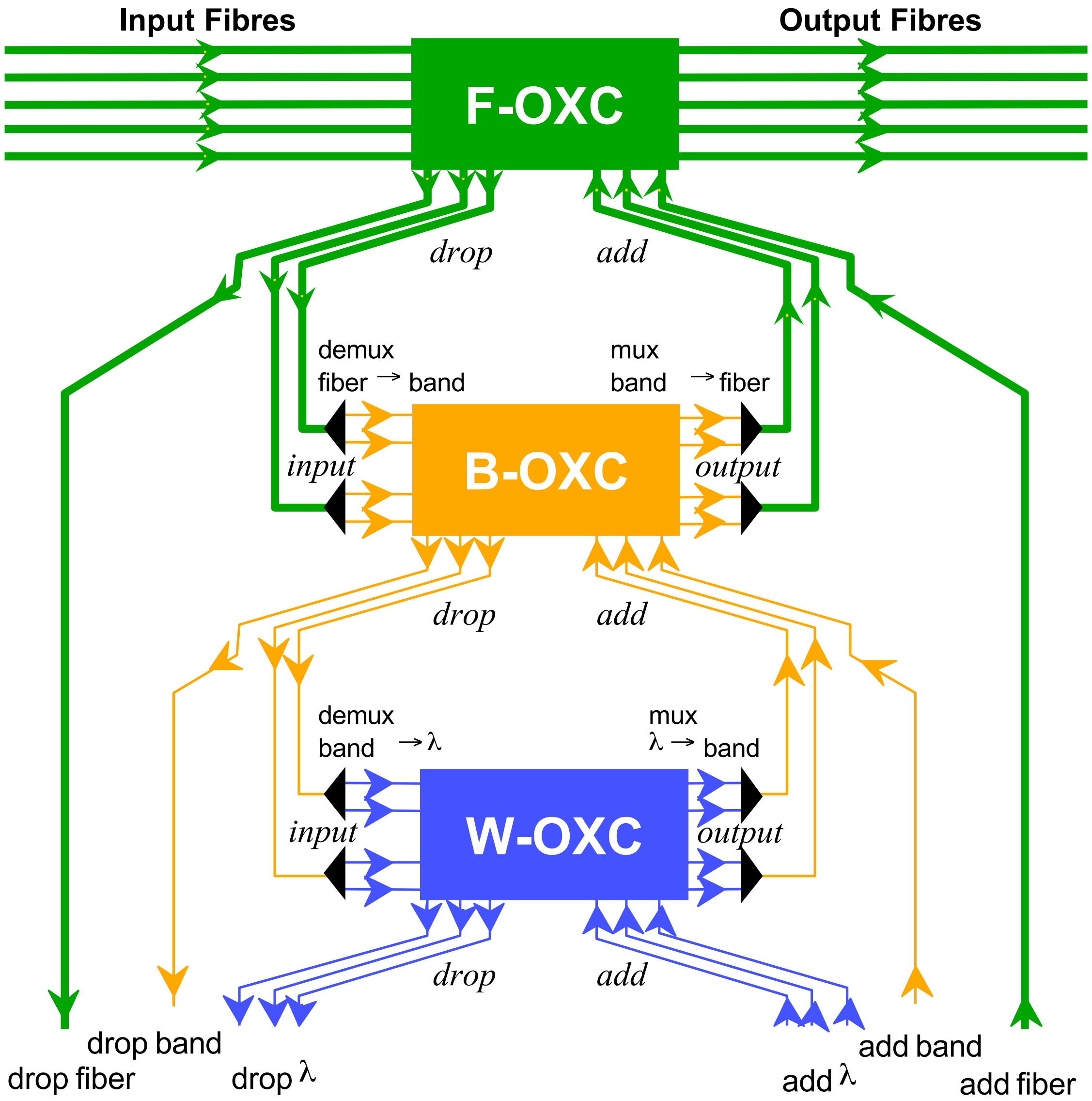
Link Restoration



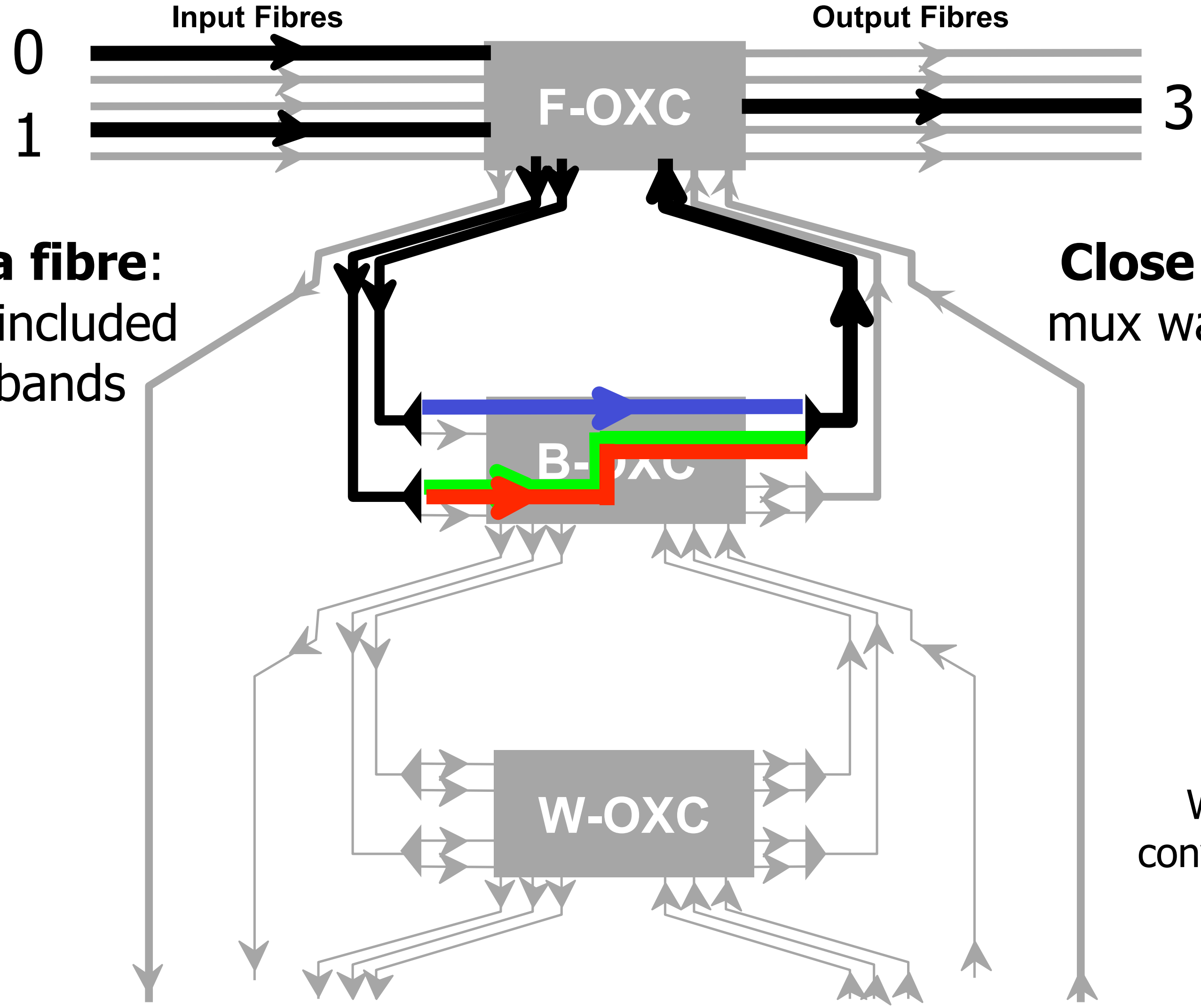
Grooming: WDM model



Functional model of nodes



Functional model of nodes

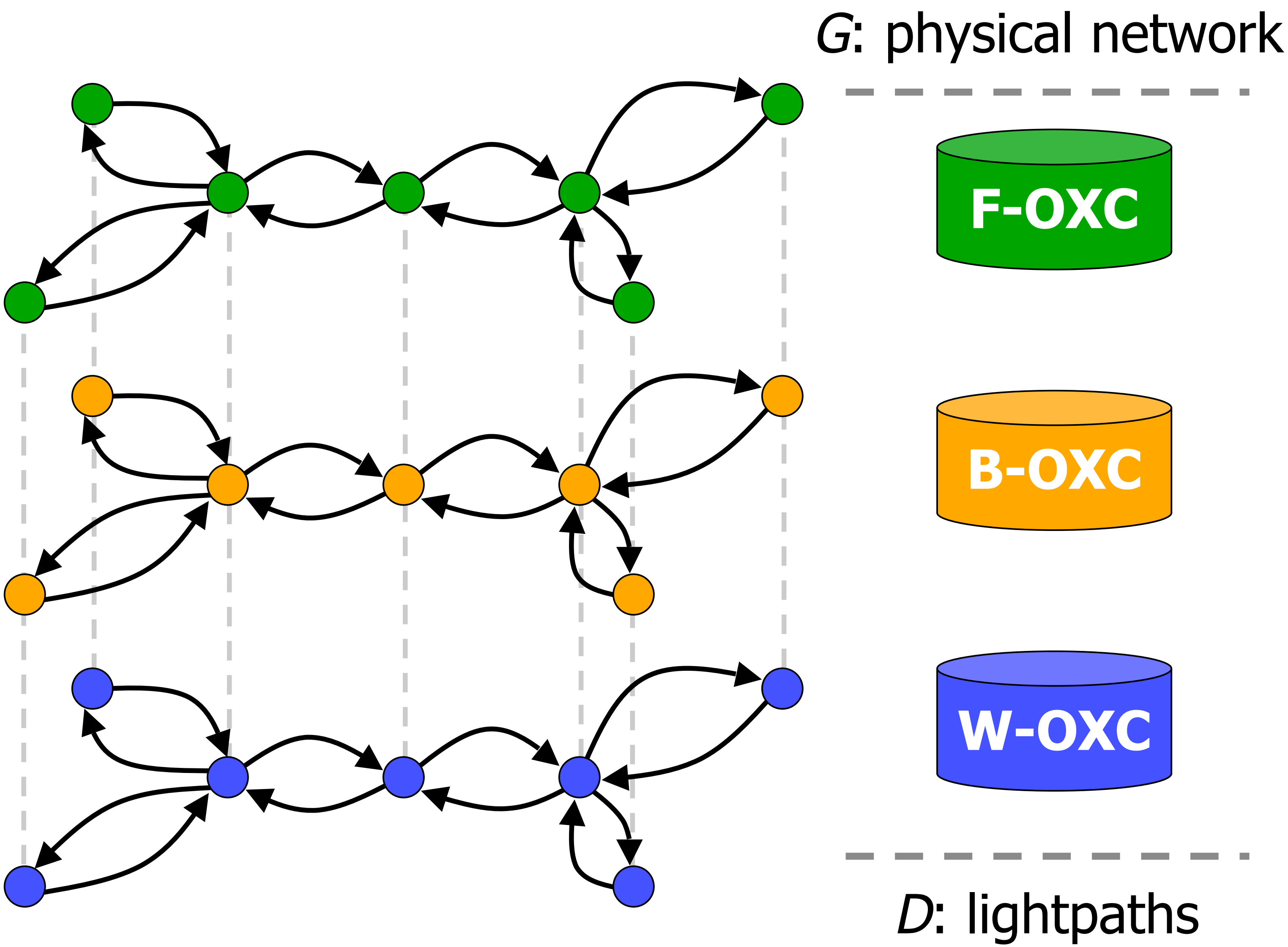


Open a fibre:
Demux included wavebands

Close a fibre:
mux wavebands

Wavelength conversion ability

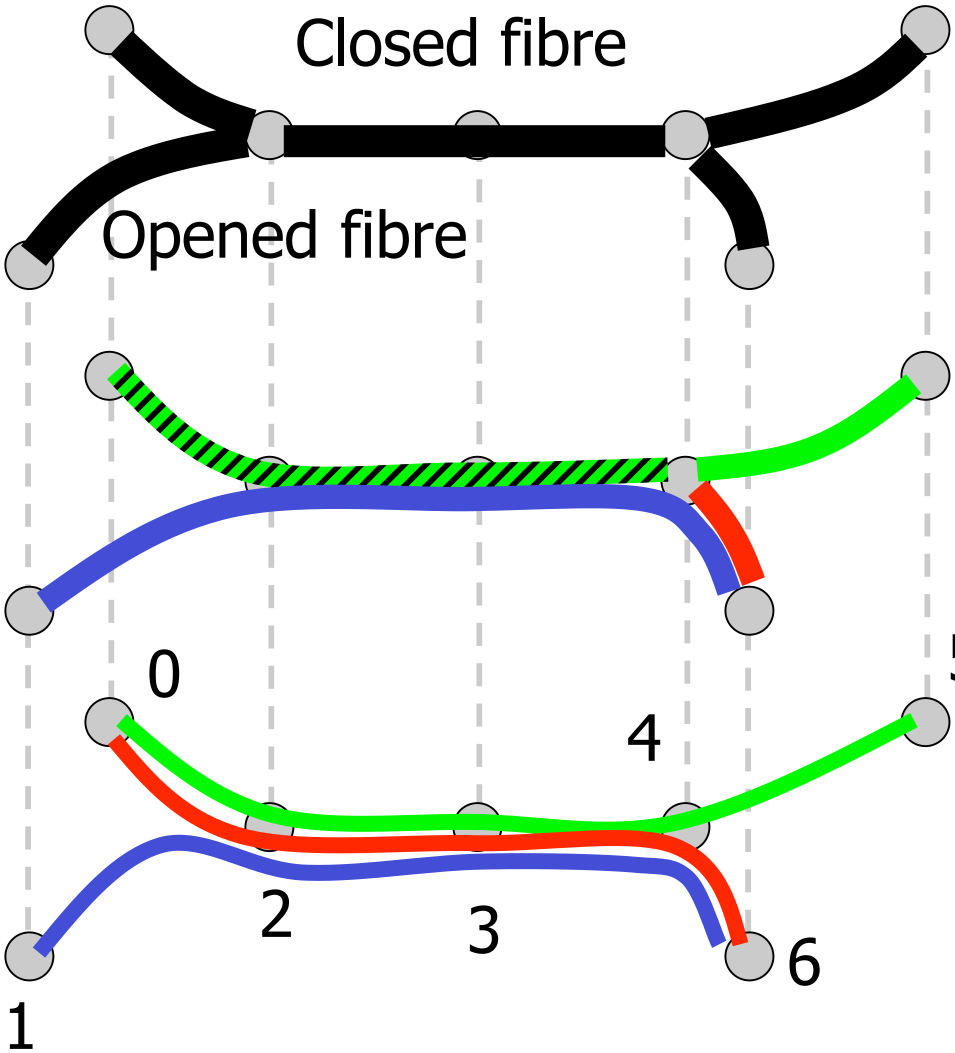
