Optical Networks

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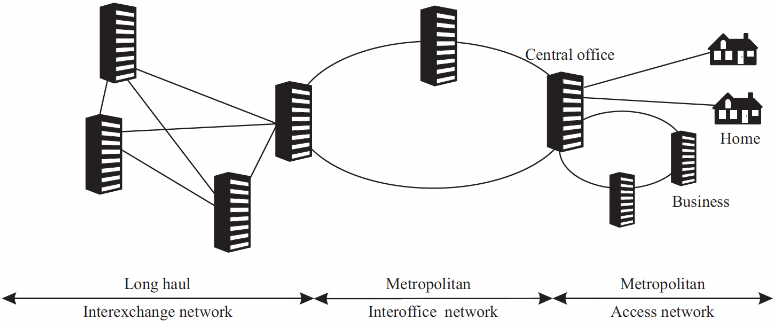
Outline

Introduction to Optical Networks

Telecommunications Network Architecture

- Transport Networks (TNs) are public infrastructures operated by service providers named *carriers*
- Carriers provide a variety of services:
  - telephone and leased line services
  - interconnect Internet Service Providers
  - provide bulk bandwidth to other carriers

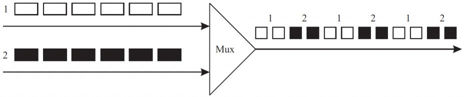


Different parts of a public network

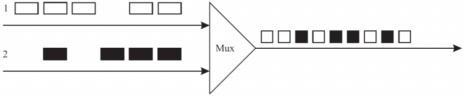
- The network can be broken up into:
  - metro network: is the part of the network that lies within a large city or a region
    - metro access network: extends from a central office out to individual businesses or homes
    - interoffice network: connects groups of central offices within a city or region
  - long-haul: network interconnects cities or different regions
- Different parts of the network may be owned and operated by different carriers
- The nodes in the network are central offices, sometimes also called points of presence (POPs)
- Links between the nodes consist of fiber pairs and, in many cases, multiple fiber pairs
  - links in the long-haul network tend to be very expensive to construct
- Two topologies are used: ring and mesh

Services, Circuit Switching, and Packet Switching

- Service can be:
  - Connection oriented: sender and receiver connect each other before communication happen
  - Connectionless: source sends messages to the receiver whenever it has something to send
- Core devices work according to one of the following switching paradigm:
  - circuit switching: static multiplexing
  - packet switching: statistical multiplexing



(a)



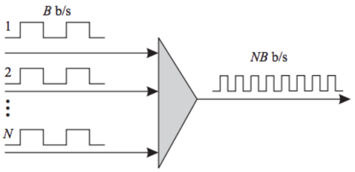
(b)

Optical Networks

- Optical Networks (ONs) can deliver bandwidth in a flexible manner where and when needed
- Optical fiber
  - offers much higher bandwidth than copper cables
  - is less susceptible to various kinds of electromagnetic interference and other undesirable effects
- Two generations of optical networks
  - First generation
    - optics essentially used for transmission and simply to provide capacity
    - switching and other intelligent network functions handled by electronics
  - Second generation
    - routing, switching, and intelligence in the optical layer

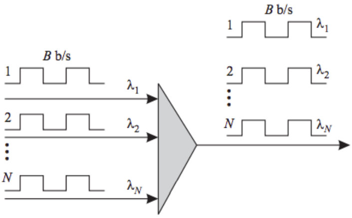
Multiplexing Techniques

- Two ways of increasing the transmission capacity on a fiber:
  - Time Division Multiplexing (TDM)
    - increase the bit rate (requires higher-speed electronics)
    - many lower-speed data streams are multiplexed into a higher-speed stream
  - Wavelength Division Multiplexing (WDM)
    - transmit data simultaneously at multiple carrier wavelengths over a fiber
    - virtual fibers



TDM or OTDM mux

(a)



