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Fine Protection of Data-Paths in Multi-Layer Networks Based on the GMPLS paradigm

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CoRiTeL

Outline

- New Generation Optical Networks
- Protection Strategy
- Optimization Problem
- Heuristic Combinatorial Algorithm
- Simulations and Results

New Generation Optical Networks

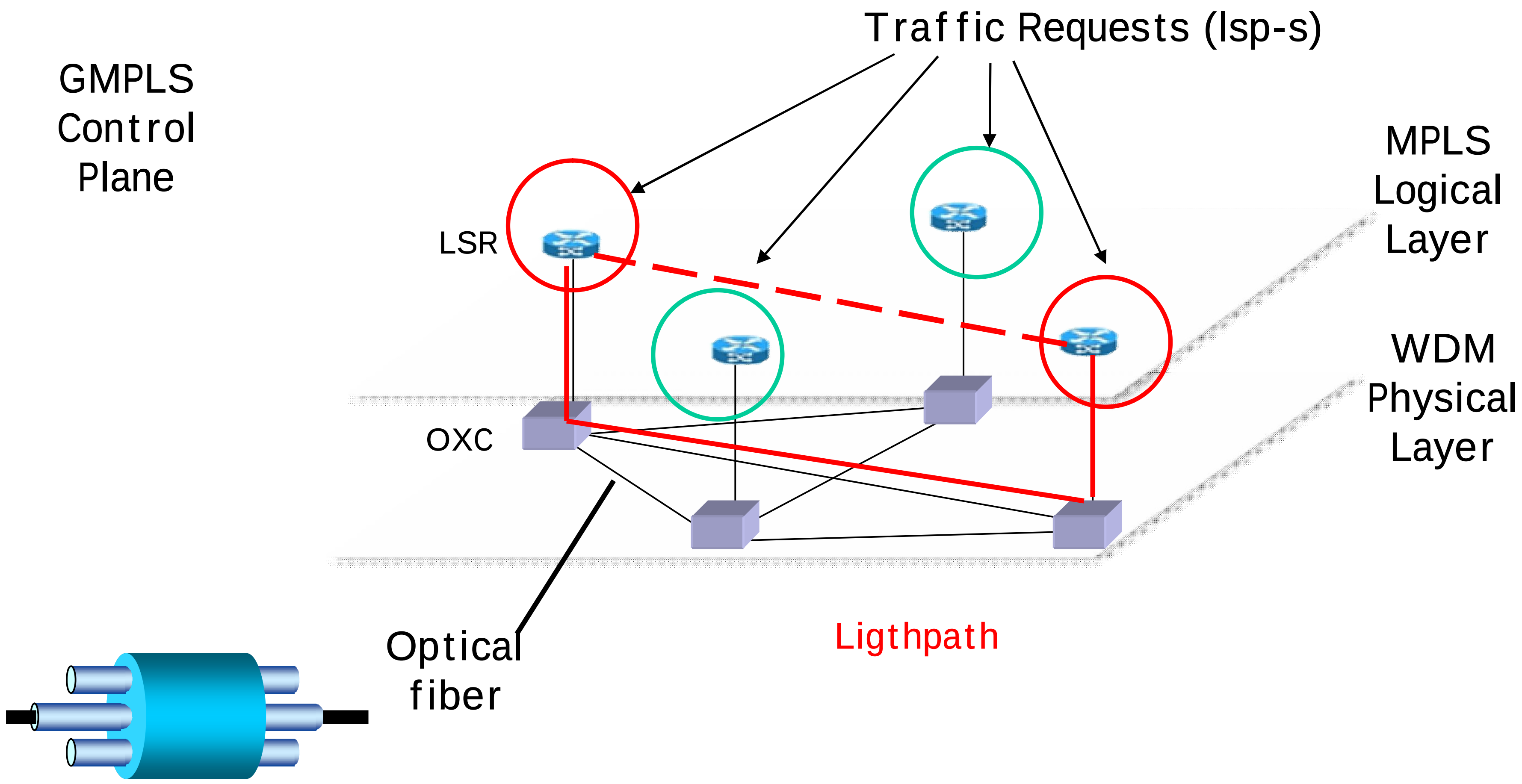
Key Issues:

- Rapid growth of Internet traffic
- Several types of traffic with different QoS

Objectives:

- Flexibility and Efficiency
- Handling different QoS and different levels of protection against failures