Layered WDM Network Model



Layered WDM Network Model

Node cost:
function of
the OXC's
degrees

Capacity:
W=1
B=2
F=2



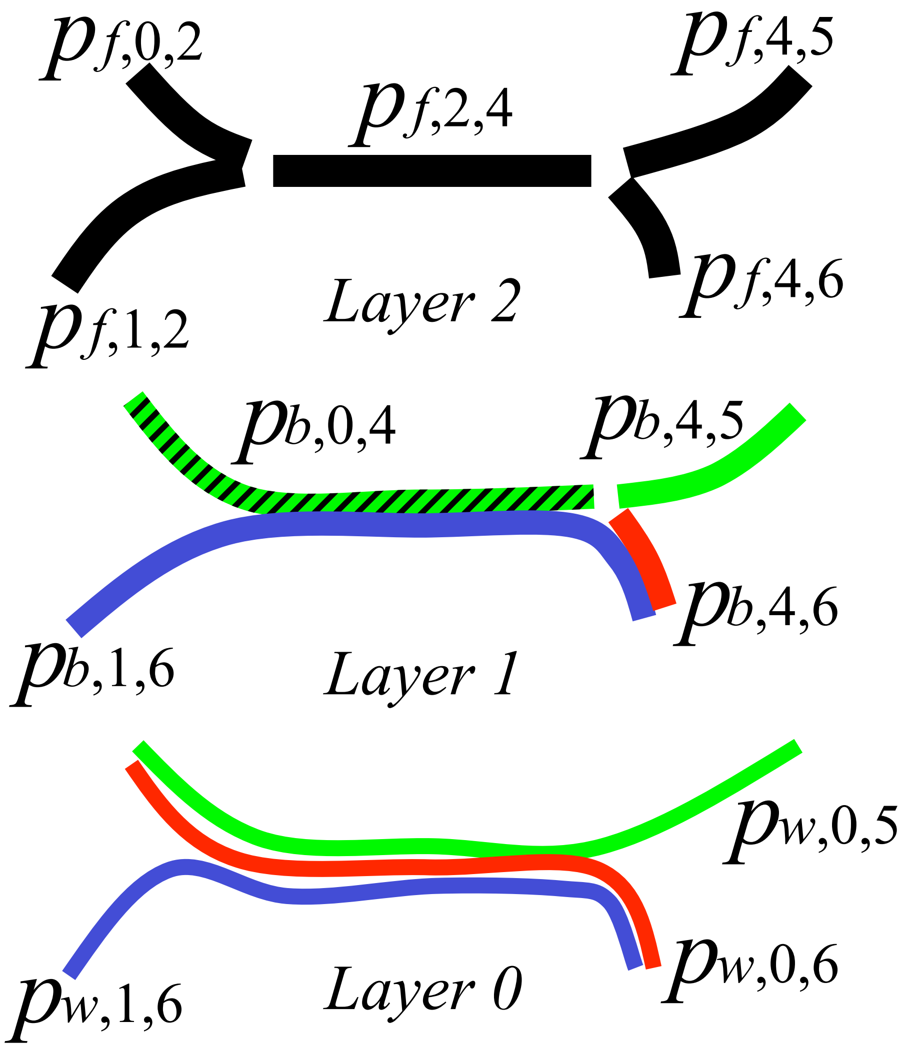
G: physical network

F-OXC
B-OXC
W-OXC

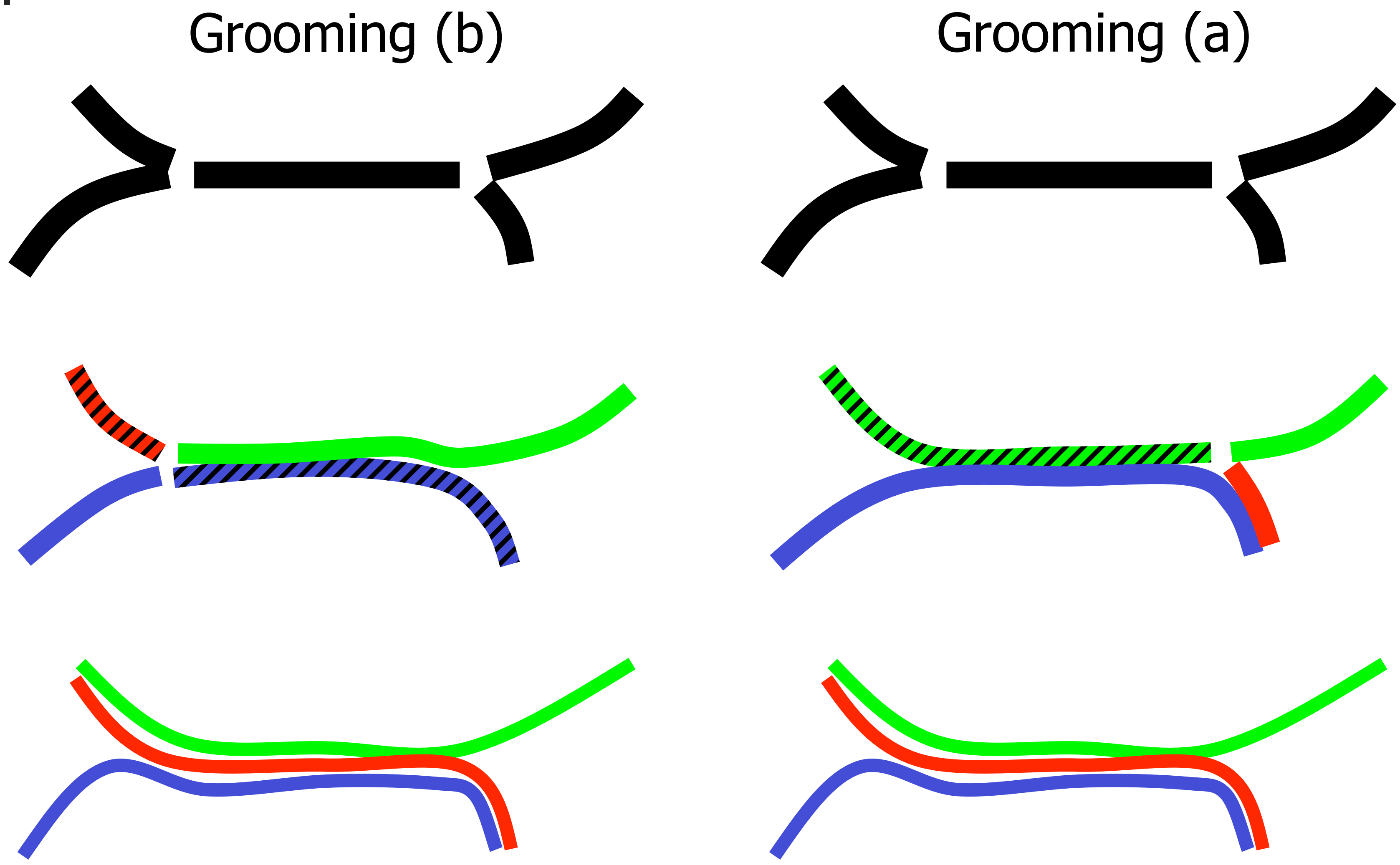
D: lightpaths

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 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

