Course: TCET 4102 Fiber-optic communications

Module 12: Optical networks - Power budget, GMPLS, protocols and standards

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Spring 2008
Module 12: Optical networks – power budget, GMPLS and protocols and standards

• Module outline:
  – Power budget of a fiber-optic communications link
  – Optical networks: Architecture and protocols
    • Architectures
      – The Internet and optical networks
      – Generalized multiprotocol label switching, GMPLS
      – Core and edge networks
      – Control plane and data plane
      – Overlay and peer models of control plane
    • Layered architecture of transport networks
  – Protocols and standards
    • Standardization organizations
    • Development of control plane standards


Notes:
  ➢ The figure numbers in these modules are the same as in the textbook. New figures are not numbered.
  ➢ Always see examples in the textbook

Key words
• Power budget and time budget
• IP over optical networks
• Generalized multiprotocol label switching, GMPLS
• Core and edge networks
• Control plane and data plane
• Layered architecture of transport networks
• Protocols and standards
• ITU-T, IETF and OIF
• ASTN – Automatically Switched Transport Network
• ASON - Automatically Switched Optical Network
• OTN – Optical Transport Network
Power budget

- A fiber-optic network is the most widespread network in the world and it continues to grow. The hottest area of growth for fiber-optic-network installations is optical access networks, specifically, PONs, as discussed in Module 11.

- One of the most important problems in installation of optical networks is their design. Design is always more art than technique; however, some general recommendations can be provided. Also, regardless the type of optical network—long-haul, metro-or access—there are several points that are common to design of this networks.

- The first step in designing an optical network is considering their physical layers. Physical layout of fiber cables, the types of cables, the types of fibers, the types of connectorization, and the hardware --making the right decisions from among all these choices is the subject of this design.

- From a logical standpoint, design is the first step in network installation, but the designer has to be familiar as well with installation systems and components. It is not our intention to make you a professional network designer; rather, our purpose here is to give you, a future professional user of these systems, some insight into the area of design.

- It should be noted that there are some standards and recommendations that help a designer in his or her work. For example, at the outset that Regulation TIA/EIA 568A, the “Commercial Building Telecommunications Cabling Standard,” is widely accepted as the industry standard for LAN installation. We’ll refer often to this standard in this section. To start with, TIA/EIA 568A accepts only two types of fiber -- 62.5/125 μm graded-index multimode and a singlemode -- as standard transmission media for local-area networks.
Power budget

• Link consideration -- power budget and rise- time budget (bandwidth)
• **Power budget**
  
  Physically, a network is a collection of nodes connected by links. Let’s consider an individual fiber link that may include splices, connectors, and some other passive components. Because of the attenuation introduced by these components, a receiver gets much less light power than was transmitted to it. The question is this: Does the light signal arriving at the destination point of a link have enough power to be detected by the receiver? This is what power budget is about. Fig. 8.21 demonstrates the concept: *Power- budget consideration allows us to calculate power at the receiving end and know the loss allocations along the link.*

  - An example shown in the graph in Fig. 8.21 illustrates the power-budget concept: The power-vs.-distance curve shows the light power at each point along the fiber link. When a transmitter radiates a light signal with the power of $-10 \text{ dBm}$ (0.1 mW), this is called initial power. A connector coupling light from a transmitter to a fiber causes an 0.2 dB attenuation; hence, notice the first decline in this curve. A patch-cord cable has an attenuation of 1.0 dB/km for 62.5 fiber at 1310 nm. This is the negative slope of the curve. Thus, after traveling 10 m, light attenuation is 1.0 dB/km x 0.01 km = 0.01 dB. At this point, a patch panel is used. The typical loss of a PC connector is 0.3 dB; hence, the curve drops at this loss level. From the patch panel, a regular fiber cable is used whose attenuation is 1.0 dB/km. Thus, the curve develops with a slope of -1.0 dB/km along the transmission distance. From the patch panel to the nearest fusion splicing point, the cable’s loss is 1.0 dB/km x 0.49 km = 0.49 dB. The attenuation introduced by fusion splicing is typically 0.2 dB; thus, the appropriate curve drop is shown in Fig. 8.21. As you continue to go along the link, you need to take into account all sources of attenuation with respect to their locations. This is shown in Fig. 8.21, and an analysis of this figure will help you understand this idea.

