QoS routing in DWDM Optical Packet Networks

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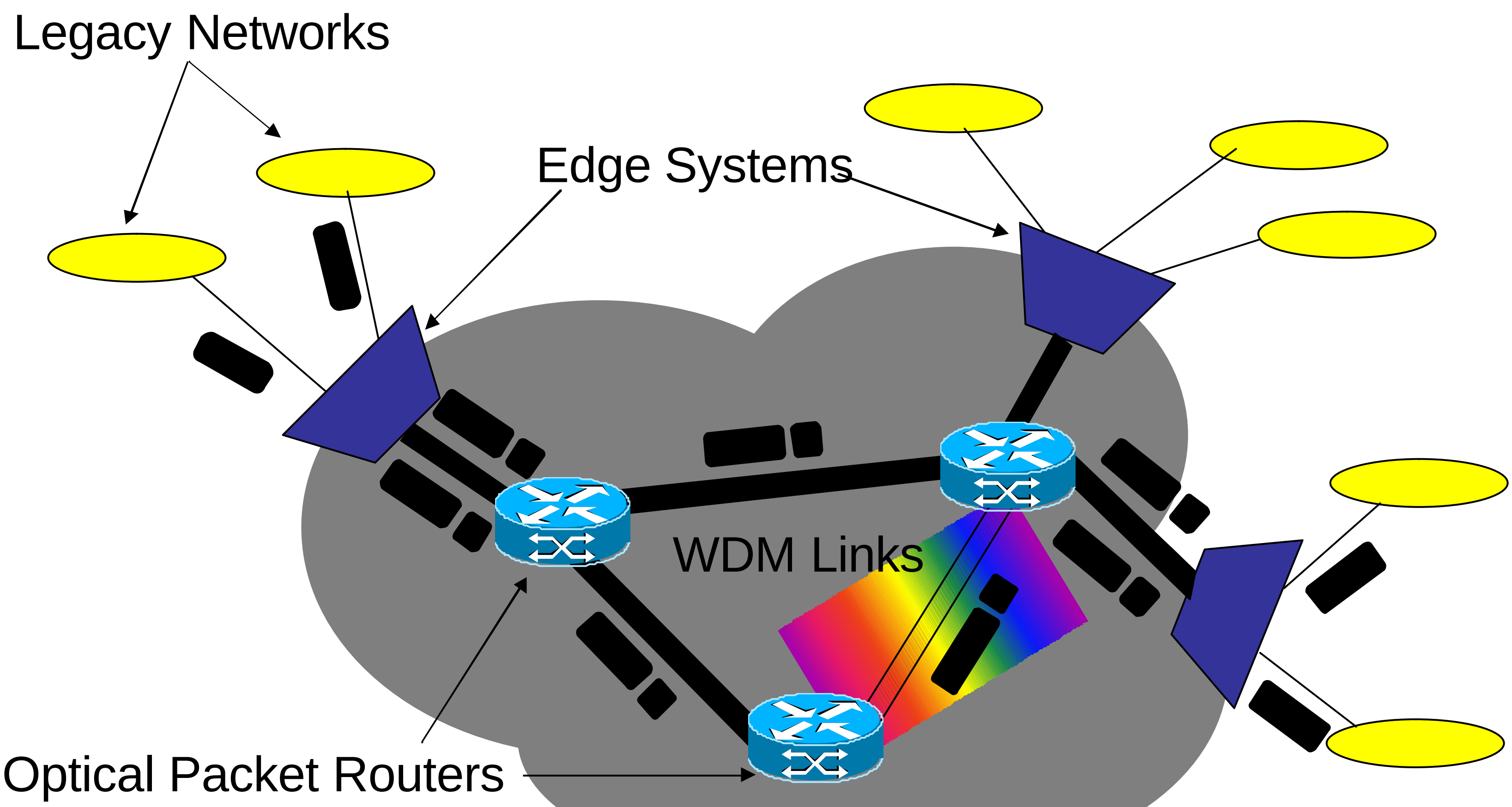
Optical Packet Switching (OPS)

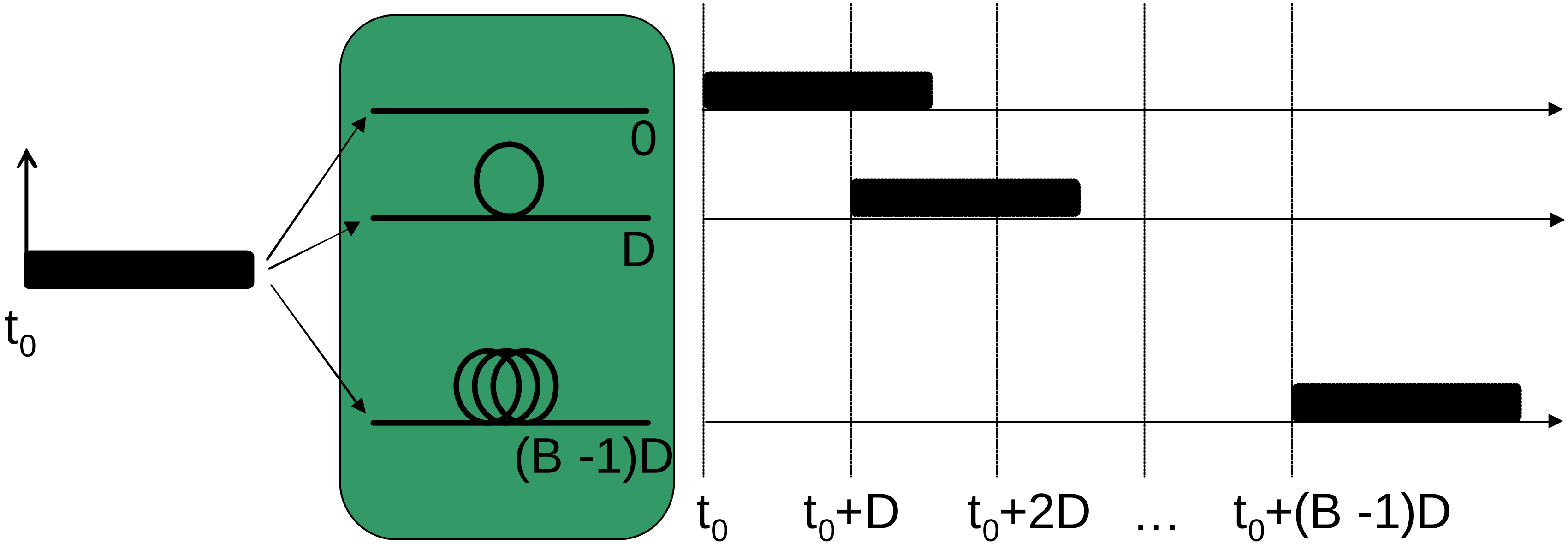
Statistical multiplexing of different flows on each wavelength