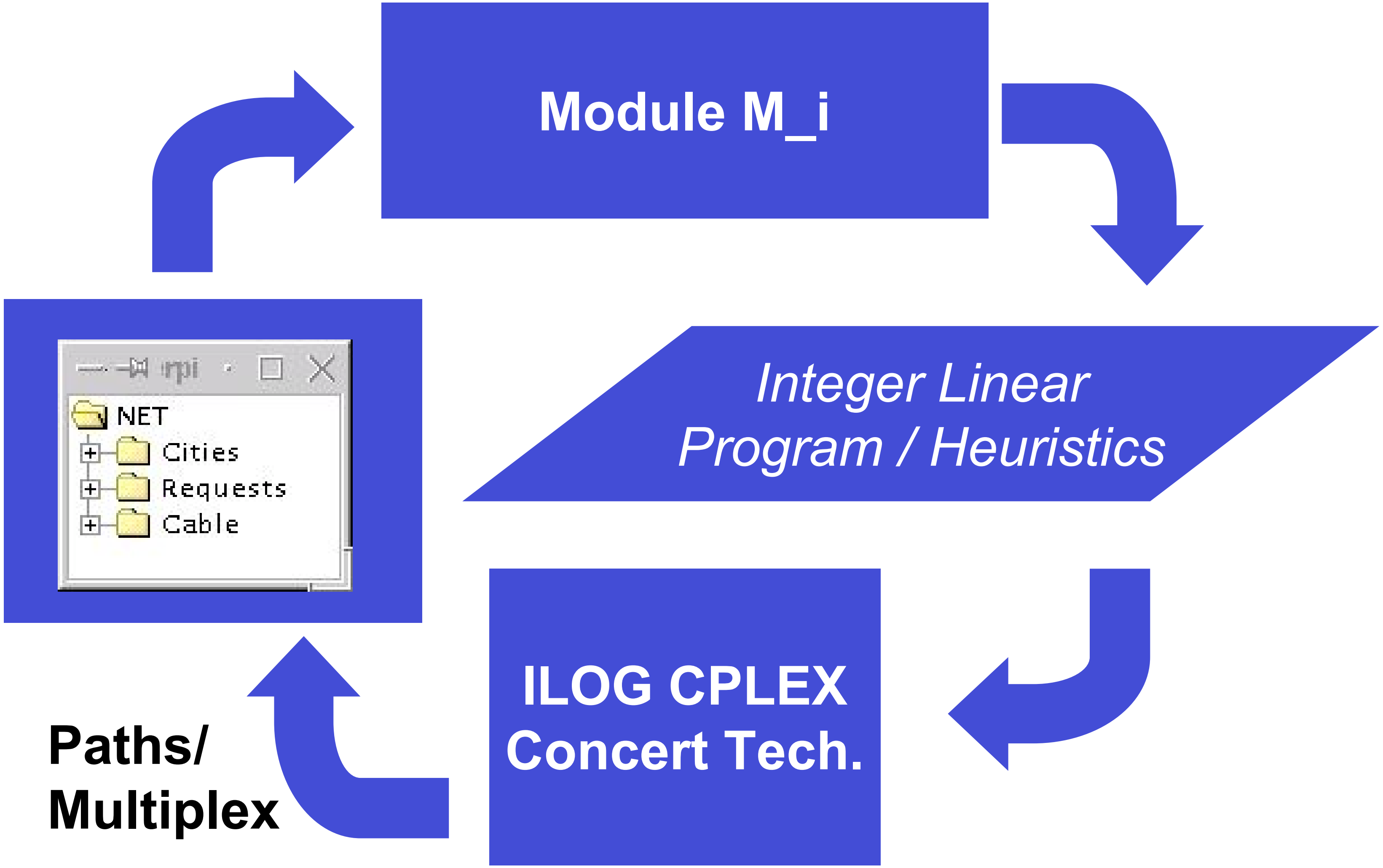
- Defined over two layers only: multi-stage grooming if #layers > 2 (iterate)
- Simple model compare to the complete detailed ILP formulation, but:

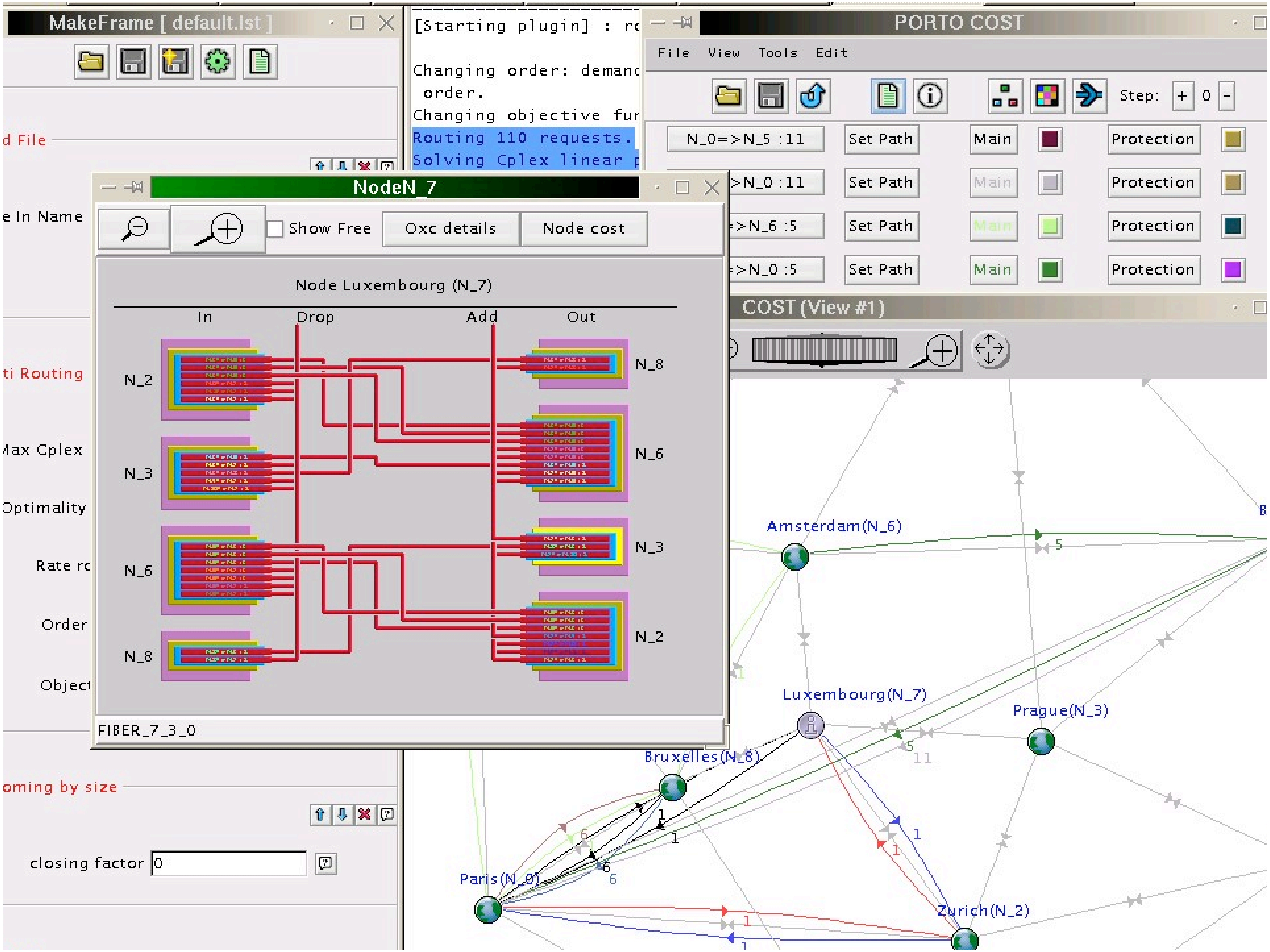
  Flexible cost objective function and cost for pipes that could be adapted to real cases

Network design problem

- Find the best possible Routing AND Grooming solution such that node cost is minimum:
  - Size (degree) of W-OXC, B-OXC, F-OXC
  - NP-complete problem (even with fixed routing) : practical solution based on heuristics and step by step optimization
  - Wavelength continuity is not considered here

Routing and Grooming modules




MakeFrame [default.lst]
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Changing order: demanc
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Changing objective fur
Routing 110 requests.
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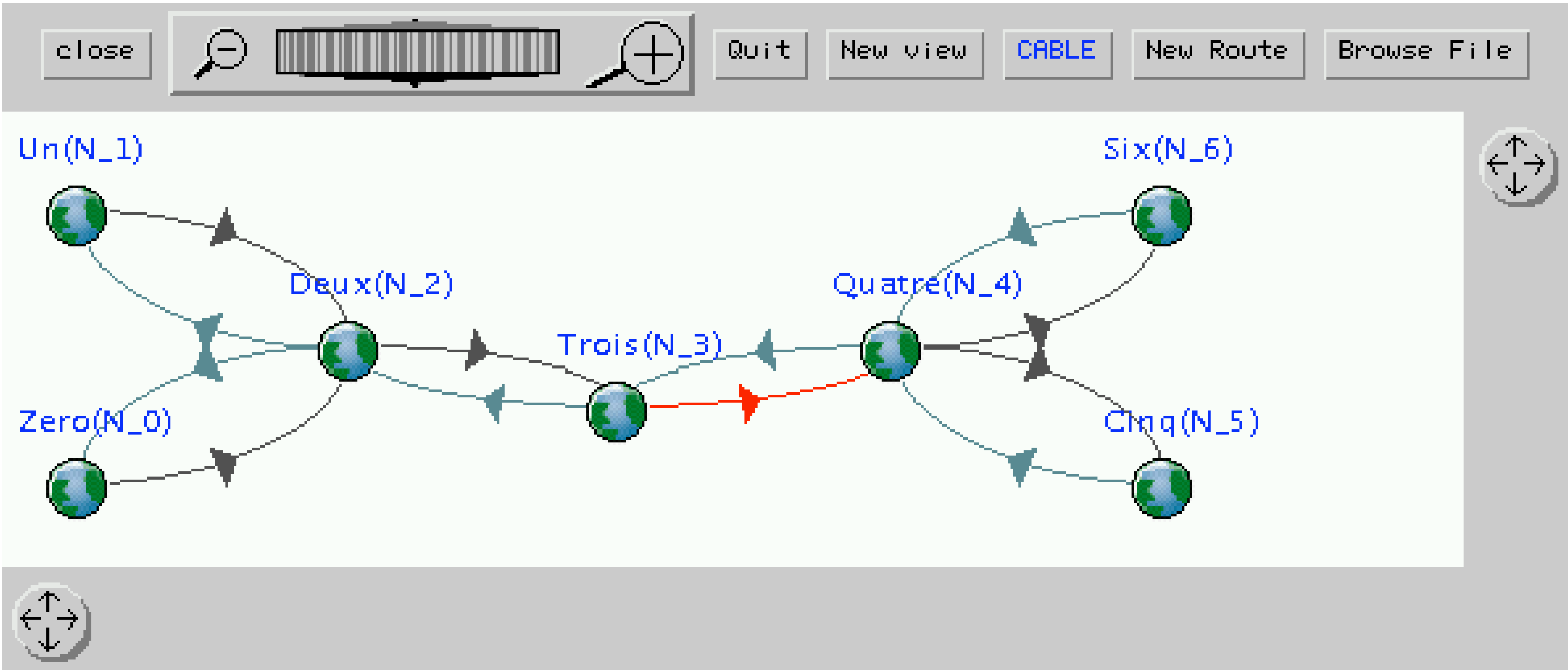
N_0=>N_5 :11
Set Path
Main
Protection
>N_0 :11
>N_6 :5
>N_0 :5
COST (View #1)
NodeN_7
Show Free
Oxc details
Node cost
Node Luxembourg (N_7)
In
Drop
Add
Out
N_2
N_3
N_6
N_8
FIBER_7_3_0
Amsterdam(N_6)
Luxembourg(N_7)
Prague(N_3)
Bruxelles(N_8)
Paris(N_0)
Zurich(N_2)

