The aim of this lecture

- To give an overview of the control and management issues in optical networks
- To give an insight into fault management and the different survivability mechanisms in optical networks

WDM network management and survivability

Introduction

- Efficient network management is a network optimization issue
- The reliability and fault management of optical high capacity networks are extremely important.
- Quality of Service (QoS) enhances competitiveness.
- Minimize CAPEX and OPEX.

Network Management

- Network management refers to the activities, methods, procedures, and tools that support the operation, administration, maintenance, and provisioning of networked systems.
- The combination of hardware and software used to monitor and administer the network is called Network Management System (NMS)

Management systems

- Hierarchical systems
- Network management system (NMS)
  - Has a network wide view
  - Carries out operator-set policies
  - Also called Operations Support System (OSS)
- Element management systems (EMS)
  - Separate for OLT, OADM and OXC
  - Communicates with elements by a data communication network (DCN)
- Protocols
  - Simple network management protocol (SNMP); Internet-protocol family
  - Common management information protocol (CMIP); OSI protocol suite
  - Common object request broker (CORBA) for NMS to EMS communication
Manager-Agent paradigm

Manager-Agent paradigm

Manager

Agent

Operation (get, set)

Notification

Management Communication protocol

Management Interface

Managed Device

Network Management System

Network management functions

- Security management
  - Data integrity
  - Access to management and control functions
- Accounting management (e.g. billing)
  - No specific issues for optical networks
- Configuration management
  - Equipment management
  - Connection management
  - Adaptation management
- Performance management
  - Fault management
  - Fault detection and isolation
  - Fault recovery

Optical layer services

- Providing lightpaths
  - Set up and tear down lightpaths
- Agreed bandwidth (capacity)
- Guaranteed level of performance
  - Bit error rate (BER)
  - Jitter
  - Maximum delay
- Adaptation to and from client layers
- Multiple levels of protection
- Fault management

Optical Sub-Layers

Optical Transport Network protocol layers

- Four layers in the OTN layer-stack:
  - Optical channel sublayer (OCh)
  - Optical multiplex section (OMS)
  - Optical transmission section (OTS)
  - Physical media layer
    - Fiber-type specification, developed in other Recommendations

Layers within the optical layer

- OTS: Optical transmission section
- OMS: Optical multiplexing section
- OCh-TS: Optical channel transparent section (i.e. all-optical section)
- OCh-S: Optical channel section
- OCh-P: Optical channel path

Optical Transport Network protocol layers

Electronic Layers

OTN

- OCh: Optical Channel
- OMS: Optical Multiplex Section
- OTS: Optical Transmission Section
- Physical media (optical fiber)
Simplified view of an optical connection

Optical channel sub-layer

- **End-to-end networking. Functions:**
  - optical channel connection rearrangement for flexible network routing
  - optical channel overhead processing for ensuring integrity of the optical channel adapted information
  - optical channel supervisory functions for enabling network level operations and management functions, such as connection provisioning, quality of service parameter exchange and network survivability
- **Typical involved devices:** switching subsystems of OXCs and OADMs
- **Optical channel entity:** the lightpath (or optical circuit)

OMS sub-layer

- Networking of a multi-wavelength optical signal (including the case of just one optical channel).
- The capabilities of OMS sublayer:
  - OMS overhead processing
  - OMS supervisory functions and management functions, such as multiplex section survivability
- **Typical involved devices:** multiplexing/demultiplexing subsystems of OXCs OADM
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**OTS sub-layer**
- Transmission of optical signals on the optical transmission media.
- The capabilities of OTS sublayer:
  - OTS overhead processing
  - OTS supervisory functions
- Typical involved devices: optical amplifiers (e.g. EDFA gain-control, etc.), transponders, all-optical regenerators

**Configuration management**
- Equipment management
  - Inventory of equipment in the network
- Adaptation management
  - Conversion between client signals and optical layer signals
- Connection management
  - Topology management
  - Route computation
  - Signaling protocol
  - Signaling network

**Adaptation management**
- Converting the user’s signal to appropriate wavelength, optical power level, etc
- Adaptation interfaces
  - Compliant wavelength interface
  - Noncompliant wavelength interface
  - Subrate multiplexing
- Adding and removing overheads
- Policing

**Connection management**
- Centralized control or distributed control
- Distributed connection control
  - Topology management
    - Discover the topology by exchanges with neighbors
    - Updates by flooding (OSPF or IS-IS)
  - Route computation
    - To provide lightpaths
    - Routing and wavelength assignment (RWA) problem
  - Signaling protocol
    - To set up and tear down routes
  - Signaling network
    - The DCN