  - *(You should recall the three basic terms used here: light power is measured in dBm and it is mostly less than 1 mW; hence, it is negative; loss is measured in dB as the difference between two dBm values of light power; attenuation is measured in dB/km as loss per distance and it is positive by convention.)*
Power budget

Figure 8.21  Power budget.
Power budget

Power-budget calculation can be made as follows:

- Cable loss 1.0 dB/km x 2.0 km = ..........2.0 dB
- Splicing loss
  - Fusion 0.2 dB x 2 = 0.4 dB
  - Mechanical = 0.3 dB
  Total splicing loss =........0.7 dB
- Connector loss
  - 0.3 dB x 2 = 0.6 dB
  - 0.2 dB x 2 = 0.4 dB
  Total connector loss =........1.0 dB

  - Total loss =.................................................    3.7 dB
  - Transmitter power launched into a fiber, Pin = -10 dBm
  - Power at the receiving end, Pout = Pin - total loss =..............-13.7 dBm
  - Receiver sensitivity, Prec =-20 dBm
  - Power margin = Pout - P_RS = ................................................. 6.3 dB

Again, these calculations introduce the idea how power budget works for network design. It allows you to calculate the maximum distance you can achieve with a given fiber cable and the number of splices and connectors you can afford to run along your link. The loss allocation shown in Fig. 8.21 helps you to find critical points and achieve a better design.

*The first piece of advice for a designer: Always keep reasonable power margins because your network will grow; therefore, you’ll need to connect new users and include new components, steps that are accompanied by power loss.*
Example:

Problem: A fiber-optic communications link includes five splices at 0.02 dB/splice, four connectors at 0.2 dB/connector, transmitter power of -10 dBm, and receiver sensitivity of -25 dBm. What is the maximum transmission distance of this link if a singlemode fiber cable with attenuation of 0.3 dB/km is used?

Solution: If we analyze the power-budget calculations given previously, we can readily write the following formulas:

\[
\text{Total loss (dB)} = \text{Pout (dBm)} - \text{Pin (dBm)}, \text{ where Pin} = \text{Prs.}
\]

On the other hand,

\[
\text{Total loss (dB)} = \text{Fiber loss (dB)} + \text{Component loss (dB)}
\]

Since we need to find a distance, we need to isolate the fiber loss, which is the only member of these equations that contain distance as a parameter. Hence,

\[
\text{Fiber loss (dB)} = \text{Total loss (dB)} - \text{Component loss (dB)}
\]

Now the maximum length of a fiber-optic link can be compute as

\[
\text{Maximum transmission distance (reach)} = \frac{-\text{Fiber loss (dB)}}{\text{Attenuation (dB/km)}}.
\]

Let’s plug the given numbers into this formulas:

\[
\text{Pin} = -10 \text{ dBm} \text{ and Pin} = \text{Prs} = -25 \text{ dBm}.
\]

Therefore,

\[
\text{Total loss} = -25 \text{ (dBm)} - (-10 \text{ (dBm)}) = -15 \text{ dB}.
\]

Component loss = 5 x -0.02 dB + 4 x -0.2 dB = -0.9 dB.

Thus,

\[
\text{Fiber loss} = -15 \text{ dB} - (-0.9 \text{ (dB)}) = -14.1 \text{ dB}.
\]

Finally,

\[
\text{Maximum transmission distance (reach)} = \frac{-14.1 \text{ dB}}{0.3 \text{ dB/km}} = 47 \text{ km}.
\]
As optical communications has migrated from point-to-point links to optical networks, switching and routing problems.

- one approach: optical packet switching

Optical networks
Architectures and protocols

Data packets
O/E conversion
Electronic packet switching
Optical packet switching
Optical (fiber/lambda) circuit switching
Internet

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TCET4102, Module 12, Spring 2008
Optical networks
Architectures and protocols

• **Internet today and tomorrow:** Delivering traffic occurs in the optical domain, while processing the signals mostly takes place in electronic domain:

• There are optical switches that provide circuit-switching operations, including fiber switching and lambda switching ➔ not efficient way to deliver the Internet traffic;

• Delivering Internet traffic requires routing packets, which is done by electronics ➔ O/E/O conversions ➔ costly and slow ➔ the strong need for optical processing:
  – There is a lot of research aimed at developing optical packet-switching technology, but there is no commercially available technology.

