Optical Communication Systems: Networks

Introduction to optical networks

Introduction to optical networks

- Introduction to optical networks
  - Evolution of TLC networks
  - Architecture of TLC networks
  - Optical TLC networks
    - Multiplation techniques
    - First generation networks
    - Second generation networks
    - All-optical networks
  - Evolution of optical networks.

Evolution of TLC networks (1)

- Growing bandwidth request for TLCs
- Internet traffic doubles every 4-6 months
- Broadband access networks (DSL)
- Broadband private networks for business
- Boradband corporate private networks
- Cost reduction ⟷ traffic increase

Evolution of TLC networks (2)

- Privatisation of service providers
  - Deregulation
  - Startup service providers
  - Cost reduction
  - New technologies
- Data traffic overcomes voice traffic
  - New business models
  - New network achitectures

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Architecture of TLC networks (1)

- Public networks
  - Service providers, carriers, *operators*
  - Different types of operators
- LEC: local services
- IXC: long-haul services
- Metro carriers vs. long-haul carriers
  - Often they coincide but…
  - Different network architectures!

Architecture of TLC networks (2)

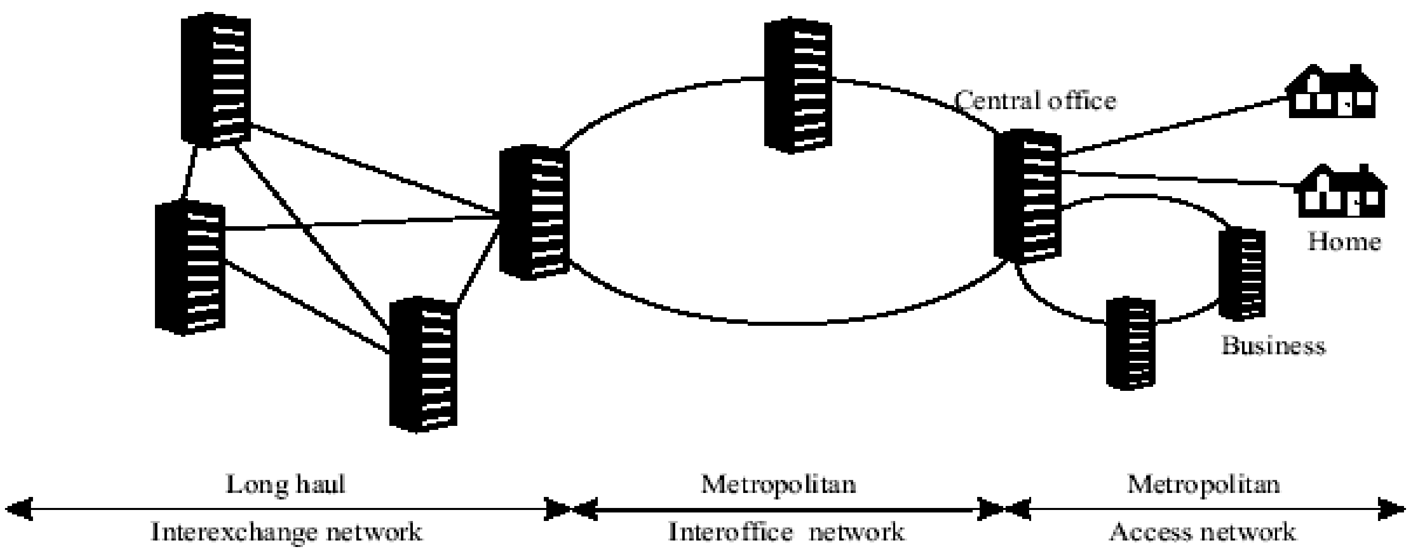
- The case with USA
  - Before 1984: AT&T monopoly
  - 1984: TLC deregulation act
    - AT&T competes with other carriers (MCI, Sprint) in the long-haul space
    - Baby Bells (ILECs) e competitors (CLECs) for local traffic
- In Italy:
  - Competition after liberalization of providers
    - Telecom, Fastweb, Wind, Tiscali …

Architecture of TLC networks (3)

- Classification
  - **LAN**: a few km
  - **MAN**: tens – hundreds of km
  - **WAN**: hundreds – thousands of km

Architecture of TLC networks (4)

- Public networks based on optical fibers
  - Submarine networks
  - Terrestrial networks
    - Access, metro, long-haul networks

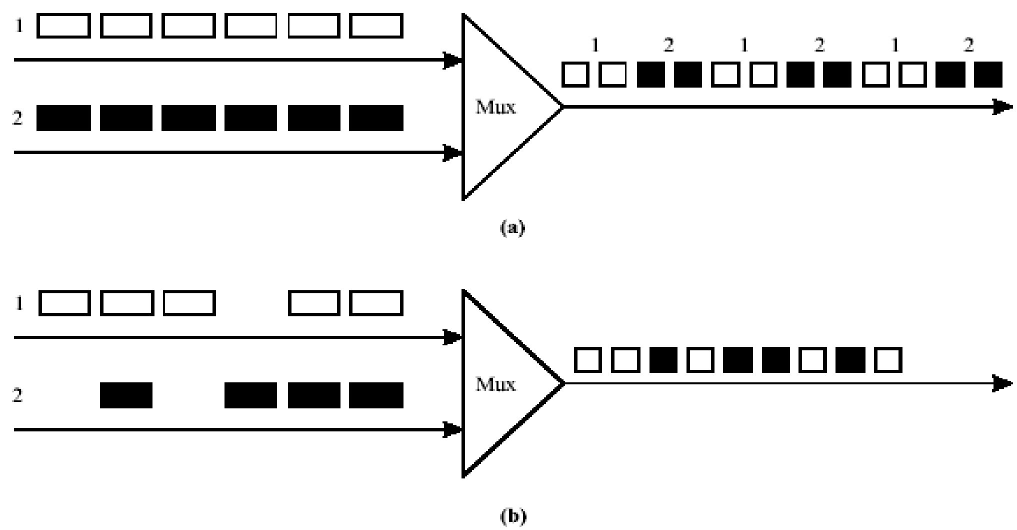


Architecture of TLC networks (5)