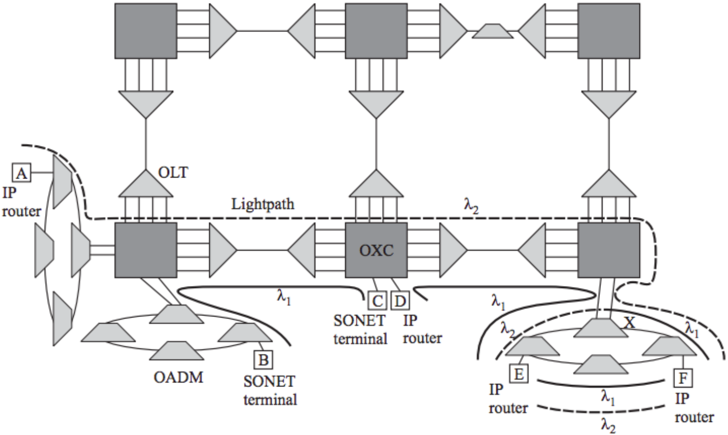
WDM mux

(b)

Second-Generation Optical Networks

- Also known as wavelength routed networks
- Main idea
  - incorporate some of the switching and routing functions into the optical part of the network
- The network provides lightpaths to its users
- Lightpaths are optical connections
  - carried end to end from a source node to a destination node
  - over a wavelength on each intermediate link
- At intermediate nodes the lightpaths are switched from one link to another link
- Lightpaths may be converted from one wavelength to another wavelength

Second-Generation Optical Networks

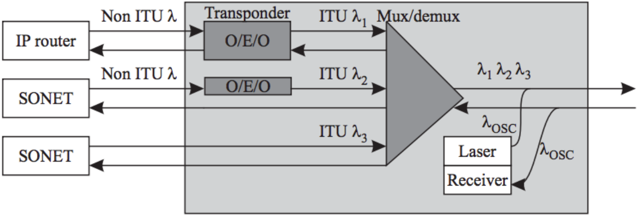


Optical Line Terminals

- OLTs are used at either end of a point-to-point link to multiplex and demultiplex wavelengths
- It is composed by three functional elements:
  - Transponders
  - Wavelength multiplexers
  - Optical amplifiers
- Transponder (a.k.a. optical-to-electrical-to-optical, O/E/O) adapts the signal coming in from a client of the optical network, and vice versa
  - converts the signal into a wavelength that is suited for use inside the optical network (from 1.3 μm to 1.55 μm)
  - adds OTN overhead (OPU, ODU, OTU, FEC, etc.)
  - monitors the bit error rate of the signal at the ingress and egress points in the network
- OLT also terminates an optical supervisory channel (OSC)

Optical Line Terminals

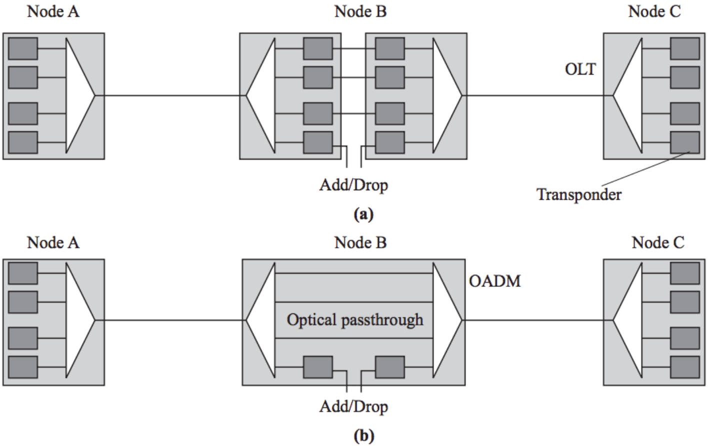
- Transponders typically constitute the bulk of the cost, footprint, and power consumption in an OLT
- Therefore, reducing the number of transponders helps minimize both the cost and the size of the equipment deployed



