S-72.3340 Optical Networks Course
Lecture 6: MultiService Optical Networks

Edward Mutafungwa
Communications Laboratory, Helsinki University of Technology,
P. O. Box 2300, FIN-02015 TKK, Finland
Tel: +358 9 451 2318, E-mail: edward.mutafungwa@tkk.fi
Lecture Outline

- Introduction
- Data-Centric Client Layers
  - ATM
  - IP
  - Ethernet
  - SAN
- Next-Generation SDH
- OTN Standard
- Conclusion
1. Introduction

- **Last week**
  - Focused on optical TDM-based circuit switched networks (PDH, SDH/SONET)
  - Optimized for voice communications

- **But...**
  - **Non-voice traffic** now dominates in quantity (80/20% reverse)
  - Voice revenues are dwindling
  - Uncertainty on non-voice revenues
  - Operators need **reliable revenue streams**
    - Broaden service offering ⇒ “One-stop shopping” for customers
    - Reduce operating expenditure by being more flexibility to meet demand all service types
1. Introduction

- Increased use of buzz words (e.g. “triple play” services for home users) and business models (e.g. “multiservice provisioning”)

- Need for multiservice networks
  - Networks that provide more than one distinct communications service type over a common physical infrastructure (optical, wireless, copper etc.)
2. ATM

- Asynchronous Transfer Mode (ATM)
  - Main goal was the integration of voice (SDH, PDH) and data (e.g. IP, frame relay) networks
  - Uses fixed length cells of 53 bytes
    - Fixed packet size enable development low-cost high-speed ATM switches

    | Overhead | Payload |
    |----------|---------|
    | 5 bytes  | 48 bytes|

- Length is compromise between conflicting requirements of voice and data
  - Small packet size good for voice since delay is short
  - Large size good for data since overhead is small fraction of cell
2. ATM

- Main motivation for use of ATM is the **quality-of-service (QoS)** guarantees it provides

- QoS guarantees in form of bounds on cell loss, cell delay and jitter (delay variations)
  - “Traffic contracts” offered to different service classes (constant bit rate [CBR], unspecified bit rate [UBR] etc.)
  - Enforcing of the traffic contracts
    - Admission control to maintain existing QoS guarantees
    - Traffic shaping at entry points
    - Continuous traffic policing for contract adherence
2.1 Functions of ATM

- ATM connections are termed virtual circuits (VC) and these are bundled into virtual paths (VP) on common links
  - Cell headers have VC identifier (VCI) and VP identifier (VPI) labels for addressing
  - Two level labels (VPI and VCI) simplifies cell forwarding and ATM switch designs
  - Switches maintain routing tables and read VCI/VPI to determine outgoing link for forwarding cells and enable rewriting of VCI/VPI fields on header
2.2 ATM Adaptation Layer

- Services/applications using ATM (e.g. video, IP) usually have variable packet sizes
- ATM adaptation layer (AAL) for mapping user data into ATM cells by segmentation and reassembly (SAR) of user data

**Segmentation (at source)**
User data (L > 48 bytes)

**Reassembly (at destination)**
User data (L > 48 bytes)

- ITU defines the following AALs depending on service type
  - AAL-1 ⇒ for CBR connection-oriented services e.g. E1 circuit emulation
  - AAL-2 ⇒ for CBR real-time data e.g. video, voice etc.
  - AAL-3/4 (merged) ⇒ for VBR data traffic e.g. frame relay
  - AAL-5 ⇒ for VBR variable packet size traffic e.g. classic IP over ATM
2.3 ATM Optical Physical Layer Interfaces

- Optical interfaces originally defined by the ATM Forum
  - Enables interfacing to SDH/SONET terminal equipment
  - Defines framing structure for the transport of ATM cells over SDH
    - Uses VC-4-Nc frames with a concatenated or locked payload, where N=1 for 155.52 Mb/s, N=4 for 622.08 Mb/s and N=64 for 10 Mb/s interfaces

ATM cells scrambled and then mapped to VC-4
## 2.3 ATM Optical Physical Layer Interfaces

- **Example:** 622.08 Mb/s Physical Layer Specification (AF-PHY-0046.000, Jan. 1996) parameters

