Fiber-Optic Network Architectures

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OSI & Layer Model

Layer 7: Application
- Provides general services related to applications (e.g., file transfer, user access)

Layer 6: Presentation
- Formats data (encodes, encrypts, compresses)

Layer 5: Session
- Maintains dialog between communicating devices

Layer 4: Transport
- Provides reliable end-to-end data transmission

Layer 3: Network
- Switches and routes information units

Layer 2: Data link
- Provides data exchange between devices on the same medium

Layer 1: Physical
- Transmits bit stream to physical medium

Responsibility of host system
- This Course

Responsibility of network
- Support user applications
- Govern the communication facilities
Types of Networks

• **Local Area Network (LAN)**
  – Interconnect users in a localized area: a building, campus or enterprise

• **Metropolitan Area Network (MAN)**

• **Wide Area Network (WAN)**
  – National, Regional

• **Special Networks**
  – Undersea, Intercontinental…
The Public Network

Long Haul Network

Metro interoffice network

Metro access network

Homes, apartments, or enterprises

Central offices
Wide-Area Networks (WAN)

- Either government-regulated or in the public network environment
  - WANS originated in telephony
- Main technologies: SONET/SDH, ATM, WDM
  - Voice circuits vs. data packets
  - Non-optical technologies: T1 (1.544 Mb/s)/E1 (2.048 Mb/s), DS-3 (44.736 Mb/s), Frame Relay
  - Standards bodies include ITU-T, IETF, ATM Forum, Frame Relay Forum, IEEE
Metropolitan-area/regional-area networks

• A MAN or RAN covers a North American metropolitan area, or a small to medium-sized country in Europe or Asia
• Main technologies: SONET, ATM, Gigabit & 10-Gigabit Ethernet, DWDM
• Non-optical technologies: T1, T3, Frame Relay
• Several LANs could be connected to MAN
Local Area / Access Networks

Local-area networks
- Main technologies: Ethernet, Fast Ethernet, Gigabit Ethernet
- Usually passive star or bus networks

Access networks
- The first (or last) network segment between customer premises and a WAN or MAN
  - Owned by a Local Exchange Carrier
- Broadband digital technologies: HFC, DSL
  - Ethernet framing vs. ATM
- Twisted pair vs. coaxial cable vs. fiber vs. wireless vs. free-space optics
Fiber in the Access End

Fiber increasingly reaches the user
Network Terminologies

[Diagram showing network connections with nodes, routers, and trunks.]

ions

Network 1

Node

Node

Stations

Trunks

Router

Trunk

Router

Network 2
Some Terms

Topology – logical manner in which nodes linked

Switching – transfer of information from source to destination via series of intermediate nodes;

Circuit Switching – Virtual circuit established

Packet Switching – Individual packets are directed

Switch – is the intermediate node that stream the incoming information to the appropriate output

Routing – selection of such a suitable path

Router – translates the information from one network to another when two different protocol networks are connected (say ATM to Ethernet)
The Optical Layer

The OL is a wavelength based concept lies just above the physical layer.
Optical Network Elements

**DWDM**
Establishes hundreds of optical wavelength

**OADM**
Wavelength add/drop subset

**Optical Switch**
Highly scalable optical management
Two Types of Optical Switches

OEO Core Optical Switch

All-Optical Switch
Optical Cross Connects
Passive Optical Network (PON) Topologies

No O/E conversion
Passive optical couplers

Folded Bus, Tree and Mesh Networks also exist
Elements of a Network

• **Passive Couplers:** A portion of the optical power is tapped off
  – 3-dB coupler; 80/20 coupler
• **Circulators, isolators, connectors…**
• **Add/Drop Multiplexers**
• **Optical Amplifiers**
• **OEO or All Optical switches**
• **Routers, Network Intelligence**
Add-Drop Bus-Coupler Losses

Linear bus coupler

Connector loss ($L_c$), Tap loss ($L_{tap}$), Throughput loss ($L_{th}$), Intrinsic loss and Fiber loss
Linear bus topology

Ex. 12.1

10\log\left(\frac{P_o}{P_{L,N}}\right) = (N - 1)\alpha L + 2NL_C + (N - 2)L_{thru} + 2L_{TAP} + NL_i
Liner Bus versus Star Network