Routing-based signalling



Long-term technical solution

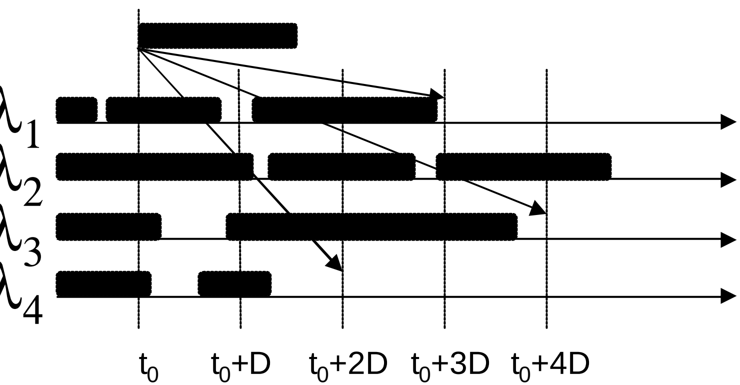
Store & forward with optical buffers

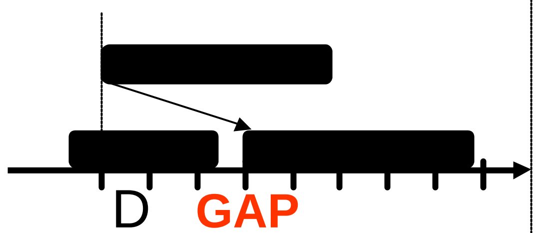


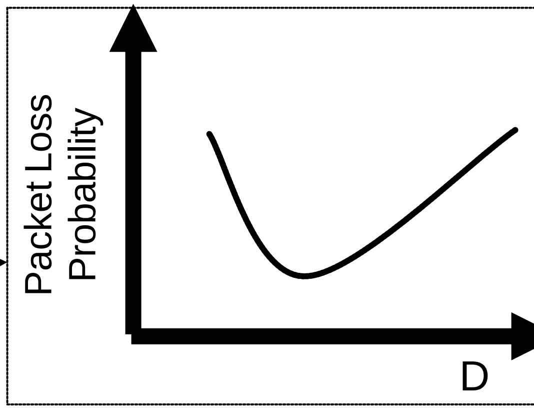
- Realized with B **Fiber Delay Lines** (FDL):
  - the delay must be chosen at packet arrival
  - packets are delayed until the output wavelength is available
  - available delays are consecutive multiples of the **delay unit** D (different choices are also possible)
  - packets are lost when the buffer is full, i.e. the required delay is larger than the maximum delay achievable $D_M = (B-1)D$

Wavelength and Delay Selection Problem

- The forwarding algorithm determines:
  - the output fiber (from the routing table) and the output wavelength
  - if all wavelengths are busy:
    - packet delayed in FDL buffer or
    - packet dropped, because the required delay is not available







- **Wavelength and Delay Selection** (WDS)
  - choose the wavelength according to availability in time
  - choose the delay in order to minimize the gaps between buffered packets and maximize the wavelength utilization

Algorithms for adaptive routing in OPS

- Routing algorithms can be
  - **static**: routing tables change only when the topology changes
  - **adaptive**: routing tables include alternatives to shortest path depending on the congestion state of the network
- DWDM OPS network must
  - combine the flexibility of adaptive routing with the resources made available by WDM
  - design routing procedures outperforming the conventional shortest path routing
  - provide QoS differentiation at the routing level

Algorithms for adaptive routing in OPS

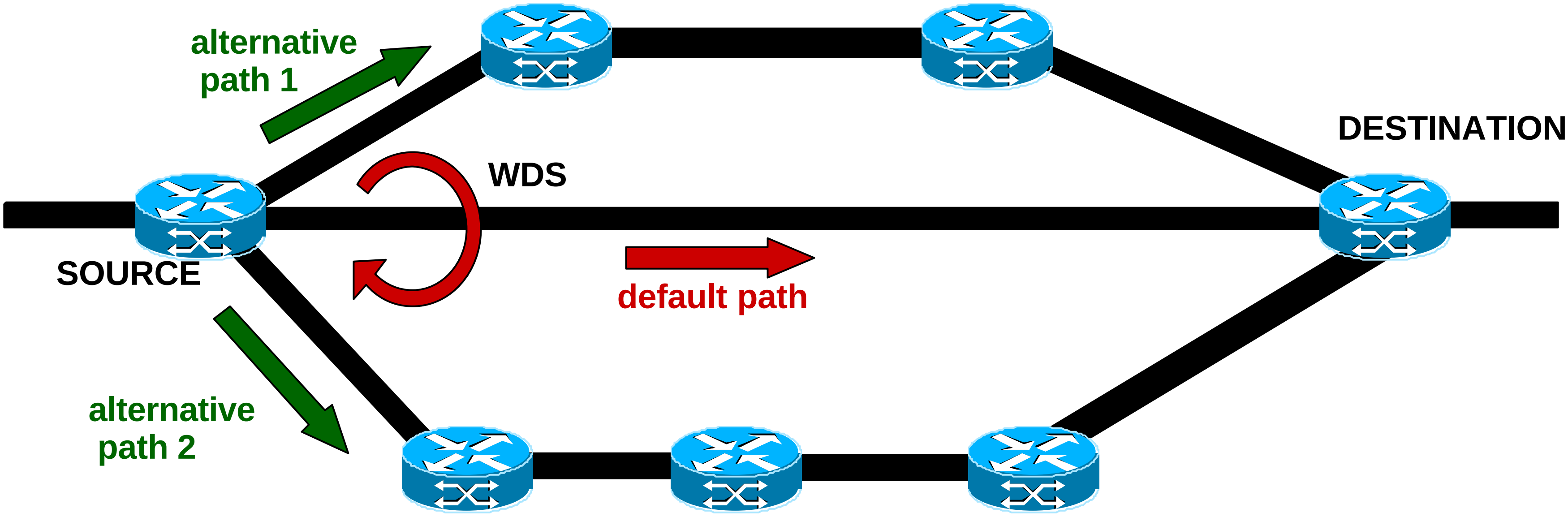
- Solutions for undifferentiated traffic presented at ONDM '04

