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Resilience schemes in WDM networks

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Outline

- Introduction to WDM network survivability
- Layer interaction in restoration
- WDM survivability: taxonomy
- Network planning
- Conclusions

WDM network survivability
Introduction

- **A very important aspect of modern networks**
  - The ever-increasing bit rate makes an unrecovered failure a significant loss for network operators
    - More than 2,000,000 customers of the public network have been affected by link and equipment failures from 92 to 94 (cable failures: $2.643 \cdot 10^6$ customer-minutes)
    - In 1987 a cut of a 12-fiber cable caused the loss of 100,000 connections, only partially rerouted after 2 hours, and millions of dollars
  - Cable cuts (especially terrestrial) are very frequent
    - Fiber cables share the same ducts of other utility transport media (gas and water pipes, etc.)
  - No network-operator is willing to accept unprotected networks anymore
- **Restoration = function of rerouting failed connections**
- **Survivability = property of a network to be resilient to failure**
  - Requires physical redundancy and restoration protocols

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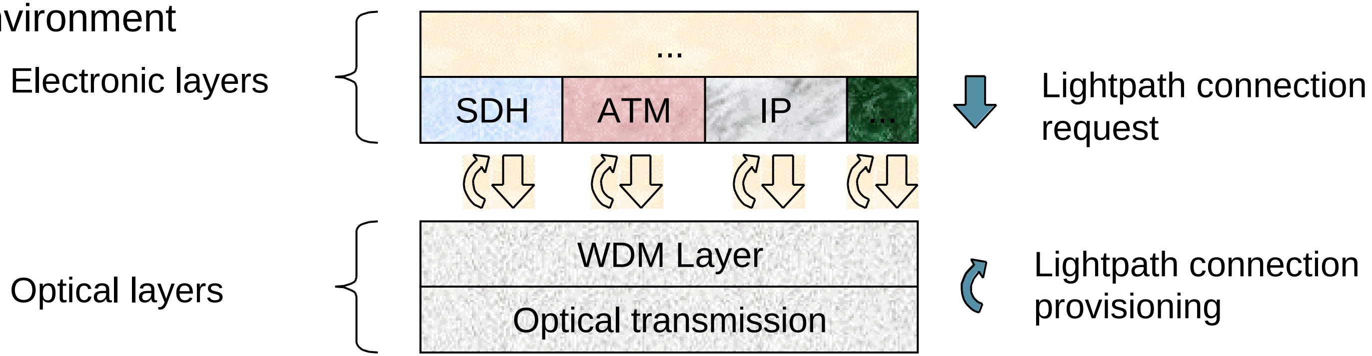
- **Introduction to WDM network survivability**
- **WDM networks: a layered vision**
- **WDM survivability: taxonomy**
- **Network planning**
- **Conclusions**

WDM optical networks: a "layered vision"

- **WDM layer fundamentals**
  - Wavelength Division Multiplexing: information is carried on high-capacity channels of different wavelengths on the same fiber
  - Switching: WDM systems transparently switch optical flows in the space (fiber) and wavelength domains
- **WDM layer basic functions**
  - Optical circuit (LIGTHPATH) provisioning for the electronic layers
  - Common transport platform for a multi-protocol electronic-switching environment



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WDM protocol layers
WDM sublayers

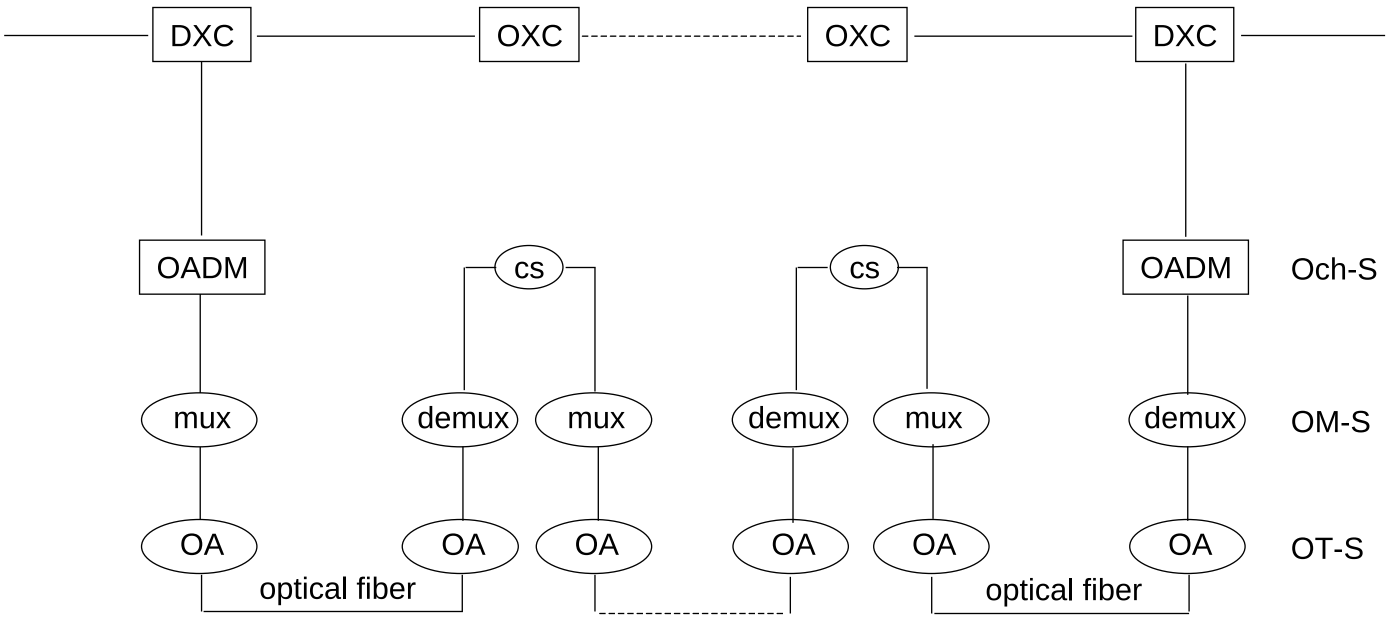
- **The WDM layer-stack is composed of four layers**
  - Optical channel sublayer (OCh)
  - Optical multiplex section (OMS)
  - Optical transmission section (OTS)
  - Physical media layer
    - Fiber-type specification, developed in other Recommendations