**Connection management. (Interaction between layers)**
- Interaction with higher layers
  - SHD/SONET over WDM
  - IP over WDM
- Interfaces
  - User network interface (UNI)
  - Network to network interface (NNI)
- Models
  - Overlay
    - Optical layer fulfills client layer demands
    - Could be augmented with cross-layer information
  - Peer
    - One network level
    - Route computation includes client and optical layers
      - Optical constraints must be abstracted

**Control plane models**
- Overlay model
- Overlay+
- Peer model
- Augmented model
DCN and signaling

- Standard data network
  - TCP/IP or OSI
- Connectivity
  - Outside optical network
    - Not available to optical amplifiers (e.g., under water)
  - Optical supervisory channel
    - Not available to OXCs
  - Framing information
    - SDH/SONET data channel
    - Digital wrapper
    - Not available to amplifiers and optical-core OXCs

Fault management and WDM network survivability

Fault management

- Motivation
- Fault detection and isolation
  - Optical monitoring
  - Alarm management
- Fault recovery
  - Terminology and concepts
  - Advantages of optical layer protection
  - Link and path protection
  - Optical layer protection schemes
  - Optical signal monitoring
  - Internetworking between layers

Motivation (2/2)

- The reliability and fault management aspects of optical high capacity networks are extremely important.
- Critical infrastructure
- Reliability performance of network elements can not guarantee a sufficient availability of optical channel
- Survivability mechanisms in optical layer are required.
- Maintaining acceptable level of survivability while reducing network protection costs has become an important challenge for network planners and engineers.

Service classes

- Service Availability

<table>
<thead>
<tr>
<th>Service Type</th>
<th>Availability</th>
<th>Down Time / Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic</td>
<td>99%</td>
<td>87.6 hours</td>
</tr>
<tr>
<td>Premium</td>
<td>99.50%</td>
<td>43.8 hours</td>
</tr>
<tr>
<td>Silver</td>
<td>99.9%</td>
<td>8.76 hours</td>
</tr>
<tr>
<td>Gold</td>
<td>99.99%</td>
<td>52.56 mins</td>
</tr>
<tr>
<td>Platinum</td>
<td>99.999%</td>
<td>5.26 mins</td>
</tr>
</tbody>
</table>

- Leads to differentiated services in mesh networks
  - Customer paying more can get better quality of service
- Leads to “availability-aware provisioning”

Fault detection and isolation

- BER monitoring
  - Requires access to the bit stream
    - In transponders and regenerators
    - Requires known bit pattern or checksums
- Optical path trace
  - An identification of the lightpath
    - For instance provided by a pilot tone
- Alarm management
  - Forward and backward defect indicators (FDIs and BDIs)
  - FDI for a section can lead to FDIs for larger sections downstream
    - Rest of the path
**Alarm management**

- Single failure might cause many alarms
- Alarm suppression necessary
  - Forward defect indicator
  - Backward defect indicator
- Defect indicators used for protection switching

**Monitoring methods**

- Physical layer monitoring using optical time domain reflectometer (OTDR) technology
- Optical signal-to-noise ratio (OSNR) using optical spectrum analyzer (OSA) technology
- Bit error rate (BER) monitoring using SONET/SDH BER test technology

**Fault diagnosis**

- **Hard failures**: unexpected events that suddenly interrupt the established channels.
- **Soft failures**: events that progressively degrade the quality of transmission.

**Fault recovery: terminology and concepts**

- Protection, restoration and survivability
- Working and protection paths
  - Often disjoint paths
- Dedicated and shared protection paths
- Revertive and non-revertive schemes
  - Revertive schemes for shared paths
- Protection switching
  - Path, span and ring switching

**Protection vs. restoration (1/2)**

- **Protection**
  - Pre-assigned capacity
  - Can be very fast
  - Protection: 1+1 (dedicated), 1:1 and 1:N (shared)
- **Restoration**
  - Dynamically provisioning of spare resources in the network after failure occurs.
  - Based on the use of capacity available in the network to replace a failed transport entity.
- **Network survivability**
  - Network’s ability to continue to provide service in the presence of failures.
    - Applying protection or restoration.
  - Usually, networks are designed to survive a single failure

**Different Fault Recovery Schemes**
### Protection

- **Path protection**
  - Find shortest link or node disjoint path pair.
  - Algorithm: e.g., Bhandari’s algorithm using modified Dijkstra algorithm
- **Link protection**
  - Find the shortest path bridging working link.
  - Algorithm: e.g., Dijkstra single source shortest path algorithm.
- **P-cycle (preconfigured protection-cycle)**
  - A sort of shared span protection
  - Shortest path as working path.
  - Find candidate cycles with a hop limit of 10.
  - Minimum Spare Capacity for 100% restorability.
  - Mixed Integer Program (MIP) problem formulation.
  - Make use of optimization tool.