• Another emerging approach is using labels for data transport through an optical core transport, thus leaving electronic processing to the edge IP routers.
Optical networks
Architectures and protocols

Label-based approach to delivering the Internet traffic.

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Overview of optical networks
Architectures and protocols: Protocols and standards

GMPLS – how it works (after [31], [35], [36]).

Data

IP router/MPLS

Internet

Optical core

Labels over packet headers
⇒ Label switched path (LSP)

Generalized labels
⇒ Generalized LSP

O/E conversion

Internet

IP router/MPLS

Optical core

Labels over packet headers
⇒ Label switched path (LSP)

Generalized labels
⇒ Generalized LSP

Data
Overview of optical networks
Architectures and protocols: Protocols and standards

GMPLS – how it works (after [31], [35], [36]).

GMPLS main features:
• It extends the MPLS concept of label switching;
• It allows for switching Layer 0 (WDM), Layer 1 (SONET/SDH), Layer 2 (ATM) and Layer 3 (IP) traffic;
• It allows for automatic provisioning bi-directional optical path through a core network;
• GMPLS nodes can operate with links with one or more of the following switching capabilities: fiber-switched capable (FSC), lambda-switched capable (LSC), TDM-switched capable (TSC), and packet-switched capable (PSC);
• GMPLS is based on extension of signaling (RSVP-TE and CR-LDP) and routing (OSPF-TE and ISIS-TE) protocols. New LMP protocol has been introduced.
• It provides separation data and control planes, which makes data plane protocol independent;
• GMPLS is still draft (final!); however, there are commercially available products.
Optical networks
Architectures and protocols

• The state of the field today can be considered evolutionary.
• Optical networks have become the main transport “facilities” for all telecommunications traffic (from ultra-long-haul to local transmissions, where the “last mile” problem is being resolved by installation of PON).
• The shift in the paradigm of optical transmission from a simply “piping” function to performing the logical upper-layer function.
• Packet routing is still done in the electronic domain.
• Optical packet switching (OPS), optical burst switching (OBS) and optical label switching (OLS) approaches are emerging.
• All these developments and research efforts are quickly melding into new cutting-edge technology that we should see being implemented commercially.
Optical networks
Architectures and protocols

Core and edge networks

End user

Core network

Edge

End user

End user

End user

End user
• Core network transmits traffic from edge to edge.
• Edge networks prepare traffic for transmission; e.g., mapping T1 and T3 traffic into SONET frames from one user while wrapping ATM traffic into SONET format from the other.
• Thus, the function of a core network is transport traffic from edge to edge while the function of a core network is to aggregate traffic from end users for core transmission.
• Core-edge classification can be applied to the networks of any scale: long-haul, metro, and access.
Optical networks include transport network, control plane, and client networks. Clients are edge IP/MPLS networks while transport are core WDM networks. Client networks request for services and transport networks provide these services in form of fixed bandwidth (lightpaths). Control plane is responsible for signaling and routing, that is, enables transport core to deliver traffic. (See next slide.)
Overview of optical networks

Architectures and protocols: Architectures

Optical transport network (OTN) needs a well-defined control plane that can handle various service requirements. Therefore, development of control plane is a critical issue toward building the intelligent optical networks.

Control and data planes of an individual network node are presented in the next slide.
Overview of optical networks
Architectures and protocols: Architectures

Control plane and data plane: Separation of control and transport functions

Control plane and data plane: Separation of control and transport functions
Overview of optical networks

Architectures and protocols: Architectures

Control plane and data plane (continued)

General remarks:

**Control plane**: A set of software and/or hardware residing in a network node that execute control and management functions. Implementation of control plane depends on protocols. An example of hardware is a router, such as label edge router, LER, or label switched router, LSR, for GMPLS control plane. Examples of control plane protocols include signaling system seven (SS7) protocol stack in voice transmission, open shortest path first (OSPF) routing protocol in data transmission and generalized multiprotocol label switching (GMPLS) protocol.