<table>
<thead>
<tr>
<th></th>
<th>Link length</th>
<th>Transmitter</th>
<th>Wavelength window</th>
<th>Receiver sensitivity</th>
<th>Dispersion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Singlemode Fiber</strong></td>
<td>2 km (SR)</td>
<td>LED (SR) MLM (IR)</td>
<td>1310 nm 1310 nm</td>
<td>-23 to -28 dBm</td>
<td>13 ps/nm (SR), 74 ps/nm (IR)</td>
</tr>
<tr>
<td></td>
<td>15 km (IR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Multimode Fiber</strong></td>
<td>300 m</td>
<td>LED</td>
<td>1310 nm</td>
<td>-26 dBm</td>
<td></td>
</tr>
<tr>
<td><strong>Multimode Fiber</strong></td>
<td>300 m</td>
<td>Short λ laser</td>
<td>850 nm</td>
<td>-16 dBm</td>
<td></td>
</tr>
</tbody>
</table>

SR: Short Reach, IR: Intermediate Reach
2.3 ATM Optical Physical Layer Interfaces

Example: An OC-1/OC-3/STM-1 ATM-SDH/SONET interface module (by Communication Automation Corporation)

- 1300 nm Transmitter and Receiver, 155 Mb/s rate, Multimode fiber
- Optical transceiver interface, Clock recovery, SDH/SONET and ATM framing
- AAL-3/4 and AAL-5 cell processing

Cell forwarding, Routing table, Transit cell buffering
3. Internet Protocol (IP)

- Most widely used wide-area networking technology
  - Underlying networking protocol used in the Internet and private intranets
  - Flexible as it is designed to work above variety of data link layers e.g. Ethernet, ATM, ISDN

- IP is a network layer protocol (routing functions etc.)
  - Therefore IP does not guarantee reliable data delivery
  - Relies on transmission control protocol (TCP) or user datagram protocol (UDP) to keep track of packets and retransmit if needed
3. Internet Protocol (IP)

- IP layer increasingly generates the majority of traffic on existing networks

and...

- Optical systems provide largest traffic carrier pipes

- A recurring theme is how best to transmit IP traffic over the optical (WDM) layer?
  - Also referred to as IP over WDM
3. Internet Protocol (IP)

- Several layering structures possible for mapping IP to optical layer

  - **Traditional Implementation**: IP packets $\rightarrow$ AAL-5 $\rightarrow$ ATM cells $\rightarrow$ SDH/SONET framing (up to 25% bandwidth wasted on overhead!)

  - IP directly over SDH or “packet-over-SONET”: IP packets $\rightarrow$ PPP (variable length) frames $\rightarrow$ SDH/SONET framing
3.1 IP QoS

- IP provides only a “best-effort delivery” service
- Arriving IP packets may be:
  - Damaged
  - Out of sequence
  - Duplicated
  - Dropped entirely

- If an application requires solid QoS assurances, it is provided by other means e.g. MPLS
3.2 IP/MPLS

- **MPLS** ⇒ **Multiprotocol Label Switching**
  - Originally a Cisco proprietary proposal then adapted by IETF for open standardization
  - Combines IP Layer 3 service opportunities with traffic management control of Layer 2 switching
  - MPLS label set and routing tables used for setting up label switched path (LSP) between nodes in networks
    - MPLS pushed or imposed between IP and layer 2 headers
    - Or in Layer VPI/VCI fields if IP packet is being carried in ATM cells

<table>
<thead>
<tr>
<th>L2 header</th>
<th>MPLS label</th>
<th>IP header</th>
<th>IP data</th>
</tr>
</thead>
</table>
3.2 IP/MPLS

- IP/MPLS enable connectionless IP networks to operate in a more connected and managed way
  - Allows LSPs to be setup by different criteria
  - Able to provide QoS assurances e.g. guaranteed bandwidth

- LER: Label Edge Router
- LSR: Label Switched-Router

Traffic classification
- LSP computation
- Label Addition

- Packets examination
- Label swapping
- Packet forwarding

- Label Removal

- Search IP table for Customer B destination port and route

Ingress LER
- Customer Site A

Penultimate LSR

Egress LER
- Customer Site B

IP/MPLS Network
- LER: Label Edge Router
- LSR: Label Switched-Router
3.2 IP/MPLS

- Today providers pursuing IP/MPLS infrastructure as convergence mechanism
  - ATM, Frame Relay, Ethernet etc. networks folded into edges of IP/MPLS core

- Also MPLS virtual private networks (VPNs) are of great interest
3.3 Wither ATM?