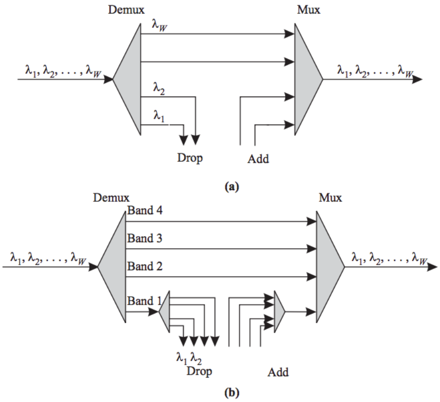
Optical line terminal

Optical Add/Drop Multiplexers

- Optical add/drop multiplexers (OADMs) provide a cost-effective means for handling passthrough traffic in both metro and long-haul networks

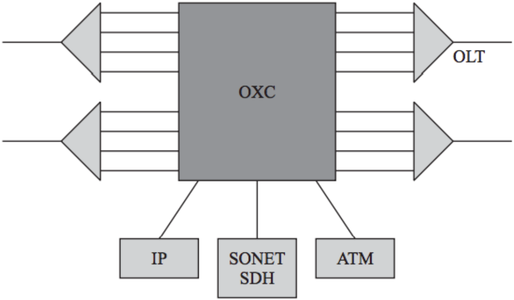


OADM Architectures



Optical Crossconnects

- OXC enables reconfigurable optical networks, where lightpaths can be set up and taken down as needed
- OXCs allow to handle complex topologies and large number of wavelengths

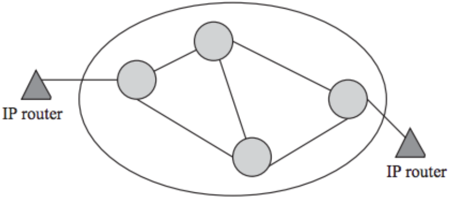


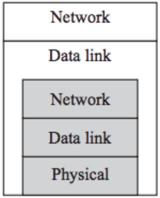
Optical Crossconnects

- An OXC provides several key functions in a large network:
  - service provisioning
    - provisioning of lightpaths in a large network in an automated manner (no manual patch panel connections)
    - reconfigure lightpaths to respond to traffic changes
  - protection
    - detect failures and rapidly reroute lightpaths around the failure
  - bit rate transparency
    - switch signals with arbitrary bit rates and frame formats
  - wavelength conversion
    - change the wavelength of an incoming signal before transmitting it
  - multiplexing and grooming
    - multiplexing and grooming capabilities to switch traffic internally at much finer granularities
    - this time division multiplexing has to be done in the electrical domain

The Optical Layer

- Network architectures can be organized by means of the ISO/OSI model
- A more realistic layered model for today's networks would employ multiple protocol stacks residing one on top of the other



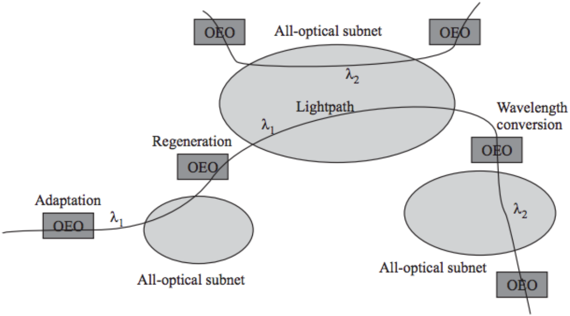


Transparency and All-Optical Networks

- Lightpaths are service transparent
  - once the lightpath is set up, it can accommodate different types of services
    - e.g., the telephone network had this property (a channel can be used to transfer voice, data, fax, etc.)
- Advantages:
  - data is carried from its source to its destination in optical form
  - no optical-to-electrical conversions along the way
- Hard to realize:
  - analog signals require higher SNR with respect to digital ones
- Optical networks almost always include a fair amount of electronics

Transparency and All-Optical Networks

- Electronics plays a crucial role in performing the intelligent control and management functions
- Electronic is required
  - at the edge of the network
    - to adapt the signals entering the optical domain
  - in the core of the network
    - for regeneration and wavelength conversion