**Data (information, or forwarding) plane**: A set of hardware and software that provides transportation of voice, data, and video traffic. An example of hardware is an OXC and an example of protocols is IP suite.
Control plane and data plane (continued)

General remarks

Control and data plane interaction: Control plane at a node generates routing and label tables and exchange this information with peers. This information is used by data (forwarding in IP routers) plane for transportation [19]. In other words, control plane protocols (OSPF and others) enable IP to forward traffic correctly [15]. Separation of control and data planes makes data plane protocol-independent. Today, control plane interact with data (forwarding) plane through open interface, which constitute the third (current) generation of the network element architecture [19].
Overview of optical networks
Architectures and protocols: Architectures

Control plane and data plane (continued)

Control domain 1

Control domain 2

Subnetwork 1

Subnetwork 2

NNI – network-network interface

NNI
Overview of optical networks
Architectures and protocols: Architectures

Control plane and data plane (continued)

Control plane - a general view: Control planes residing in nodes of any given subnetwork make up a control domain of this subnetwork. Control planes enable traffic transportation within and between their subnetworks.

The main functions of an optical control plane are targeted solving the problem of ”find, route, and connect,” which requires the follows [17], [18]:

• Naming and addressing scheme (find)
• A routing process to handle the network resources usage and route calculation (route), including routing and wavelength assignment (RWA) and topology and resources discovery
• A signaling network that provides communication between entities requesting services and those provision these services
• A signaling protocol for the setup, maintenance, and tear down of optical trails, including lightpath signaling and maintenance

In addition, control plane has to support network survivability based on fault monitoring and protection and restoration.
Control plane and data plane (continued)

**UNI and NNI: Definition and Placement**

- **Switched Connection**: initiated by clients over UNI interface
- **Soft Permanent Connection (SPC)**: initiated by management agent

**Definitions**
- **UNI**: User to Network Interface
- **NNI**: Network to Network Interface

Source: [21]
Control plane and data plane (continued)

Control plane – UNI and NNI: Control domains of different subnetworks of transport network communicate through network-to-network (NNI) interface, while client networks get access to the transport network through user-to network (UNI) interface. When GMPLS is used, NNI provides interface between two network-side label-switched routers (LSRs).

UNI are subdivided into client UNI (UNI-C) and network UNI (UNI-N) interfaces. UNI-C provides a signaling termination function, whereas UNI-N provides pass-through and internetworking function, circuit routing, and reachability information. They communicate to one another in IP packets. When GMPLS is used, UNI provides interface between edge GMPLS node and network-side LSR [20].
Overview of optical networks
Architectures and protocols: Architectures

Control plane and data plane (continued)

Development of an User-Network Interface (UNI) by the Optical Internetworking Forum (OIF) [22]:

- UNI enables client user devices to dynamically request services from the optical transport network
- Client devices include IP routers, ATM switches, SONET/SDH network elements, etc.

- Main functions of an UNI:
  - Signaling (in-fiber and out-of fiber)
  - Addressing (use a special address space do not reveal topology, resources, and addressing of the optical network to the clients)
  - Link management (used, in particular, to create, delete, and query the status of connections).

UNI/NNI interoperability was demonstrated at OFC’03 and following conferences.

- UNI determines the visibility that a client (IP router) has into the optical transport network. The service model that uses UNI concept is called overlay model.
Overview of optical networks
Architectures and protocols: Architectures

Control plane models.

**Control plane overlay model:**
Client control is independent of the optical layer \(\Rightarrow\) OTN is opaque to IP network \(\Rightarrow\) two control planes.

After [24], [25], and [26].
Control plane models

Control plane peer model: Single control for both client and optical domains $\Rightarrow$ OTN is transparent to IP network $\Rightarrow$ one control plane.

After [24], [25], and [26].
Overview of optical networks

Architectures and protocols: Architectures

Control plane and data plane (continued)

Problems in developing control planes [16], [20], [21], [22]:

• Optical control plane is **distributed** in contrast to traditional centralized plane ➔ multiplicity of control planes ➔ control planes of optical networks must be able to work with other control planes (multiple operator networks; multiple vendors; different technologies; multiple administrative domains, e.g., core-metro application) ➔ interoperability between equipment from different vendors.

