8. Protection and restoration in optical networks

Optical Communication Systems and Networks
BIBLIOGRAPHY

- **Optical Networks. A practical perspective**

- **Redes Ópticas**
Introduction to Network Survivability

Objectives:

- To provide a resilient network against failures. It becomes an essential requirement during the design of high speed optical networks
- To offer a reliable service when large volume of traffic is transmitted even in the presence of failures and anomalous operation. A large amount of data can be lost unless restoration mechanisms are set quickly

Frequently faults:

- Fiber cuts (human errors)
- Failure of active components (transmitters, receivers, amplifiers, controllers)
- Disruption of service (software)
- Catastrophic events (flooding, fire)
- Aging of components

Protection mechanisms operate in the optical domain, and they profit from inherent transparency and scalability in order to provide high capacity networks
Incorporate functions such as monitoring, fault detection and ability to activate protection and restoration (mainly performed in optical switches)
Introduction to Network Survivability

The optical layer can handle some faults more efficiently than the client layers. Optical layer protection can provide an additional degree of resilience in the network to protect against multiple failures.

**Advantages:**

- Optical layer is taken in advantage to provide protection resources among users, independently of their origin and format.
- Protection and restoration functions are supplied to electronic networks which lack them (PDH, ESCON ...).
- It is used simpler techniques implying a reduced number of network entities.
- They do not need electronic coordination from higher layers.

**Limitations:**

- Optical protection can not solve failures in higher layer equipment, For example: It is not able to detect high BER.
- The optical switches are not as safe as electronics due to their young age.
- Difficulty in coordination between the various entities involved in the processes of optical protection and higher levels.
- Proposed restoration routes (depending on the scheme) may assist the development of degrading phenomena.
Protection concepts

- Restoration must be performed in the shortest time possible: the longer is out of service, the greater volume of information is lost

- The maximum time to perform traffic restoration is 60 ms (imposed by SONET/SDH) to avoid the loss of frame synchronization
  - This time includes: time of fault detection and location, time of signal propagation, delay and switching times

- **Working paths:** optical paths established for carrying traffic under normal operation (SDH, ATM, IP...)

- **Protection paths:** optical paths are established to provide alternative routes and to reroute the work traffic when failures occur. Then protection can be performed by:
  - **Path switching**
    - It occurs between source and destination: traffic is rerouted end to end along an alternative path.
  - **Line switching**
    - It takes place between the two nodes that define where the failure has occurred.
    - It may be also performed by span-basis protection (an alternative route between both nodes) or by protection line
Protection concepts

- According to how protection resources are located, we can use:

  - **Dedicated protection schemes**:
    - A fixed bandwidth is dedicated to each working connection over which it can be used in case of failure (working fiber)
    - A working copy of the traffic is usually sent through the second fiber (protection fiber)
      - Left in reserve for use in case of needing to restore the traffic. Furthermore
      - Also used to transmit low priority traffic

  - **Shared protection schemes**
    - It is assumed that all links/nodes can not be broken down simultaneously
      - This allows determine and assign carefully multiple paths in order to share the same protection bandwidth
      - Protection bandwidth can be dedicated to the transport of low priority traffic while no faults occur
Protection schemes

- Optical path under normal operation
- Fiber cut. Path switching
- Span switching
- Line Switching

Figure based on the source:
Protection in point-to-point links

1+1 protection

- This scheme is used to operate in line and multiplex section layer
- Traffic is transmitted simultaneously on two fibers following disjoint routes
- Restoration is based on unidirectional protection switching
- Destination is switched to the fiber over signal is present (in case of fiber cut/node failure) or select the fiber transmitting data with a higher quality
- Very fast protection scheme is achieved, which requires no signal protocol between ends
Protection in point-to-point links

1:1 protection

- This scheme is also used to operate in line and multiplex section layer
- Unlike 1+1 protection, traffic is transmitted only on one fiber at a time (working fiber), while the second fiber remains waiting for a failure (protection fiber)
- Meanwhile, the second fiber can be used for transmitting low priority traffic
- Traffic restoration requires the use of a signaling protocol APS (*automatic protocol-switching*) to coordinate the retransmission between transmitter and receiver
Protection in point-to-point links

1:N protection

[Diagram showing 1:N protection scheme with switches, working fibers, and protection fibers.]
Protection in point-to-point links

1:1 Protection

- Protection scheme based on two fibers which generally run over disjoint routes
- Service traffic is transmitted only along the working fiber, whereas protection fiber remains for restoring the service in case of failure in the working link

- When a fiber cut occurs, both source and destination switches immediately changes to the protection fiber
  - This performance requires an APS protocol *(automatic protection switching)* for signaling between source and destination
  - This scheme is slower than 1+1 scheme

- In normal operation, protection fiber remains available and may be used to transmit low priority traffic (it is rapidly stopped when a failure occurs)

- This scheme can be easily applied to a set of working fibers sharing only one protection fiber ➔ 1:N scheme
  - Only traffic from one fiber is allow to be restored at a time
  - APS protocol switchs traffic from the failed fiber to the protection fiber
Protection in ring-based networks

• Ring topologies are best suited for its safety and durability to provide reliable services in case of node failures or fiber cuts
  → Allows the traffic routing away from the failure preventing information loss.
  → Compared to mesh networks, rings are capable of providing a simpler, more rapid restoration traffic and with lower requirements in the network management system.
  → SDH ring denominated SHR (Self Healing Ring) detect and reroute traffic far away from the affected node or fiber to the correspondent protection fiber or bandwidth.