Electronic Layers	
WDM	OCh- Optical Channel
	OMS- Optical Multiplex Section
	OTS- Optical Transmission Section
	Physical media (optical fiber)

WDM Transport Layer

- Optical channel section: provides end-to-end networking allowing electrical connections to be routed in the optical layer.
- Optical multiplexing section: acts on multiwavelength optical signal, providing (de)multiplexing functionality
- Optical transport section: allows to accomplish optical connection on optical media
- Survivability at the optical path layer provides a survivable common platform for the variety of transport signals

WDM protocol sublayers
Simplified scheme of a WDM connection



OXC optical Cross Connect
DXC digital Cross Connect
OADM optical Add-Drop Multiplexer

CS optical Channel Switching
mux WDM multiplexer
demux WDM demultiplexer

OA Optical Amplifier

WDM network survivability
Layer interaction in restoration

- **A complete and well defined set of restoration techniques already exists in the upper electronic layers**
  - SDH / Sonet
  - ATM
  - IP
- **Restoration in the upper layers is relatively slow and may require intensive signaling**
  - 50-ms range when automatic protection schemes are implemented in the transport layer
- **Purpose of performing restoration in the WDM layer**
  - To decrease the outage time by exploiting fast rerouting of the failed connections
- **Main problem in adding protection function in a new layer**
  - Instability due to duplication of functions
  - This is one of the main drivers that pushes towards the merging of WDM and electronic transport layer control and management

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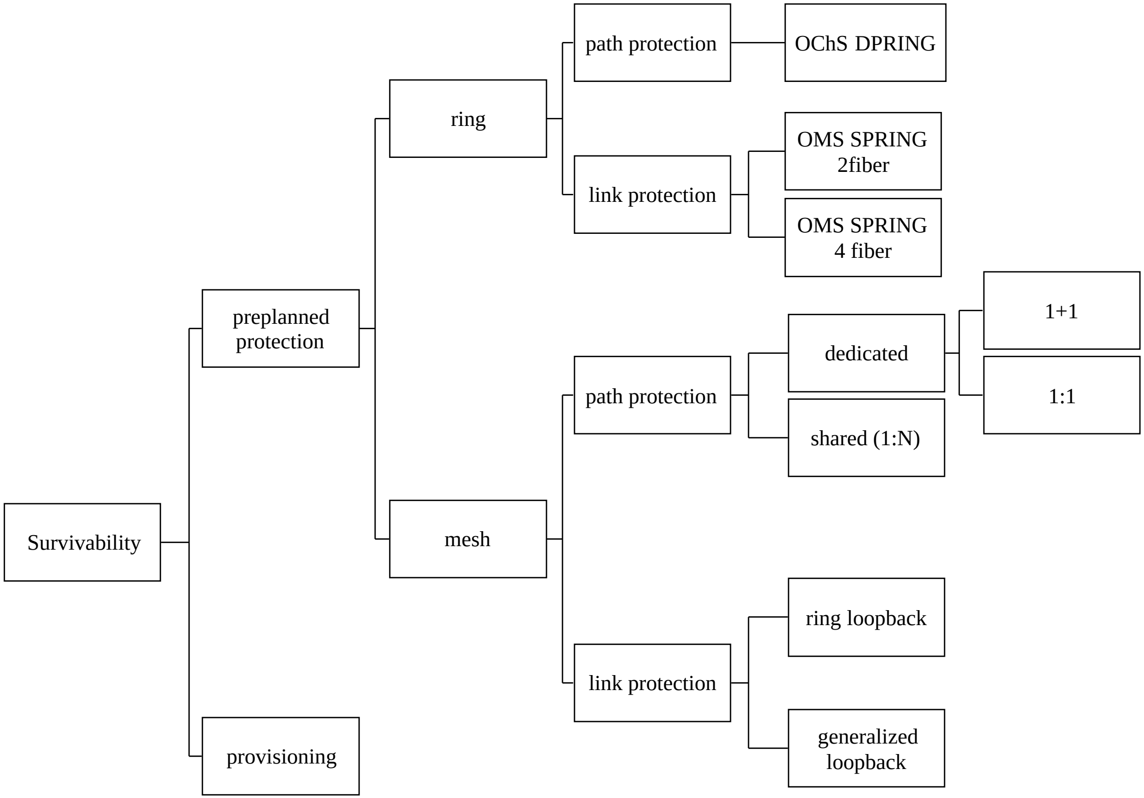
WDM network survivability
WDM protection techniques classification

- **Restoration techniques can protect the network against**
  - Link failures
    - Fiber-cables cuts and line devices failures (amplifiers)
  - Equipment failures
    - OXCs, OADMs, electro-optical interfaces
- **Protection can be implemented**
  - In the optical channel sublayer (OChS protection)
  - In the optical multiplex sublayer (OMS protection)
- **Different protection schemes are used for**
  - Ring networks
  - Mesh networks

WDM network survivability
Classification of resilience schemes



WDM network survivability
Protection in the optical channel sublayer (OChS)

- **Also called <u>path protection</u>**
  - Each lightpath is protected by end-to-end rerouting when a failure occurs
  - A routing-diversity path must be ready for the protected lightpath
- **Pros**
  - The exact failure localization is not important
- **Cons**
  - Problems in restoration control and managing may rise when more lightpaths are involved in the failure