- Services…
  - Connection-oriented vs. connectionless
- Switching of…
  - **circuit**: telephone
    - Guarantee of bandwidth
    - Orderly delivery
    - Fixed multiplexing
  - **packet**: “bursty” traffic
    - Average bandwidth, peak bandwidth
    - Unorderly delivery
    - Statistical multiplexing

Architecture of TLC networks (6)

- Statistical multiplexing
  - Bandwidth is better exploited
  - Buffering dei packets
    - Variable delivery delay



Architecture of TLC networks (7)

- IP network: packet services
  - Connectionless services
  - Packets are routed as independent units
  - TCP ensures the re-ordering of packets
  - The networks is “best effort” (as the frame relay)

- ATM network (asynchronous transfer mode): *virtual circuits*
  - Management of QoS

Architecture of TLC networks (8)

- Modern model of service
  - Connection bandwidth is growing
  - Rapid delivery of necessary bandwidth
    - *When needed where needed…*
  - Reliability 99.999%
  - **Today**: multiple services on multiple networks
  - **Tomorrow**: migration towards a single architecture which may deliver multiple services

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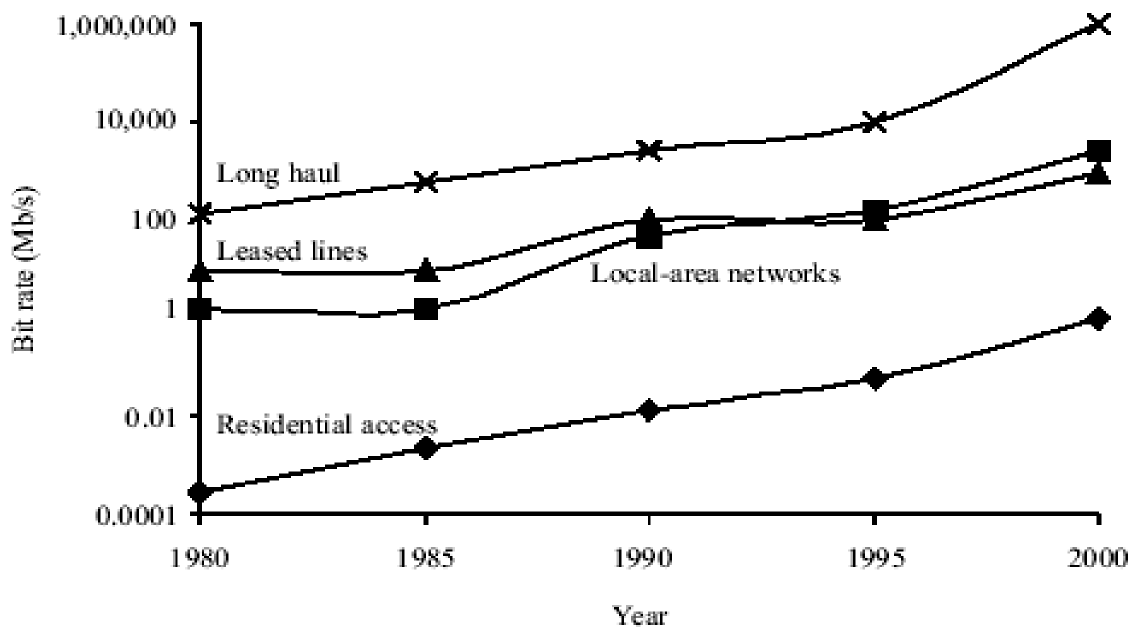
Optical TLC networks (1)

- Huge transmission capacity
- Common infrastructure for multiple services
- Flexible bandwidth management
  - *When needed where needed…*
- High bit-rate links from short to long distances
- Optical fibers are installed in all networks… possibly except for access networks

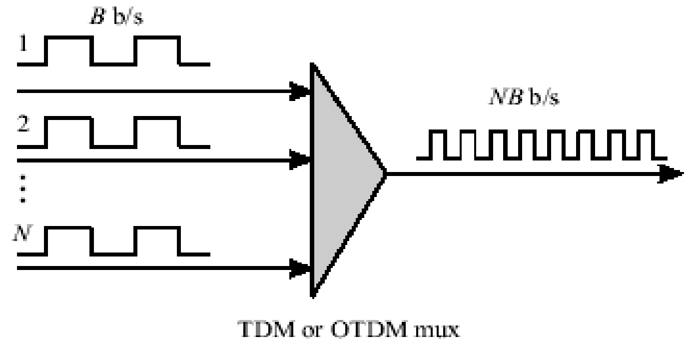
Optical TLC networks (2)