- The routing algorithm provides:
  - **a default path**: shortest path used as a first chance
  - **a few alternative paths**: used in case the default is congested

- Traffic flows are routed according to different path selection strategies (increasing complexity):
  - **SL (Single Link)**: only the default path is used (static routing)
  - **SA (Single Alternative)**: a single alternative path is used (ineffective: performance close to SL)
  - **MA (Multiple Alternative)**: more than one alternative paths are used

Multiple alternative routing

In case the default path is congested, the best wavelength is chosen on one of the alternative path



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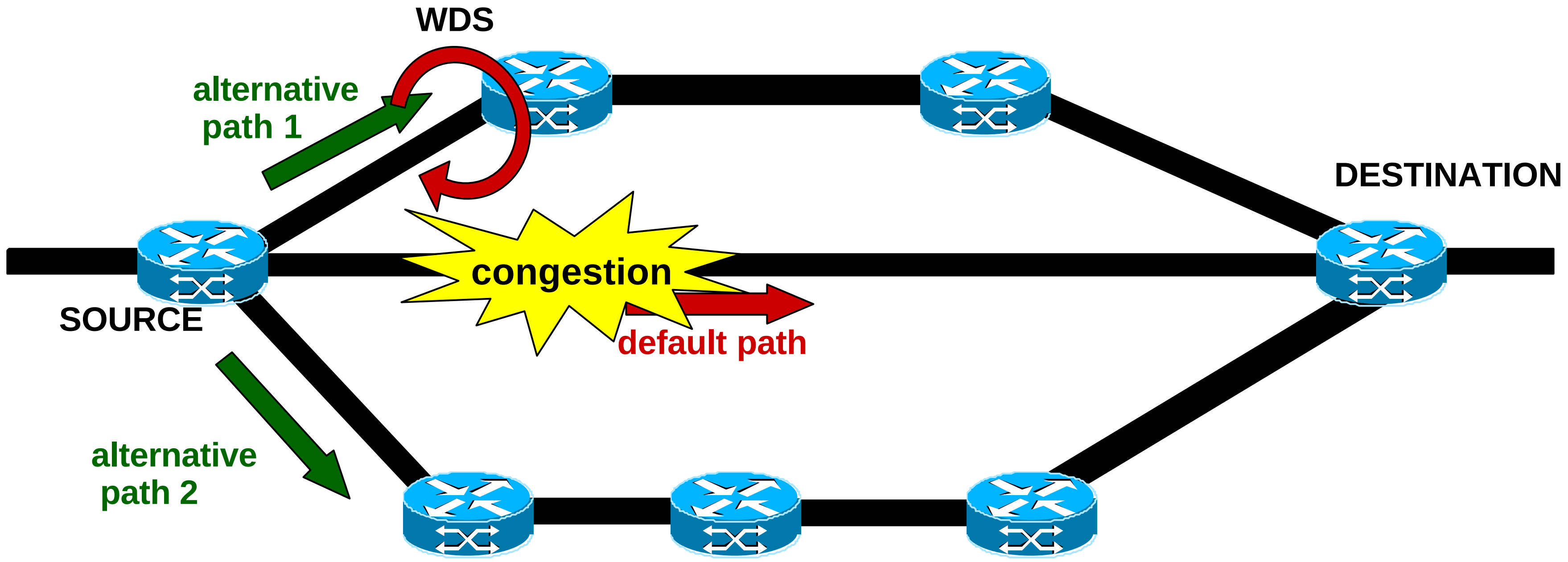