• Different types of ring architectures depend on:

  1) Directionality of traffic:
     – Unidirectional ring: carries working traffic in only one direction of the ring
     – Bidirectional ring: carries working traffic in both directions

  2) Protection switching: according to the ITU-T G.872 recommendation:
     – fiber-line: fiber link connecting two adjacent nodes
     – wavelength-path: Optical connection supported by a wavelength between source and destination nodes
Protection in ring-based networks

Depending on the traffic direction and the place where switching process is carried out (source and destination or intermediate nodes), there are two switching schemes:

**Path-wavelength switching**
- It is performed at source and destination nodes of wavelengths carrying affected traffic
- Restoration takes place when source and destination nodes switch the affected wavelength to the protection wavelength propagating in the opposite direction in the second fiber
- It is performed in UPSR y BPSR schemes

**Line-fiber switching**
- It is performed in nodes delimiting the place where the failure occurs. Generally, involved nodes do not correspond to source and destination (intermediate nodes)
  - **Fiber cut** → switching in nodes connected by the link failed
  - **Total or partial failure in a node** → switching in adjacent nodes
- Working traffic is switched over the protection wavelength and routed back in opposite direction by a procedure called loop-back switching
- It is performed in BLSR schemes
Unidireccional Path-Switched Ring – UPSR scheme

• Unidirectional ring: working traffic travels in only one direction
• The path chosen to reach the destination is not always the shortest.

• UPSR rings consist of two fibers:
  – The first fiber is used as the working fiber
  – The second fiber is used as the protection fiber

• Traffic from one node to another is sent simultaneously on the working fiber in the clockwise direction and on the protection fiber in the counterclockwise direction

• Destination node continuously monitors both the working and protection fiber to select the better signal
  – Essentially, this performance corresponds to a 1+1 scheme operating at the path layer in a ring rather than at the line layer in point-to-point configurations
  – The destination node does not require notifications to the transmitter or to carry out a signaling protocol (APS, Automatic protection switching).
Unidireccional Path-Switched Ring – UPSR scheme

- Protection wavelengths are dedicated to carry a copy of wavelengths circulating through the working fiber in the opposite direction
  - As a result, this protection capability can not be used to carry low priority traffic

This architecture is implemented typically in applications where nor data amount nor number of users is high
  - Example: rings used in access networks and local area networks provide a low-moderate capacity: OC-3 and OC-12

- **Advantages**: Unlike bidirectional rings, simple and low cost scheme which only needs action from receiver without complicated signaling protocols

- **Disadvantages**: Inefficient use of protection capacity and no spatial reuse of wavelengths
Unidireccional Path-Switched Ring – UPSR scheme

Source node

Destination node

UPSR scheme

Working paths

Protection ring

Working connection

Fiber cut

Source node

Destination node

UPSR scheme

Optical Communication Systems and Networks
Bidireccional Line-Switched Ring - BLSR scheme

- BLSR can be implemented by 2 or 4 fiber rings, depending on the required capacity, providing: BLSR/2 or BLSR/4 (50% traffic bandwidth and 50% protection bandwidth).

- BLSR is a bidirectional ring over which working traffic is sent in both directions:
  - Optical connections reach destination following the shortest path

- Both schemes (2 and 4-fiber rings) present mechanisms of line protection switching, since span protection is not implemented usually in this architecture

- Service traffic is transferred to the corresponding protection wavelength placed on the other fiber (called Loop-back process switching, LBS)
  - This wavelength carries the traffic along the ring in opposite direction until reaching the second node, where the wavelength is switched again (LBS) to set the protected traffic on the working wavelength initially assigned
  - This wavelength propagates along the first fiber according to the initial direction until reaching the destination node
Bidireccional Line-Switched Ring - BLSR scheme

Unlike UPSR:

- BLSR requires an APS protocol to perform line switching between nodes delimiting the affected place (cut or node failure)
- Performance and features of involved elements in protection are more complex
- Line switching makes operation wavelengths run over longer distances with regard to the normal operation mode. There are several consequences:
  - Impairments due to nonlineearities can be increased
  - Restoration process slower than UPSR and BPSR schemes

Advantages vs UPSR:

- Working wavelengths can circulate in both directinos:
  - Working wavelengths follow the shorter route to reach the destination node
  - Spatial reuse of wavelengths is allowed
- BLSR are based on shared protection schemes:
  - Under normal operation mode, protection wavelengths carry low priority traffic
    - When a failure occurs, the low priority traffic will be emptied and wording traffic will be transferred to protection wavelengths by protection mechanisms
Tema 7: Técnicas de Protección

Bidireccional Line-Switched Ring – BLSR scheme

- Working paths
- Protection ring
- Working connection

Source node to Destination node

Switching line Span Protection

BLSR/4 scheme

Switching line Line Protection

BLSR/4 scheme
Bidirectional Line-Switched Ring – *BLSR scheme*

Each fiber carries half of its capacity for working wavelengths and the other half to protection.

