Overview

- Optical Transmission
  - Dense Wavelength Division Multiplexing (DWDM)
  - Synchronous Optical Network (SONET)
  - Generic Framing Procedure (GFP)

Fiber Attenuation

- Telecommunications industry uses two windows: 1310 & 1550 nm
- 1550 window is preferred for long-haul applications
  - Less attenuation
  - Wider window
  - Optical amplifiers

Dispersion

- Dispersion causes the pulse to spread as it travels along the fiber
- Chromatic dispersion
  - Light propagation in material varies with the wavelength
  - Degradation scales as (data-rate)^2
(Figure from http://lw.pennnet.com/)
Dispersion

- Modal dispersion
  - Only for fiber that carry multiple light rays (modes)
  - Different modes travel at different speeds
  - Multimodal fiber used only for short distances

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Dense Wavelength Division Multiplexing (DWDM)

- 40.80 km
- Regenerator - 3R (Reamplify, Reshape and Retime)

DWDM System Design

- 120 km
- Optical Amplifiers (OA)
- OA amplifies all λs

All-Optical Switching

- Natively switch λs while they are still multiplexed
- Eliminate redundant optical-electronic-optical conversions
1-D MEMS

- MEMS: Micro-electromechanical systems
- 1-Dimensional array of micro-mirrors
  - 1 mirror per wavelength
- Digital control; no motors

Optical Switch

- 1-input 2-output illustration with four wavelengths
  - 1-D MEMS with dispersive optics
    - Dispersive element separates the λ’s from inputs
    - MEMS independently switches each λ
    - Dispersive element recombines the switched λ’s into outputs

Optical Add-Drop Multiplexer

- Add-drop one λ
- Each λ is associated with a fixed add/drop port
- Used to implement ring topologies

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SONET

- Encode bit streams into optical signals propagated over optical fiber
- Uses Time Division Multiplexing (TDM) for carrying many signals of different capacities
  - A bit-way implementation providing end-to-end transport of bit streams
  - All clocks in the network are locked to a common master clock
  - Multiplexing done by byte interleaving
Synchronous Transport Signal (STS)

- First two bytes of each frame contain a special bit pattern that allows to determine where the frame starts
- Receiver looks for the special bit pattern every 810 bytes
  - Size of frame = 9x90 = 810 bytes

Encoding

- Overhead bytes are encoded using Non-Return to Zero
  - high signal → 1; low signal → 0
- To avoid long sequences of 0’s or 1’s the payload is XOR-ed with a special 127-bit pattern with many transitions from 1 to 0
  - Duration of a frame is 125 µsec (51.84 Mbps for STS-1)

SONET Overhead Processing

- Three layers of overhead
  - Path overhead (POH): end-to-end transport
  - Line overhead (LOH): mux-to-mux transport
  - Section overhead (SOH): adjacent network element

STS-1 Frame Format

- Two-dimensional: 9*80 = 810 bytes
- Time Frame: 125 µsec
- Rate: 810*8 bit/125 µsec = 51.84 Mbps
- For STS-3 only the number of columns changes (3*80 = 270)

STS-1 Headers

- First 3 lines in the header
- Main functions
  - Framing (A1, A2)
  - Monitor performance
  - Local orderwire (E1): select repeater/terminal within communication complex
  - Proprietary OAM (Operation, Administration, and Maintenance) (F1)

Section Overhead (SOH)
**Line Overhead (LOH)**

- Last 3 lines in the header
- Main functions
  - Locating payload (SPE) in the frame (H1, H2)
  - muxing and concatenating signals
  - Performance monitoring
  - Automatic protection switch (K1, K2)
  - Switchover in case of failure
- Line maintenance

**Path Overhead (POH)**

- 1st column in SPE
- Main functions
  - Info about SPE content
  - Performance monitoring
  - Path status
  - Path trace
- SPE can start anywhere in the current frame and span the next one
  - Avoids buffer management complexity & artificial delays

**STS-N Frame Format**

- 9xN bytes or "columns"
- N Individual STS-1 Frames
- Composite Frames:
  - Byte Interleaved STS-1's
  - Clock Rate = N x 51.84 Mbps
  - 9 columns overhead

Examples:
- STS-1: 51.84 Mbps
- STS-3: 155.52 Mbps
- STS-12: 622.08 Mbps
- STS-48: 2.48832 Gbps
- STS-192: 9.95328 Gbps

Multiple frame streams, w/ independent payload pointers
Note: header columns also interleaved

**STS-N: Generic Frame Format**

**STS-Nc Frame Format**

- 99xN bytes or "columns"
- Transport Overhead: SOH+LOH
- Concatenated modes:
  - Same header structure and data rates as STS-N
  - Not all header bytes used
  - First H1, H2 Point To POH
  - Single Payload In Rest Of SPE

Current IP over SONET technologies use concatenated mode: OC-3c (155 Mbps) to OC-192c (10 Gbps) rates a.k.a "super-rate" payloads
Protection Technique Classification

- Restoration techniques can protect the network against:
  - Link failures
  - Fiber-cable cuts and line devices failures (amplifiers)
  - Equipment failures
  - OXCs, ADMs, electro-optical interface.
- Protection can be implemented:
  - In the optical channel sublayer (path protection)
  - In the optical multiplex sublayer (line protection)
- Different protection techniques are used for:
  - Ring networks
  - Mesh networks

1+1 Protection

- Traffic is sent over two parallel paths, and the destination selects a better one
- In case of failure, the destination switch onto the other path
- Pros: simple for implementation and fast restoration
- Cons: waste of bandwidth

1:1 Protection

- During normal operation, no traffic or low priority traffic is sent across the backup path
- In case failure both the source and destination switch onto the protection path
- Pros: better network utilization
- Cons: required signaling overhead, slower restoration

Protection in Ring Network

- UPSR (Unidirectional Path Switched Ring) 1+1 Path Protection
  - Used in access rings for traffic aggregation into on-net office
- BLSR/4 (Bidirectional Line Switched Ring) 1:1 Line Protection
  - Used in metropolitan or long-haul rings
- BLSR/2 1:1 Span and Line Protection
  - Used for interface rings

Protection in Mesh Networks

- Network planning and survivability design
  - Disjoint path idea: service working route and its backup route are topologically diverse.
  - Lightpaths of a logical topology can withstand physical link failures.
Path Switching: restoration is handled by the source and the destination.

Line Switching: restoration is handled by the node adjacent to the failure. A shared protection is possible if additional fiber is available.

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Generic Framing Procedure (GFP)

- Frame-mapped
  - Need to know the client protocol
  - Associate a length to each higher level frame
  - Efficient: eliminate the need for byte stuffing of for block encoding (e.g., 8B/10B)
- Transparent
  - No need to know the client protocol
  - Less efficient: can transmit signal even when the client is idle