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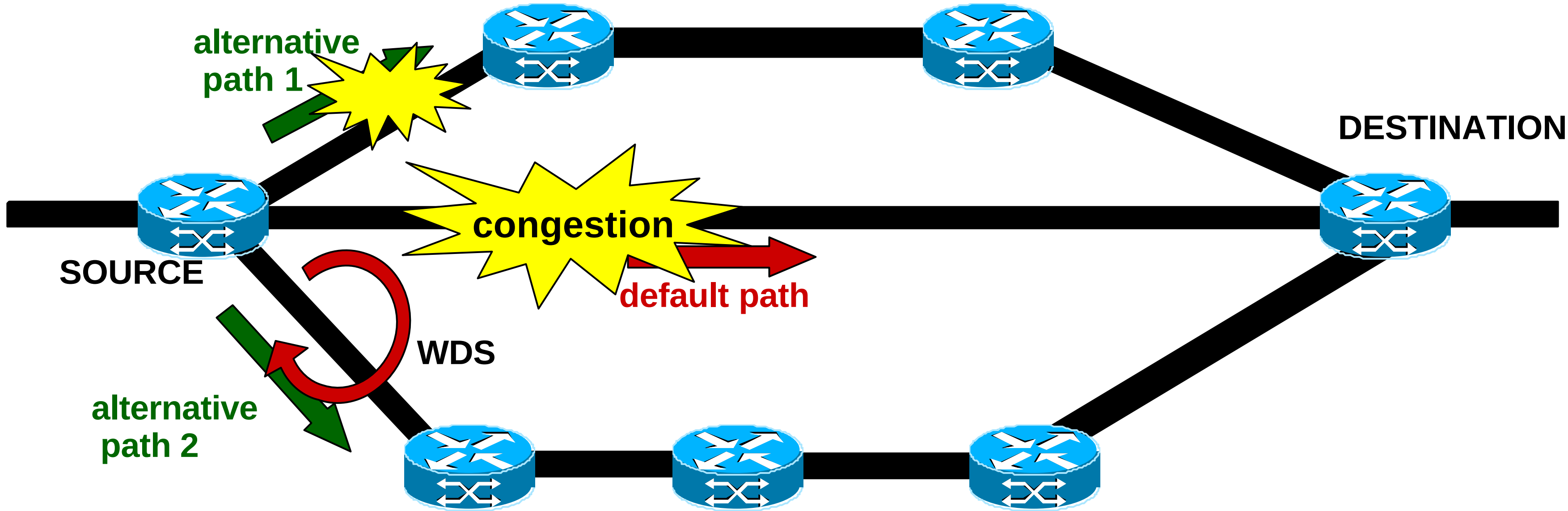
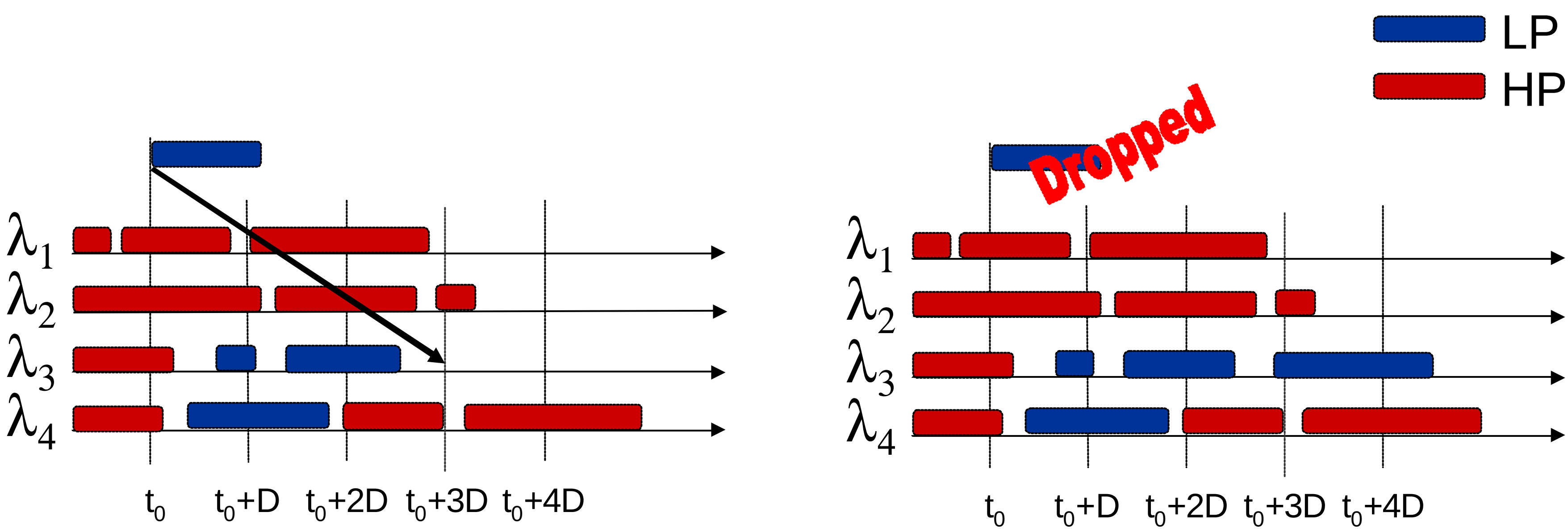


QoS differentiation at the routing level

- Due to FDL buffering constraints, traditional priority queuing and scheduling techniques are not feasible
  - QoS differentiation at the OPS node level possible through resource partitioning (cf. JSAC Jan. 2000, Comp. Net. 15/03/2004)
- Integration of QoS management into adaptive routing algorithms
  - aggregate QoS classes (sort of DiffServ approach)
  - simple set-up: 2 priority classes
  - **High-Priority** (HP) traffic: always routed along the shortest path (SL) using resource partitioning
    - limited packet loss
    - limited delay and packet jitter
  - **Low-Priority** (LP) traffic: two options
    - always routed along the shortest path (SL) using available resources
    - overflow traffic re-routed to alternative paths (MA)

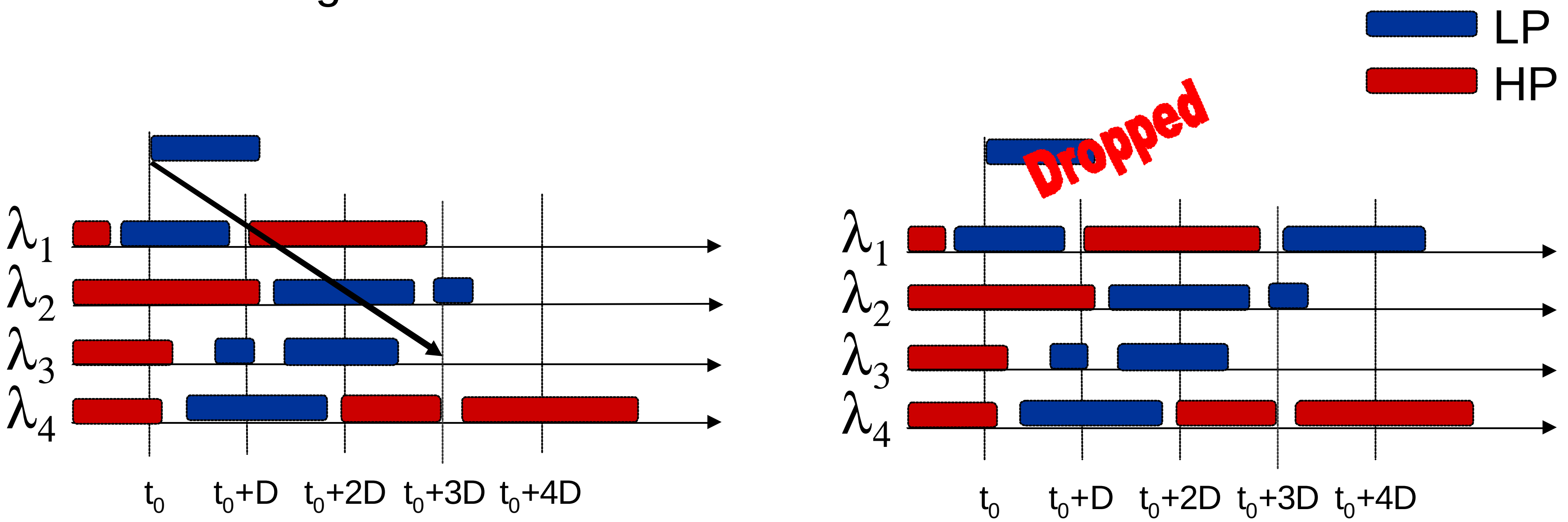
Resource partitioning: FIX strategy

- H wavelengths out of W are reserved to HP traffic
  - the remaining W – H wavelengths are shared between HP and LP traffic
- The reserved wavelengths are fixed
  - e.g. H=2 → ?$_1$ and ?$_2$ are reserved
  - when ?$_1$ and ?$_2$ are busy, HP and LP experience the same loss