The loss linearly increases with number of stations in a Bus connection.
Synchronous Optical Networks

- SONET is the TDM optical network standard for North America (It is called SDH in the rest of the world)
- We focus on the physical layer
- STS-1, Synchronous Transport Signal consists of 810 bytes over 125 us
- 27 bytes carry overhead information
- Remaining 783 bytes: Synchronous Payload Envelope
## SONET/SDH Bit Rates

<table>
<thead>
<tr>
<th>SONET</th>
<th>Bit Rate (Mbps)</th>
<th>SDH</th>
</tr>
</thead>
<tbody>
<tr>
<td>OC-1</td>
<td>51.84</td>
<td>-</td>
</tr>
<tr>
<td>OC-3</td>
<td>155.52</td>
<td>STM-1</td>
</tr>
<tr>
<td>OC-12</td>
<td>622.08</td>
<td>STM-4</td>
</tr>
<tr>
<td>OC-24</td>
<td>1244.16</td>
<td>STM-8</td>
</tr>
<tr>
<td>OC-48</td>
<td>2488.32</td>
<td>STM-16</td>
</tr>
<tr>
<td>OC-96</td>
<td>4976.64</td>
<td>STM-32</td>
</tr>
<tr>
<td>OC-192</td>
<td>9953.28</td>
<td>STM-64</td>
</tr>
</tbody>
</table>
Digital Transmission Hierarchy (T-Standards)

Predominant before optical era

Additional framing bits stuffed at each level to achieve synchronization

Not possible to directly add/drop sub-channels
Fig. 12-5: Basic STS-1 SONET frame

STS-1 = (90 * 8 bits/row) * (9 rows/frame) * 125 \( \mu s \) / frame = 51.84 Mb/s
Fig. 12-6: Basic STS-N SONET frame

STS-N signal has a bit rate equal to $N$ times 51.84 Mb/s
Ex: STS-3 $\rightarrow$ 155.52 Mb/s
### TABLE 17.2. Transmission Distances and Their SONET and SDH Designations, Where x Denotes the STM-x Level

<table>
<thead>
<tr>
<th>Transmission distance</th>
<th>Fiber type</th>
<th>SONET terminology</th>
<th>SDH terminology</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 2 km</td>
<td>G.652</td>
<td>Short-reach (SR)</td>
<td>Intraoffice (I-1)</td>
</tr>
<tr>
<td>15 km at 1310 nm</td>
<td>G.653</td>
<td>Intermediate-reach (IR-1)</td>
<td>Short-haul (S-x.1)</td>
</tr>
<tr>
<td>15 km at 1550 nm</td>
<td>G.653</td>
<td>Intermediate-reach (IR-2)</td>
<td>Short-haul (S-x.2)</td>
</tr>
<tr>
<td>40 km at 1310 nm</td>
<td>G.655</td>
<td>Long-reach (LR-1)</td>
<td>Long-haul (L-x.1)</td>
</tr>
<tr>
<td>80 km at 1550 nm</td>
<td>G.655</td>
<td>Long-reach (LR-2)</td>
<td>Long-haul (L-x.3)</td>
</tr>
<tr>
<td>120 km at 1550 nm</td>
<td>G.655</td>
<td>Very long-reach (VR-1)</td>
<td>Very long (V-x.3)</td>
</tr>
<tr>
<td>160 km at 1550 nm</td>
<td>G.655</td>
<td>Very long-reach (VR-2)</td>
<td>Ultralong (U-x.3)</td>
</tr>
</tbody>
</table>

### TABLE 17.3. Wavelength Ranges and Attenuation for Transmission Distances up to 80 km

<table>
<thead>
<tr>
<th>Distance</th>
<th>Wavelength range at 1310 nm</th>
<th>Wavelength range at 1550 nm</th>
<th>Attenuation at 1310 nm, dB/km</th>
<th>Attenuation at 1550 nm, dB/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤15 km</td>
<td>1260–1360 nm</td>
<td>1430–1580 nm</td>
<td>3.5</td>
<td>Not specified</td>
</tr>
<tr>
<td>≤40 km</td>
<td>1260–1360 nm</td>
<td>1430–1580 nm</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td>≤80 km</td>
<td>1280–1335 nm</td>
<td>1480–1580 nm</td>
<td>0.5</td>
<td>0.3</td>
</tr>
</tbody>
</table>
SONET Add Drop Multiplexers

ADM is a fully synchronous, byte oriented device, that can be used add/drop OC sub-channels within an OC-\(N\) signal.

