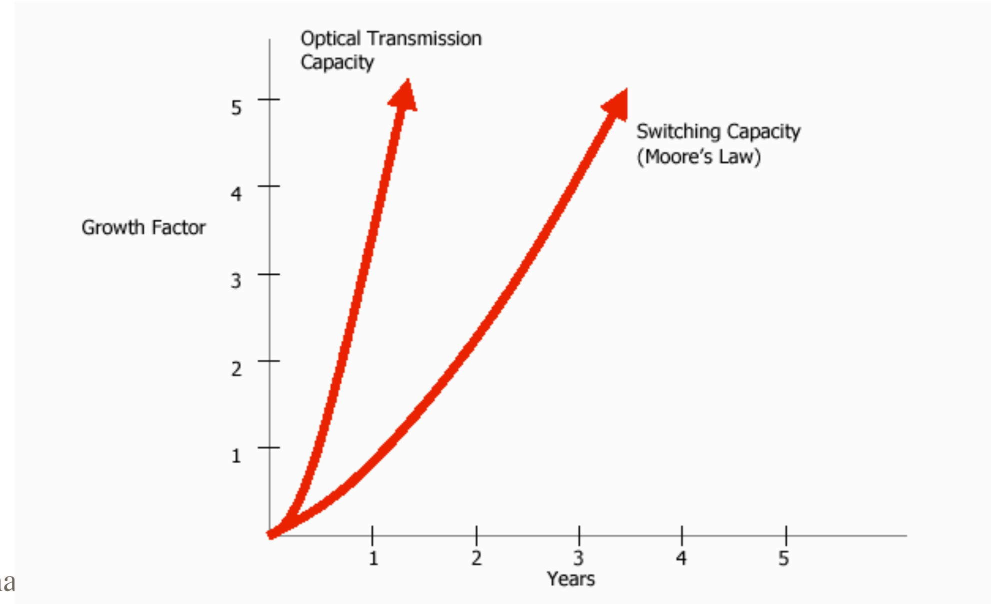
Lecture 1: Introduction to Fiber Optic Networks

Fiber-Optic Network Applications

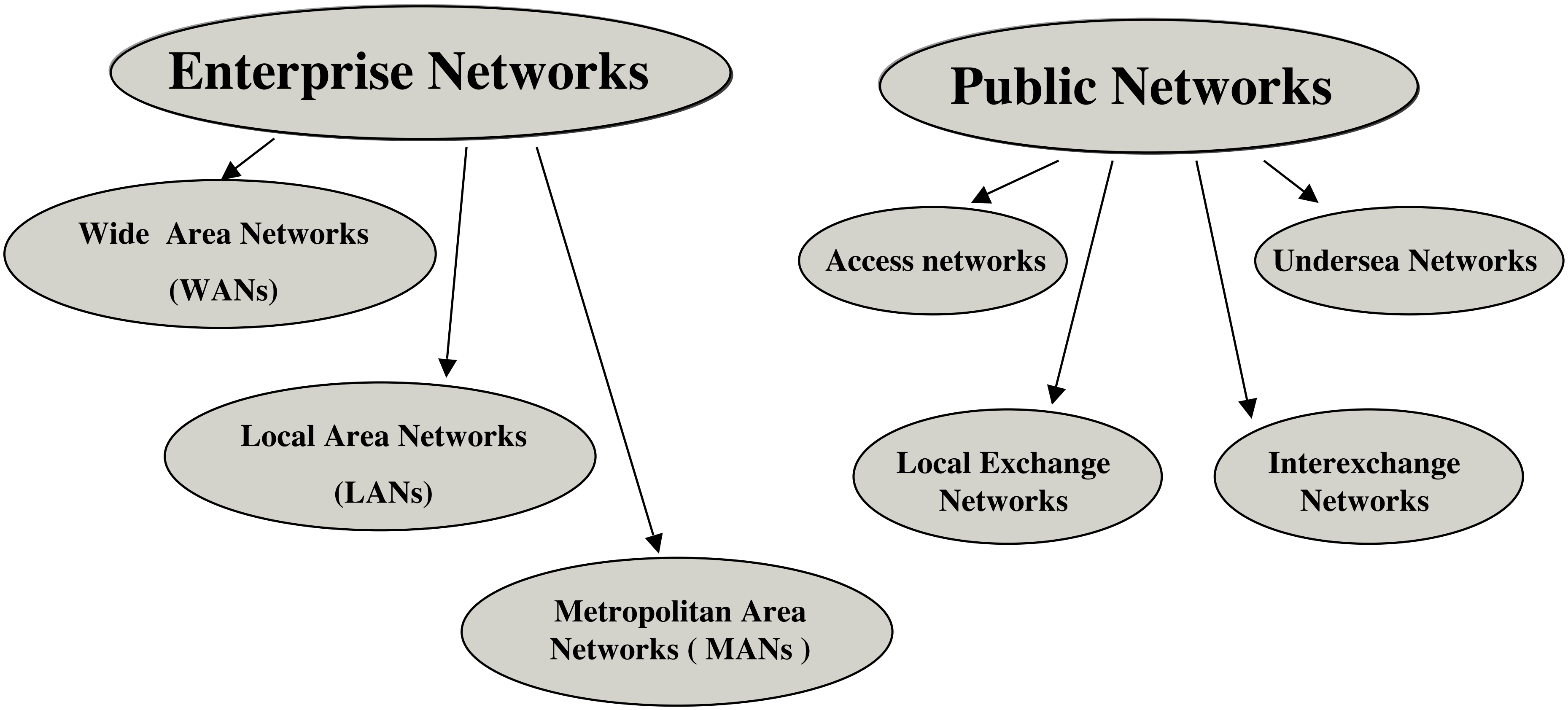
- Main application: digital transmission
  - Voice, telephone
  - Data
    - IP Networks
    - ATM, Gigabit Ethernet, FDDI, etc.
    - Distributed Computing and Databases
    - Video, Multimedia
- Microwave Photonics
  - Fiber/Wireless
  - Hybrid Fiber/Coax
- Other applications
  - Fiber/Wireless
  - Hybrid Fiber/Coax