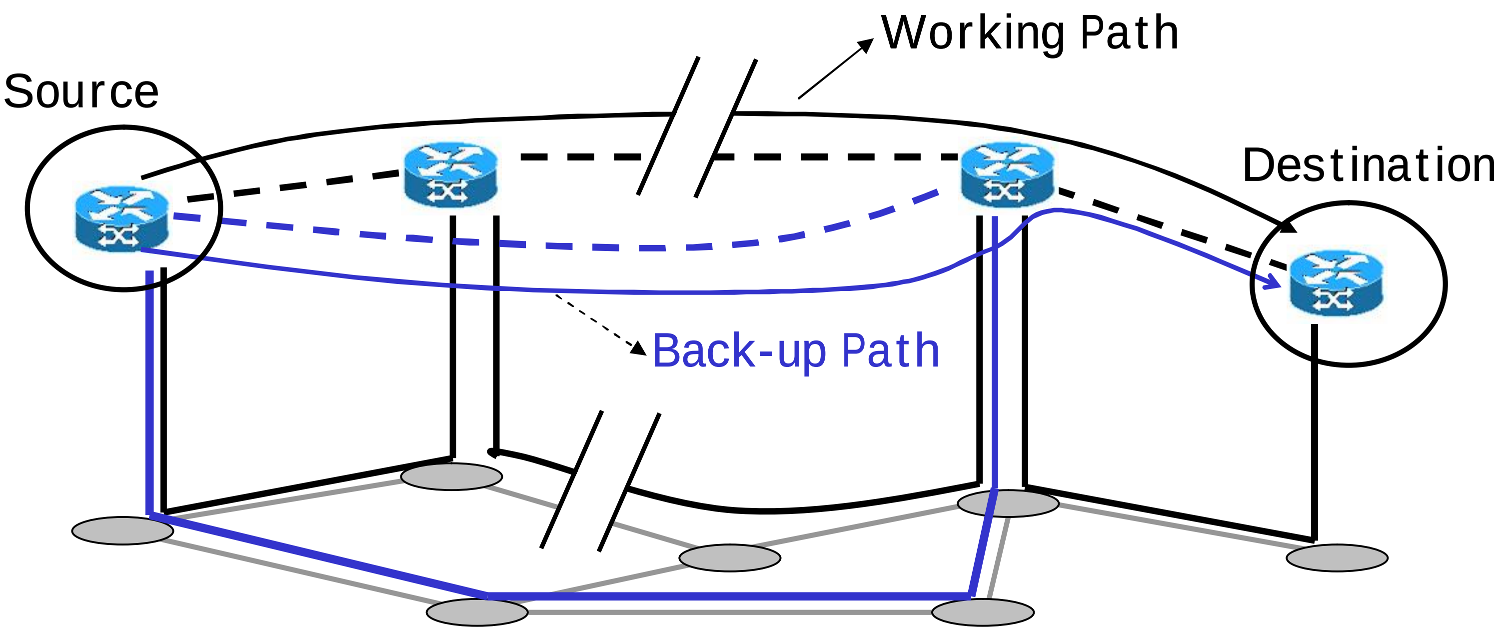
Multi-Layer Network Scenario



The Protection Problem

- Given a multilayer network and a set of traffic requests

Set up a set of lightpaths and assign to each HP traffic request a *logical path*, i.e. a sequence of lightpaths, for the working scenario…



- … and a logical path for each failure scenario (*back-up paths*)

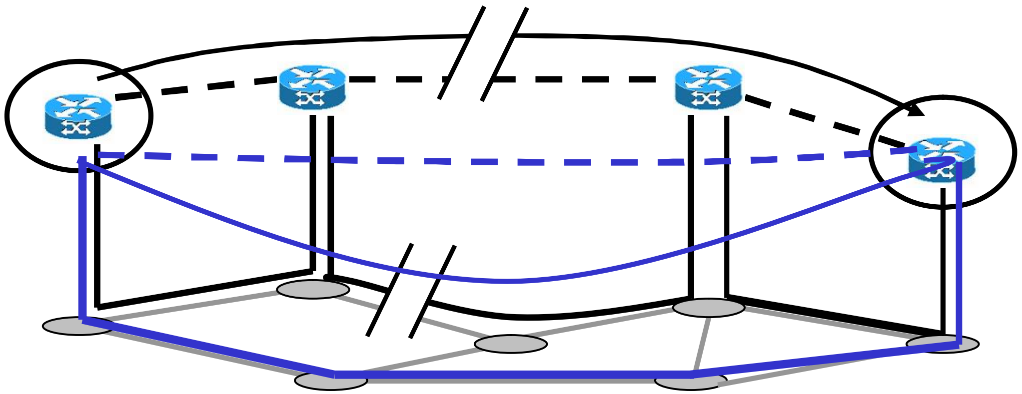
End to End Protection

§ Assign to each traffic request one working path and one back-up path that are disjoint

§ Wei Wei, Qingji Zeng, Yun Wang, "Multi-layer Differentiated Integrated Survivability for Optical Internet" Photonic Network Communications, vol 8, number 3, pp 267-284, 2004