- ATM initially viewed as replacement for IP because of its QoS capabilities
  - ATM has suffered because of slow development of standards
  - ATM also has complex provisioning and high cost interfaces
  - IP has survived due to its ubiquity and service creation capabilities
3.3 Wither ATM?

- MPLS now provides IP networks with QoS capabilities similar to ATM
  - MPLS better optimized for larger data packets (~1500 bytes)
  - Running IP packets through AALs increases overhead (inefficient)
  - IP/MPLS is expected to gradually displace ATM in the network core

- ATM still employed in various areas
  - Wireless backhaul
  - Multiplexing in DSL networks
  - Some LAN backbones
4. Optical Ethernet

- Widespread use of **10 Mb/s Ethernet** and **100 Mb/s Ethernet** (Fast Ethernet)
  - The de facto Layer 2 standard for local area networks (LANs)

- Numerous devices now shipped with Ethernet ports
  - PCs, servers, switches, routers, WiFi access points, VoIP equipment etc.
  - Example: Broadcom shipped 2 billion Ethernet ports between 1995 and June 2006 (Source: PRNewswire)
4. Optical Ethernet

- Now Ethernet deployments extend from LANs into access networks, MANs and WANs
- Advantages of Ethernet/IP compared to SDH/SONET and ATM implementations
  - A mature well understood technology
  - Low cost technology in terms of equipment and operations costs
  - Easier to provision connections
  - Dynamic bandwidth usage and sharing
  - Adaptable to any topology type (ring, star, mesh etc.)
  - Flexible capacity scaling with standards now existing for Gigabit Ethernet and 10 Gigabit Ethernet
4.1 Optical Ethernet PHY

- **Gigabit Ethernet** or **GbE** (IEEE 802.3z)
  - Offers nominal 1 Gbit/s rate in both directions
  - Backward compatible with 10 Mbit/s and 100 Mbit/s Ethernet technologies

- Transmission media used for GbE
  - Category 5e (or higher) unshielded twisted copper pairs (1000Base-T)
  - Singlemode and multimode fibers, 1000Base-x, where x depends on the physical layer interface used
    - Example: 1000Base-SX for 850 nm operation over a short-reach multimode fiber
4.1 Optical Ethernet PHY

- **10 Gigabit Ethernet** or **10GbE** (IEEE 802.3ae)
  - 10 Gbit/s in both directions
  - Backward compatible with previous Ethernet standards

- **10GbE mostly fiber only technology**
  - 10GBase-x, where x depends on the physical layer interface used (SR: short reach etc.)
  - Copper interface (10G BASE-T) recently proposed for very short (<30m) links
4.1 Optical Ethernet PHY

- Physical layer (PHY) of GbE and 10GbE defined to move Ethernet traffic:
  - Across SDH networks (WAN PHY for 10GbE)
  - Directly over single wavelength channel or WDM networks (LAN PHY for 10GbE)
4.2 Pluggable Optics

- GbE initially proposed for LANs with range of about 2km over multimode fibers
- The move into MAN/WANs requires Ethernet optical transceivers suitable for:
  - Long range singlemode fiber transmission
  - WDM (either CWDM or DWDM) operation
  - Optical amplification
- But operators also need to extend useful life of existing GbE and 10GbE switching products
4.2 Pluggable Optics

- Use pluggable optical transceivers to adapt GbE for operation in access networks, MANs or WANs
  - Converts electrical signals within Ethernet switch port into optical signals
  - Could also provide measurements of optical signal power, wavelengths etc. for monitoring purposes

Source: Endace
4.2 Pluggable Optics

- **Pluggable optics for GbE**
  - **Gigabit Interface Converters (GBICs)**
    - Plug-and-play
    - Hot-swappable
    - About 3cm width
  - **Small Form-factor Pluggable (SFP)**
    - Plug-and-play
    - Hot-swappable
    - Width about 13 mm ⇒ better port density
    - Just wider than RJ-45 connector

Source: Extreme Networks, Asante
Source: Finisar
4.2 Pluggable Optics

- Pluggable optics for 10GbE
  - 10G Small Form-factor Pluggable (XFP)
  - XENPAK
  - X2
  - XPAK

Evolution of 10GbE pluggable transceivers (Source: FiberSystems Europe)
5. Storage Area Networks (SAN)

- Enterprises, Government agencies and public sector organizations
  - Discarding paper in favour of electronic data
  - Migrating some of their main business operations (customer care, billing, e-filing etc.) online
  - 24hr × 365days availability requirement for data and applications
    - Always open web storefront, outsourced care, globalization
5. Storage Area Networks (SAN)

- Disaster recovery planning to rescue or recover mission-critical data is now absolutely essential
  - **Example 1**: 93% of companies that had data outage for 10 days or more filed for bankruptcy within a year (Source: US National Archives and Records...)
  