PORTO Software Demo

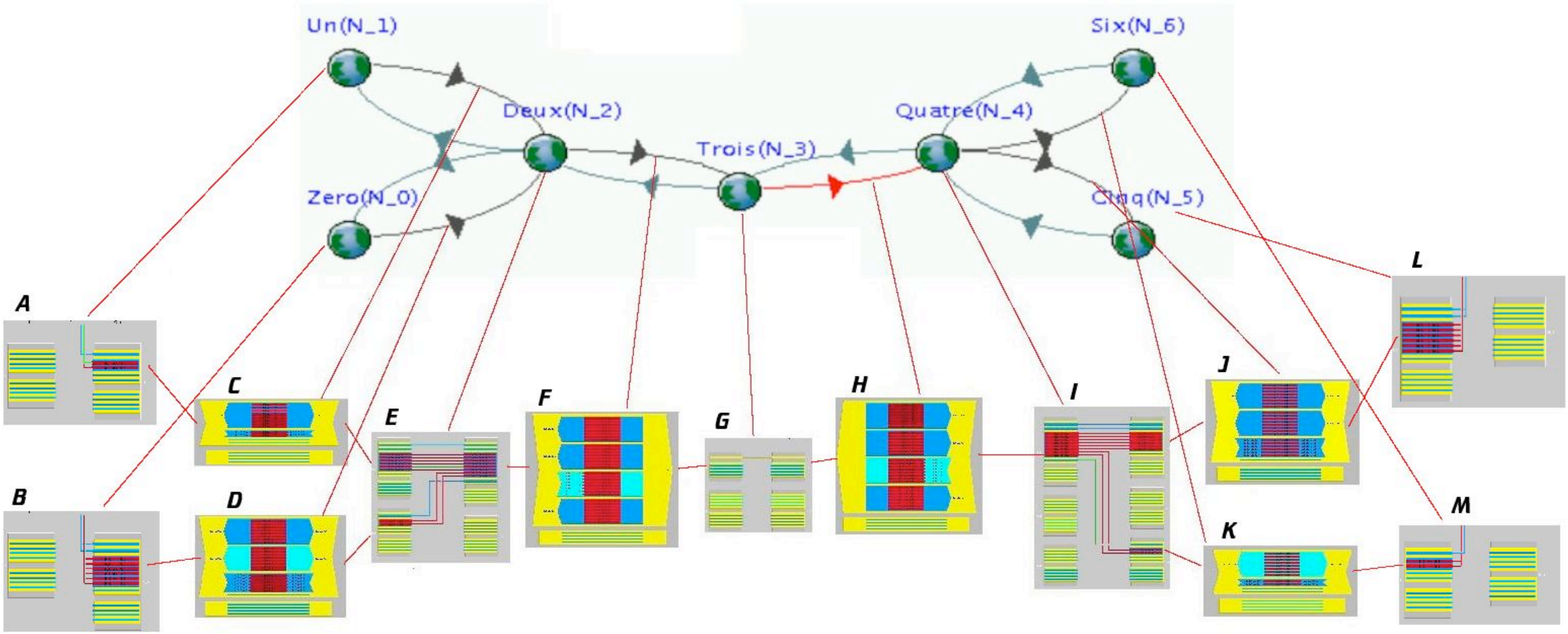
Toy example: F=4 B, B=8 λ

Two demands: N_1 to N_6 (10λ) and N_0 to N_5 (22λ).



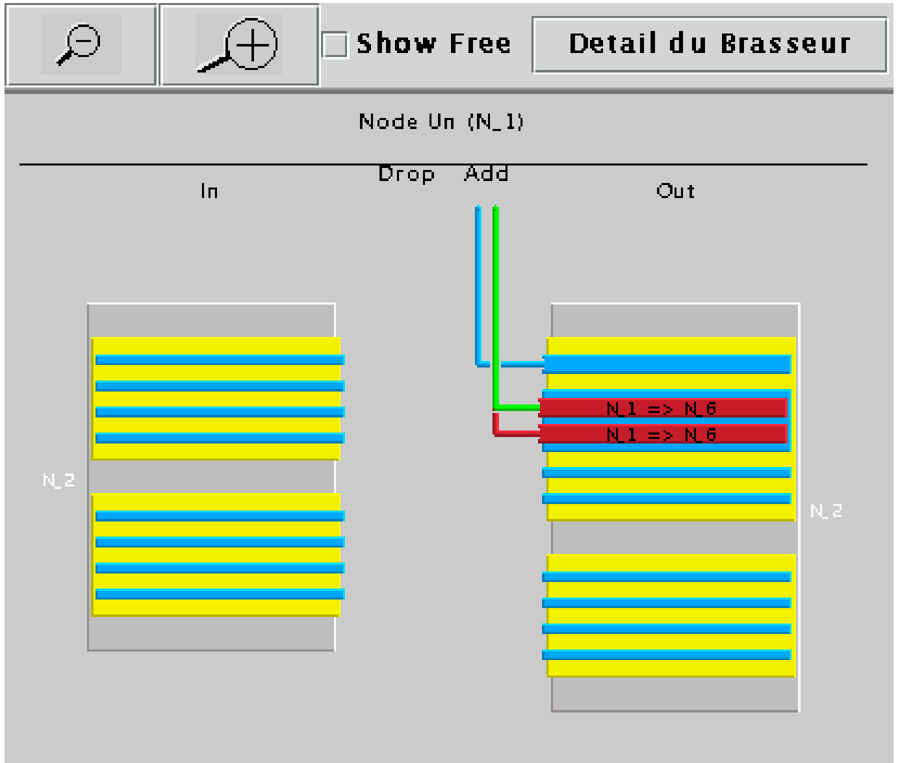
- NET
  - Cities
  - Requests
  - Cable
    - CABLE CABLE_0_2 length=100
    - CABLE CABLE_1_2 length=100
      - FIBER F_1_2_0 InputState:open Prev:null OutputState:open Next:null
        - BAND B_1_2_0_0 InputState:close Prev:B_1_1_0_0 OutputState:close Next:B_2_3_0_3
          - LAMBDA L_1_2_0_0_0 N_1=>N_6
          - LAMBDA L_1_2_0_0_1 N_1=>N_6
          - LAMBDA L_1_2_0_0_2 N_1=>N_6
          - LAMBDA L_1_2_0_0_3 N_1=>N_6
          - LAMBDA L_1_2_0_0_4 N_1=>N_6
          - LAMBDA L_1_2_0_0_5 N_1=>N_6
          - LAMBDA L_1_2_0_0_6 N_1=>N_6
          - LAMBDA L_1_2_0_0_7 N_1=>N_6
        - BAND B_1_2_0_1 InputState:open Prev:null OutputState:open Next:null
          - LAMBDA L_1_2_0_1_0 N_1=>N_6 Prev:L_1_1_0_0_0 Next:L_2_3_0_2_6
          - LAMBDA L_1_2_0_1_1 N_1=>N_6 Prev:L_1_1_0_0_0 Next:L_2_3_0_2_7
          - LAMBDA L_1_2_0_1_2
          - LAMBDA L_1_2_0_1_3
          - LAMBDA L_1_2_0_1_4
          - LAMBDA L_1_2_0_1_5
          - LAMBDA L_1_2_0_1_6
          - LAMBDA L_1_2_0_1_7
        - BAND B_1_2_0_2
        - BAND B_1_2_0_3
      - FIBER F_1_2_1
    - CABLE CABLE_2_0 length=100
    - CABLE CABLE_2_1 length=100
    - CABLE CABLE_2_3 length=100
    - CABLE CABLE_3_2 length=100
    - CABLE CABLE_3_4 length=100
    - CABLE CABLE_4_3 length=100
    - CABLE CABLE_4_5 length=100
    - CABLE CABLE_4_6 length=100
    - CABLE CABLE_5_4 length=100
    - CABLE CABLE_6_4 length=100