§ Qin Zheng, G.Mohan "Protection Approaches for Dynamic Traffic in IP/PMLS-over-WDM Network" Communications Magazine, IEEE, vol 41, pp 24-29, 2003

§ Yinghua Ye, Assi C., Dixit S., Ali M.A, "A Simple Dynamic Integrated provisioning/protection scheme in IP over WDM networks", IEEE Communications Magazine, Nov 2001 – pp 174-182



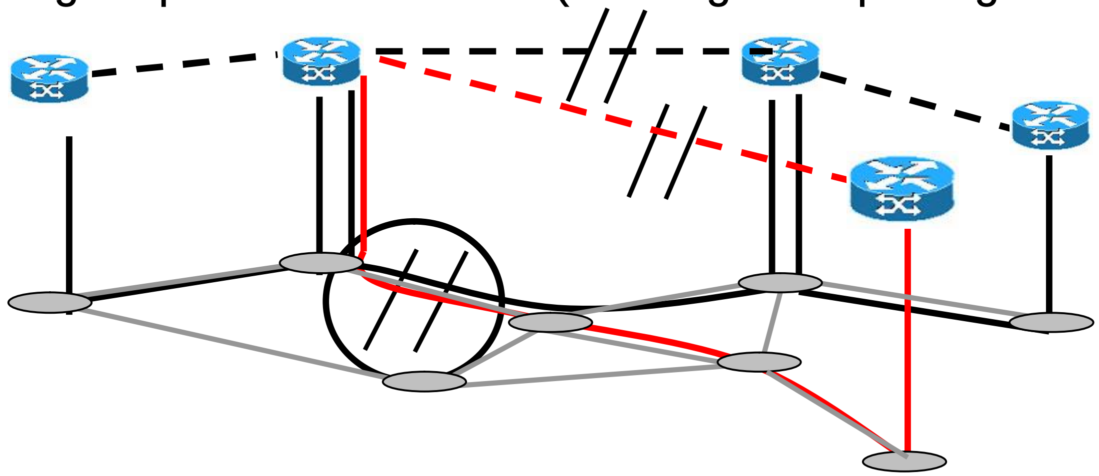
Protection Strategy

§ We want to assign to each traffic request one working path and one back-up path for each possible failure scenario

§ We associate a scenario with each failure event + one for the normal state

§ … therefore we want to assign to each traffic request a (logical) path for each possible scenario

§ Failure event: single optical link failure (causing multiple logical failures)

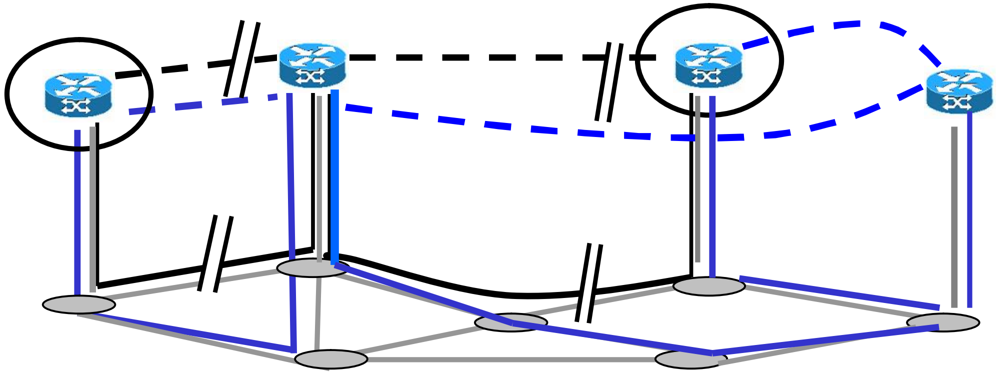


§ The protection strategy can be directly extended as to deal with different types of failures (as node ports)

Protection Strategy 2

Recovery Base Lightpath:

we reconnect the source and the destination of the failed lightpath while keeping fixed the rest of the logical path



Advantages:

§ confines signaling to the portion of the network that has failed

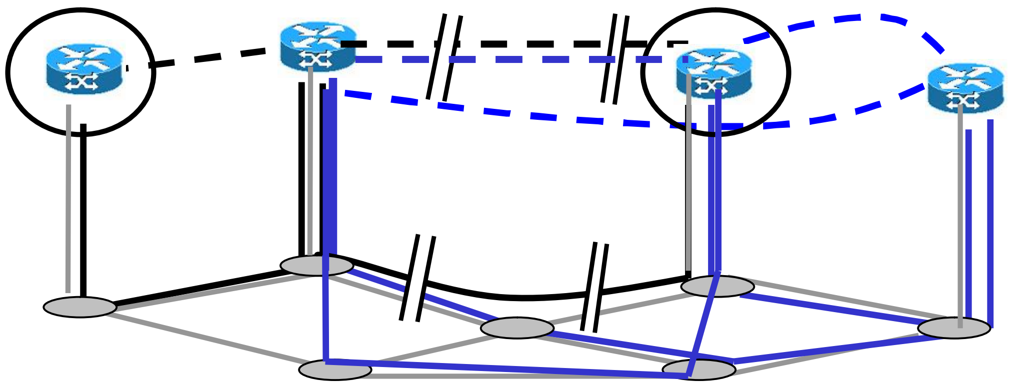
§ saves time of processing and reaction

§ makes easier fault management

Protection Strategy 3

A traffic request is diverted from its working path *p* only if some lightpath of *p* fails