  - **Example 2**: Basel II Accords (June 2004) providing international standardized measure of banks credit rating ⇒ data-backup strategy one of the considered factors
  
  - **Example 3**: Average revenue loss per hour caused by data unavailability for different business types:
    - €53,300/hr for tele-ticket sales
    - €5m/hr for brokerage operations (Source: Dataquest)
5.1 SAN Architecture

- Previously data exchange and backup confined to enterprise LAN (likely in the same building)
  - Traffic **congestion** commonplace
  - **No redundancy** by directly attaching storage devices to LAN servers
  - Little or nothing to recover if disaster hits the enterprise’s site

![Diagram of SAN Architecture]

Directly or network attached storage devices
5.1 SAN Architecture

- **LAN-free** backup using SANs necessary
  - Dedicated *high speed links* for data recovery
  - *Shared storage* ⇒ reduced cost
  - Storage capacity and resources can be added *without shutting down* LAN servers or networks
  - Could employ two (primary and secondary) data centers for increased redundancy

Storage area networks (SANs)
5.1 SAN Architecture

- Now fashionable to move SANs to very distant locations from enterprise sites
  - Secondary data centers 10s or 100s km from enterprise site
  - Provides more resilience against disasters e.g. earthquakes
  - Allows company to locate large peripherals in cheaper suburban areas

Hurricane Katrina, 2005  Kobe Earthquake, 1995
5.2 SAN Standards

- SAN data rates (usually expressed in **Bytes/second**) should be easily scalable for future growth
  - Amount of electronically stored data growing at a rate of 40%-80% per year
  - Data from remote storage site should appear like it's coming from a local source

- Storage connectivity earlier used copper links
  - Insufficient capacity and unreliable

- Now mostly use high capacity optical systems
  - Fiber links (multimode and singlemode)
  - Low cost optical components e.g. LEDs, multilongitudinal mode (MLM) lasers, GBICs etc.
  - SDH/SONET, GbE/10GbE, DWDM or CWDM transmission
### 5.2 SAN Standards

Various optical SAN proprietary technologies and standards exist

<table>
<thead>
<tr>
<th>Technology</th>
<th>Developer / date</th>
<th>Profile</th>
<th>Max. Rate (MByte/s)</th>
<th>Physical Interface</th>
</tr>
</thead>
</table>
| **ESCON: Enterprise Systems Connection** | IBM/ 1980s       | • Serial interface, half duplex  
• I/O switches capable of providing dynamic connectivity for up to 60 fiber optic links   | 17                  | LED/MMF, MLM/SMF   |
| **HIPPI: HIgh Performance Parallel Interface** | ANSI/ 1980s      | • Widely deployed in supercomputer installations  
• Uses switches like ESCON                                                                                                                   | 200                 | MLM/SMF            |
| **FC: Fiber Channel**       | ANSI/ Early 1990s | • Initially used for supercomputers, now a popular SAN standard  
• Deployed in point-to-point, arbitrated loop and switched topologies  
• Runs other protocols e.g. HIPPI, ESCON  
• FC over TCP/IP (FCIP) and internet FC protocol (iFCP) allows FC to use IP networks and routers | 800  
2400 (not backward compatible) | MLM/SMF            |
| **FICON: Fiber Connection** | IBM              | • Takes the ESCON protocol and maps it onto FC transport  
• Improves ESCON by increasing distance, rates, concurrent connections etc.                                                                | 400                 | MLM/SMF            |
| **iSCSI: Internet Small Computer System Interface** | IETF/ 2003       | • SCSI protocol popular storage access protocol  
• iSCSI is SCSI protocol over a TCP/IP network  
• Main competitor of the FC protocol                                                                                                         | IP network capacity limit | Installed fiber base |
5.2 SAN Standards