- Bandwidth growth over the past 20 years
  - Pushed by DSL technologies

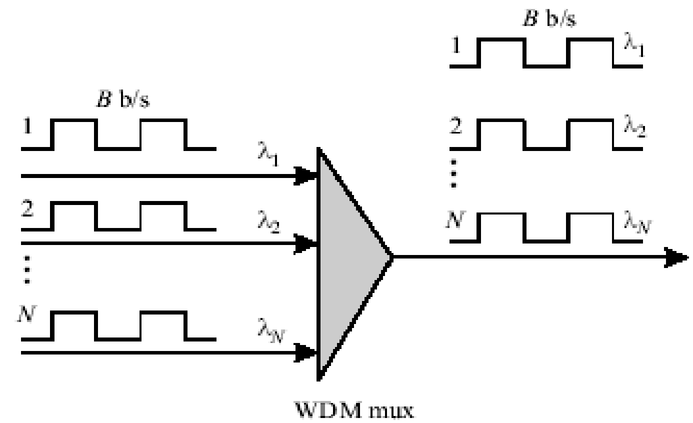


Multiplation techniques

- Multiplation techniques
  - TDM, requires high-speed electronics of photonics
  - WDM: *virtual fibers*
    - Metro and long-haul networks
- TDM+WDM leads to 1 Tb/s capacities
- Better 32 x 2.5 Gbit/s or 10 x 8 Gbit/s ?



(a)



(b)

First generation optical networks

- First generation optical networks
  - Sonet/SDH (USA/Europa)
  - Optical layer as transmission medium for high-capacity and low BER
  - Electrical signal processing
- Second generation optical networks
  - Perform some intelligent operations optically
    - Routing, switching…

Second generation optical networks (1)

- Second generation optical networks
  - Difficult for electronics to handle high bit-rates
    - Processing of an ATM packet with 53 bytes
      - 100 Mb/s: 4.24 μs for the entire operation
      - 10 Gb/s: 42.4 ns for the entire operation
  - All-optical switching/routing

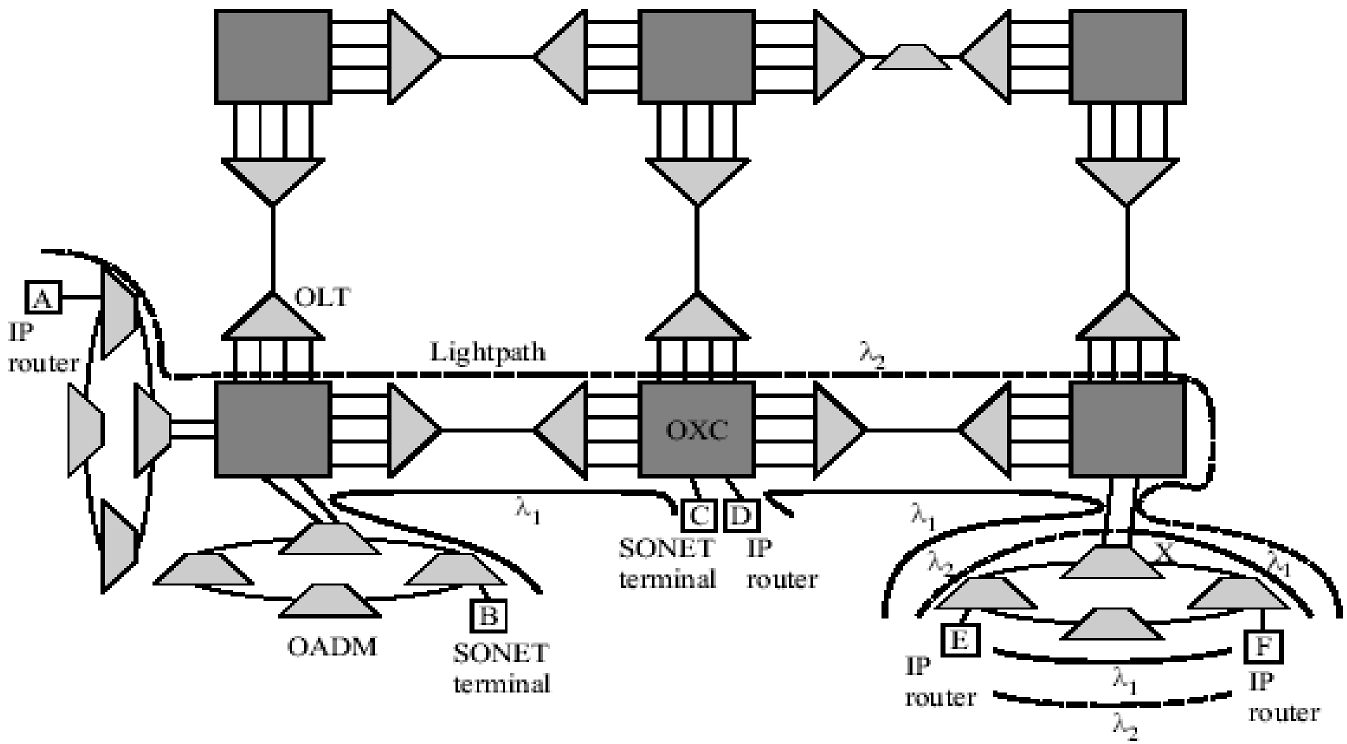
  - ***Wavelength-routing networks***
    - The optical network provides a *lightpath* between sender and receiver

Second generation optical networks (2)

- **Lightpath**: end-to-end optical connection at given wavelength on each link
- At each node, routing/switching of lightpaths
- Devices for optical networking
  - Optical line terminals (OLT)
  - Optical add/drop multiplexers (OADM)
  - Optical cross-connects (OXC)

Second generation optical networks (3)