Note:

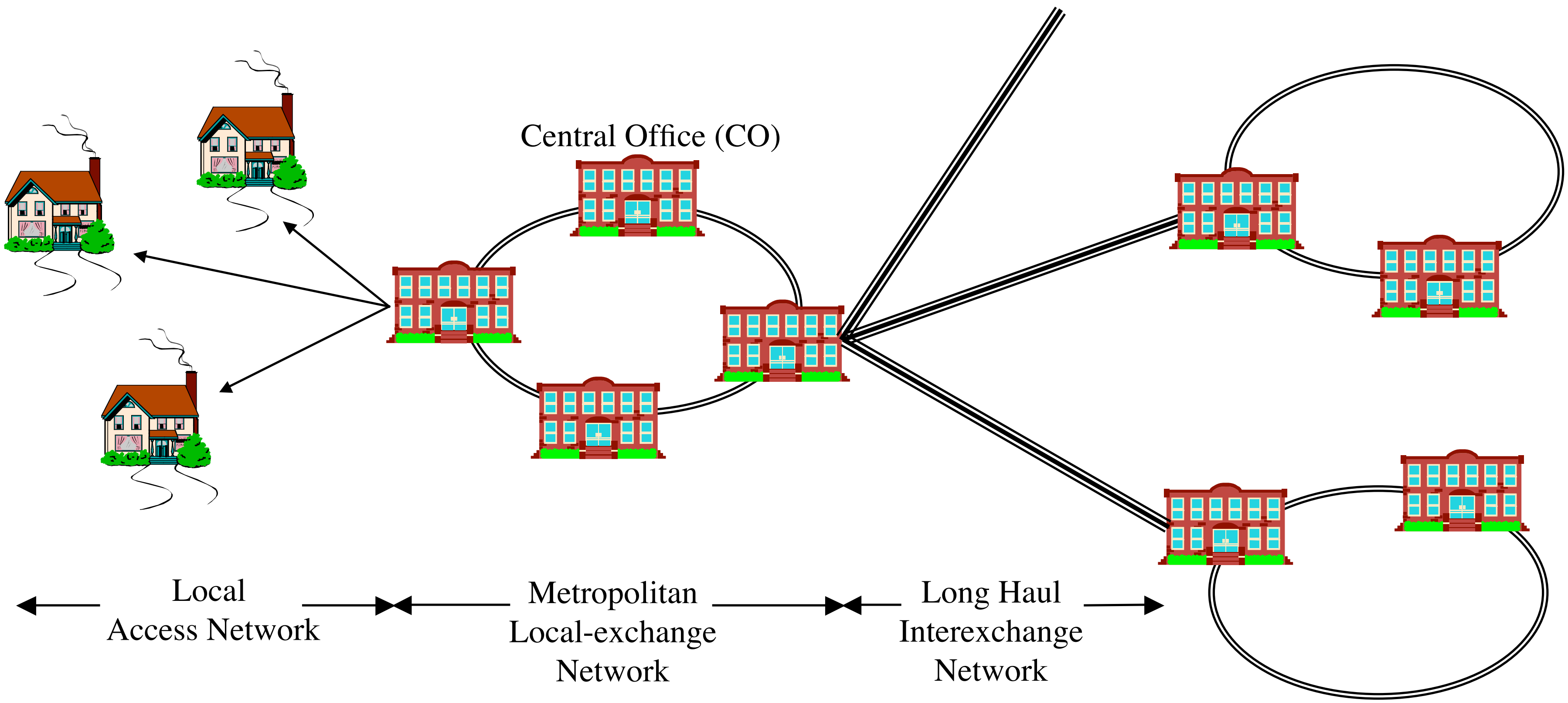
Traffic generated by data-centric application (mainly IP) is rapidly surpassing the voice-centric traffic