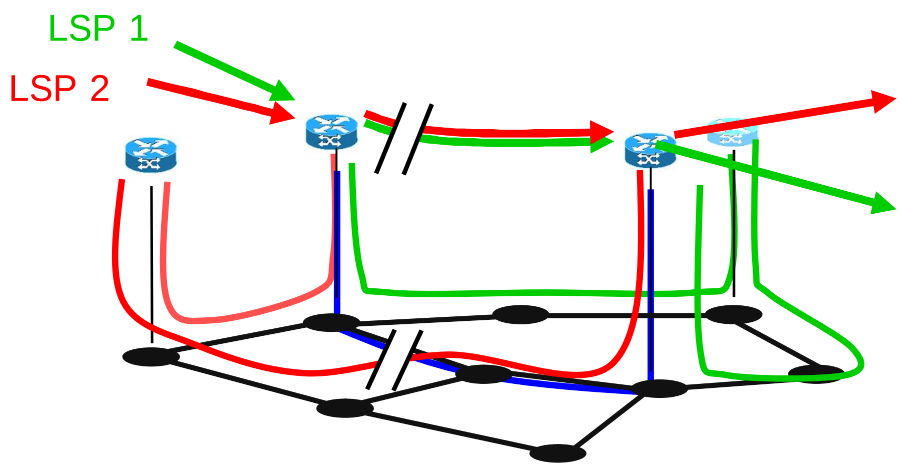
A traffic request might be diverted to different back-up paths when two edges e,f of a same lightpath of *p* fails



§ Advantage: in each scenario resource sharing is maximized

Protection Strategy 4

Two traffic requests sharing a same lightpath *j* on their working paths may have different back-up paths when some edge *e* of *j* fails



§Advantage: in each scenario resource sharing is maximixed

More Assumptions

Lightpaths must be set-up in advance; still a lightpath may carry different traffic requests in different scenarios

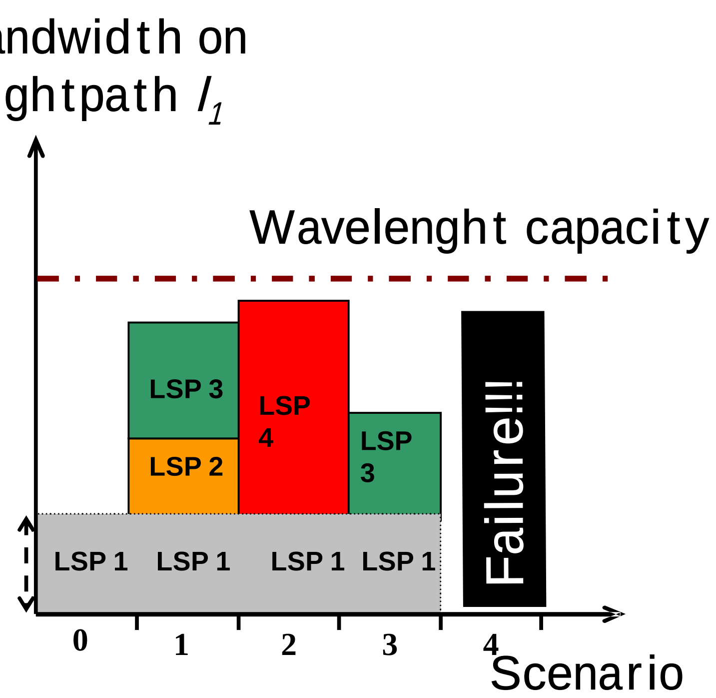
After a failure is repaired, working paths are reinstated (*revertive strategy*)

Feasibility of a solution (logical layer)

	Scenario 0	Scenario 1	....	Scenario m
LSP 1	l_1-l_2-l_3	l_1-l_2-l_3	....	l_1-l_5-l_3
LSP 2	l_4-l_6	l_4-l_1-l_7		l_1-l_2
. . . .				
LSP k				

Consistency check

Capacity check



Feasibility of a solution (optical layer)