• Control plane has to work with all-optical networks ➔ change in technology will require new developments in control plane.

• Control planes have to operate over disparate transport technologies (IP, ATM, SONET/SDH, and WDM). (This problem is resolved by developing unified control plane (UCP) that represents a common set of control functions and interconnection mechanisms that allow unified communication, routing, and control across all these transport technologies).

• Testing (Some platforms have been developed by Agilent Technologies).
Definition of control plane is the critical issue because this plane is responsible for routing and signaling processes in optical networks. In other words, it is a control plane that adds intelligence to the optical networks.

- There are two main approaches to control plane definition: GMPLS based (widely accepted) and PNNI based (proposed [25],[26]).

  (GMPLS – generalized multiprotocol label switching. ; PNNI – private network-network interface, the control plane developed and widely used in ATM networks.)

- Development of GMPLS-based control plane interacts with the development of ASON-based optical network architecture. [30] (ASON – automatic switched optical network.)
Overview of optical networks
Architectures and protocols: Architectures

Layered architecture of optical transport networks

• Yesterday and today:
  – Initially optical fibers were used as pipes to transport large volume of traffic while all processing (intelligent) work was relegated to electronics. Thus, multiplexing, switching and routing was done in electronic domain. Optical transport was simply sets of point-to-point links.
  – Today optical networks have reached the point where the need arise for execution of all transport tasks in optical domain.
  – Now we are in transition stage.
Overview of optical networks

Architectures and protocols: Architectures

Layered architecture of optical transport networks

- **Best effort IP** → **IP**
- **QoS data** → **ATM**
- **Voice and leased line** → **SONET**

- **WDM optical layer**

**Data services**

**Bandwidth utilization and QoS**

**Transport and network resilience**

**Optical transmission capacity**

Optical networks: Typical today architecture.
Overview of optical networks

Architectures and protocols: Architectures

Layered architecture of optical transport networks – physical connections

Data

IP router

ATM switch

SONET switch

WDM network

Data

IP router

ATM switch

SONET switch

WDM network

Transport
Overview of optical networks

Architectures and protocols: Architectures

Layered architecture of optical transport networks – physical connections

Modern multi-layer network architecture is translated into physical implementation as shown in the previous slide:

Data packets from IP routers go to ATM switches; the ATM switches connect to SONET switches; and the SONET switches connect to DWDM network. Optical network transport traffic and at the destination point the reverse process takes place.

This type of data transmission is ineffective and costly because:

• Each layer has its own management and control
• Each layer is managed separately by different types of service providers
• Interfacing between layers requires manual provision.
Overview of optical networks
Architectures and protocols: Architectures

Layered architecture of optical transport networks

Best effort IP, QoS data, voice, private lines

IP/MPLS

Data services

Data transport with flexible bandwidth, QoS, and network resilience

Optical Ethernet and circuit-oriented applications

GMPLS-based intelligent optical layer

Optical networks: Architecture of today and tomorrow.

After [22], [27].
Layered architecture of optical transport networks – physical connections

As the network migrates, intermediate layers will begin to disappear:
• ATM will be eliminated by using MPLS
• SONET migrates to next-gen SONET with GMPLS
• DWDM will migrate to optical intelligent network with switching
In this architecture, data packets will be transported directly by optical layer.
Overview of optical networks
Architectures and protocols: Architectures

Layered architecture of optical transport networks – migration to next-gen network

Today

- IP
- ATM
- SONET
- WDM optical layer

Today and tomorrow

- IP/MPLS
- GMPLS-based intelligent optical layer
- MPLS
- VoIP
- GMPLS
- DWDM/CWDM

New!
Overview of optical networks
Architectures and protocols: Architectures

Layered architecture of optical transport networks – migration to next-gen network

Telecommunications technology is undergoing two significant changes (we could call them "revolutions"): rapid migration to MPLS and aggressive deployment of VoIP. VoIP is considered as a complement technology (and the future replacement) to the traditional TDM-based voice circuits.