Example: Time to recovery 60 terabytes ($60 \times 10^3$ GB) of data across a metro area

- Using STM-1 connection ⇒ 49 days
- Using ESCON connection ⇒ 45 days
- Using 200 MB/s FC connection ⇒ 8 days
- Using 400 MB/s FC over 64 wavelength channel DWDM system ⇒ 1.5 hours

If recovery durations longer than several days

- May be better to use PTAM or “Pick-up truck access method”
- Manually transport storage devices from data center
5.2 SAN Standards

- Enterprise IT departments decision making on SAN solutions
  - **Recovery Time Objective** ⇒ how long an enterprise can wait before systems are recovered, resynchronized and back in service
  - **Recovery Point Objective** ⇒ amount of data an enterprise can afford to have lost once operations are restored

### Storage Services: Something for Everyone

<table>
<thead>
<tr>
<th>Service</th>
<th>RTO</th>
<th>RPO</th>
<th>Number of sites</th>
<th>Storage/server</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business</td>
<td>zero to</td>
<td>zero to</td>
<td>2 to 3</td>
<td>server clusters with synchronous disk mirroring and</td>
<td>DWDM/CWDM</td>
</tr>
<tr>
<td>continuity</td>
<td>minutes</td>
<td>minutes</td>
<td></td>
<td>stand-by servers</td>
<td></td>
</tr>
<tr>
<td>Fast data</td>
<td>hours</td>
<td>minutes</td>
<td>1 to 2</td>
<td>synchronous disk mirroring and stand-by servers</td>
<td>DWDM/CWDM</td>
</tr>
<tr>
<td>recovery</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fibre Channel over IP</td>
</tr>
<tr>
<td>Slow disaster</td>
<td>day</td>
<td>hours</td>
<td>1 to 2</td>
<td>asynchronous disk mirroring or electronic tape</td>
<td>CWDM</td>
</tr>
<tr>
<td>recovery</td>
<td></td>
<td></td>
<td></td>
<td>vaulting</td>
<td>Fibre Channel over IP</td>
</tr>
<tr>
<td>Off-site backup</td>
<td>day(s)</td>
<td>day(s)</td>
<td>1 to 2</td>
<td>tape and “safe”</td>
<td>PTAM (Pick-up truck access method)</td>
</tr>
</tbody>
</table>

Source: FibreSystems Europe
6. Next Generation SDH/SONET

- Conventional SDH/SONET has several limitations
  - Traffic carried in streams with fixed speeds (e.g. STM-16, E4 etc.)
  - Lack of built in capability to dynamically alter speed of streams according to usage
- SDH/SONET originally designed for circuit-switched voice traffic
  - Unsuitable for asynchronous packet-switched bursty data traffic
  - Four-fold capacity increase increments (e.g. from STM-1 to STM-4) ⇒ Inflexible provision of capacity to users
- Facing competition from data-centric standards (e.g. Ethernet)
6. Next Generation SDH/SONET

- Carrier choices
  - Invest in a new parallel data-centric network infrastructure?
  - ...or maximize reuse of existing SDH/SONET networks
    - Tried and tested
    - Excellent management features
    - Resilient design configurations (e.g. SNCP rings)
    - Reduce capital expenditure
    - Extending network’s lifespan
6. Next Generation SDH/SONET

- Upgrade current systems with next-generation SDH/SONET (NG-SDH) solutions
  - Virtual Concatenation (ITU-T G.7043)
  - Link Capacity Adjustment Scheme (ITU-T G.7042)
  - Generic Framing Procedure (ITU-T G.7041)

- These upgrades only needed at source and destination terminal equipment of required service
  - Intermediate equipment do not need to be aware and can interoperate with upgraded equipment
  - Enables operator to make only partial network upgrades on as-needed basis
6.1 Virtual Concatenation (VCAT)

- Fixed and contiguous rates leads to waste of bandwidth
  - Example: Mapping 1 GbE (1 Gbit/s) to VC-4-16c payload of an STM-16c (2.5 Gbit/s) frame

```
  1 GbE
  Mapping
  SOH  VC-4-16c payload

[Diagram of SOH, VC-4-16c payload, and 58% bandwidth wasted]
```

```
270 x 16 Bytes
261 x 16 Bytes
9 Rows
```

```
RSOH
MSOH Pointer
SOH
POH
```

```
VC-4-16c
```
6.1 Virtual Concatenation (VCAT)