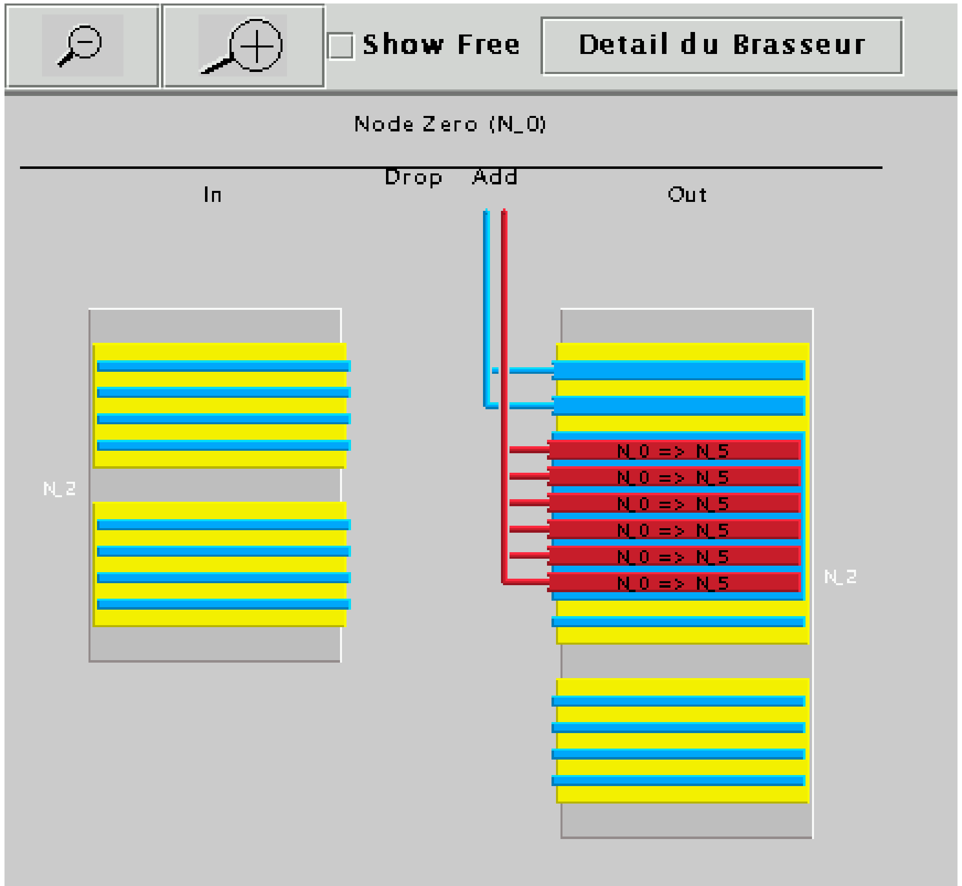
Detailed views in PORTO



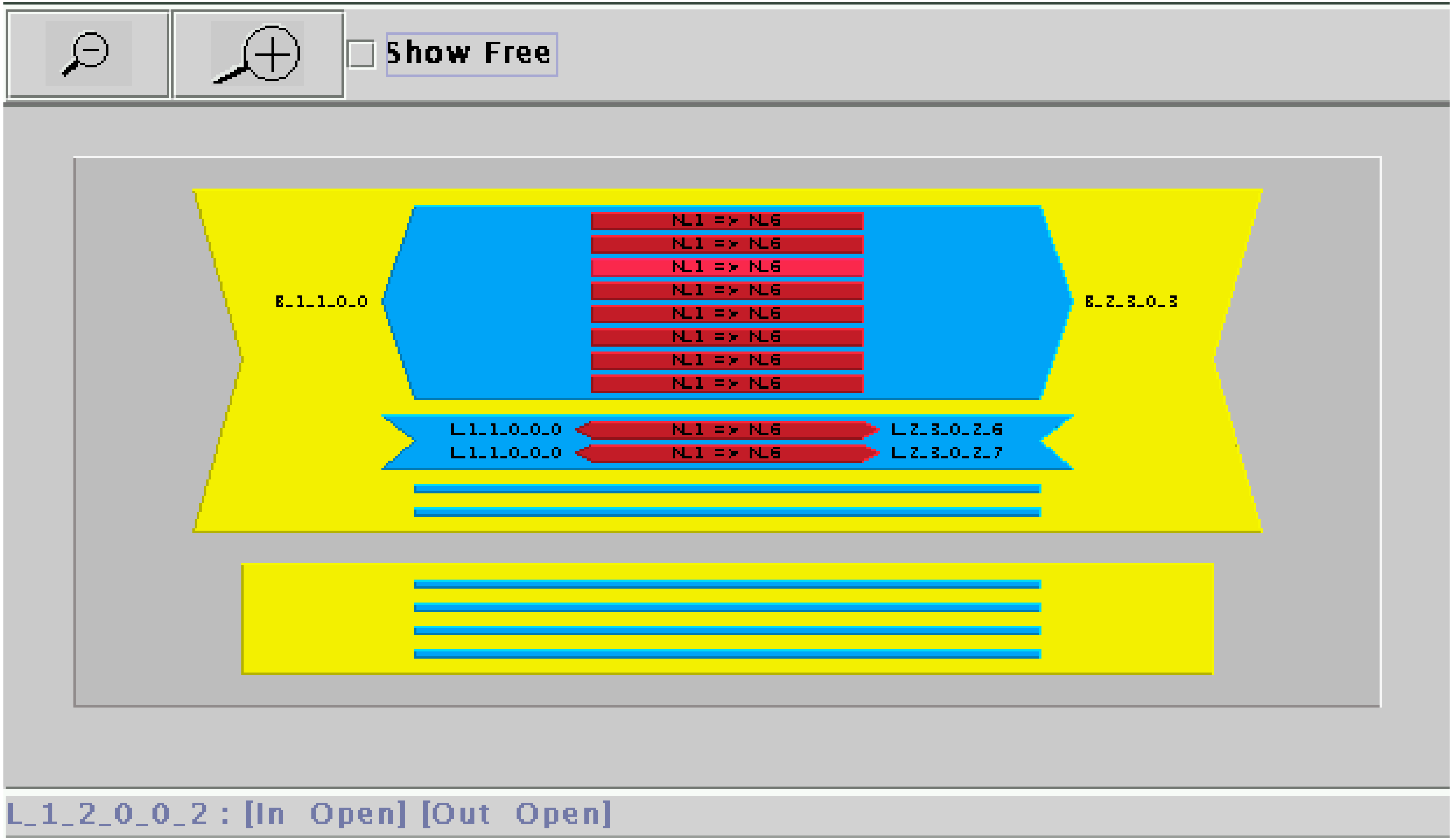
Nodes N_1 and N_0

- 1 fibre (yellow) : 4 wavebands
- 1 bande (blue) : 8 λ (red)