- Wavelength-routing network
  - Example of actual network

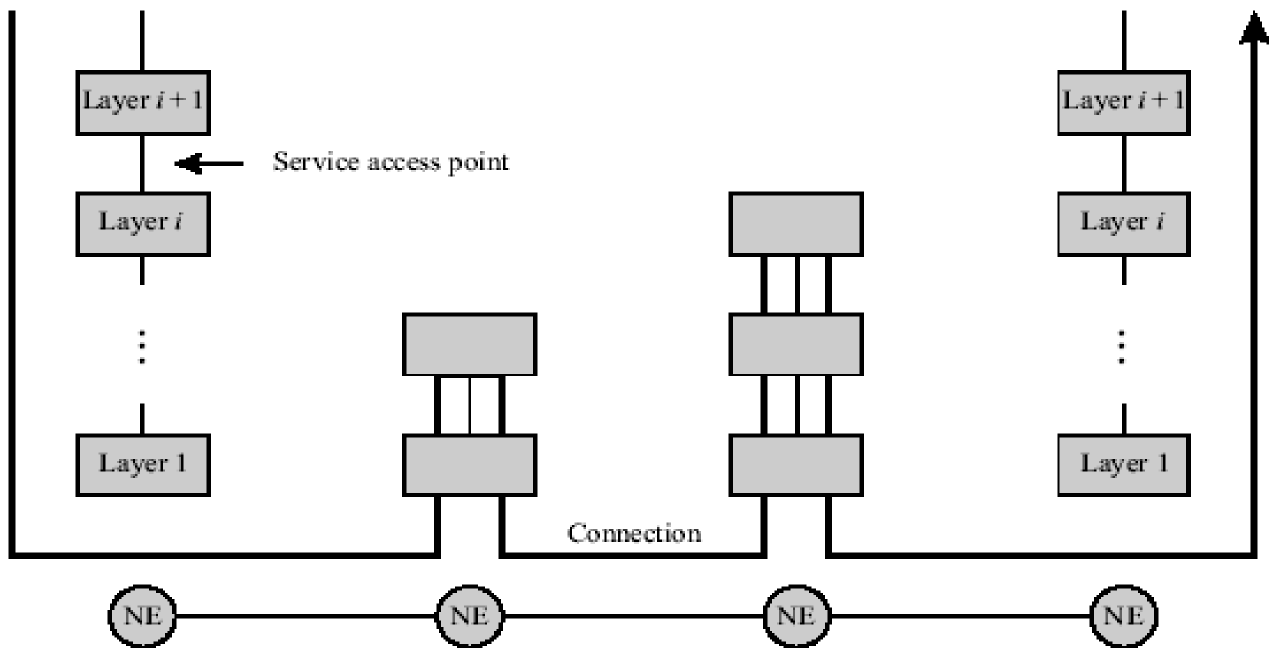


Layer model (1)

- Layer model for TLC networks
  - Each layer provides services to the layer above it
  - Each layer receives services from the layer below it
  - SAP (Service Access Point)
  - Each layer multiplexes data from the upper level by adding overhead
  - Each network element implements a portion of the stack only

Layer model (2)

- It is important to define functions and interfaces of each layer
  - Standardization for inter-operability

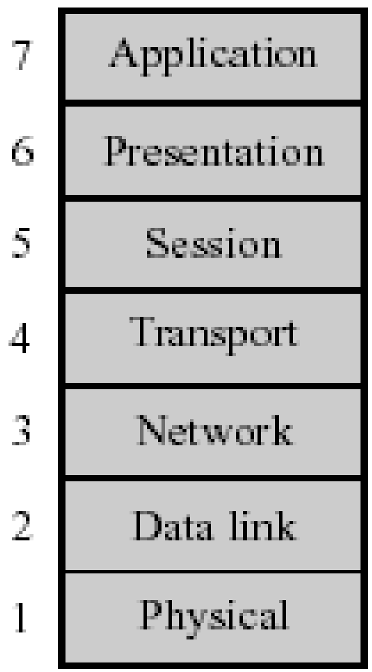


Layer model (3)

- Different standards and implementations for each layer
- **Each type of optical network that we will consider here provides a layer**
- Each layer may be divided in sub-layers

Layer model (4)

- Layer model ISO/OSI



- Levels
  - Physical
  - Data-link
  - Network
  - Trasport
  - Session
  - Presentation
  - Application

Layer model (5)

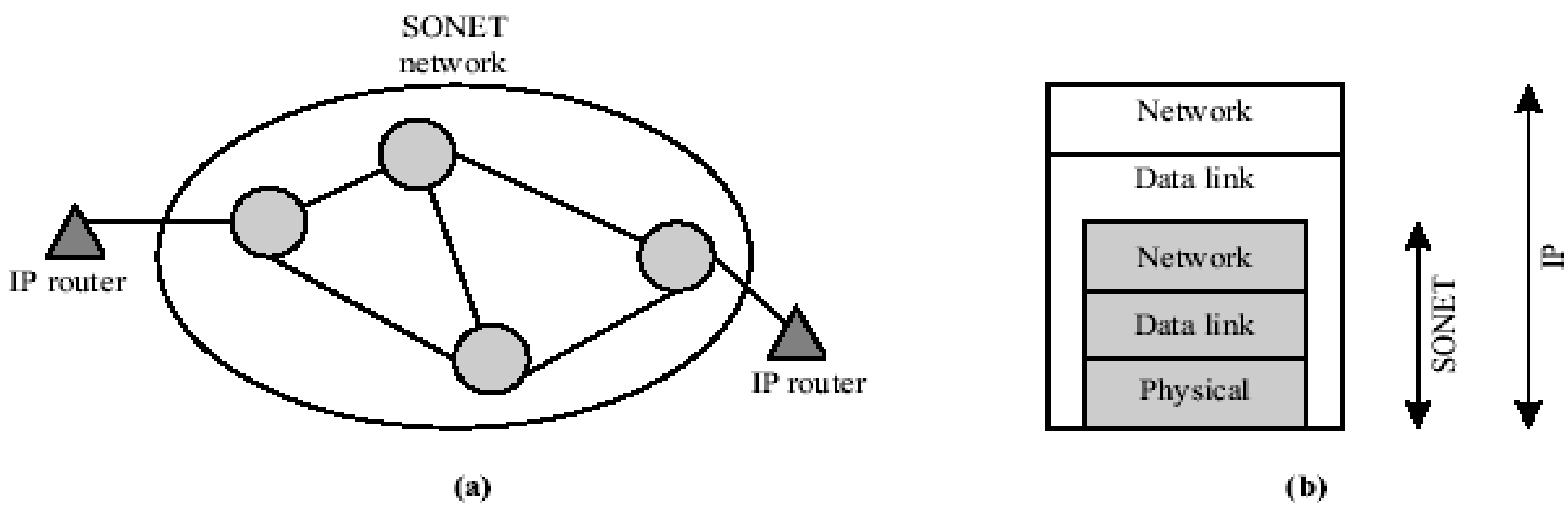
- Physical layer: transmission medium which provides *bandwidth*
- Data-link layer: manages framing, multiplexing, demultiplexing, MAC (media access control layer)
- Network layer: provides packets or virtual circuits (VC)
  - VC: end-to-end connection with fixed QoS and orderly delivery (ATM)
  - packets: connectionless service with statistical multiplexing (IP)