And using an interleaved wavelength distribution.
Bidirectional Path Switched Ring – *BPSR scheme*

- BPSR is a combination of the previous schemes studied

- Bidirectional ring consisting of 2 or 4 fibers, where each fiber dedicates half of its capacity for protection and the other half to working traffic

- As in the BLSR scheme, BPSR achieves the same efficiency in wavelength use (higher than UPSR): Wavelengths reach their destination following the shortest path
  - Allows spatial reuse of wavelengths
  - All working lengths share the same protection capability
  - The protection wavelengths are permanently ready to restore the working wavelength traffic

- They can be used to carry low priority traffic while their use is not required
- As in UPSR scheme, BPSR implements *path-wavelength switching* → performs protection switching is performed in the source and destination nodes
Bidirectional Path Switched Ring – \textit{BPSR scheme}

- Optical paths dedicated to protection will not be formed until failure occurs \(\rightarrow\) meanwhile protection capacity is shared
- When a failure occurs, the destination node will realize the absence of signal. Then, a protocol APS run by the destination will notify the source of the need to start jointly the protection switching process
- Working traffic initially transmitted along one of the fibers in clockwise direction is switched in the source node to the protection wavelength. This wavelength propagates in counterclockwise direction along the second fiber, using the unaffected part of the ring.
- \textit{At the same time, destination node will switch to this wavelength in order to receive the service traffic}
- Generally, this length is generally much shorter than the distance employed in BLSR protection schemes (the same in UPSR scheme), then:
  - \(\rightarrow\) Restoration time is faster than BLSR schemes
  - \(\rightarrow\) As a result of a shorter length, it is more difficult to reach thresholds providing degrading (dispersion or attenuation) and nonlinear effects
Bidirectional Path Switched Ring – *BPSR scheme*

**Normal operation**
- Source node
- Destination node
- BPSR/2 Scheme

**Restored traffic**
- Source node
- Destination node
- BPSR/2 Scheme

Work and protection are distributed over Fiber 1 and Fiber 2 using an interleaved wavelength distribution.
Ring interconection redundancy (Dual-Homing)

- When a node “falls down” in the network, it is seen by the rest of the nodes as a link failure connecting with the failed node
  - Unlike a fiber cut, when a node is out of service, all their traffic generated or received is lost
  - This problem may worsen considerably when the node is a hub (where both traffic at optical an electronic domain is concentrated and processed)

- **Solution**: the implementation of a Dual- Homing architecture
  - This scheme is based on using two hubs jointly in order to simplify the assignment and routing functions (adjacent nodes)
  - If one of them falls down, there is always a second hub which performs the same functions
    - During this process, the rest of the nodes do not realize the interruption of service (transparency)
Ring interconnection redundancy (Dual-Homing)
Protection in meshed networks

- Application of protection schemes in meshed topologies is more complex than point-to-point and ring topologies.

- As the number of nodes and links grows, a greater number of alternative routes can be established to restore traffic in case of failure.

- To apply protection and restoration mechanisms a division into small domains is made from the mesh:
  - Each domain is able to be implemented protection schemes addressed previously.
    - Optical network supports the generation of simultaneous failures in different domains.
    - In domains with a small size a higher security level is achieved at the expense of inefficient use of network resources.

Problems:
- Coordination of protection activation becomes a difficult task.
- Alternative routing paths must satisfy time and power budgets as well as recovery within 50 ms time interval to avoid losing sync of SDH/SONET.
Optical Channel Mesh Protection

- Generally, the more meshed the topology, the greater improvement of mesh protection is achieved.
- Protection paths are applied from ring protection schemes.

Figure based on the source: “Redes Ópticas”, José Capmany, Beatriz Ortega, Ed. Servicio Publicaciones UPV, 2006
Optical Channel Mesh Protection

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Optical Channel Mesh Protection

Mesh broken down into different BLSR rings

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Optical Channel Mesh Protection

Mesh broken down into different BPSR rings

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Operation between layers

• A layered network usually presents protection mechanisms in each layer

• The layered solution presents advantages in terms of cost savings and reduction of equipment

• There are some points to consider:
  → As each layer works independently, a failure could simultaneously trigger different protection actions in the same network
  → This could lead to generate an unnecessary number of alarm signals which could collapse the management center.

• For this reason is necessary to determinate coordination mechanisms among different layers and determine limits in the recovery time for each layer