WDM network survivability
Protection in the optical multiplex sublayer (OMS)

- **Also called <u>line protection</u> or <u>link protection</u>**
  - All the WDM channels crossing a failed fiber are rerouted together
  - An idle alternative fiber path must be available
- **Switching features**
  - Protection switching is performed by spatial switches operating on the entire WDM multiplex (fiber switches)
  - Switching time may be very short (tens of milliseconds to tens of microseconds), if signaling is not considered

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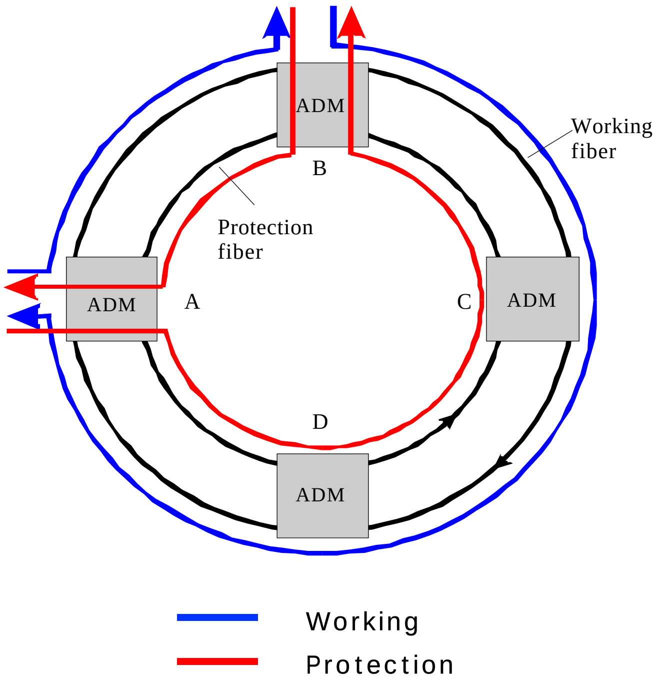
WDM path protection
Ring protection (self-healing rings): OCh-DPRING

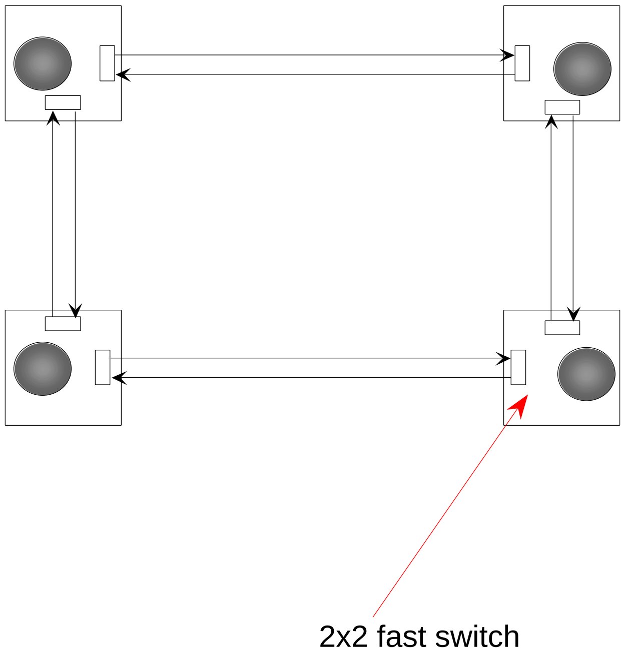
- **Two-fiber bidirectional ring**
  - One fiber is used for working and the other counter-propagating one for protection
  - The optical signal is physically split at the transmitter and routed onto two different paths (as in 1+1)
  - The receiver receives both signals and selects the best one
  - Dedicated protection (50% capacity reserved for protection)
  - No signaling required



WDM OMS protection

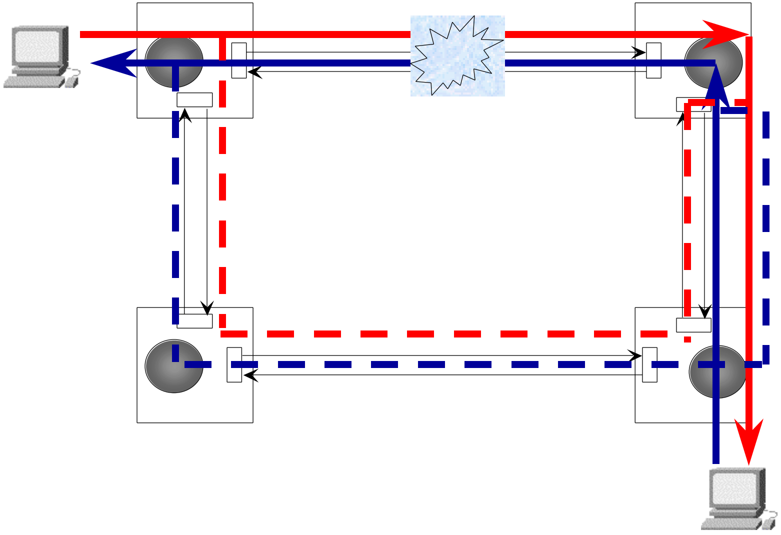
Ring protection (self-healing rings): OMS-2 SPRING

- **Two-fiber bidirectional ring**
  - Fibers are counter-propagating
  - On fiber 1 working wavelengths are from 1 to W / 2 and the other are for protection
  - On fiber 2 working wavelengths are from W / 2 to W and the other are for protection
  - Recovery is performed by 2x2 fast switches
- **In case of failure traffic can be looped back without wavelength collision**



WDM OMS protection
OMS-2 SPRING – Link failure recovery

- **Example**
  - After link failure the working paths are routed in the protection fibers with the same wavelengths