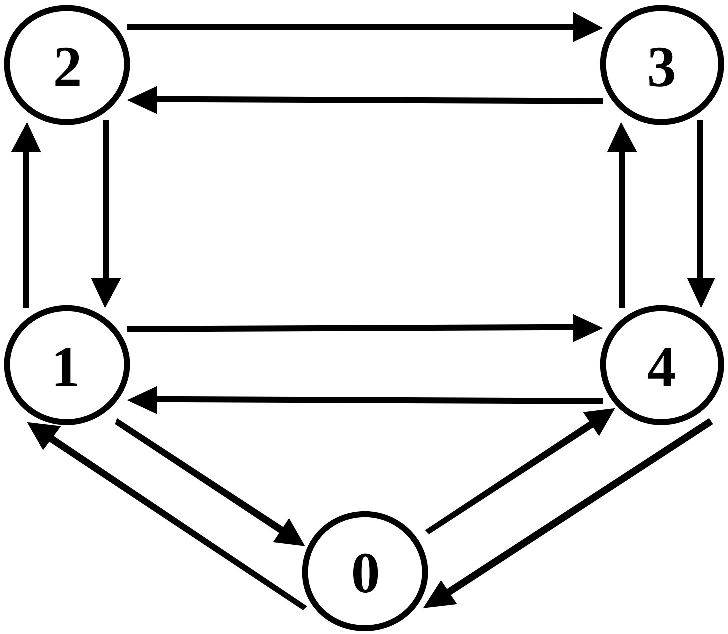
Resource partitioning: RES strategy

- H wavelengths out of W are reserved to HP traffic
  - the remaining W – H wavelengths are shared between HP and LP traffic
- Any H wavelengths are reserved based on the actual occupancy
  - e.g. H=2 → LP packets are allowed as long as more than 2 wavelengths are available

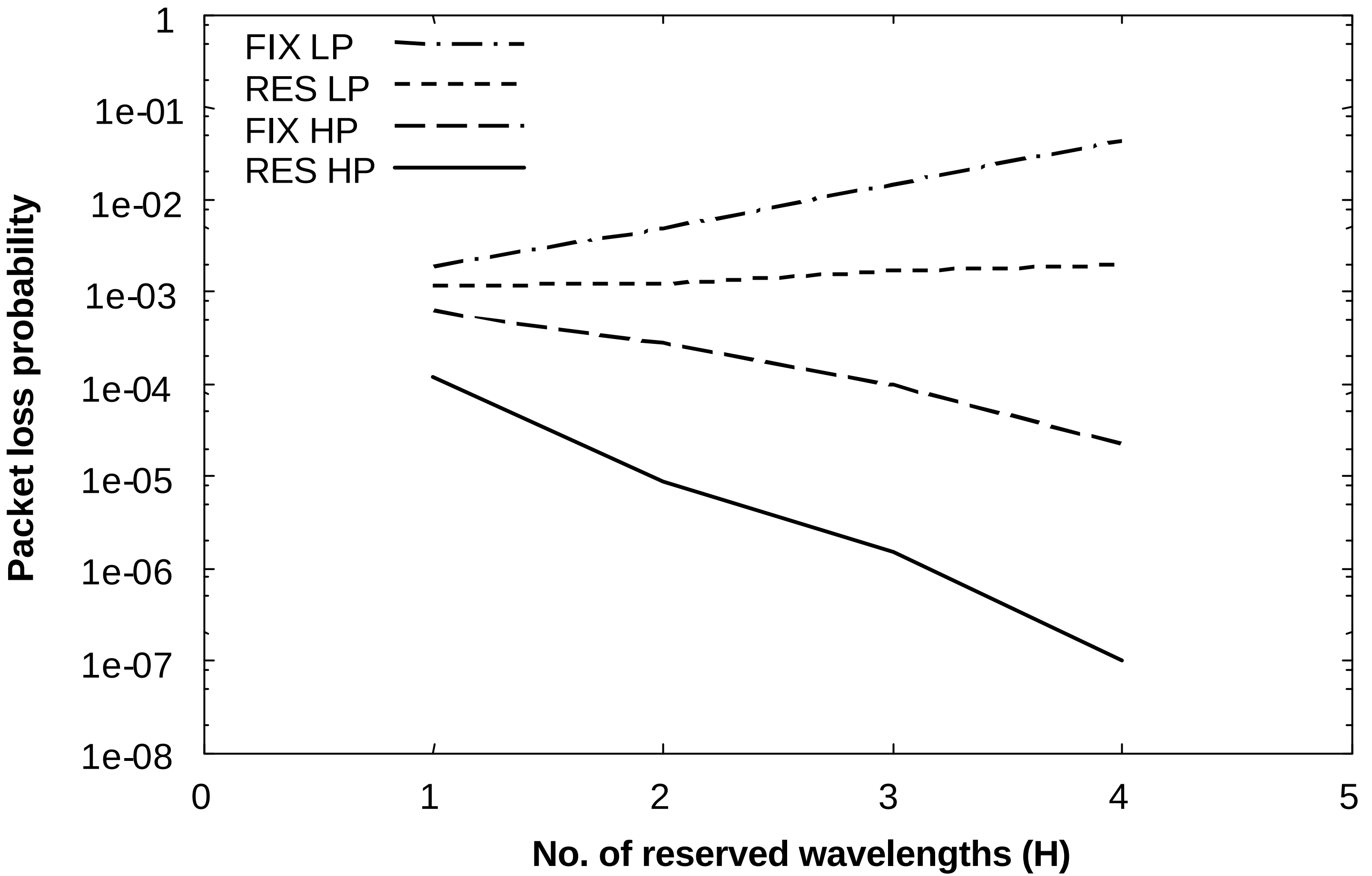


Network performance evaluation

- First evaluation on a simple topology
  - 5 nodes, 12 links
  - W = 16 wavelengths per link
  - connectionless transfer mode
  - Poisson arrivals at each node
  - exponential packet size (optimal average value according to node dimensioning)
  - traffic distribution on the network:
    - **balanced** (B): each wavelength is loaded by 0.8 → traffic generated accordingly
    - **unbalanced** (U): each node generates the same traffic → wavelengths on different links carry different loads (max. 0.8)