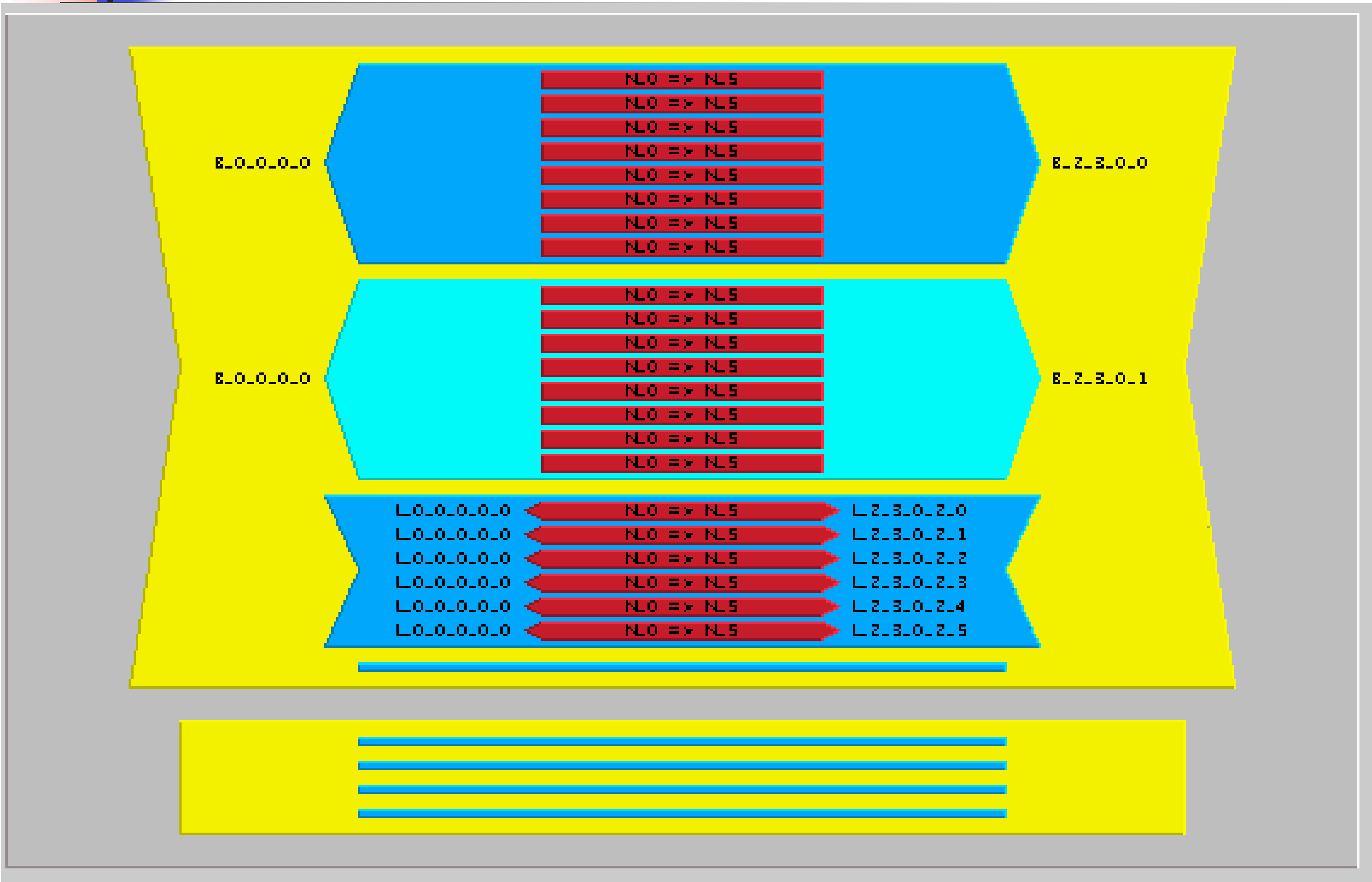




Cable from N_1 to N_2

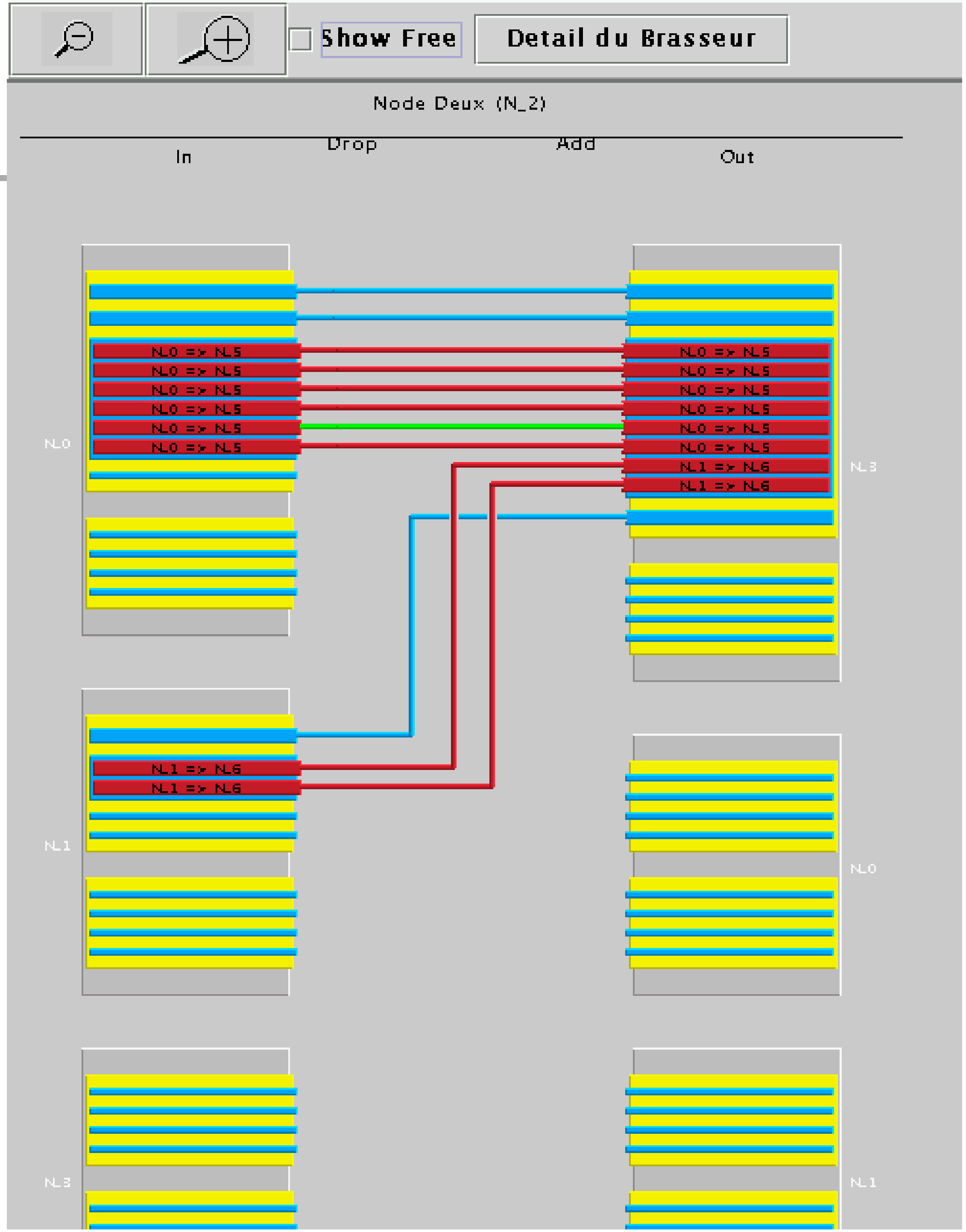


Cable from N_0 to N_2

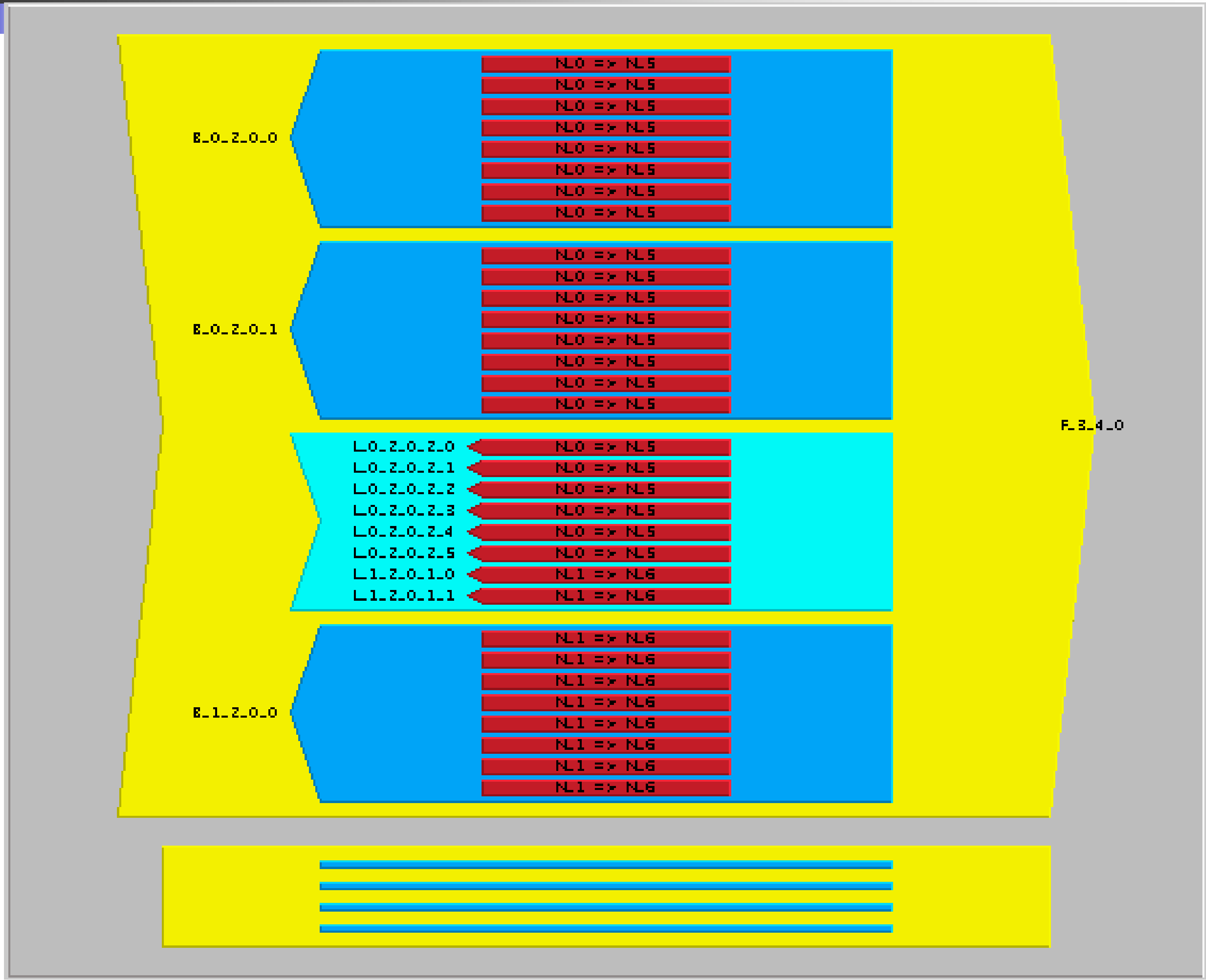


N_2

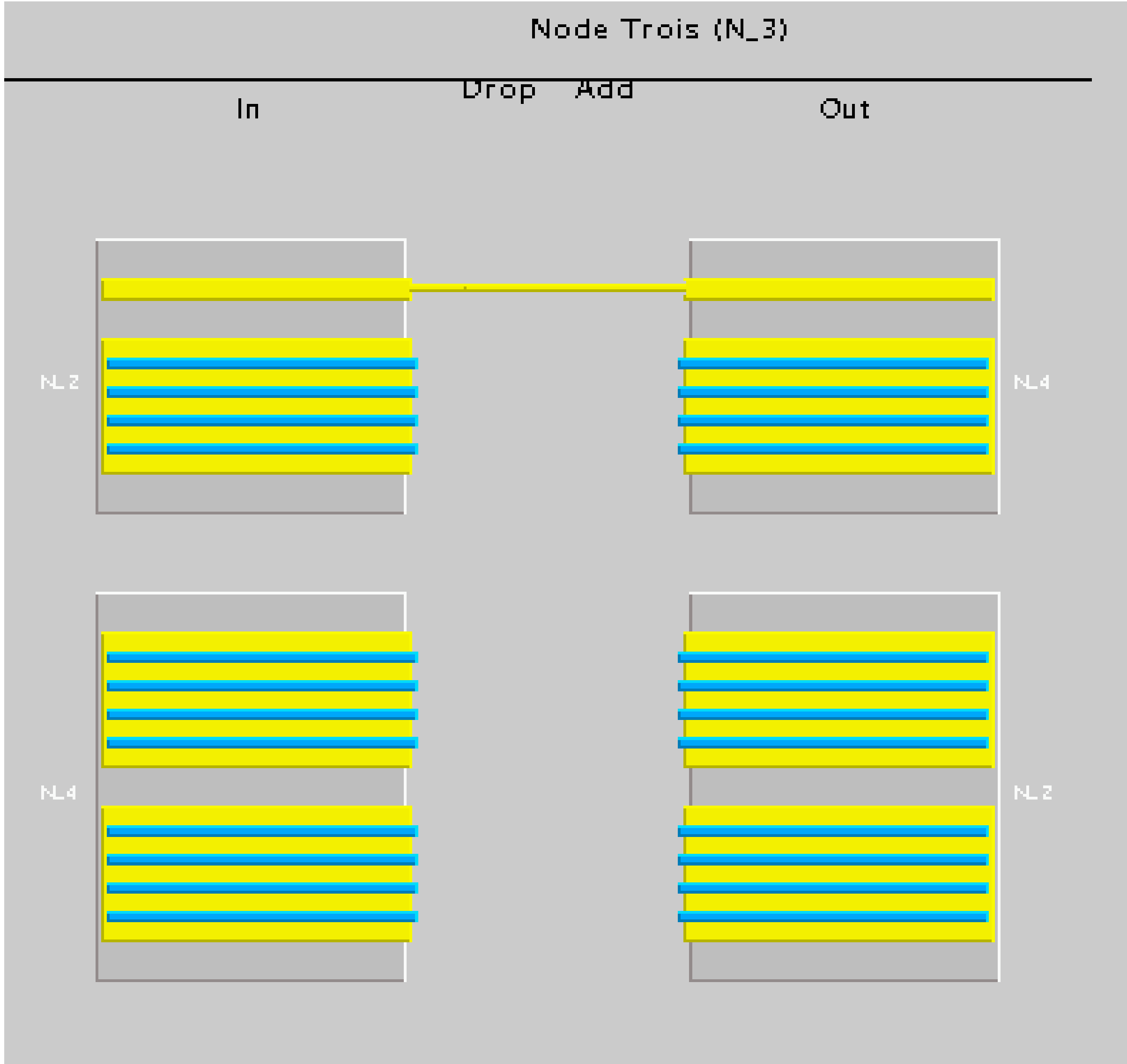
- ✓ 6 λ from demand N_0 → N_5 are grouped in one band along with 2 λ from demand N_1 → N_6
- 1 band from demand N_1 → N_6 are grouped in one fibre along with 3 bands from demand N_0 → N_5