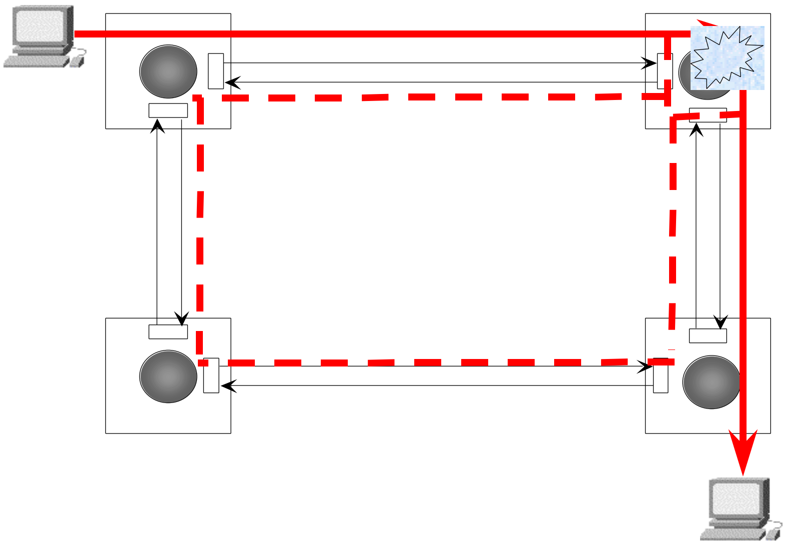
Working path at λ_1 on fiber 1

Working path at $\lambda_{W/2+1}$ on fiber 2

WDM OMS protection

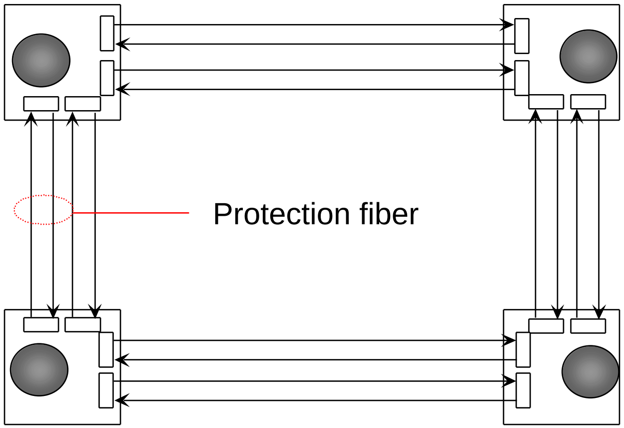
OMS-2 SPRING – Node failure recovery

- **Node failure recovery is also possible**
  - Recovery is performed by 2x2 fast switches
  - Working path is routed in the outer fiber ring
  - After node failure the path is switched in the inner ring at the same wavelength



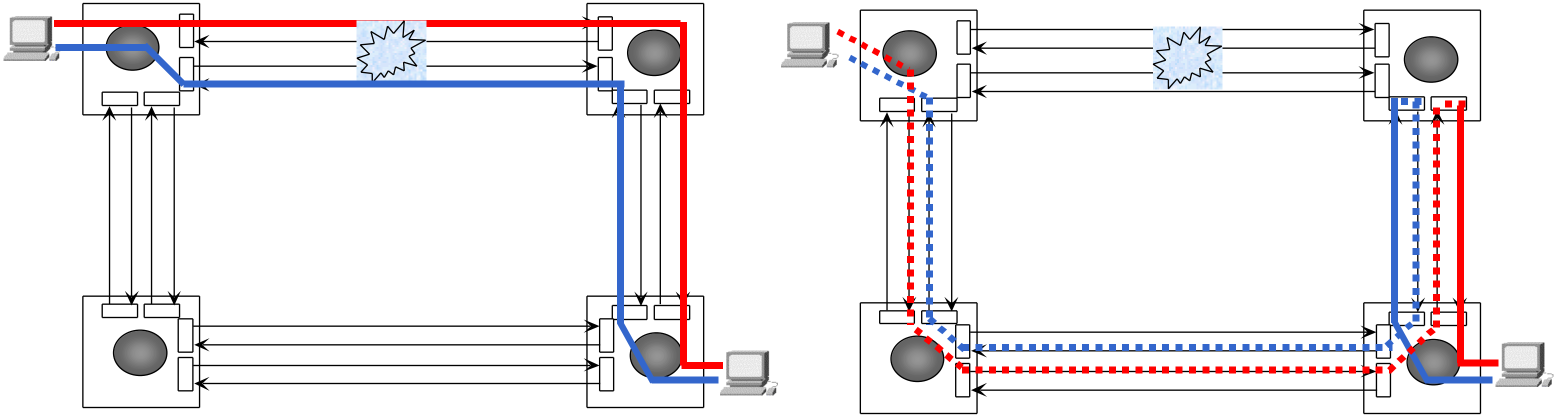
WDM OMS protection
Ring protection (self-healing rings): OMS-4 SPRING

- **Four-fiber bidirectional ring**
  - A fiber-pair is used for working and the other for protection
  - Protection-switching is performed by 2x2 fast switches
    - Optomechanical or other technology
  - 50% capacity reserved for protection



