SDH and WDM: a look at the physical layer

Physical layer (not only in telephone networks)
- TDM based scheme
- No store and forward in nodes
- Two technologies
  - Plesiochronous Digital Hierarchy (PDH)
    - No global network synchronization
    - T and E hierarchies
  - Synchronous Digital Hierarchy (SDH)
    - Global network synchronization
    - Fiber based (optical) transmission
- Phone channels named tributaries

PDH: T and E hierarchies

<table>
<thead>
<tr>
<th>Level</th>
<th>USA (T-)</th>
<th>Europe (E-)</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.064 Mb/s</td>
<td>0.064 Mb/s</td>
<td>0.064 Mb/s</td>
</tr>
<tr>
<td>1</td>
<td>1.544 Mb/s</td>
<td>2.048 Mb/s</td>
<td>1.544 Mb/s</td>
</tr>
<tr>
<td>2</td>
<td>6.312 Mb/s</td>
<td>8.488 Mb/s</td>
<td>6.312 Mb/s</td>
</tr>
<tr>
<td>3</td>
<td>44.736 Mb/s</td>
<td>34.368 Mb/s</td>
<td>32.064 Mb/s</td>
</tr>
<tr>
<td>4</td>
<td>274.176 Mb/s</td>
<td>139.264 Mb/s</td>
<td>97.928 Mb/s</td>
</tr>
</tbody>
</table>

USA: T-1 carrier system
- Frame duration 125 µs
- One sample (8bit) per channel every 125 µs
- 24 TDM PCM channels
- Transmission rate (24*8+1)*8000=1.544 Mb/s
- 1 signalling channel (1 bit per frame)
- No support for management functions
PDH: synchronization

- Each device has its own clock (no network wide global synchronization)
- Local clocks would lead to synchronization errors
- To solve it
  - TXs faster than receivers
  - Short buffer to store in transit bits
  - Insert bits through bit stuffing at the end of a frame
- Stuffed bits must be signalled to the other end to permit bit removal

PDH limitations

- Lack of efficiency
  - Difficult to extract slower tributaries from high speed aggregates
- Lack of flexibility
  - No monitoring standard
  - No management standard
- No common physical standard
  - Every manufacturer goes alone
  - No NNI standard

SONET/SDH

- Exploits network-wide synchronization
- Hierarchies
  - SONET - Synchronous Optical NETwork
    - Used in USA
    - Based on fiber transmission
    - Base signal at 51.84 Mbit/s
  - SDH - Synchronous Digital Hierarchy
    - International and European
    - Base signal at 155.52 Mbit/s
  - STS - Synchronous Transport Signal
    - Labels to identify electrical signals
- Introduction of management, signalling, protection

SONET/SDH Goals

- Main goals of SONET/SDH:
  - Fault tolerance as required by telecom providers
    - 99.999%, or five nines availability
  - Interoperability among different manufacturers
  - Flexibility of upper layer formats to adapt to different source (not only voice)
  - Complex monitoring capabilities of performance and traffic
    - 50 ms of recovery time after failure

SONET/SDH framing

- Continuous bit transmission
- Complex TDM scheme
  - Designed to permit a very efficient VLSI implementation
- Each frame includes a PCI (Protocol Control Information) or overhead which includes
  - Synchronization info
  - Voice channels for QAM services
  - Support for complex fault/error management procedures
- Layered architecture
  - Path, Line, Section (each including overhead info)
SONET/SDH reference model

- Path layer (similar to OSI layer 3)
  - Manages end-to-end connections
  - Monitoring and management of user connection
- Line Layer (similar to OSI layer 2)
  - Multiplexing of several path-layer connection among nodes
  - Protection and Fault Management
- Section Layer (similar to OSI layer 2-1)
  - Frame alignment
  - Define regenerator functions
- Photonic Layer (same as OSI layer 1)
  - Defines all the transmission requirements of signals.

SONET/SDH equipment

- Regenerators
  - 3-R functions
  - SDH processing and regeneration
- Two multiplexer types
  - Terminal multiplexer (TM)
  - Add-drop multiplexer (ADM)
- PDH and SDH tributaries
- Used in ring topologies
- Transmit traffic forwarded transparently
- Digital cross-connect
  - PDH and SDH tributaries
  - Operate links with different speed

SONET/SDH transport scheme

- Transport of digital tributaries through SDH equipment
SONET/SDH Network Configurations

- **Point-to-point topology**
  - Simplest topology
  - The point-to-point start and end on a PTE (Path Terminating Equipment), which manages the mux/demux of tributaries
  - No routing, and no demux along the path
  - Regenerators may be used to cope with transmission problems

- **Linear add-drop topology**
  - Still a linear topology
  - ADM (and regen) along the line
  - ADM allow to add and drop tributaries along the path
  - ADM are designed to work in this kind of simple topologies, which often translates to rings
    - there is no need to mux and remux in transit tributaries

- **Hub network setup**
  - Typically on large aggregation point
  - Adopt Digital Cross connect (DCX) working at high rate
  - DCXs are much more complex that ADMs
    - they have to manage both single tributary and SONET stream

- **Meshed topologies**
  - Often seen as interconnected rings

SONET Network Configurations

- **SONET Rings**
  - The most used topology. Can use two or four fibers and an ADM at each node
  - Bidirectional topology
  - Simple protection functions against single failure
    - Bidirectional ring becomes unidirectional ring

WDM: Optical transmission

- **Fibers can carry huge bandwidth**
- **Signals are generated in the electronic domain**
  - Limited ability to exploit the optical bandwidth
  - Today 10Gbit/s transmission systems are the standard commercial for high speed transmission
  - 40Gbit/s are the next step
  - Still a huge bandwidth gap
- **WDM (a FDM technique well suited to the optical domain)**
  - Many wavelengths on a single fiber
  - Each wavelength transport an independent electronic signal
  - 128 × 2.5 Gbit/s or 32 × 10 Gbit/s

WDM for optical networks

- **Which functions can be performed in optics?**
  - Transmission
  - Switching/routing
    - Implies buffering?
    - Management
- **First generation optical networks**
  - Optics for transmission only
- **Second generation optical networks**
  - Perform also switching/routing in the optical domain
  - Wavelength routing approach
Wavelength Routing (WR) networks

- WDM is exploited to route and switch information in the optical domain using wavelengths
- Transparent or opaque optical circuits, called lightpaths, are used to connect network nodes.
- Lightpaths are optical circuits that may span one or more hops in the physical topology, and may cross switching elements in the optical layer
- Traffic carried by a lightpath may be
  - packet-based, e.g., IP datagrams
  - circuit oriented, e.g., telephone streams.
- The optical network is not aware of traffic formats

WR devices

- In a wavelength routed network
  - Optical Line Terminal (OLT): line termination, taking care of physical functions, signal regeneration, wavelength adaptation, amplification, traffic multiplexing/demultiplexing
  - Optical Add-Drop Multiplexer (OADM): it allows to add and drop traffic carried by one or more wavelengths in a (bidirectional) WDM link
  - Optical Cross Connect (OXC): switches incoming wavelengths to multiple outgoing fibers
- These devices are similar to the equivalent first-generation SONET/SDH devices