Transparency and All-Optical Networks

- Electronic regenerators reduce the transparency of the network
- Three types of electronic regeneration techniques for digital data
  - 1R: regeneration (can be seen as an Optical Amplifier)
    - PRO: supports analog signals
    - CONS: poor performance
  - 2R - regeneration with reshaping
    - PRO: offers transparency to bit rates
    - CONS: limits the number of regeneration steps allowed due to the accumulated jitter
  - 3R - regeneration with retiming and reshaping
    - PRO: produces a “fresh” copy of the signal
    - CONS: it eliminates transparency to bit rates and the framing protocols

Network Evolution

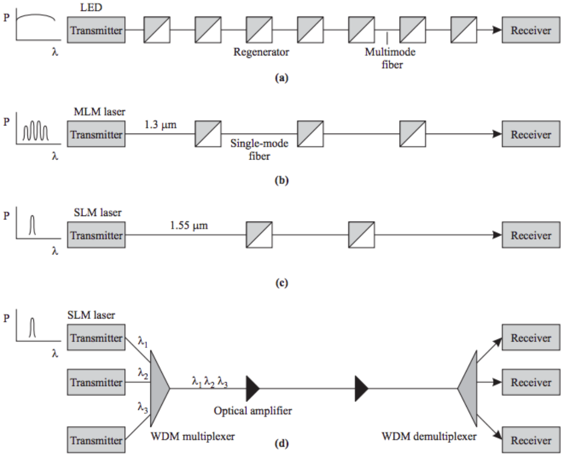
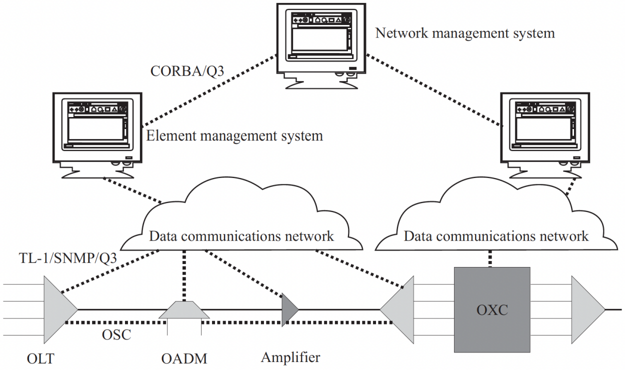


Figure 1.13 Evolution of optical fiber transmission systems. (a) An early system using LEDs over multimode fiber. (b) A system using MLM lasers over single-mode fiber in the 1.3 μm band to overcome intermodal dispersion in multimode fiber. (c) A later system using the 1.55 μm band for lower loss, and using SLM lasers to overcome chromatic dispersion limits. (d) A current-generation WDM system using multiple wavelengths at 1.55 μm and optical amplifiers instead of regenerators. The P-λ curves to the left of the transmitters indicate the power spectrum of the signal transmitted.

Control and Management

Management Framework

- Most functions of network management are implemented in a centralized manner by a hierarchy of management systems
- Due to latency, some management functions are performed in a decentralized manner (e.g., responding to failures and setting up and taking down connections)



Optical Layer Services and Interfacing

- Client layers can specify to the optical layer the following services during lightpath setup:
  - the endpoints to interconnect
  - the amount of bandwidth that is required
  - it can specify if an adaptation function is needed at the ingress or egress point
  - the targeted Bit Error Rate (BER)
  - the level of protection against failure events
  - requirements related to jitter and maximum end to end delay
- Enabling the delivery of these services requires a control and management interface between the optical layer and the client layer
  - The simple interface used today is through the management system
  - It works fine as long as lightpaths are set up fairly infrequently and remain nailed down for long periods of time

