WDM Passive Optical Networks:
Protection and Restoration

Calvin C K CHAN

Lightwave Communications Laboratory
Department of Information Engineering
The Chinese University of Hong Kong
HONG KONG
Network Survivability in PONs

- Conventional PONs have limited protection features to keep the cost low.

- The traffic on PONs is getting more data-centric. Subscribers are requesting high-availability services and connections.

→ need to provide resilience against failures due to catastrophic events like fires, flooding, earthquakes, etc.
Network Survivability in PONs

Fault Management in optical networks

Conventional approach: diagnosis on high layers
- based on status reports collected from various checkpoints on the managed optical network
- incurred overhead in network signaling and network management system
- no guarantee that higher layers could provide recovery from faults in the physical layer.

Network protection in optical layer
- simple fiber link or equipment duplication with protection switching or some other intelligent schemes with minimal resource duplication
- faster response
Network Survivability in PONs

For PONs

- Equipment failures at either OLT or ONU
  - having a backup unit in a controlled environment.

- Fiber cut
  - takes a relatively long time to perform the repair

Survivable network architectures for PONs with protection switching is highly desirable to bypass the failed fiber links and re-route the affected traffic.
## Survivable WDM-PONs

### Design Consideration: Protection / Restoration

<table>
<thead>
<tr>
<th>Protection</th>
<th>Restoration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protection lightpaths are <em>pre-planned</em> at the network design stage.</td>
<td><em>Dynamically search</em> for spare lightpaths to restore the disrupted traffic after network failure.</td>
</tr>
<tr>
<td><strong>Low traffic restoration time</strong></td>
<td><strong>Maybe long traffic restoration time</strong></td>
</tr>
<tr>
<td>→ only protection switching is needed to enable the protection lightpath.</td>
<td>→ depending on the dynamic re-routing of the disrupted traffic, and the routing decision computation.</td>
</tr>
</tbody>
</table>

For **WDM-PONs**, topology is regular (tree / ring)

- Preplanned protection
- Protection on optical layer → further reduce the traffic restoration time
- Minimize the disturbance to the higher layers
Survivable WDM-PONs

Design Consideration: Wavelength Routing

In addition to lightpath diversity with fiber link duplication and switching, WDM-PONs offer one more dimension (Wavelength)

→ wavelength routing
  → may reduce the amount of resource duplication

Design Consideration: Network Topology

Network topology determines the paths or connections between the OLT and the ONUs

→ influences how the protection lightpaths or fibers be duplicated or incorporated

Tree topology: feeder fibers, distribution fibers
Ring topology: dual fiber ring, or single fiber ring with uni-/bi-directional OADM in each network node
Survivable WDM-PONs

Design Consideration: Single / Multiple Failures

Mostly consider single failure at a time

→ the occurrence of a fiber or equipment failure is statistically independent in a network.

→ mean time between failures is generally much longer than the mean time to repair a failure

Protection against multiple failure scenarios has also been investigated recently.

Design Consideration: Automatic Protection Switching (APS)

Centralized control → all APS at OLT

→ better APS management

→ requires monitoring and collection of fault alarms throughout the network

Distributed control → APS at individual ONUs,

→ requires protection switches at the ONUs, transparent to OLT

→ ONU only monitors the status of its attached fibers

→ increases the complexity and cost of ONUs
Survivable WDM-PONs

Design Consideration: Fault Monitoring

Fault monitoring units have to be installed at strategic checkpoints to gather the network status information.

- Can be as simple as mere optical power level monitoring (loss of signal) or presence of a particular wavelength, etc.

Collected monitoring information has to be delivered to APS units for appropriate remedies, a signaling channel may be needed in some cases.

Design Consideration: Traffic Restoration Time

Time period between when the failure is detected and when the affected traffic is restored.

- should be kept small, say a few tens of milliseconds
- depends on:
  - the intrinsic response of the optoelectronic detection and the optical switching devices used in APS,
  - possible induced additional latency of the protection lightpath
Protection Architectures for PONs

ITU-T G.983.1

(a)

(b)

(c)

(d)

OLT  RN  ONU#1

OLT  RN  ONU#1

OLT  RN  ONU#1

OLT  RN  ONU#1

optical line interface/ optical transceiver
Group Protection Architecture

OLT

1xN AWG

RN

WC : WDM coupler

Blue/Red filter

WC

PD

LD

Data router

LAN / subscribers

Group 1

Onu1

Onu2

Onu(2i-1)

Onu(2i)

Down- & Upstream Wavelengths for Onu1

Down- & Upstream Wavelengths for Onu2

Remote Node Duplication

RN Duplication

Fig. 3. Self-protecting architecture against both feeder and distribution fiber failures.

Using $N \times N$ AWG at RN

Survivable Single-Fiber Access Ring

Issues

For evaluation of various feasible survivable network architectures, here are some issues to consider / compare:

- Degree of Protection: feeder fiber, and/or distribution fibers, and/or WDM router at remote node, and/or ONUs, and/or transceivers at OLT, etc.
- Network Availability
- Ease of management and control (at OLT or ONU)
- Amount of duplicated and additional fibers/components \(\rightarrow\) cost / complexity
- Intrusiveness to the other in-service traffic
- Traffic restoration time
- Practical issues, such as availability of laid fiber, power consumption, etc.