Layer model (6)

- Transport layer: it ensures the end-to-end delivery, well-ordered, error-free
- Upper layers: not of interest in this course
- **Modern networks**: multiple stacks on top of each other
  - IP over Sonet, IP over ATM over Sonet

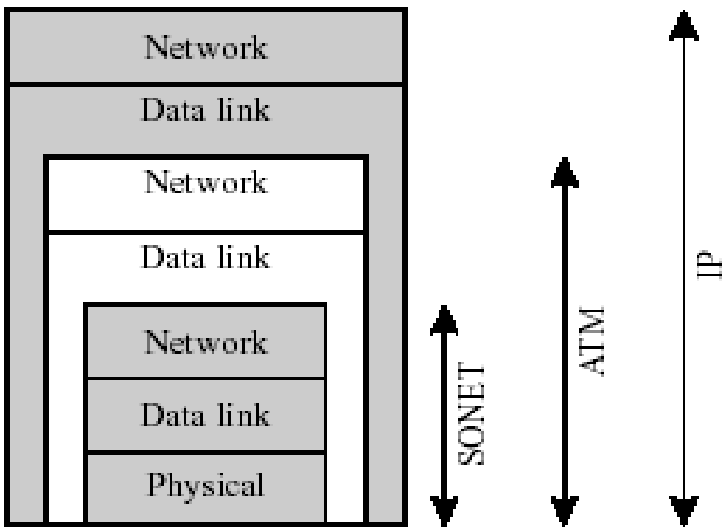
Layer model (7)

- IP over Sonet
  - The Sonet network provides point-to-point connections to the IP
  - Each stack includes different sub-layers



Layer model (8)

- IP over ATM over Sonet
  - Sonet infrastructure, over with the ATM network is created to provide services to IP users



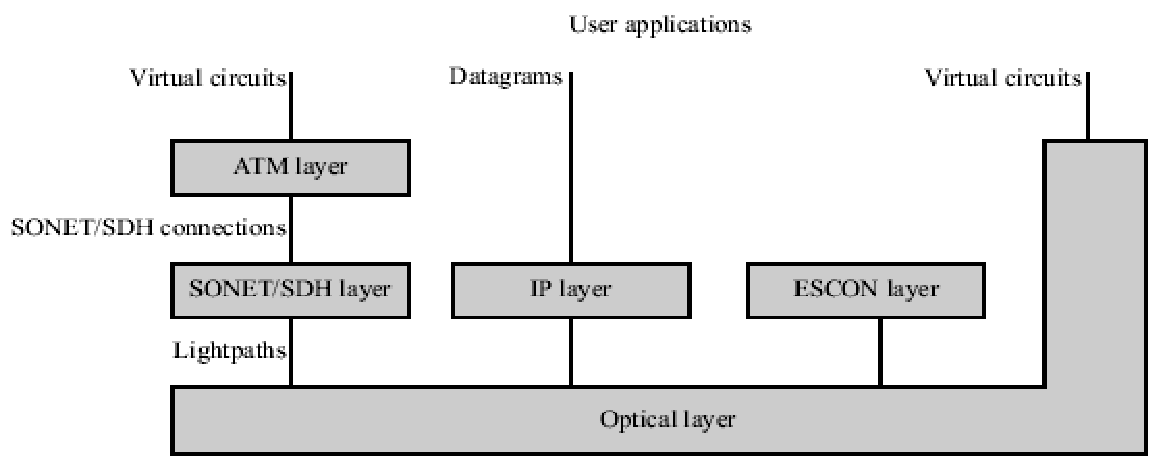
- The IP network sees the ATM network as a data-link layer
- The ATM network uses Sonet as a data-link layer

Sonet / SDH

- First generation networks
  - Sonet/SDH as transmission layer
    - End-to-end connections with circuit switching
    - Multiplexing of low bit rate fluxes
    - Demultiplexing of individual fluxes at nodes
    - High reliability(99.999%)
    - Efficient network monitoring and management
    - Network elements: line terminals, ADM, DCS, regenerators

Optical layer (1)