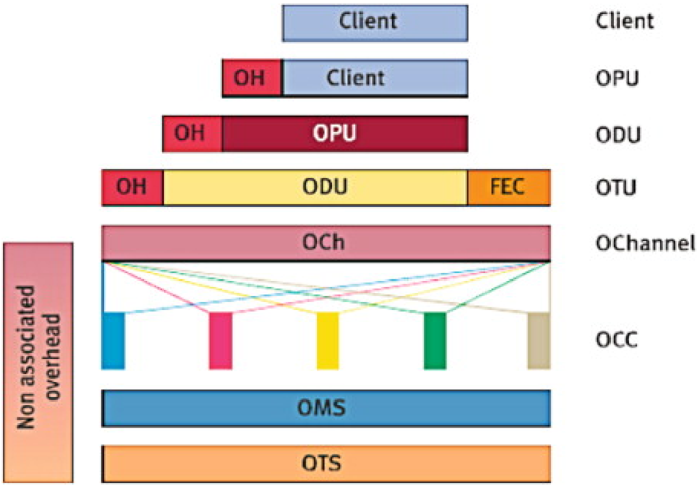
Layers within the Optical Layer

- The optical layer performs several functions (multiplexing, switching and routing, and performance monitoring)
- In order to help delineate management functions it is useful to further subdivide the optical layer into several sublayers:
  - *Optical Channel* layer (OCh):
    - takes care of end to end routing of the lightpaths
  - *Optical Multiplex Section* layer (OMS):
    - each link between OLTs or OADMs represents an optical multiplex section carrying multiple wavelengths
  - *Optical Transmission Section* layer (OTS):
    - link between two optical amplifier stages

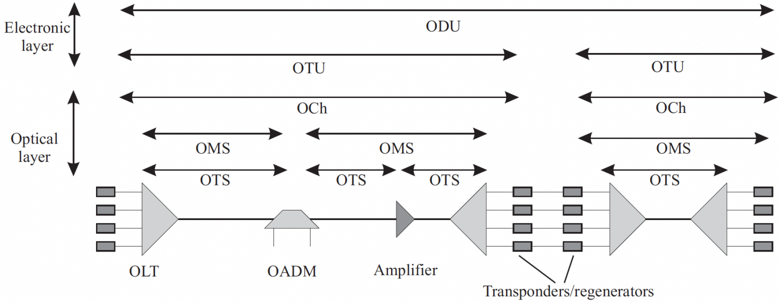
Layers within the Electronic Layer

- Optical channel transport unit (OTU)
  - delineate OTN frames
  - provide identification of the optical connection
  - monitor bit error rate (BER) performance
  - carry alarm indicators to signal failures
  - provide a communication channel between the end points of the optical connection
- Optical channel data unit (ODU)
  - as OTU, but at a higher layer
  - includes the Optical channel Payload Unit (OPU) sublayer that adapts client signals to the OTN frames

OTN Encapsulation



Layers within the Optical Layer



Performance and Fault Management

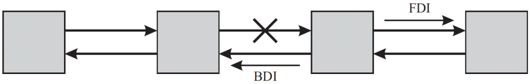
- The goal of *performance management* is to enable service providers to provide guaranteed quality of service to the users of their network
- This usually requires:
  - monitoring of the performance parameters for all the connections
  - taking any actions necessary to ensure that the desired performance goals are met
- *Fault management* involves:
  - detecting problems in the network
  - alerting the management systems appropriately through alarms
- Fault management also includes restoring service in the event of failures

BER and Optical Trace

- *BER*
  - The bit error rate (BER) is the key performance attribute associated with a lightpath
  - The BER can be detected only when the signal is available in the electrical domain, typically at regenerator or transponder locations
  - Overhead inserted in OTN frames, which consists of parity check bytes, allows for BER computation
- *Optical Trace*:
  - Lightpaths pass through multiple nodes and through multiple cards within the equipment deployed at each node.
  - It is desirable to have a unique identifier associated with each lightpath
  - This identifier is called an optical path trace
  - The trace enables the management system to identify, verify, and manage the connectivity of a lightpath

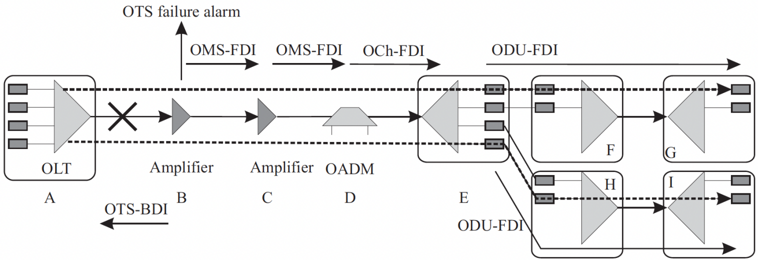
Alarm Management

- In a network, a single failure event may cause multiple alarms to be generated
  - in a network with 32 lightpaths on a given link, each traversing through two intermediate nodes, the failure of a single link could trigger a total of 129 alarms
- Alarm management it is required to identify the root-cause alarm of the failure and suppress the redundant alarms
  - Alarm suppression is accomplished by using a set of special signals, called the forward defect indicator (FDI) and the backward defect indicator (BDI)