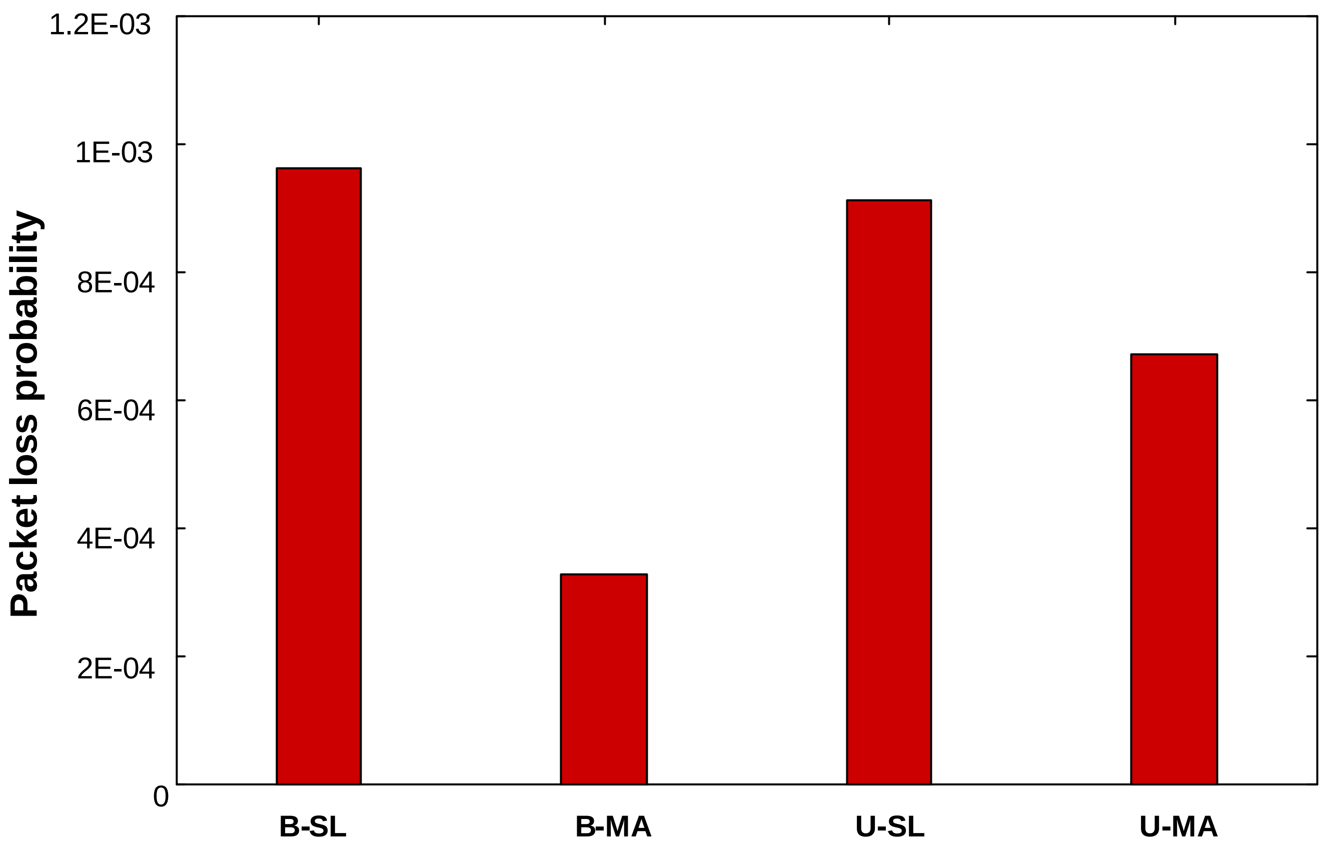


Resource partitioning: FIX vs. RES



→ **From now on, always adopt the RES strategy**

Performance for undifferentiated traffic



B = balanced traffic
U = unbalanced traffic

SL = shortest path only
MA = multiple paths

Not very high improvement due to the limited number of paths in the test network

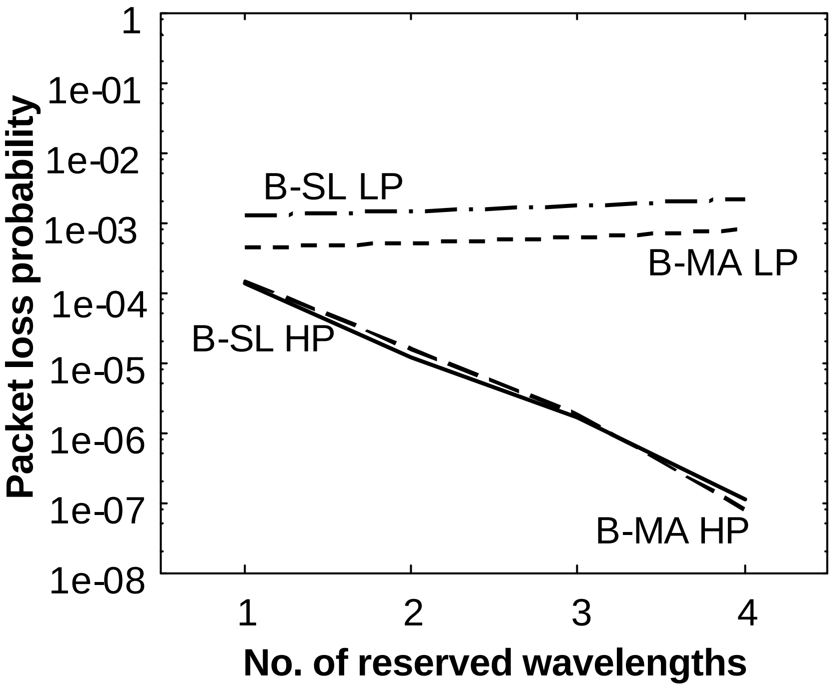
→ **MA proves to be more effective on larger networks (cf. ONDM '04)**