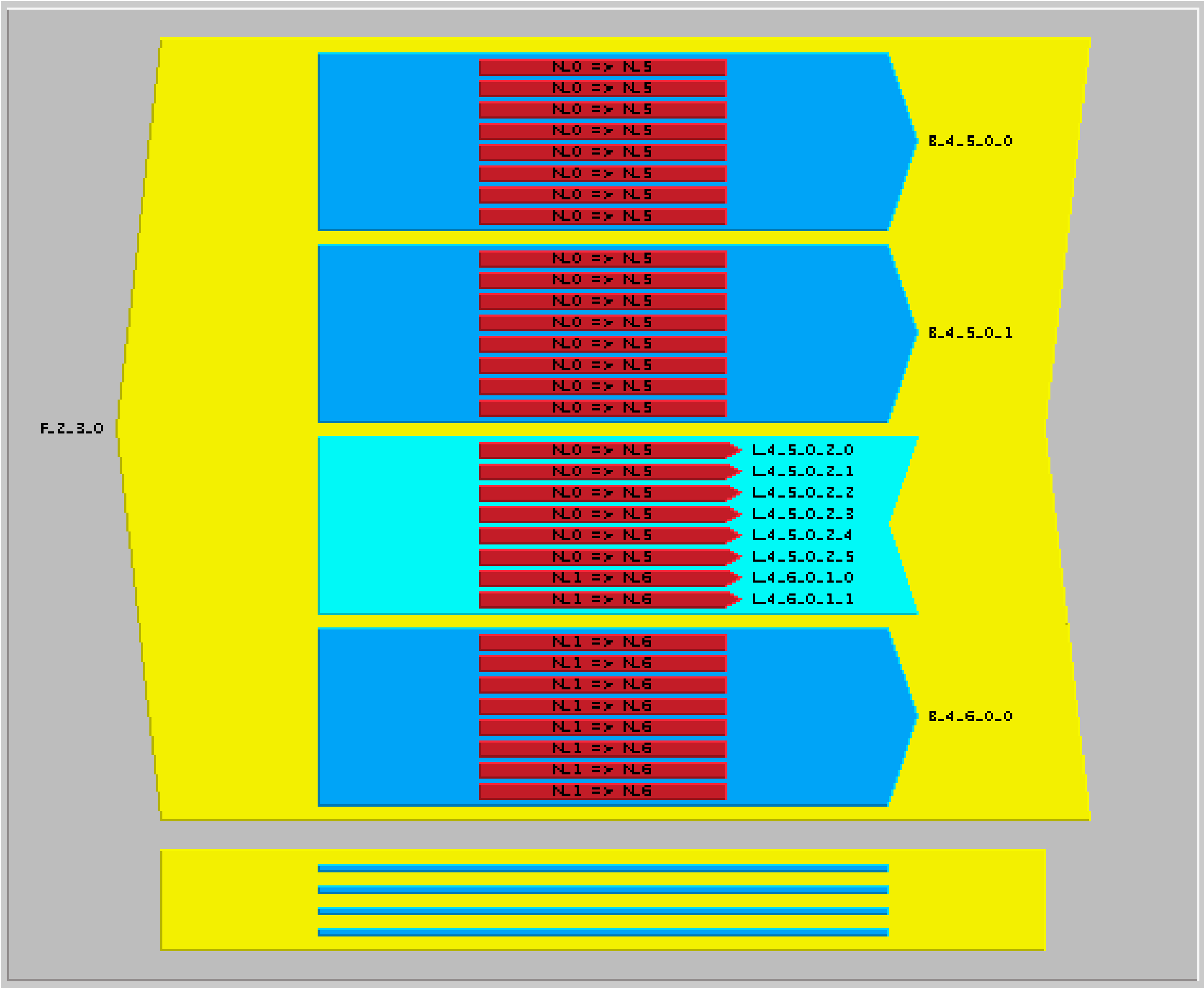
Cable from N_2 to N_3



N_3 : F-OXC equipped only



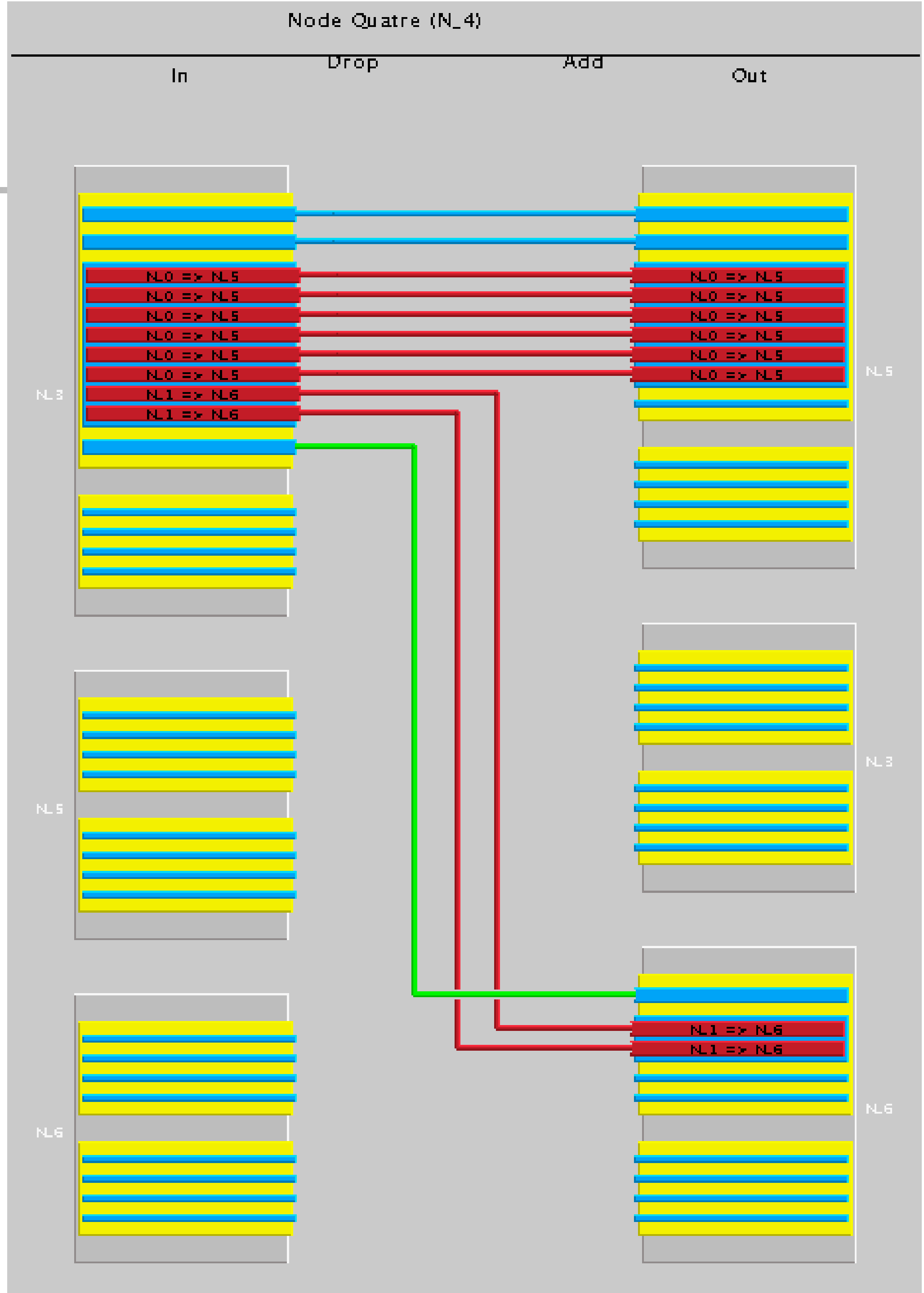
Cable from N_3 to N_4



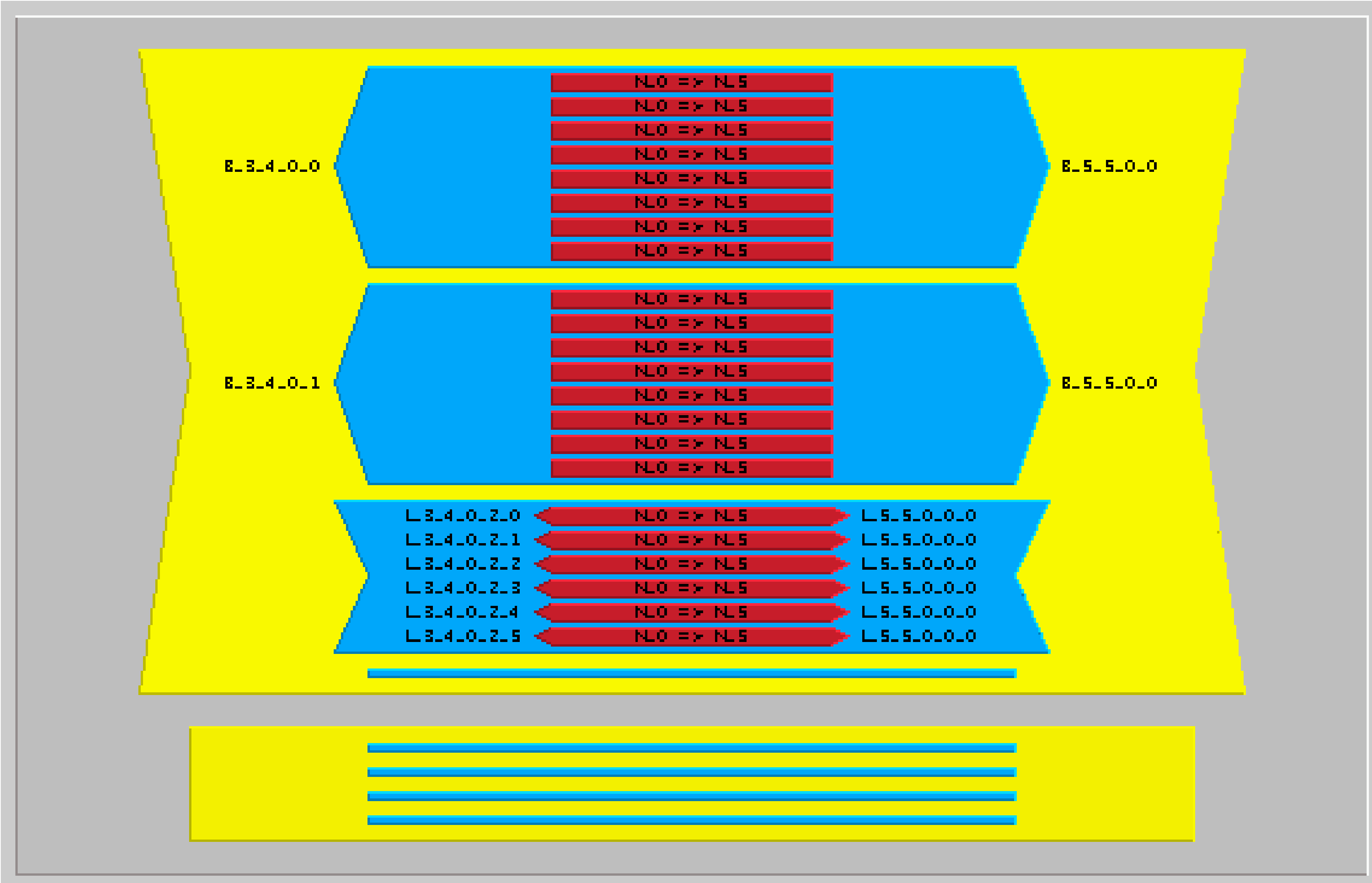
N_4

One has to demultiplex 1 band and 2 λ grouped in N_2 :