- VCAT ⇒ improve bandwidth efficiency by fragmenting streams and placing in many smaller containers
  - Example: Mapping 1 GbE to payload of seven basic VC-4 containers

![Diagram showing VCAT process]

Virtual Concatenated Group (VCG)

[v] added to indicate that this is a VCG
6.1 Virtual Concatenation (VCAT)

- **Low-order (LO) VCGs** for low-speed applications e.g. network edges
- **High-order (HO) VCGs** for higher-speed applications e.g. core networks

<table>
<thead>
<tr>
<th>SDH VCAT type</th>
<th>Component Signal</th>
<th>X range</th>
<th>Capacity (kb/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC-11-Xv</td>
<td>VC-11</td>
<td>1 to 64</td>
<td>1600 to 102 400</td>
</tr>
<tr>
<td>VC-12-Xv</td>
<td>VC-12</td>
<td>1 to 64</td>
<td>2176 to 139 264</td>
</tr>
<tr>
<td>VC-2-Xv</td>
<td>VC-2</td>
<td>1 to 64</td>
<td>6784 to 434 176</td>
</tr>
<tr>
<td>VC-3-Xv</td>
<td>VC-3</td>
<td>1 to 256</td>
<td>48 348 to 12.5 Gb/s</td>
</tr>
<tr>
<td>VC-4-Xv</td>
<td>VC-4</td>
<td>1 to 256</td>
<td>149 760 to 38.3 Gb/s</td>
</tr>
</tbody>
</table>


e.g. X=16 for 25 Mbit/s ATM

e.g. X=5 for 10 Mbit/s Ethernet

e.g. X=4 for 200 MB/s ESCON

e.g. X=7 for GbE
6.1 Virtual Concatenation (VCAT)

- VCG members routed and transported independently over SDH network
  - VCG recombined at destination VCG receiver
  - If a link fails only a fraction of the VCG is lost
6.2 Link Capacity Adjustment Scheme (LCAS)

- LCAS \(\Rightarrow\) Enable increase and decrease VCG capacity on increments of member container bandwidths
  - Without affecting or taking down the entire VCG service (hitless)
  - Once a VCG is defined, the source and destination (sink) equipment are responsible for agreeing which members will carry traffic

1. **Normal operation [VC-4-4v]**

2. **Requests sent for 2 more VC-4s [VC-4-4v]**

3. **Updated bandwidth [VC-4-6v]**
6.2 Link Capacity Adjustment Scheme (LCAS)

- Capacity control is **unidirectional**
  - Forward LCAS VCG capacity can differ to that of the reverse direction
  - Both can change without coordination

- Note that VCAT can be used without LCAS, but LCAS only possible with VCGs therefore requires VCAT
6.2 Link Capacity Adjustment Scheme (LCAS)

- LCAS flexibility has several practical benefits
  - Allows bandwidth-on-demand provisioning
    - Time-of-day demands
    - Special events
    - Pay-as-you-grow
    - Introducing new service granularities
  - Enables removal of failed VCG members and eventual member reinstatement without affecting services
  - Could be used to enhance other functions
    - Load-sharing
    - Congestion-avoidance
    - QoS differentiation
6.3 Generic Framing Procedure (GFP)

- GFP provides mechanism for mapping packet and circuit-switched data traffic to SDH frames
  - Traffic mapped onto general purpose GFP frames
  - GFP frames then mapped to SDH VCs
  - Only needed at source and destination equipment

GbE, ATM, Fiber channel, IP, digital video broadcast etc.

```
Mapping
         GFP frame
         Mapping
SOH       VC-N payload
```
### 6.3 Generic Framing Procedure (GFP)

GFP defines **different length frames and different client-specific frame types** for payload and management.