Ex: OC-3 and OC-12 signals can be individually added/dropped from an OC-48 carrier.
SONET/SDH Rings

- SONET/SDH are usually configured in ring architecture to create loop diversity by self-healing
- 2 or 4 fiber between nodes
- Unidirectional/bidirectional traffic flow
- Protection via line switching (entire OC-N channel is moved) or path switching (sub channel is moved)
2-Fiber Unidirectional Path Switched Ring

Ex: Total capacity OC-12 may be divided to four OC-3 streams
2-Fiber UPSR

- Rx compares the signals received via the primary and protection paths and picks the best one
- Constant protection and automatic switching
4-Fiber Bi-directional Line Switched Ring (BLSR)

Node 1 → 3; 1p, 2p  
3 → 1; 7p, 8p

All secondary fiber left for protection
In case of failure, the secondary fibers between only the affected nodes (3 & 4) are used, the other links remain unaffected.
If both primary and secondary are cut, still the connection is not lost, but both the primary and secondary fibers of the entire ring is occupied.
Generic SONET network

Versatile SONET equipment are available that support wide range of configurations, bit rates and protection schemes.
WDM Networks

- Single fiber transmits multiple wavelengths $\Rightarrow$ WDM Networks
- One entire wavelength (with all the data) can be switched/routed
- This adds another dimension; the Optical Layer
- Wavelength converters/cross connectors; all optical networks
- Note protocol independence
WDM Networks

• **Broadcast and Select**: employs passive optical stars or buses for local networks applications
  – Single hop networks
  – Multi hop networks

• **Wavelength Routing**: employs advanced wavelength routing techniques
  – Enable wavelength reuse
  – Increases capacity
Several OC-192 signals can be carried, each by one wavelength.
Single hop broadcast and select WDM

- Each Tx transmits at a different fixed wavelength
- Each receiver receives all the wavelengths, but selects (decodes) only the desired wavelength
- Multicast or broadcast services are supported
- Dynamic coordination (tunable filters) is required
A Single-hop Multicast WDM Network
Multi-hop Architecture

Four node broadcast and select multihop network

Each node transmits at fixed set of wavelengths and receive fixed set of wavelengths

Multiple hops required depending on destination

Ex. Node1 to Node2: N1 $\Rightarrow$ N3 ($\lambda_1$), N3 $\Rightarrow$ N2 ($\lambda_6$)

No tunable filters required but throughput is less
In multihop networks, the source and destination information is embedded in the header.

These packets may travel asynchronously (Ex. ATM)
Shuffle Net

Shuffle Net is one of several possible topologies in multihop networks

\[ N_\lambda = (\text{# of nodes}) \times (\lambda \text{ per node}) \]

Max. # of hops = \[2(\text{# of columns}) - 1\]

(-) Large # of \( \lambda \)'s

(-) High splitting loss

A two column shuffle net

Ex: Max. 2 X 2 - 1 = 3 hops
Wavelength Routing

• The limitation is overcome by:
  – $\lambda$ reuse,
  – $\lambda$ routing and
  – $\lambda$ conversion

• As long as the logical paths between nodes do not overlap they can use the same $\lambda$
12X12 Optical Cross-Connect (OXC) Architecture

This uses space switching
Optical Cross Connects (OXC)

- Works on the optical domain
- Can route high capacity wavelengths
- Space switches are controlled electronically
- Incoming wavelengths are routed either to desired output (ports 1-8) or dropped (9-12)
- What happens when both incoming fibers have a same wavelength? (contention)
- Try Ex. 12.5
Ex: 12.5: 4X4 Optical cross-connect

Wavelength switches are electronically configured. Wavelength conversion to avoid contention.