The impact of resource partitioning

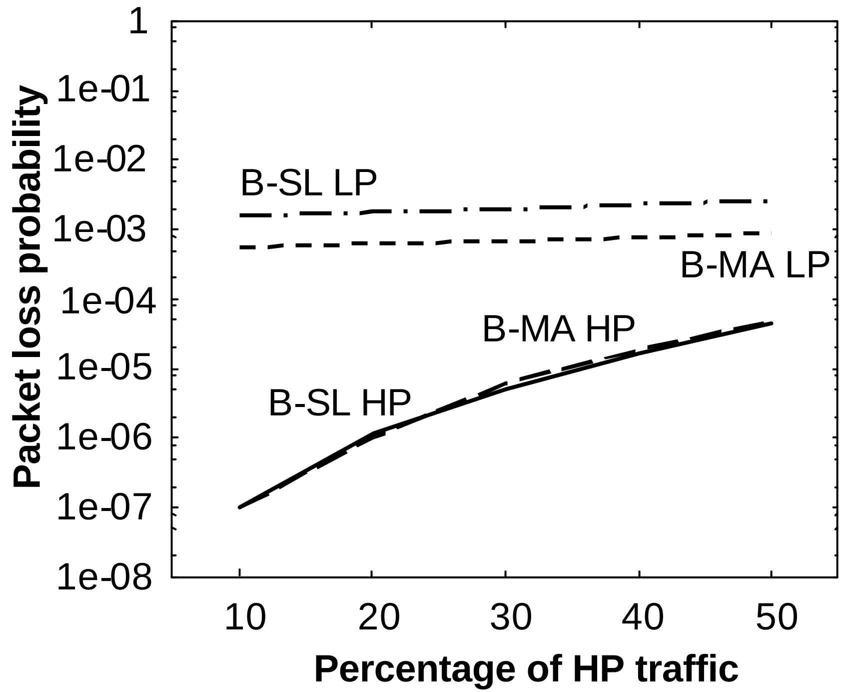
B = balanced traffic

SL/MA = routing policy adopted for LP traffic (HP uses always SL)

Percentage of HP traffic = 20%



No. of reserved wavelengths = 3



Accurate HP dimensioning gives a good degree of traffic differentiation

→ **LP routing policy does not affect HP**

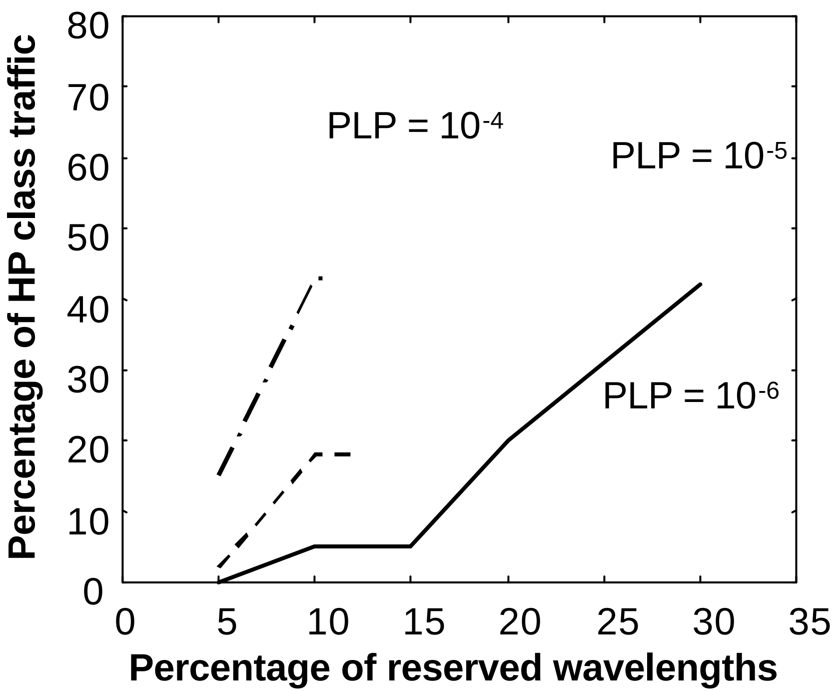
→ **LP performance slightly affected by HP dimensioning (within the range considered)**

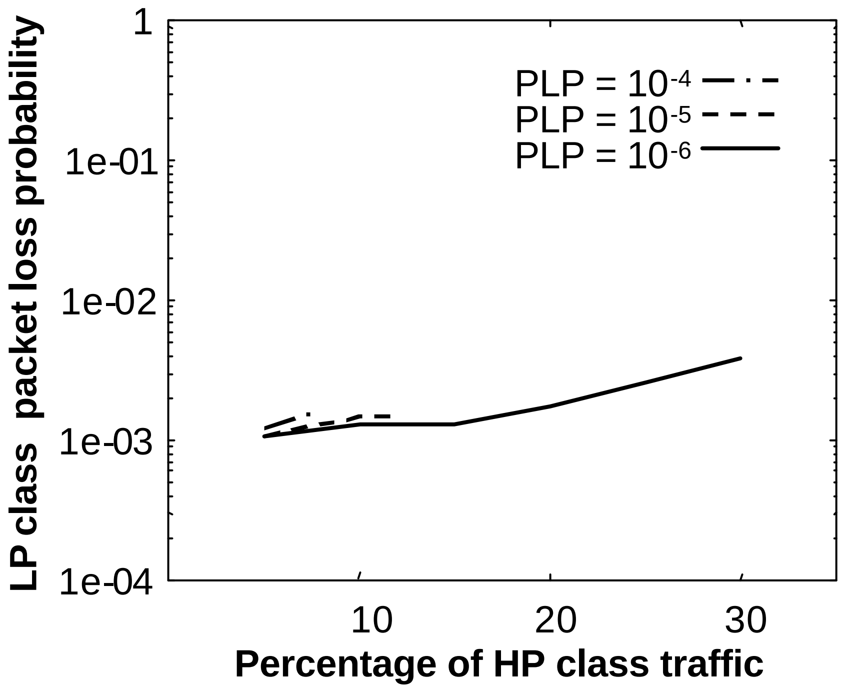
Resources needed for guaranteed HP loss

balanced traffic

SL routing policy adopted for LP traffic

PLP = loss probability for HP packets





→ HP dimensioning required for a given PLP

Network design for unbalanced traffic

- Each node generates the same amount of traffic, uniformly distributed towards the other nodes
  - each link is subject to a different load, depending on the traffic matrix (assuming shortest paths only)
  - no reason to waste resources on underloaded links
  - provide the links with the resources (i.e. no. of wavelengths) required to obtain a given average load per wavelength

$$\text{no. of wavelengths} = \left\lceil \frac{\text{total load on the link}}{\text{required load per wavelength}} \right\rceil$$