	Physical link 1	Physical link 2		Physical link m	Intra-ports LSR 1	Intra-ports LSR 2		Intra-ports LSR n
Lightpath 1	yes	yes	....	no	yes	yes		no
Lightpath 2	no	no		yes	no	yes		yes
·								
Lightpath p	yes	no		yes	no	no		no

Consistency check

Capacity check

The Off-line Protection Problem

Given:

- A Multilayer Network
- A set of HP traffic requests (LSP-s) $k = 1 \dots K$, with source $s(k)$ destination $d(k)$ and bandwidth $b(k)$

Find:

- The Logical Topology
- Working Paths for each traffic request
- Back-up Paths for each traffic request, for each scenario

As to:

- Serve as many traffic requests as possible

An ILP formulation 1

Define:

§N_{el} := the set of LSR-s nodes
§N_{opt} := the set of OXC-nodes
§E_{opt} := the set of (directed) optical links
§E_{port} := the set of (directed) intra-ports links
§$n_{opt}(i,j)$: = the number of wavelengths in (i,j) E_{opt}
§$n_{port}(u,v)$:= the number of incoming/outgoing intra-ports in (u,v) E_{port}
§w = bandwidth available on a wavelength/intra-port
§K := the set of LSP-s
§s_k - t_k - b_k := respectively LSR-source, LSR-destination and requested bandwidth of k K
§S := $\{s_0, \dots, s_m\}$ the set of failure scenarios. s_0 is the working scenario, $m = |E_{opt}|/2$
§L := the set of candidate lightpaths to be set up
§$L_{opt}(i,j)$:= the set of lightpaths L using (i,j) E_{opt}
§$L_{port}(u,v)$:= the set of lightpaths L using (u,v) E_{port}
§$L^{+}(u)$:= the set of lightpaths L starting from node u N_{el}
§$L^{-}(u)$:= the set of lightpaths L ending in node u N_{el}
$L(s)$:= the set of lightpaths L failing in the scenario s S (with $L(s_0) = \emptyset$)

An ILP formulation 2

Decision Variables:

$$x_k = \begin{cases} 1 & \text{lsp } k \text{ is served} \\ 0 & \text{else} \end{cases}$$

$$z_{kls} = \begin{cases} 1 & \text{lsp } k \text{ is routed on lightpath } l \text{ in scenario } s \\ 0 & \text{else} \end{cases}$$

$$z_{le} = \begin{cases} 1 & \text{lightpath } l \text{ is routed through optical link } e \\ 0 & \text{else} \end{cases}$$

An ILP formulation 3

$$Max \sum_{k\in K} x_k$$

s.t.

(1) $\sum_{l\in L_{opt}(ij)} y_l \le n_{opt}(i,j) \quad \forall\ (i,j)\in E_{opt}$

(2) $\sum_{l\in L_{port}(uv)} y_l \le n_{port}(u,v) \quad \forall\ (u,v)\in E_{port}$

(3) $\sum_{l\in L^+(s_k)} z_{kls} - \sum_{l\in L^-(s_k)} z_{kls} = x_k \quad \forall\ k\in K,\ \forall s\in S$

$\sum_{l\in L^+(u)} z_{kls} - \sum_{l\in L^-(u)} z_{kls} = 0 \quad \forall\ k\in K,\ \forall u\in N_{el,} u\ne s_k, t_k$

(4) $\sum_{k\in K} d_k\, z_{kls} \le w y_l \quad \forall s\in S, \forall l\in L$

(5) $z_{kls_0} \le z_{kls} \quad \forall k\in K, \forall s\in S, \forall l\in L\setminus L(s)$

(6) $z_{kls_0} = 0 \quad \forall k\in K, \forall s\in S, \forall l\in L(s)$

(7) $x_k \in \{0,1\} \quad \forall\ k\in K$

$y_l \in \{0,1\} \quad \forall\ l\in L$

$z_{kls} \in \{0,1\} \quad \forall k\in K, \forall s\in S, \forall l\in L$

The objective is to maximize the number of served LSP-s

(1) The total number of lightpaths using the optical link (*i,j*) does not exceed the number of available wavelengths

(2) The total number of lightpaths using an intra-port between LSR *u* and OXC *v* does not exceed the number of available intra-ports

(3) Flow-constraints for LSP *k* in scenario *s*

(4) The total amount of traffic passing through each lightpath in each scenario does not exceed the capacity of the lightpath itself

(5) If *k* is routed on a lightpath *l* in the working scenario, it must be routed on *l* in each scenario *l* is active