At the same time, optical communications technology, bolstered by the relatively mature DWDM technology and the rapidly developing CWDM, is migrating from simple point-to-point "pipes" to intelligent networks. This migration is based on the development of optical control plane, where GMPLS- and ASON-based approaches are emerging to provide signaling and routing in these new networks.

All these developments constitute a new step in making optical intelligent networks a reality.
Overview of optical networks

Architectures and protocols: Architectures

Layered architecture of optical transport networks – physical connections and interfaces


Overview of optical networks

Architectures and protocols: Architectures

Layered architecture of optical transport networks

- IP router mesh
- ATM mesh
- SONET rings
- Point-to-point WDM

Topology view at the traditional multi-layer architecture
Overview of optical networks

Architectures and protocols: Architectures

Layered architecture of optical transport networks

Topology view at the emerging collapsed-layer architecture

After [22].
Overview of optical networks
Architectures and protocols: Architectures

Optical network overlay model

Optical transport network

IP network

UNI

IP network

UNI
Overview of optical networks
Architectures and protocols: Architectures

Optical network overlay model

IP edge router requests a service (for instance, a label switched path connection) from an adjacent OTN router. An optical network interconnects its core nodes to provide the requested service but doesn’t inform IP network. Thus, OTN offers high-bandwidth connectivity in the form of lightpaths. No routing or other type of information from the optical network is available to the IP networks; that is, OTN (service provider) is opaque to the the IP network (service requester). (After [28]). See also overlay model of a control plane.
Overview of optical networks

Architectures and protocols: Architectures

Optical network overlay model: individual connection with GMPLS

Two separate control planes: One in OTN and the other in the LSRs. Advantage: It is easily to deploy since transport and clients are independent. Disadvantage: data and control traffic are combined $\Rightarrow$ limited number of LSRs can participate in the network [34].
Overview of optical networks
Architectures and protocols: Architectures

Optical network peer model

IP network

IP and optical domain

Optical transport network

Modified!
IP and OTN are treated as a single integrated network. Here, an OXC is treated like another router as far as the control plane is concerned. From routing and signaling points of view there is no difference between a router-to-OXC interface and OXC-to-OXC interface. Once a lightpath is established across the OTN, it can be considered as a virtual link between edge routers. Therefore, edge IP routers are involved in optical transmission \(\Rightarrow\) OTN is transparent to IP.

After [28]).
Overview of optical networks

Architectures and protocols: Architectures

Optical network peer model: individual connections with GMPLS
Overview of optical networks
Architectures and protocols: Architectures

Optical network peer model: individual connections with GMPLS

Main features:
• Lightpath is used exclusively for data forwarding
• A control plane (signaling and routing) spans across both OTN and edge IP routers (LSRs)
• More flexible and effective than an overlay model
• Difficult to deploy because it requires interoperability between edge and core networks ➔ long-term perspective.
Overview of optical networks

Architectures and protocols: Protocols and standards

Next generation of optical networks must be able to handle a larger set of applications. This is why new networking architectures and protocols need to be developed. In this subsection we will review optical network protocols and standards. We will concentrate only on optical standardization issues, while leaving outside of our discussion generic Internet and other data-networking protocols and standards.
## Overview of optical networks

### Architectures and protocols: Protocols and standards

Standardization organizations and areas of their activities:

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<th>Organization</th>
<th>Main activity in optical networking</th>
<th>Comments</th>
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<td>Automatically Switched Optical Network (ASON), Automatically Switched Transport Network (ASTN), Optical Transport Network (OTN)</td>
<td>Architecture and framework of optical control plane and optical transport plane</td>
</tr>
<tr>
<td>IETF</td>
<td>Generalized Multiprotocol Label Switching (GMPLS), Common Control and Measurement Plane (CCAMP), IP over Optical (IPO)</td>
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<td>OIF</td>
<td>User-to-Network Interface (UNI), Network-to-Network Interface (NNI)</td>
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Overview of optical networks

Architectures and protocols: **Protocols and standards**

Standardization organizations, main areas of their activities and their relationship: (after [30].)
Overview of optical networks

Architectures and protocols: Protocols and standards

Standardization organizations and areas of their activities:

Standardization efforts in the optical networking area are concentrated today mostly on development of optical control plane standards; these standards are necessary to

1. allow next-generation optical networks to be built out of devices from a mixture of vendors and

2. they specify the minimum set of features that these devices must support [30].