<table>
<thead>
<tr>
<th>Core Header (bytes)</th>
<th>Payload Area (bytes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>X = 0-60</td>
<td>0 to (65531 – X)</td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PLI</th>
<th>cHEC</th>
<th>Type</th>
<th>tHEC</th>
<th>GEH</th>
<th>Client payload information field (fixed or variable length)</th>
<th>Optional pFCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload length indicator</td>
<td>Core header error checking</td>
<td>Payload type</td>
<td>Type header error checking</td>
<td>GFP extension headers</td>
<td>Payload</td>
<td>Payload frame check sequence</td>
</tr>
</tbody>
</table>

**Byte Transmission Order**

0 to (65531 – X)
6.3 Generic Framing Procedure (GFP)

- GFP specification allows 2 different transport modes
  - The **frame-mapped GFP** (GFP-F): optimized for framing variable length packets (e.g. Ethernet, IP/MPLS)
    - Whole data frames mapped in its entirety
    - Variable GFP frame length depending on client packet or frame size
  - The **transparent-mapped GFP** (GFP-T): optimized for services that require bandwidth efficiency and are delay sensitive (e.g. DVB)
    - Data mapped byte by byte
    - May span multiple GFP frames
    - Fixed length GFP frame
6.3 Generic Framing Procedure (GFP)

- Example ways of transporting IP packets over optical (WDM) networks

Diagram:

- IP
  - 10GbE, AAL5(ATM), PDH
  - PPP/HDLC, PoS
  - 10GbE, GbE, Ethernet
  - DVB, Fiber Channel, ESCON
    - Frame-Mapped GFP
    - Transparent-Mapped GFP
  - SDH/NG-SDH
    - Optical (WDM)
7. Optical Transport Network (OTN)

- DWDM has significantly increased fiber capacity for SDH
  - But also introduced new network elements (e.g. wavelength MUX/DEMUX) that require monitoring to ensure reliability
  - SDH monitoring and management only available for SDH sublayers

![Diagram of Optical Transport Network](image-url)
7. Optical Transport Network (OTN)

- OTN ⇒ a relatively new standard (ITU-T G.709, G.872)
  - Truly global standard unlike SDH/SONET
  - Enables SDH-like Operations, Administration, Maintenance and Provisioning for WDM networks
    - Reduces the requirement to run every service through SDH/SONET to benefit from the management features
  - More efficient multiplexing, provisioning, and switching of high-bandwidth (≥ 2.5 Gbit/s) services
  - Improved multivendor and inter-carrier interoperability
  - Forward error correction (FEC) from the beginning
  - Less complex than NG-SDH ⇒ easier to manage
7.1 OTN Framing and Multiplexing

Optical Payload Unit (OPU)

OPU OH for identifying and mapping client signals adaptation

Optical Data Unit (ODU)

ODU OH for end-to-end path supervision, TCM

Optical Transport Unit (OTU) or Digital Wrapper

FA: Frame Alignment, FEC: Forward Error Correction  RS(255,239)
7.1 OTN Framing and Multiplexing

- OTU frame size is fixed but duration changes with order k where k=1, 2 or 3
  - In SDH, STM-N frame duration fixed (125 µs due to legacy 8 kHz digital voice sampling rate) but size varies with N

**Figure**: Dimensions of an k order OTU frame (OTU-k)

**Figure**: STM-N frame structure
7.1 OTN Framing and Multiplexing

Table: Date rates and durations for standardized k order ODU and OTU frames

<table>
<thead>
<tr>
<th>ODU-k</th>
<th>Data rate</th>
<th>OTU-k</th>
<th>Data rate</th>
<th>Order</th>
<th>Duration (µs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODU-1</td>
<td>2.5 Gb/s</td>
<td>OTU-1</td>
<td>2.67 Gb/s</td>
<td>k=1</td>
<td>48.971</td>
</tr>
<tr>
<td>ODU-2</td>
<td>10 Gb/s</td>
<td>OTU-2</td>
<td>10.7 Gb/s</td>
<td>k=2</td>
<td>12.191</td>
</tr>
<tr>
<td>ODU-3</td>
<td>40 Gb/s</td>
<td>OTU-3</td>
<td>43 Gb/s</td>
<td>k=3</td>
<td>3.035</td>
</tr>
</tbody>
</table>

- Low k order ODU frames interleaved to form higher order frames

Example: $4 \times$ ODU-1 $\Rightarrow$ $1 \times$ ODU-2 $\Rightarrow$ $1 \times$ OTU-2
7.1 OTN Framing and Multiplexing

- Virtual concatenation also available for OTN
  - Realized by concatenating OPUk frames into OPUk-Xv groups
  - Enables very flexible support of line rates $\geq 2.5$ Gbit/s
  - Rates over 10 Tbit/s possible (OPU3-256v) for future!