→ **Drawback: resource partitioning is not very effective on links with a small no. of wavelengths**

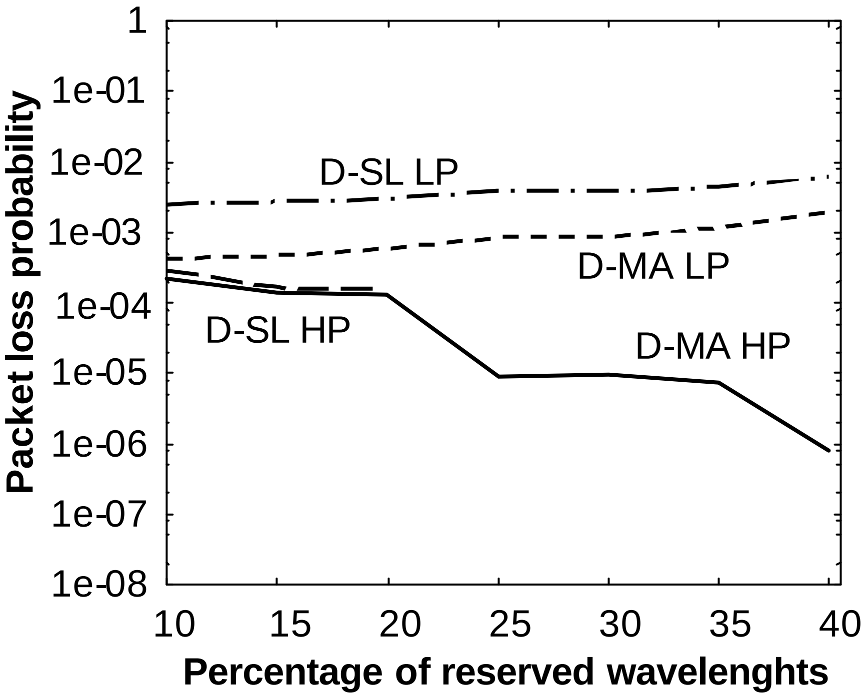
Performance of unbalanced network design

D = network design under unbalanced traffic

SL/MA = routing policy adopted for LP traffic (HP uses always SL)

Network cost (in terms of total no. of wavelengths) as close as possible to the balanced case (i.e. 16*12=192) → amount of traffic generated at each node accordingly

Percentage of HP traffic = 20%



Resulting resource distribution:

→ from 7 to 28 wavelengths/link

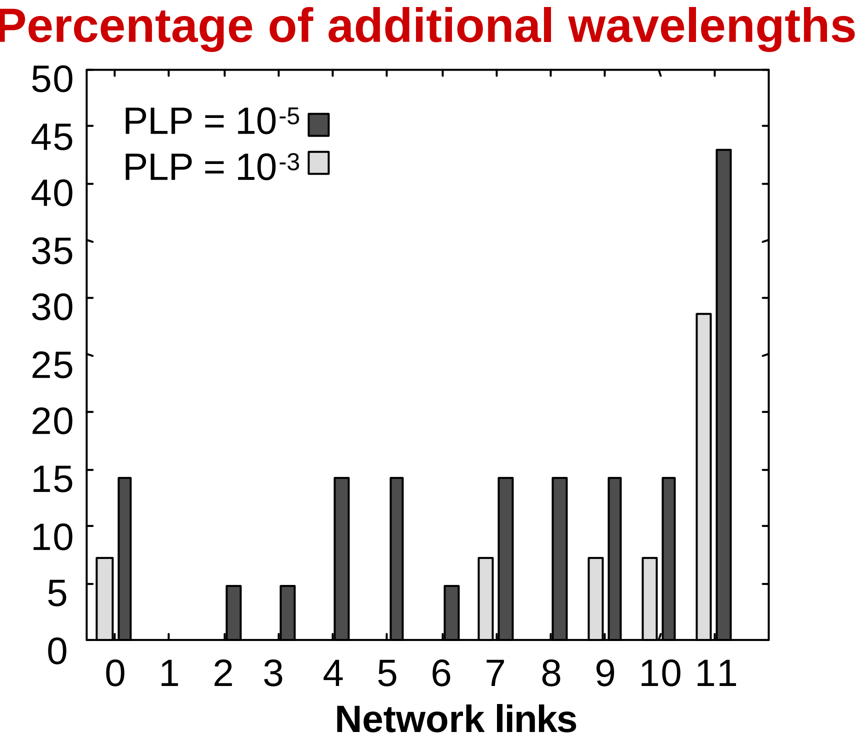
Resulting loss distribution:

→ from 10^{-2} to 10^{-6}

→ Heavy unfairness

Design with constraint on packet loss

- Fix a maximum acceptable value of packet loss probability
- Perform the design procedure and evaluate packet loss
- Iterate the simulation by increasing the no. of wavelengths on links with loss exceeding the acceptable value, until the loss constraint is satisfied on all links



→ **still unfair loss distribution among links**

→ **at least the loss constraint is satisfied**

→ **increased overall network cost**

→ **increased simulation time**

Conclusions

- QoS differentiation in DWDM OPS networks achieved by exploiting resource partitioning and adaptive routing
- Iterative design procedure to satisfy loss constraints
- Open issues:
  - need for extensive simulations on large networks to prove the effectiveness of MA approach
  - evaluation of the impact of adaptive routing on packet delay and sequence
  - extension to a connection-oriented transfer mode and impact on virtual circuits routing