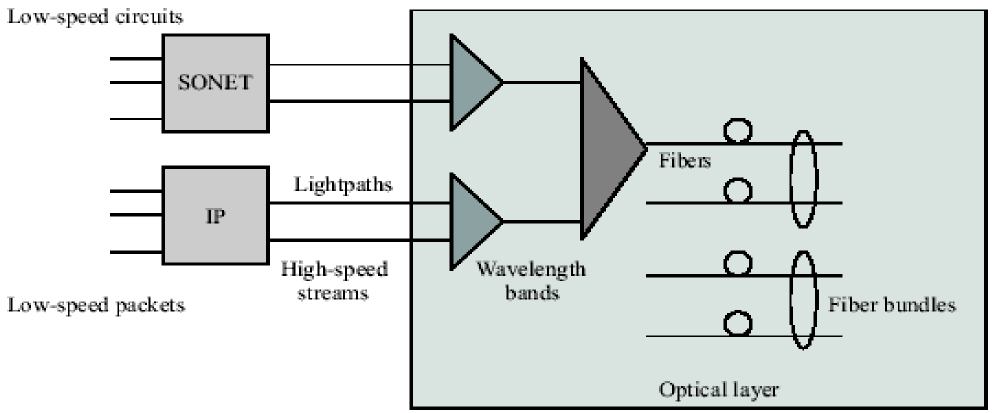
- Second generation networks
  - **Optical layer:** *server layer*, provides services at the optical level to *client layers*
    - Wavelength-routing networks: the optical layer provides *lightpaths* to upper layers
    - In the future: it will also provide VC and packets



Optical layer (2)

- Client layers: IP, ATM, Sonet, Gigabit Ethernet, ESCON, Fibre Channel
- Example: Sonet over optical
  - The optical later provides *lightpath*
  - For Sonet terminals, these are like fibers
  - *Lightpath*
    - Permanent
    - Circuit switching
- At the moment most of the optical layer acts at the physical level

Optical layer (3)



- IP over optical and Sonet over optical
  - Sonet and IP use *lightpaths* as transmission medium
  - Multiplexing in the optical layer:
    - *Lightpath*, bands, fibers, fiber ensembles

Optical layer (4)

- Why using multiple layers with similar functionalities?
  - Cost reductions
  - Different layers operate in efficient way at different bitrates
    - Optical layer: processing of wide bandwidth wavelength-by-wavelength
    - Sonet: processing of small quantities of bandwidth with low bit-rate flux
    - Fault management

All-optical networks (1)

- Transparence of a lightpath with respect to bitrate and protocols
- In general, transparence with respect to
  - Services, bitrate, protocols
  - ex. Telephone network (voice, data, fax)
- All optical network
  - From sender to receiver at the optical level
  - **Fully transparent network**

All-optical networks (2)

- **Nontransparent network**(opaque)
  - Single bitrate and protocol
  - ex. 2.5 Gb/s, Sonet service
- **“Practical”** (real) network
  - Handles a range of bitrates and different protocols
  - ex. Max. 10 Gb/s, Sonet and IP services
  - It is not possible to completely eliminate electronics
    - Signal regeneration
    - Wavelength conversion

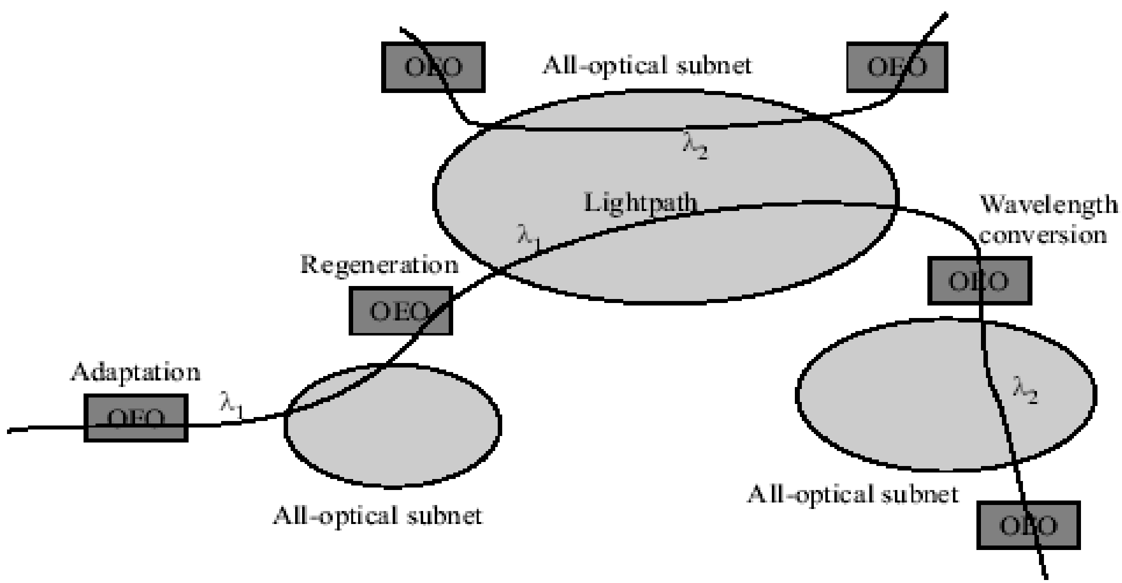
All-optical networks (3)

- Regeneration
  - 1R: amplification (optical amplifiers)
  - 2R: 1R + reshaping
  - 3R: 2R + retiming
    - Requires clock extraction
      - Loss of transparency
      - 3R trasparent: optical, or with “programmable” electronics
  - Modern networks
    - 2R or 3R regeneration
    - O-E-O conversion where necessary

All-optical networks (4)

Table 1.1 Different types of transparency in an optical network.

