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: $2.643 \times 10^6$ 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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- WDM networks: a layered vision
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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 (LIGHTPATH) provisioning for the electronic layers
  - Common transport platform for a multi-protocol electronic-switching environment

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<th>Electronic layers</th>
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<td>SDH</td>
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<th>Optical layers</th>
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<td>WDM Layer</td>
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<td>Optical transmission</td>
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Lightpath connection request

Lightpath connection provisioning
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

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<tr>
<th>WDM</th>
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<tr>
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<td>OCh- Optical Channel</td>
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<td>OMS- Optical Multiplex Section</td>
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<td>OTS- Optical Transmission Section</td>
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<td>Physical media (optical fiber)</td>
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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

Och-S
OM-S
OT-S
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

Survivability
- preplanned protection
  - ring
    - path protection
    - link protection
  - mesh
    - path protection
      - dedicated
    - link protection
      - ring loopback
      - generalized loopback

provisioning

OChS DPRING
OMS SPRING 2fiber
OMS SPRING 4 fiber

1+1
1:1
Also called path protection
- 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 line protection or link protection
  - 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
Example

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

![Diagram of a four-fiber bidirectional ring with protection fiber](image)
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
Node-failure recovery is also possible
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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

![Diagram showing 1+1 protection scheme](image)
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**
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*
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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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**

![Diagram of WDM mesh Och-protection network planning solution](image)

- OXC without converters
- 2 fiber WDM links
- \( \lambda_1, f_1 \) plane
- \( \lambda_2, f_1 \) plane
- \( \lambda_1, f_2 \) plane
- \( \lambda_2, f_2 \) plane

working

spare
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 but require more than 100% excess network capacity
  - The shared methods are more cost-effectiveness
- We have proposed a heuristic approach to planning of protected networks with dedicated or shared schemes