Two organizations—ITU-T and IETF—are the most active in this area. Mapping between their standardization efforts are shown in the next slide.

In addition, OIF (non-profit organization with more than 300 members, including many of the world’s leading carriers and vendors) is active in the development and deployment of interoperable product and services for data switching and routing using optical networking technologies [29]. The main outcome of the OIF efforts is UNI 1.0 specification. OIF has started NNI standardization project.

IEEE is active in developing standards for optical Ethernet.
Overview of optical networks
Architectures and protocols: Protocols and standards

Development of control plane standards

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<th>ITU-T generic architectures</th>
<th>ASTN G.8070</th>
<th>OTN G.872</th>
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<td>ASON G.8080</td>
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**IETF protocols**

- GMPLS signaling functional
  - RSVP-TE and CR-LDP SDH/SONET

- GMPLS routing functional
  - OSPF-TE and IS-IS SDH/SONET

- Link management

After [29].
Overview of optical networks
Architectures and protocols: **Protocols and standards**

Legend:
- ASTN – Automatically Switched Transport Network
- ASON – Automatically Switched Optical Network
- OTN – Optical Transport Network
- CAC – Connection Admission Control
- GMPLS – Generalized Multiprotocol Label Switching
- RSVP – Resource Reservation Protocol
- TE – Traffic Engineering
- LDP – Label Distribution Protocol
- CR-LDP – constraint-based LDP
- LMP – Link Management Protocol
- OSPF – Open Shortest Path First
- IS-IS – Intermediate System-to-Intermediate-System

After [29].
Overview of optical networks
Architectures and protocols: Protocols and standards

ITU-T standardization efforts are concentrated on developing optical network architectures. The result is ASTN, which is an optical transport network architecture with the dynamic connection capabilities. This architecture includes management, control, and transport planes. Control plane architecture is determined by ASON that defines components in the optical control plane and interaction among those components. Transport plane is determined by OTN that enables optical transmission of various types of client signals through the use of Forward Error Correction (FEC) bytes. (After [28]). This architecture is shown in the following slide.
Overview of optical networks
Architectures and protocols: Protocols and standards

OCC – Optical connection controller
CCI – Connection controller interface
UNI – User-network interface
I-NNI – Interior network-network interface
E-NNI – Exterior network-network interface

aversal ASON control plane

Optical transport network

Clients:
IP, ATM, TDM, etc.

ITU-T ASTN architecture (after [28]).
Overview of optical networks

Architectures and protocols: Protocols and standards

The following communications models help to summarize discussion on standardization activities (after [31]).

- **OIF model**
  - Subnetwork 1
  - Subnetwork 2
  - IP layer
  - UNI
  - NNI

- **IETF model**
  - IP layer
  - UNI
  - GMPLS

- **ITU-T model**
  - Client
  - Subnetwork 1
  - NNI
  - UNI
  - Client

- **GMPLS model**
  - IP layer
  - UNI
  - GMPLS
  - Subnetwork 1

- **ASTN/ASON model**
  - Client
  - Subnetwork 1
  - UNI
  - NNI
  - Subnetwork 1
  - UNI
  - Client
Conclusion

- Network paradigm is shifting: While we still want from network more and more capacity (raw bandwidth), main focus has shifted to bandwidth-on-demand paradigm ("pay as you grow") -- that is, flexibility and scalability based on virtually unlimited bandwidth. Components will have to meet this new reality.

- Bottom line for network operators: Reduce cost per bit of transmitted signal and meet customer requirements!
Conclusion

• Critical issues for tomorrow’s networks:
  – Standards on optical control plane (GMPLS-based, others?)
  – Standards on transmission technology (Circuit and packet switching ➔ SONET-based protocols vs. IP-based protocols)
  – Components (more functionality, cost effective).
Conclusion

In spite of all the problems, optical communications keeps growing and continues to be the linchpin of modern telecommunications. What would we have without optical communications?
References

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