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### EXAMPLE

![Path protection](image)

- **Link protection**
- **Path protection**
- **P-cycles**

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### Survivable network topologies

- Point-to-point
- Mesh
- Self-healing ring (SHR): fiber break
- SHR: node failure

### Protection techniques for Pt-Pt links

- 1+1
- 1:1
- 1:N
Mesh recovery: Link protection

Mesh recovery: Path protection

Connection Availability Modeling

- Unprotected connection
- Dedicated-link/span protected connection
- Dedicated-path protected connection
- Self healing ring
- Shared protection

Dedicated link protection. RBD

Dedicated path protection. RBD

Self Healing Ring. RBD.

U_{Add} = U_C + U_T, U_{Drop} = U_C + U_R
U_1 = (0_n - 2)U_{node} + (L/50 - 1)U_{OFA}
U_{FP} = (0_n - 2)U_{node} + (L/50 - 1)U_{OFA}

L. Wosinska and L. Pedersen, "SCALABILITY LIMITATIONS OF OPTICAL NETWORKS DUE TO RELIABILITY CONSTRAINTS" in Proc. of NFOEC'01, Baltimore, USA, July 2001
Mesh recovery: dedicated vs. shared protection

Path Protection: Failure Recovery

Example: Path Protection

Protection taxonomy

Optical layer protection

- Advantages
  - Faster reaction to optical layer failures
  - More efficient
- Disadvantages
  - Cannot handle client layer failures
  - Limits to monitoring due to transparency
  - Smallest protected unit is a wavelength channel (no grooming)
  - Interworking with higher layers
  - Protection paths might be substantially longer than working paths
Restoration

- Only for mesh topology
- Link Restoration
  - End nodes of the failed link dynamically discover route around link for each connection; link restoration is faster than path restoration
- Path Restoration
  - The source and destination nodes of each connection independently discover back-up route on end-to-end basis; path restoration is slower than link restoration

Restoration Schemes

- Advantages
  - Adaptable to network (traffic and topology) changes
  - Small spare bandwidth required (< 50%)
- Drawbacks
  - Usually slow (recovery time > 50ms)
  - Coordination required upon failure

Restoration Scheme Characteristics

- Centralized
  - Simplicity of a central controller + possible optimal solution
  - Need for reliable controller + reliable controller communication network
- Distributed
  - High restorability + capacity efficiency
  - Difficult protocol implementation + high message contention degree
- Real-time
  - High restorability because up-to-date information
  - Slow recovery time + high resource contention
- Preplanned
  - Fast recovery time
  - Low restorability because out-of-date information

Preplanned Restoration. Example

TE vs. NE vs. NP

- Traffic Engineering (TE)
  - “Put the traffic where the bandwidth is”
- Network Engineering (NE)
  - “Put the bandwidth where the traffic is”
- Network Planning (NP)
  - “Put the bandwidth where the traffic is forecasted to be”

Example: NP Problem – Path Protection

Problem Statement (Network Planning)
- Given:
  - Network topology
  - Static traffic demands
- Need/Requirements/Constraints:
  - Set up a primary path and a backup path for each demand
  - The two paths must be link disjoint (node disjoint too?)
  - Dedicated or shared backup (based on problem specs)
  - Guaranteed to recover from a single fiber cut
- Goal: minimize cost, e.g., # of wavelength channel
Example: TE Problem – Restoration

Problem Statement (Traffic Engineering)
• Given:
  ▪ Network topology (including # of wavelengths per fiber)
  ▪ Dynamic traffic demands (or connections)

• Need/Requirements/Constraints:
  ▪ Set up only one path (primary path) for each connection
  ▪ Try to quickly restore the connection when a fault occurs
  ▪ Control signaling (GMPLS?) for connection setup + restoration
  ▪ Note: This method can handle multiple network failures
• Three restoration methods: path, sub-path, link

Cross-layer protection

• Multiple layers provide survivability
  ▪ IP
  ▪ MPLS
  ▪ SDH/SONET
• Each layer acts independently of other layers
  ▪ Protect paths on all layers, wasteful
  ▪ Possible contention and unpredictable behavior
  ▪ Add coordination or separate timescales

Summary

• Management functions key to services in optical networks
  ▪ To provide lightpaths on demand
• Management system and network
• Configuration management
  ▪ equipment, adaptation, connection
• Performance and fault management
  ▪ Fault detection, isolation and recovery

Problem 9.1

• Which sublayer within the optical layer would be responsible for handling the following functions:
  a) Setting up and taking down lightpaths in the network
  b) Monitoring and changing the optical wrapper overhead in a lightpath
  c) Rerouting all wavelengths (except the optical supervisory channel) from a failed fiber link onto another fiber link
  d) Detecting a fiber cable cut in a WDM line substem
  e) Detecting failure of an individual lightpath
  f) Detecting bit errors in a lightpath