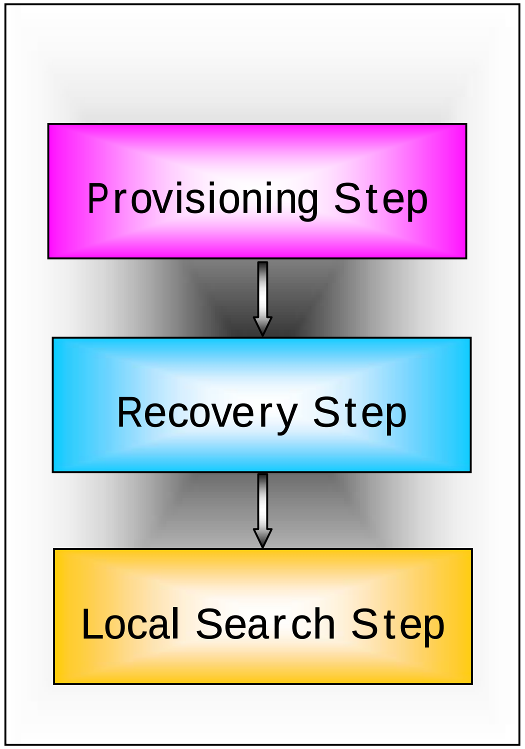
(6) *k* cannot be routed on a lightpath *l* that is not active in a scenario *s*

(7) For sake of shortness we assume that a set *L* of candidate lightpaths is given

Heuristic Approach

Sequential procedure based on successive shortest paths computations:

- simple and easy to implement
- can be extended to on-line HP traffic



Working paths research

Back-up paths research

Local search to improve the solution

Lightpaths are set-up dynamically while searching for the routing of an LSP

Provisioning Step

- § LSP-s are sorted according to non decreasing values of the minimum bandwidth they need, i.e. MinHop(k)*b(k)

- § For each LSP *k* the Routing Engine searches a working path, taking into account the working paths and the set of lightpaths set-up so far

- § If such a path is not found, then LSP *k* is temporary discarded

Recovery Step

§ Failure scenarios are sorted according to the loads on each optical link induced by the working paths

§For each failure scenario, LSP-s affected by the failure are sorted according to non decreasing values of the minimum bandwidth they need

§ For each LSP *k* the Routing Engine searches an alternative path for the failed lightpath, taking into account: the working paths, the back-up paths and the set of lightpaths estblished so far

§ If such a path is not found, then the LSP is temporary discarded

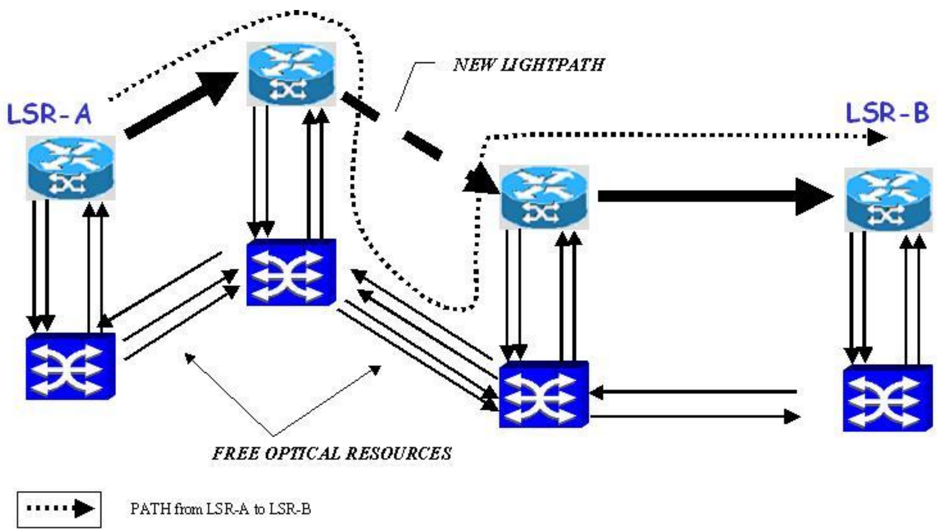
Local Search Step

- We try to accommodate LSP-s that have been discarded so far
- This is done by simple swapping rules and by means of the Routing Engine

Routing Engine

It uses Dijkstra's algorithm on an auxiliary network composed by:

- Two types of nodes
  1. OXC-s
  2. LSR-s
- Three types of links
  1. optical links
  2. intra-ports
  3. lightpaths set up so far



and it may establish new lightpaths

Link weights

1) $W_{lightpath}$ = # optical hops — lightpaths links

2) $$w_{ij} = \begin{cases} 1 - \beta \ln\left(1 - \frac{1}{\Lambda^a_{ij}}\right) & \text{if } \Lambda^a_{ij} > 1 \\ 1 + \beta & \text{if } \Lambda^a_{ij} = 1 \end{cases}$$ optical links