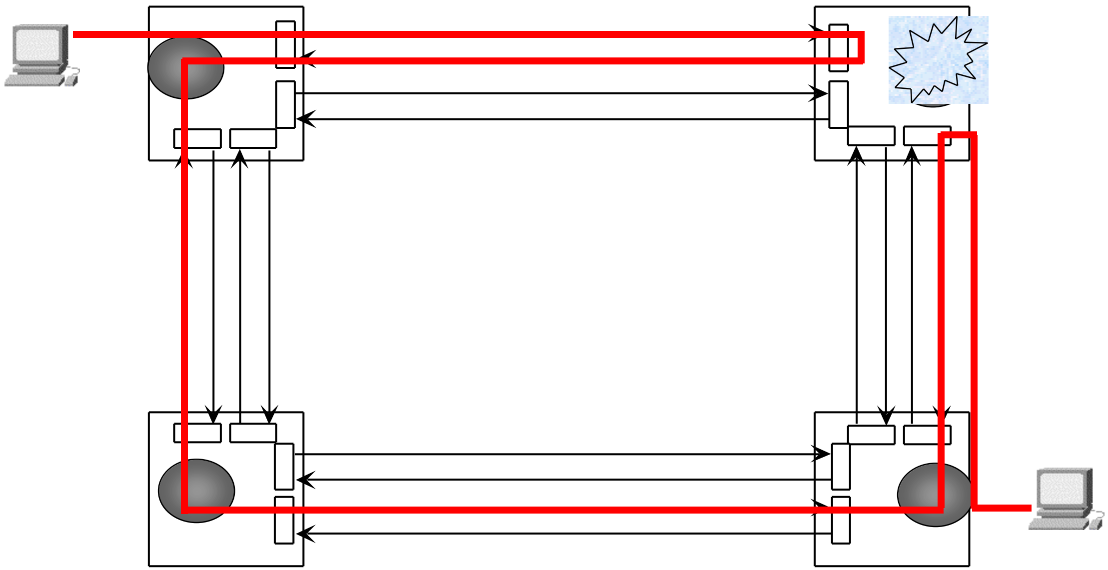
WDM OMS protection
OMS-4 SPRING – Link failure recovery

- **In case of failure of a link the ring connectivity is restored by employing the protection fibers**
- **Signaling is required to coordinate switching at both ends of the failed node**
  - An open issue in standardization



WDM OMS protection
OMS-4 SPRING – Node failure recovery

- **Node-failure recovery is also possible**



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  - Mesh networks
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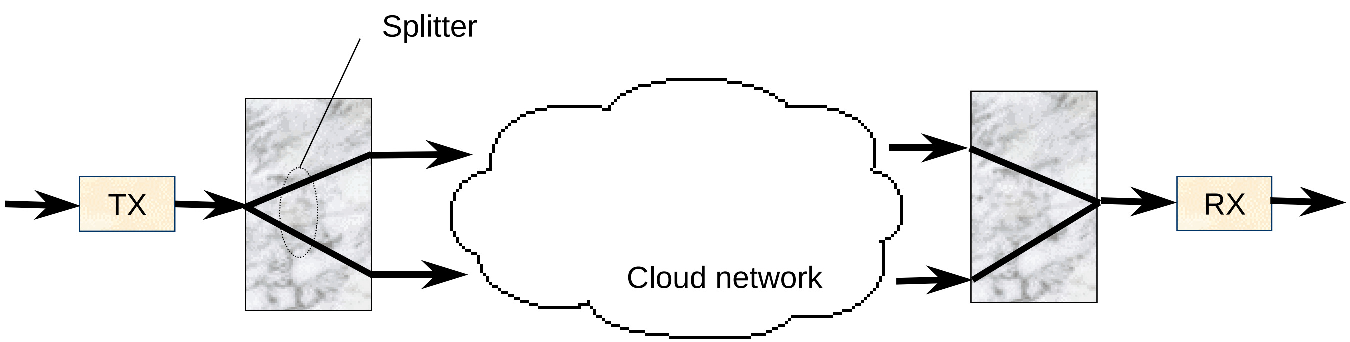
WDM network survivability
WDM protection in mesh networks

- **Various options available**
  - OChS protection
    - Path protection
  - OMS protection
    - Link protection
    - Span protection (backup resources are reserved in the same link)
  - Restoration by provisioning
- **Largely an open and pre-standard issue**
- **Much more difficult to plan and control than in rings**

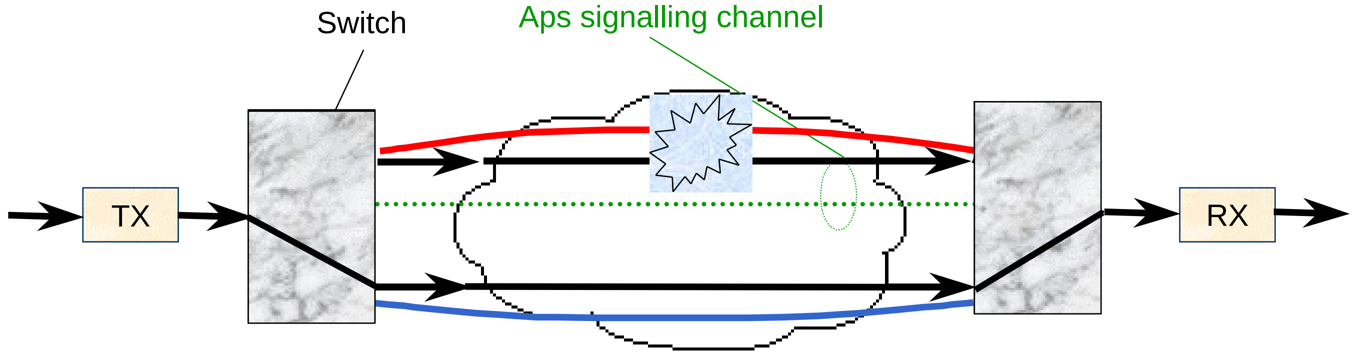
WDM path protection
Dedicated Path protection schemes

- **1+1 protection**
  - The optical signal is physically split at the transmitter and routed onto two different paths
  - The receiver receives both the signals and selects the best one
  - Dedicated protection
  - No signaling required
  - The protection path is always in-use