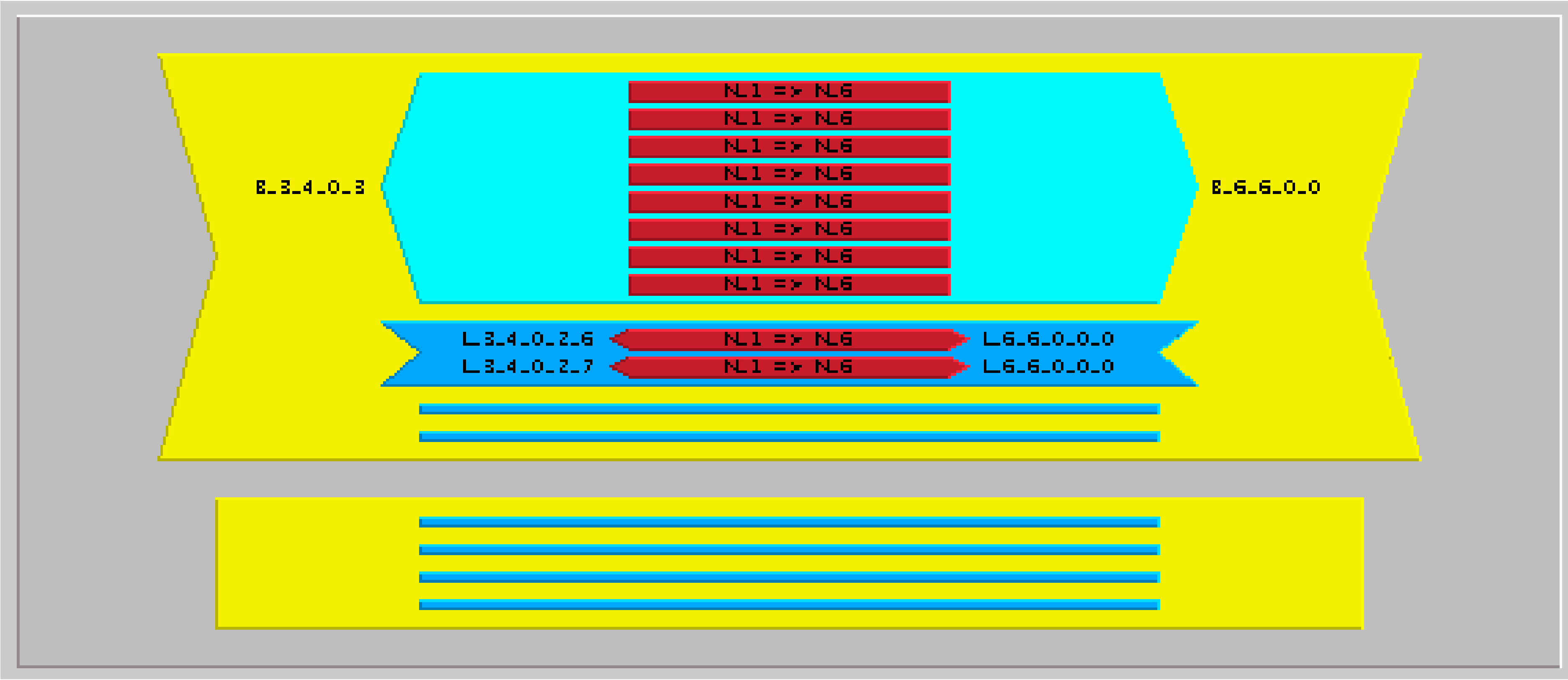
B-OXC and W-OXC



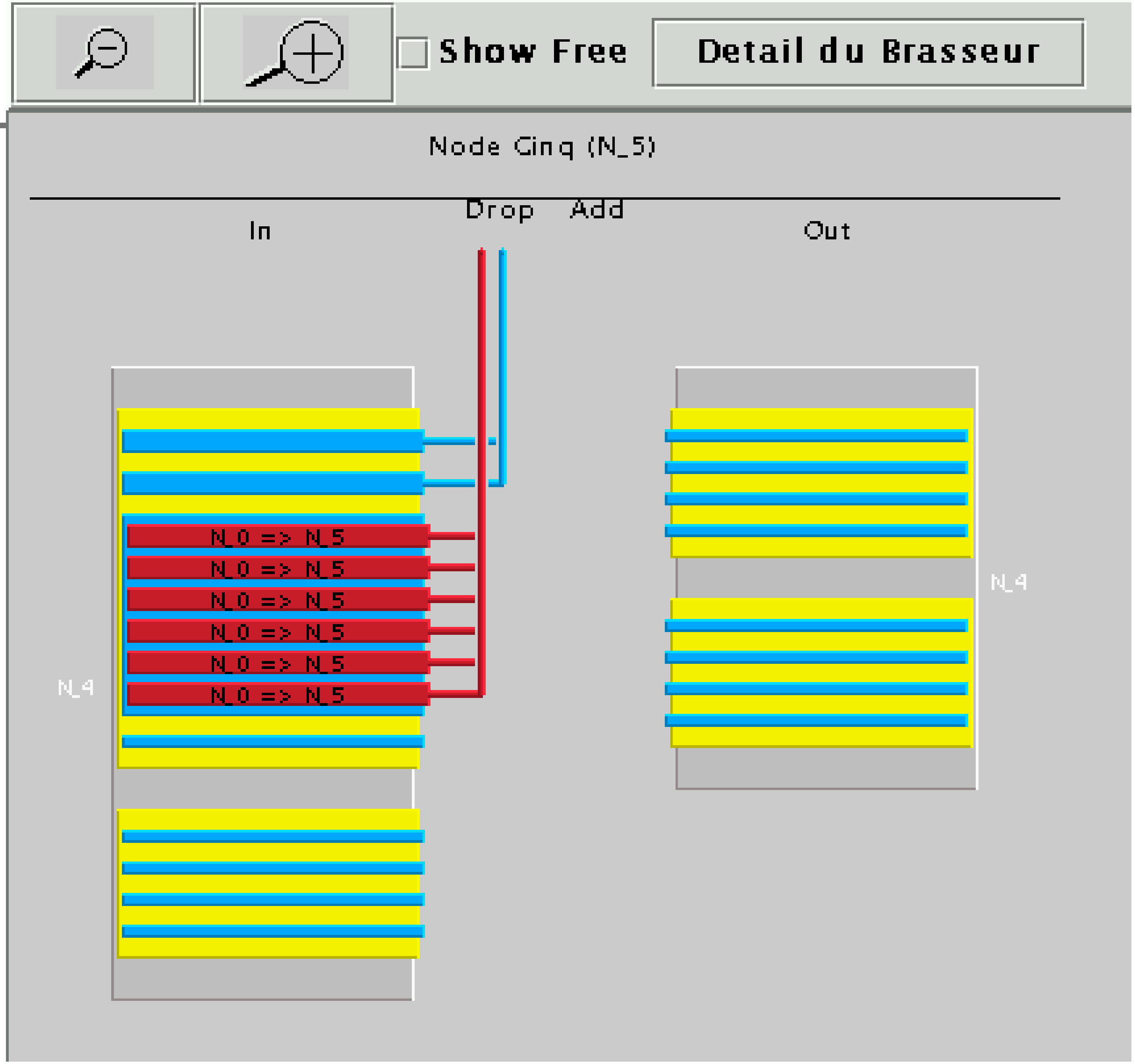
Cable from N_4 to N_5



Cable from N_4 to N_6



N_5



Show Free
Detail du Brasseur
Node Cinq (N_5)
Drop
Add
In
Out
N_0 => N_5
N_0 => N_5
N_0 => N_5
N_0 => N_5
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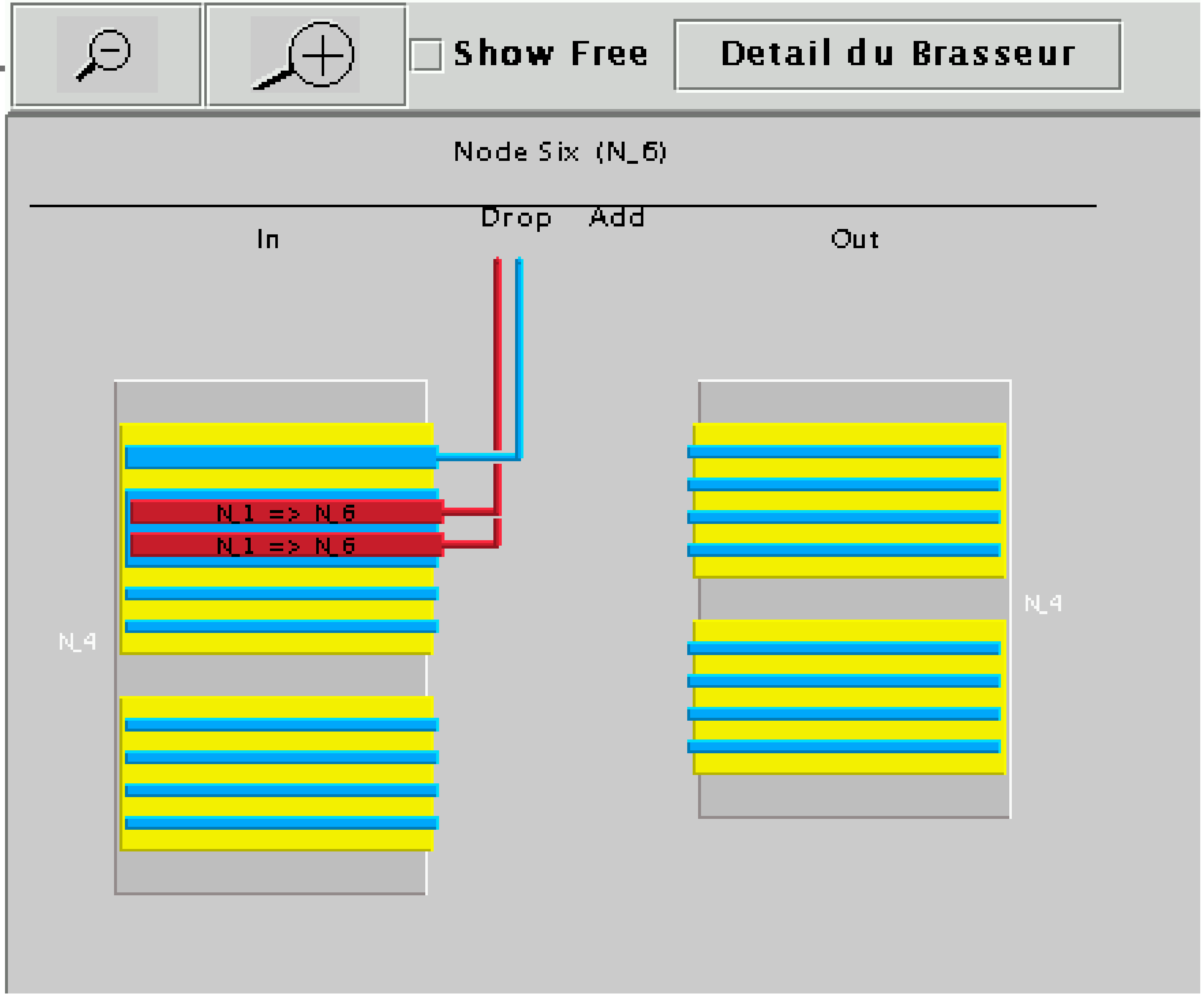
N_0 => N_5
N_4
N_4

N_6


Show Free
Detail du Brasseur
Node Six (N_6)
Drop
Add
In
Out
N_1 => N_6
N_1 => N_6
N_4
N_4

Conclusion

- Software tool able to process real network instances (France, Europe, USA)
- Allow us to test new algorithms, heuristics
- Perspectives:
  - PORTO-2, Mascopt, …