	Transparency type		
Parameter	**Fully transparent**	**Practical**	**Nontransparent**
Analog/digital	Both	Digital	Digital
Bit rate	Arbitrary	Predetermined maximum	Fixed
Framing protocol	Arbitrary	Selected few	Single

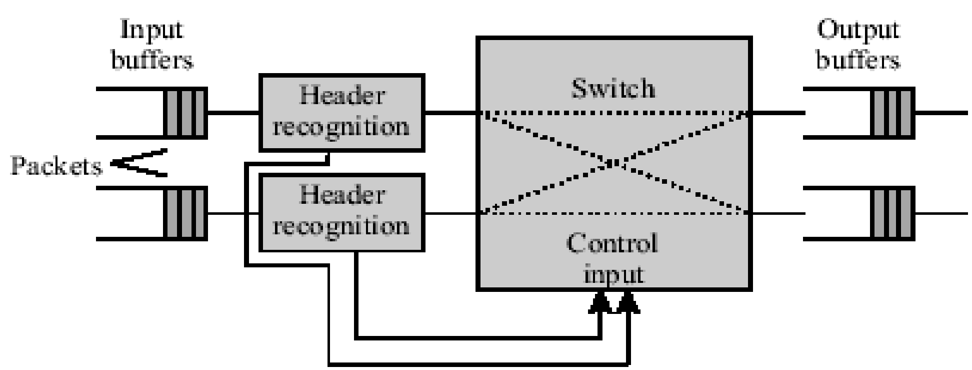


Optical packet switching (1)

- Wavelength-routing networks
  - Lightpath ➡ circuit switching
  - Future evolution
    - Providing packets or VCs (IP, ATM)
- Optical level TDM (OTDM)
  - Lightpath shared among several connections
  - OTDM
    - Fixed
    - Statistical: optical packet switching

Optical packet switching (2)

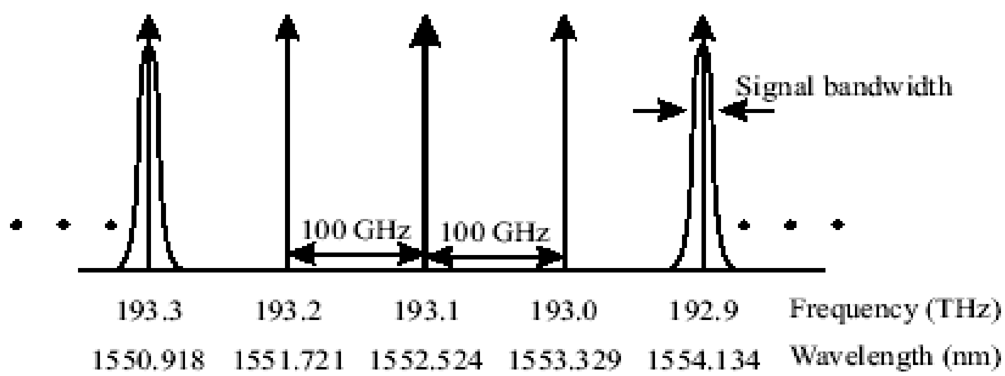
- Optical switching nodes
  - Higher Bitrates with respect to electronics
  - Ideally, all functions done optically
  - In practice, some functions remain in electrical domain
    - Buffering, complex operations



Optical Communication Systems (1)

- Wavelength, frequency
  - Three windows: 800, 1300 e 1550 nm
- Channel spacing in WDM systems
  - 0.8 nm means 100 GHz
- Bitrate [Gb/s]
- Spectrum
- Bandwidth [GHz]
- Spectral efficiency[bitrate/bandwidth]
  - About 0.4 bit/s/Hz in optical systems (OOK)

Optical Communication Systems (2)

- ITU-T Grid
  - Standard grid for DWDM systems at 1550 nm
    - Grid equispaced in frequency anchored at 193.1 THz (1552.524 nm)
  - Channel spacing 50 or 100 GHz
    - 

Optical Communication Systems (3)

- Optical power, losses
  - dBW: absolute power with reference to 1W
  - dBm: absolute power with reference to 1 mW
    - 1 mW means -30 dBW and 0 dBm
  - Fiber loss[dB/km]
    - A signal that propagates for120 km in a fiber with loss of 0.25 dB/km loses 30 dB
    - 30 dB means attenuation by a factor 1000