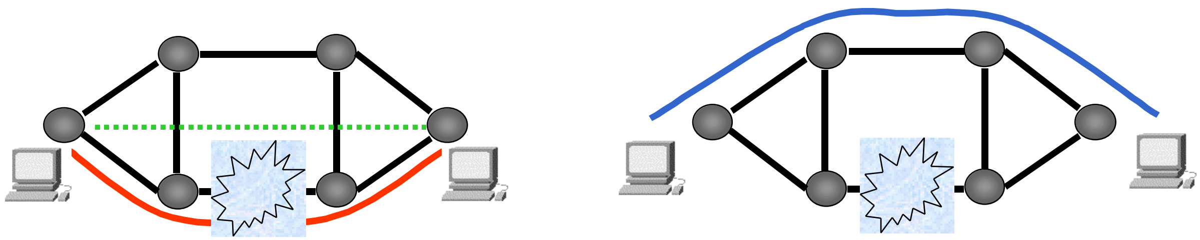


WDM path protection
Dedicated Path protection schemes (II)

- **1:1 protection**
  - The working lightpath is switched on the protection path only when a failure occurs
  - Dedicated protection
  - Signaling is required to advertise the source that a failure occurred
  - Protection resources can be used by low-priority traffic in normal conditions



WDM mesh protection
Dedicated OChS protection

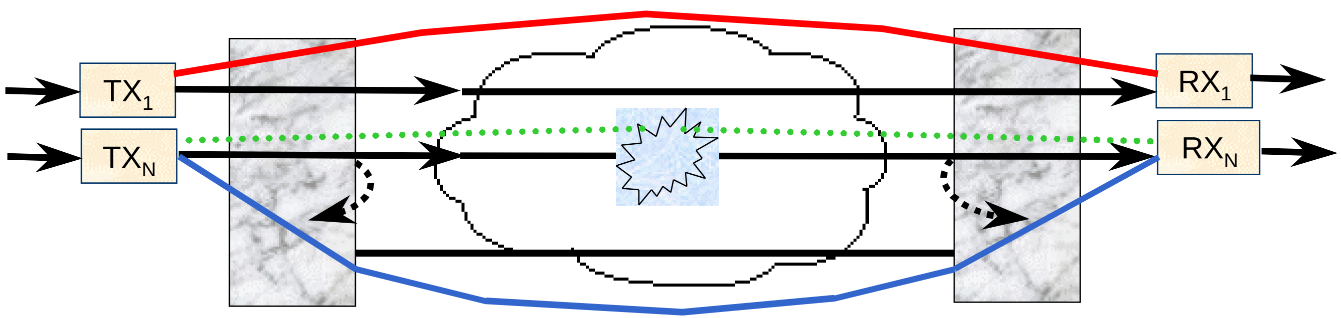


- **1+1 and 1:1 dedicated protection (>50% capacity for protection)**
  - Both solutions are possible
  - Each connection-request is satisfied by setting-up a lightpath pair of a working + a protection lightpaths
    - RFWA must be performed in such a way that working and protection lightpaths are link disjoint
    - If the connection must be protected against OXC failures, the two lightpaths must be also node disjoint

    Additional constraints must be considered in network planning and optimization or in dynamic RFWA
  - 1+1 requires signaling to activate protection-switching in the source node
- **Transit OXCs must not be reconfigured in case of failure**

WDM path protection
Shared Path protection scheme

- **1:N protection**
  - A single protection path is used to protect a set of N paths
  - All the paths involved must be in routing diversity
  - It is assumed that a single failure can happen on the protected lightpaths
  - The working lightpath is switched on the protection path only when a failure occurs
  - Shared protection: the amount of resources reserved for protection is decreased
  - Signaling is required to advertise the source that a failure occurred
  - Protection resources can be used by low-priority traffic in normal conditions
  - This type of protection is ***reverting***



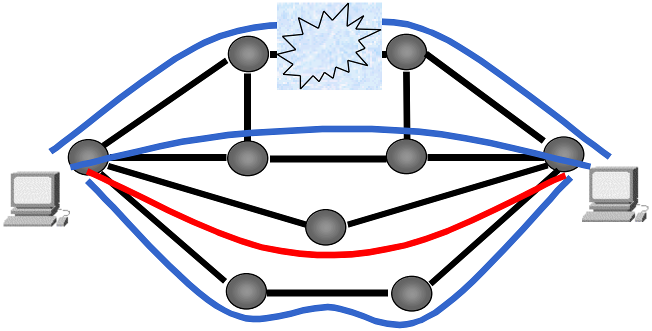
WDM mesh protection
Shared OChS protection

- **Sharing is a way to decrease the capacity redundancy and the number of lightpaths that must be managed**
- **1:N shared protection**
  - A single protection lightpath between two nodes is setup to protect N working lightpaths between the same nodes
  - The connection-requests must be processed all-together
    - RFWA must be performed in such a way that the N working lightpaths and the protection lightpath are mutually link (node) disjoint

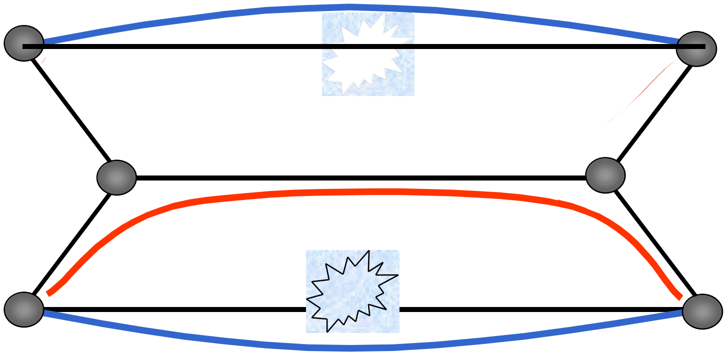
  Additional constraints must be considered in network planning and optimization or in dynamic RFWA: network control can become enormously complicated

    - Severely limited by physical topology: a node degree greater than N+1 and a highly interconnected topology is needed