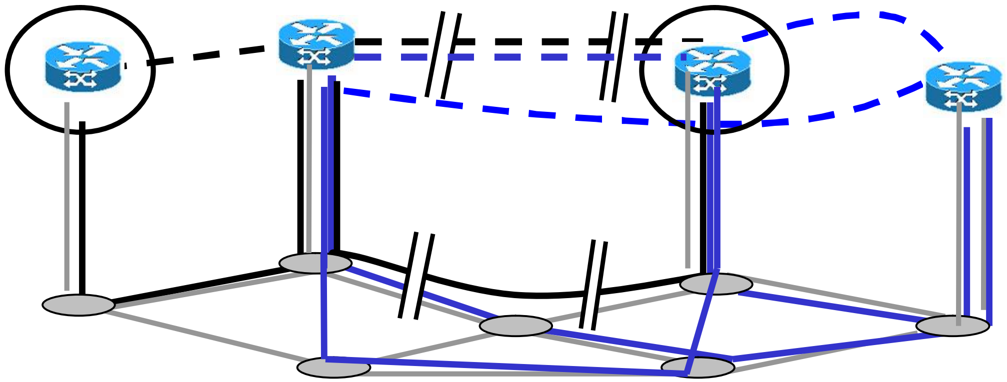
3) $$w^{intra}_{ij} = \begin{cases} \gamma - \gamma\beta \ln\left(1 - \frac{1}{\Lambda^a_{ij}}\right) & \text{if } \Lambda^a_{ij} > 1 \\ \gamma + \gamma\beta & \text{if } \Lambda^a_{ij} = 1 \end{cases}$$ intra-ports links

Alternative Strategies for Simulation

Objective: comparing our strategy wrt to other possible strategies

Up to now: comparing our strategy wrt to 2 less refined strategies defined by:

1) forcing an LSP to use the same backup path for the failure of edges in a same lightpath