<table>
<thead>
<tr>
<th>OTN VCAT type</th>
<th>Component signal</th>
<th>X range</th>
<th>Capacity (kb/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPU1-Xv</td>
<td>OPU1</td>
<td>1 to 256</td>
<td>2,488,320 to 637,009,920</td>
</tr>
<tr>
<td>OPU2-Xv</td>
<td>OPU2</td>
<td>1 to 256</td>
<td>“9,995,277 to “2,558,709,902</td>
</tr>
<tr>
<td>OPU3-Xv</td>
<td>OPU3</td>
<td>1 to 256</td>
<td>“40,150,519 to “10,278,532,946</td>
</tr>
</tbody>
</table>

**TABLE 3.** OTN component and VCAT signals.

7.2 Optical Channel (OCh)

- OTU-k is an electric signal $\Rightarrow$ converted to an optical channel (OCh) signal for fiber transmission
  - OCh transports an OTU-k between electronic transponders in an OTN
  - OCh overhead transported on an out-of-band wavelength channel $\Rightarrow$ optical supervisory channel (OSC)

- $n$ distinct OCh carriers (OCC) of bit rate index $m$ can be multiplexed (using WDM) to form an OCC group (OCG-$n.m$) to share a common fiber

**Figure**: Block diagram of OTN transmitter
7.2 Optical Channel (OCh)

Optical Transport Hierarchy (OTH)

Digital (electrical)

Optical

Client PDU

OPUk OH

OCh Payload Unit (OPUk)

OCh Data Unit (ODUk)

OPUk OH

OCh Transport Unit (OTUk)

FEC

Optical Channel Layer

OCh Carrier (OCC)

OCh Carrier Group (OCG-n.m)

Optical Transport Module (OTM-n.m)
8. Multiservice Platforms

- Optical network operators now faced with a difficult choices to make among a multitude of standards
- How to build new networks or evolve existing network?
  - NG-SDH
  - Ethernet
  - OTN
  - IP/MPLS
  - CWDM or DWDM
  - etc.
8. Multiservice Platforms

- Multiservice provisioning platform (MSPP)
  - Multiservice provisioning using NG-SDH features
  - Diverse optical and electrical interfaces (GbE, SAN, IP, OTN etc.)
  - Support for CWDM or DWDM transmission

![Multifunctional tool]

*Major Technologies Used in MSPPs*

- Sonet/SDH
- Gigabit Ethernet
- Sonet/SDH Virtual Concatenation
- DWDM
- Sonet Link Capacity Adjustment Scheme (LCAS)
- MPLS
- IP
- Packet Ring (RPR or other)
- CWDM
- 10-Gigabit Ethernet

*Source: Heavy Reading*
8. Multiservice Platforms

**Figure**: Example service mix supported by deployment of MSPPs

- **MSPP**: Multiservice Provisioning Platform
- **PBX**: Private Branch Exchange
- **MPLS**: Multiprotocol Label Switching
- **ATM**: Asynchronous Transfer Protocol
- **MSC**: Mobile Switching Center
- **BSC**: Base Station Controller
- **NIU**
- **PDH**: Pulse-Digitized Hierarchy
- **FC, FICON, iSCI**
- **Public WiFi**
- **2G/3G/WiMAX**
- **Wireless local loop**
- **Metro Access / Edge**
- **Storage Center**

**Network Protocols and Services**

- **IP/MPLS**
- **10/100/1000 Mbit/s Ethernet**
- **ATM**
8. Multiservice Platforms

Example MSPP: Cisco ONS 15454

Cisco ONS 15454
8. Multiservice Platforms

- Supported interfaces
  - Electrical (DS1, E1, E3, STM-1E etc.)
  - SDH (up to STM-64)
  - CWDM and DWDM (OTN)
  - Ethernet (up to GbE)
  - SAN (Fiber Channel and FICON)
  - Video (D1 video, HDTV)

- Cross-connection levels
  - DS1/E1 up to STM-64

Cisco ONS 15454
Conclusions

 This week
   Discussed various client layers (PDH, IP, SDH etc)
   Multiservice provision capabilities are crucial for operators
   OTN standards expected to play significant part in the future

 Next lecture
   WDM network elements, design, management etc.
Thank You!