  In many cases there is no solution

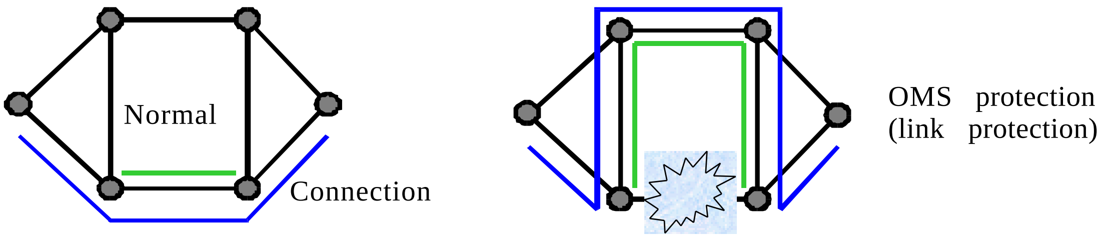


WDM mesh protection
Shared OChS protection (II)



- **OChS protection-resources sharing**
  - Protection lightpaths of different channels share some wavelength channels
  - Based on the assumption of single point of failure
  - Working lightpaths must be link (node) disjoint
- **Very complex control issues**
  - Also transit OXCs must be reconfigured in case of failure
    - Signaling involves also transit OXCs
    - Lightpath identification and tracing becomes fundamental

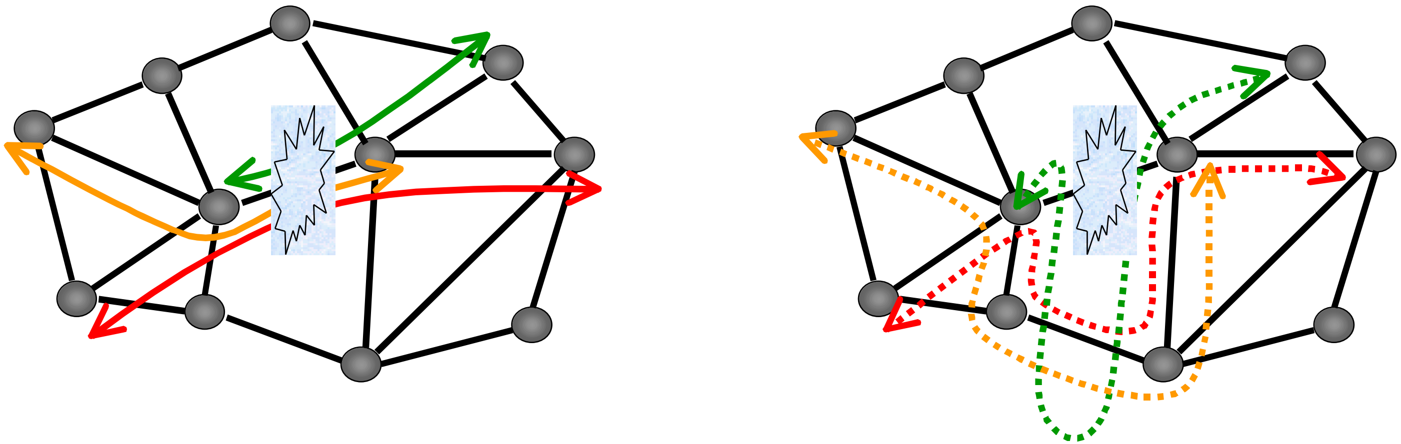
WDM mesh protection
Link (OMS) protection



- **Link protection (≥50% capacity for protection)**
  - Each link is protected by providing an alternative routing for all the WDM channels in all the fibers
  - Protection switching performed by fiber switches (fiber cross-connects)
  - Signaling is local; transit OXCs of the protection route can be pre-configured
  - Fast reaction to faults
  - Some network fibers are reserved for protection
- **Span protection (50% capacity for protection)**
  - Similar to link protection, but exploiting protection-reserved wavelengths on the same link (as in the 2-fiber OMS SPRING)

WDM mesh protection
Link (OMS) protection (II)

- **Link-shared protection**
  - Protection fibers may be used for protection of more than one link (assuming single-point of failure)
  - The capacity reserved for protection is greatly reduced
  - An efficient way of planning a mesh network supporting shared-link protection is ring covering with SPRING-like rings



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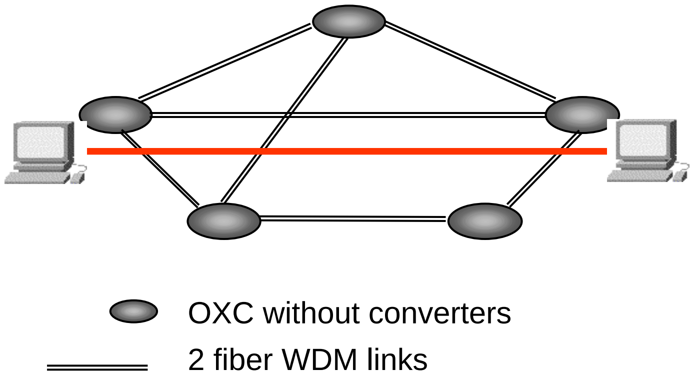
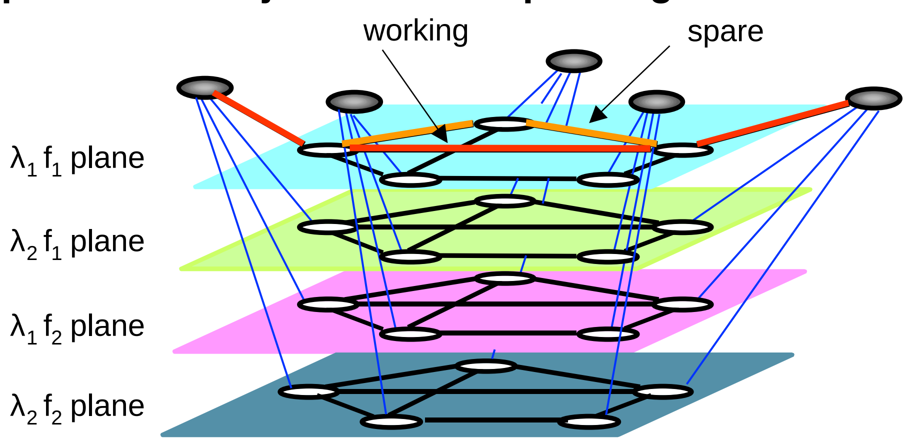
WDM mesh OCh-protection
Network planning solution