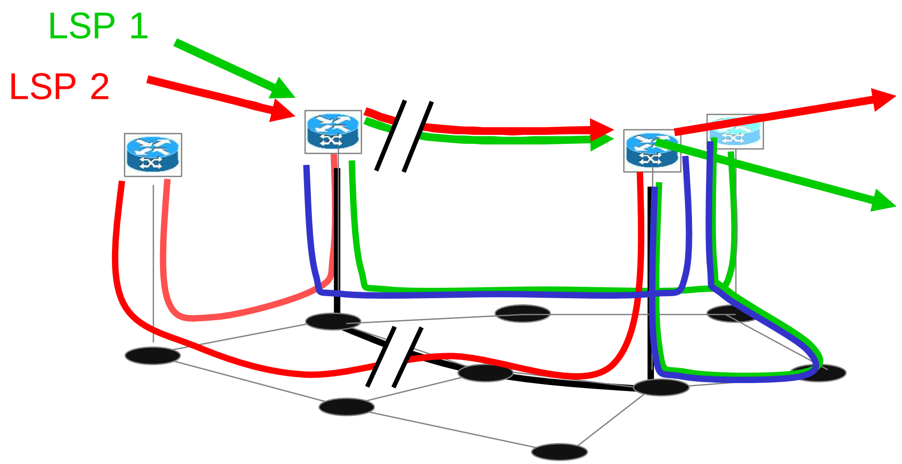


Alternative Strategies for simulation

Objective: comparing our strategy wrt to other possible strategies

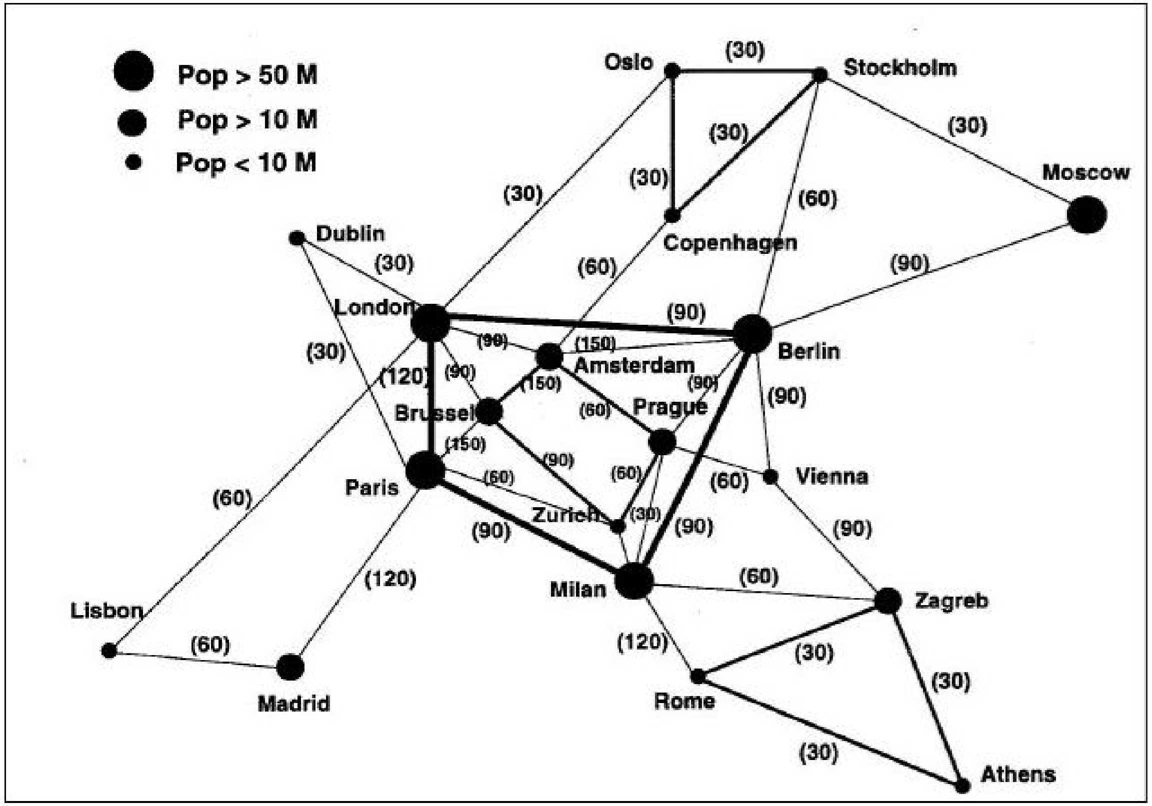
Up to now: comparing our strategy wrt to 2 less refined strategies defined by:

2) forcing two LSP-s sharing a lightpath *j* to share also the back-up path when an edge *e* of *j* fails



Simulation

Network: 19 nodes 36 links



Hypothesis

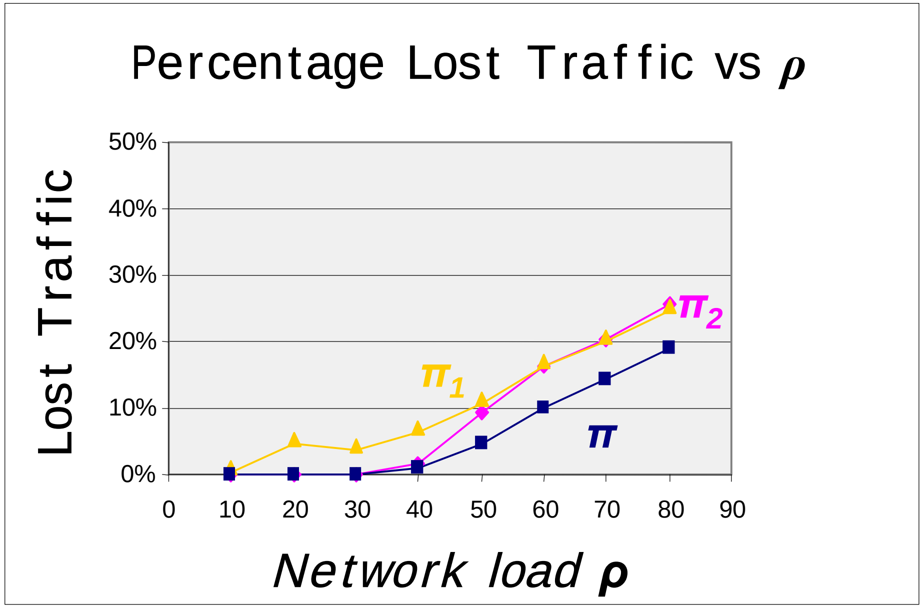
- Each OXC connected with an LSR
- Each optical link is bi-directional
- Number of intra-ports = 70% number of λ crossing the OXC
- w_λ=2,5 Gb/s

Network load

$$\rho = \frac{\sum_k min\_hop(k)\ b(k)}{C_{tot}}$$

Results

- π = percentage of lost traffic by the main strategy
- π_1 = percentage of lost traffic by the alternative strategy (1)
- π_2 = percentage of lost traffic by the alternative strategy (2)



Network Load ρ	$\frac{\pi_1 - \pi}{\pi_1}$	$\frac{\pi_2 - \pi}{\pi_2}$
10%	100%	0
20%	100%	0
30%	96%	0
40%	87%	44%
50%	60%	51%
60%	41%	39%
70%	30%	29%
80%	25%	26%

Conclusions

§ Fine Routing / Protection strategy for MPLS over WDM network via a simple shortest path algorithm

§ Main elements of the protection strategy: scenario dependency, LSP granularity, ligthpath recovery base, high resource sharing

§ First computational tests show the advantages of our strategy

Future Work

§ Exact comparison with End to End protection strategies via ILP techniques