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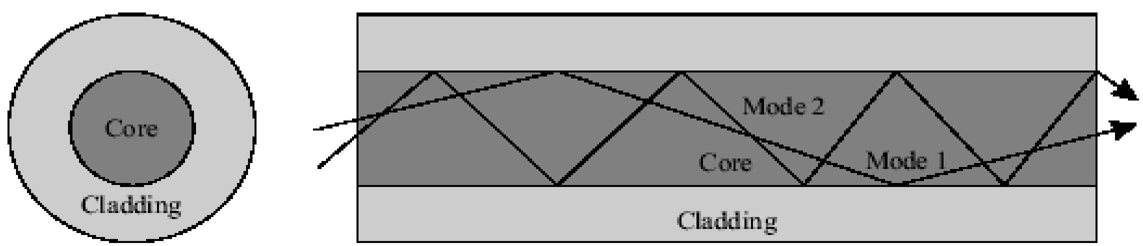
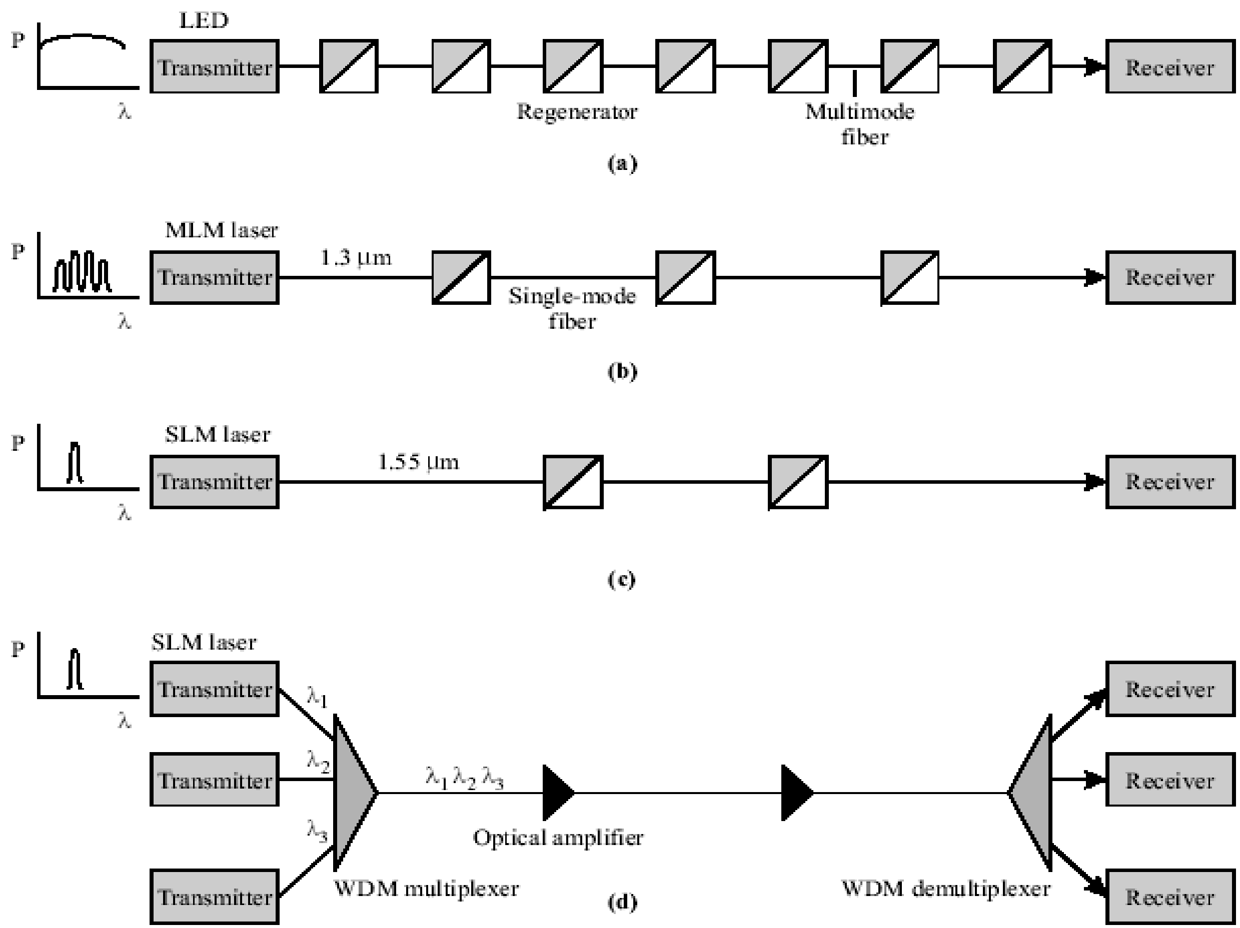
Evolution of optical networks (1)

- Objective: the highest capacity over the longest possible distance
  - Capacity keeps growing
  - Cost of bit per km keeps decreasing
- Transmission medium
  - Optical fiber



(a) (b)

Evolution of optical networks (2)



Evolution of optical networks (3)

- 1960: first waveguides
- 1970: low loss optical fibers
- 1970-1980 (a)
  - Multimode fibers
  - LED sources at 800 or 1300 nm
    - Wideband
    - Low power
  - Strong intermodal dispersion
    - 32 - 140 Mb/s with regenerators every 10 km
    - Still used today for low cost connections

Evolution of optical networks (4)

- 1984 (b)
  - Monomode fibers
  - Fabry Perot Laser MLM at 1300 nm
  - Regeneration every 40 km
  - Bitrate > 100 Mb/s
- End of 1980
  - Fabry Perot Laser MLM at 1550 nm
  - Limiting factor: chromatic dispersion
  - Dispersion-shifted fibers

Evolution of optical networks (5)

- 1990 (c)
  - Single mode laser with DFB
  - Bitrate > 1 Gb/s
- Today (d)
  - EDFA optical amplifiers
    - Large bandwidth amplification
  - WDM systems with hundreds of channels
  - Regeneration after hundreds-thousands of km
  - Bitrate > 1 Tb/s (40 Gb/s per channel)

Evolution of optical networks (6)

- Dispersion compensation
- Nonlinear effects
- Available bandwidths for WDM
  - C, L with EDFA
  - S, U with Raman amplification

Table 1.2 Different wavelength bands in optical fiber. The ranges are approximate and have not yet been standardized.

Band	Descriptor	Wavelength range (nm)
O-band	Original	1260 to 1360
E-band	Extended	1360 to 1460
S-band	Short	1460 to 1530
C-band	Conventional	1530 to 1565
L-band	Long	1565 to 1625
U-band	Ultra-long	1625 to 1675

Evolution of optical networks (7)

- In recent years…
  - 1980-1990: first generation networks
    - FDDI: MAN networks at 100 Mb/s
    - ESCON: SAN networks at 200 Mb/s
    - Sonet (USA), SDH (Europe, Japan)
  - 1990-2000: Second generation networks
    - Optical LANs
    - Wavelength-routing networks
      - Commercial OADM e OXC
    - FTTC, FTTH
    - Optical packet switching