- **Pre-planned spare wavelengths allow fast failure recovery**
- **A design tool has been developed**
  - The ***static lightpath establishment (SLE)*** is solved in mesh optical multifiber networks providing full shared or dedicated protection
  - The network cost is minimized (i.e. total fiber length, total fiber number) with (VWP) or without (WP) wavelength-conversion capability
- **Protection paths can be**
  - Link disjoint
  - Node disjoint
- **Two different approaches**
  - Protection lightpaths are dedicated (1+1 or 1:1): each working entity has its own spare lightpath
  - Protection lightpaths can be partially shared by more working lightpaths
    - Provided that the working paths are link/node disjoint

WDM mesh Och-protection
Network planning solution (II)

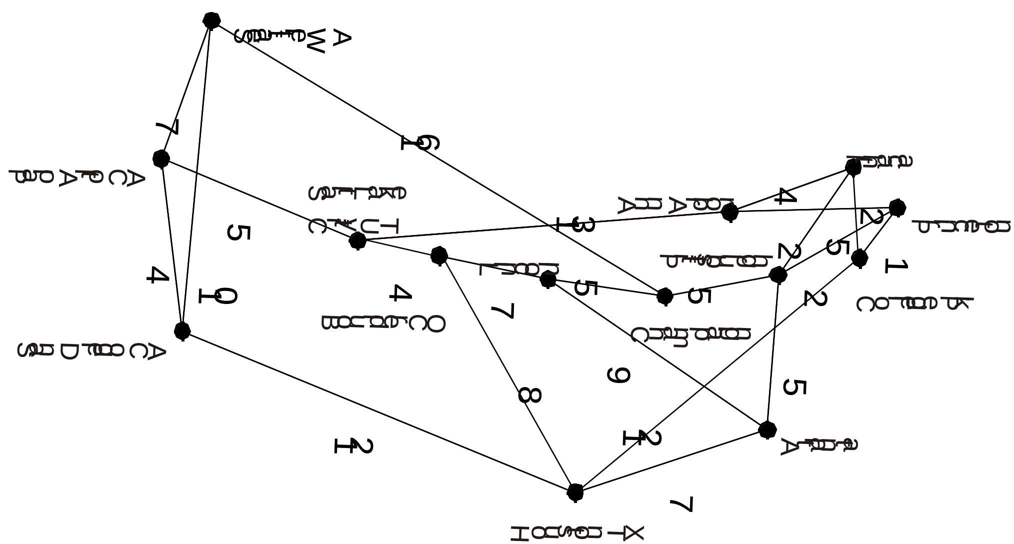
- **Heuristic approach**
  - quasi-optimal solution
  - low complexity
  - flexible
  - scalable as the network size grows
- **Based on layered graph and optimal k=2 disjoint shortest path algorithm**





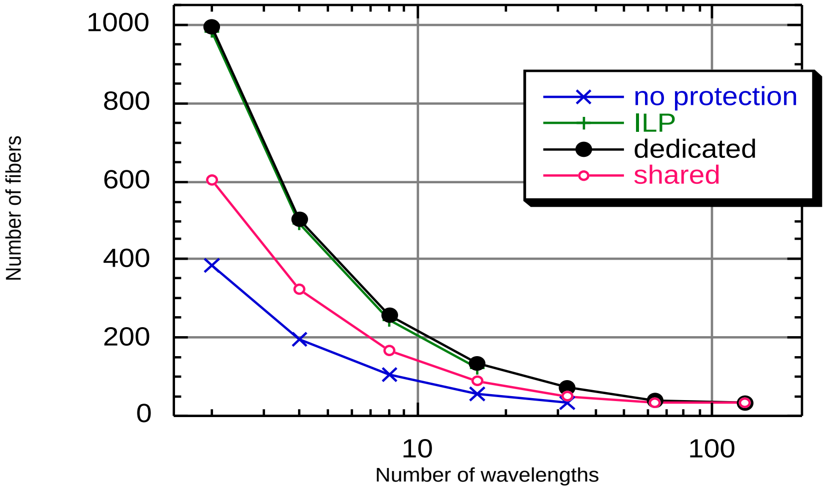
WDM mesh OCh-protection
A network case study: NSFNet

- **A USA backbone network**
  - 14 nodes
  - 44 uni-directional fiber link



WDM mesh OCh-protection
Results

- **VWP network**
  - W=2, 4 , 8, 16, 32
  - RFWA: SP-F-C-LLR
- **Results**
  - Heuristic solution is about only 4% more expensive than ILP (ILP is computationally intensive when applied to large networks)
  - Node-disjoint protection is similar to link-disjoint since nodal degree is less or equal 3
  - Dedicated schemes required more than 100% extra-fibers compared to the unprotected case
  - Sharing is a good compromise between survivability and network cost



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Conclusions

- **We have discussed the different resilience schemes applicable in WDM optical networks**
- **We have explained the motivation for the implementation of protection in the optical path layer**
  - Optical layer protection must detect the failures, activate protection switching, and complete the recovery before higher layers detect the failure
  - Protection routes usually need to be preplanned so that fast fault recovery is possible <u>but require more than 100% excess network capacity</u>
  - The shared methods are more cost-effectiveness
- **We have proposed a heuristic approach to planning of protected networks with dedicated or shared schemes**