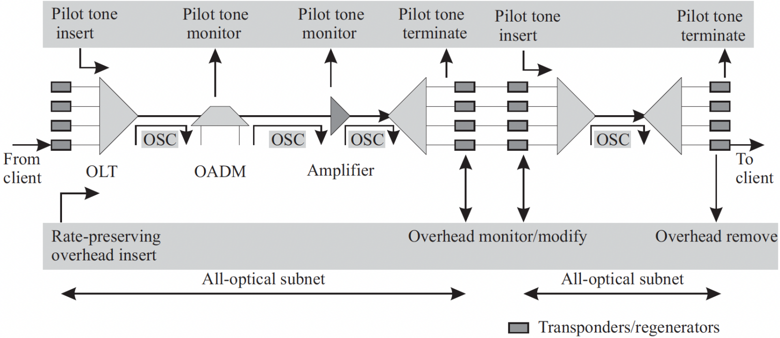
Alarm Management: Example

- When a link fails, the node downstream of the failed link inserts an FDI signal downstream to the next node
- The FDI signal propagates rapidly, and nodes further downstream receive the FDI and suppress their alarms
- The node also sends a BDI signal upstream to the previous node, to notify that node of the failure
- FDI and BDI are sent at different sublayers of the optical layer



Optical Layer Overhead

- Supporting the optical path trace, defect indicators, and BER measurement requires the use of some sort of overhead in the optical layer



Optical Layer Overhead

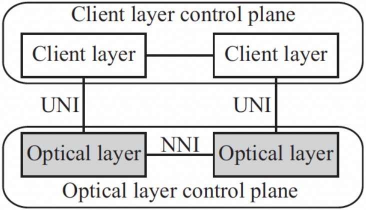
	All-Optical Subnet		End-to-End
Application	OSC	Pilot Tone	Rate-Preserving
Trace	OTS	OCh	OTU ODU
DIs	OTS OMS OCh	None	OTU ODU
Performance monitoring	None	Optical power	BER
Client signal compatibility	Any	Any	Any

Connection Management

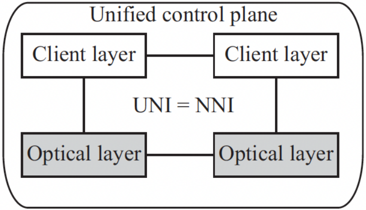
- Connection management deals with setting up connections, keeping track of them, and taking them down when they are not needed anymore
- Two different approaches
  - client-server model
    - the client layer (IP, SDH, ATM, etc.) asks to the server layer the establishment of a connection (lightpath) without having knowledge of the internal structure of the optical network
    - centralized control
    - suitable as long as lightpaths are set up fairly infrequently
  - peer model
    - tight coupling between the client and optical layers: the optical layer primarily serves a single client (IP)
    - distributed control
    - useful if there is a need to set up and take down connections rapidly

Interaction with Other Layers

- *Overlay Model*



- *Peer Model*



Distributed Connection Management

- Distributed connection control has several components
  - topology management: each node in the network maintains a database of the network topology and the current set of resources available
    - OSPF–Traffic Engineering (OSPF-TE) used to distribute link state info
  - link management: nodes monitor the status of the link by exchanging periodic "hello"
    - BER can also be considered to assess the status of a link
  - route computation: routing algorithm applied on the topology database
  - signaling protocol: set of messages used to set up a connection once the path has been calculated
    - RSVP Traffic Engineering (RSVP-TE) and Constraint-based Routing LDP (CR-LDP)