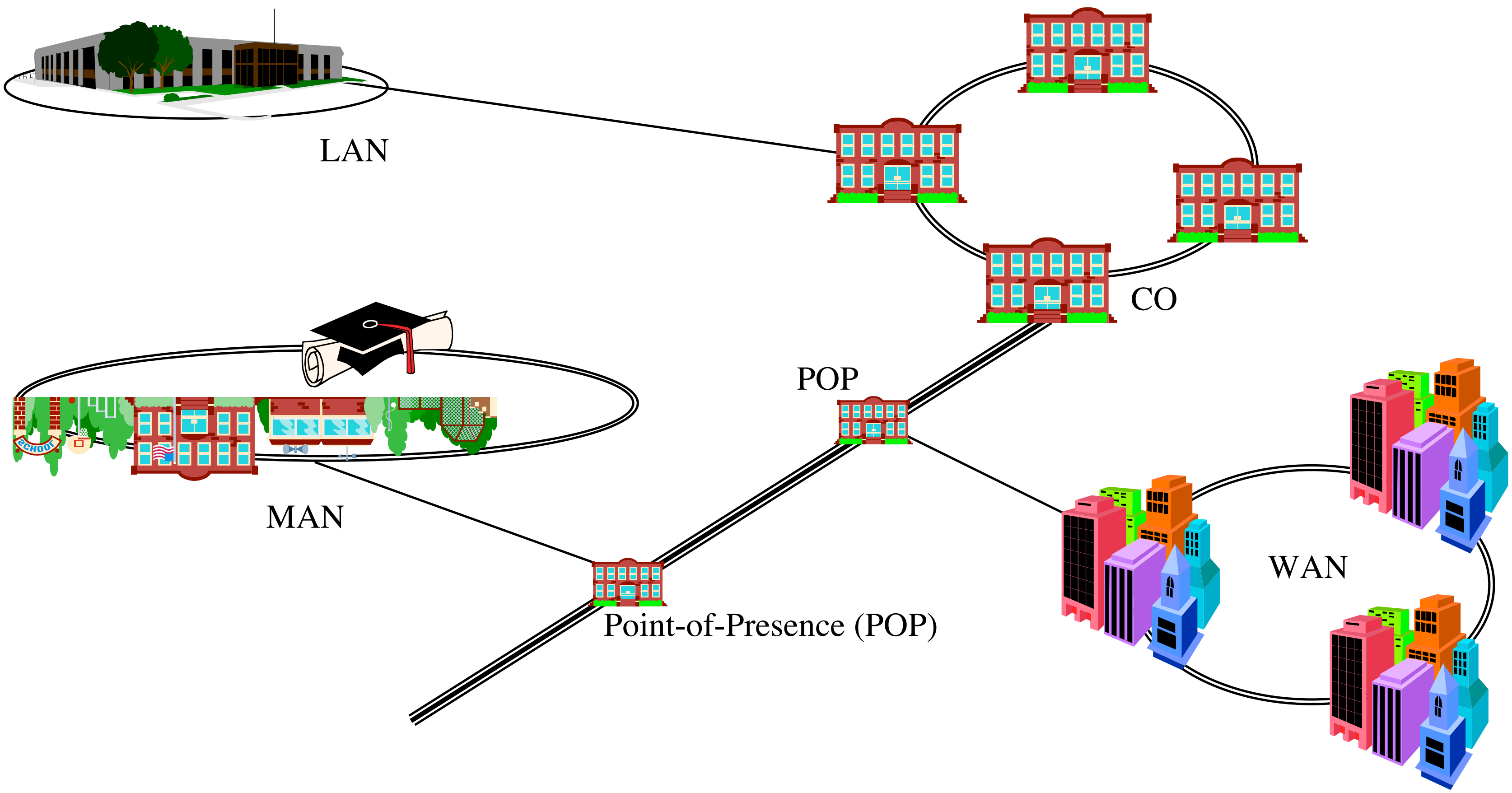
Network Classification



Public Networks



Enterprise Networks



Evolution of Fiber-Optic Point-to-Point Transmission

Early 70s

Multimode fiber-optic waveguides >5dB/km attenuation

Room temperature GaAs LEDs and multimode FP Lasers @ 830 nm

Early 80s

Low loss Single mode optical fibers 1 dB/km @ 1310 nm

Multimode Fabry-Perot 1310 nm lasers

Mid to Late 80s

Operation in the low loss window of 0.2 dB/km @ 1550 nm but high dispersion @ 1550 nm

Development of single frequency DFB 1310 nm and 1550 nm lasers

New dispersion shifted fiber yields Zero dispersion @ 1550 nm and 0.5 dB/km loss @ 1310 nm

Late 80s to Early 90s

Multichannel erbium doped fiber amplifiers (EDFAs) @ 1550 nm deployed.

Mid 90s

AT&T True Wave Fiber and Corning Large Optical Core Fiber reduce fiber FWM

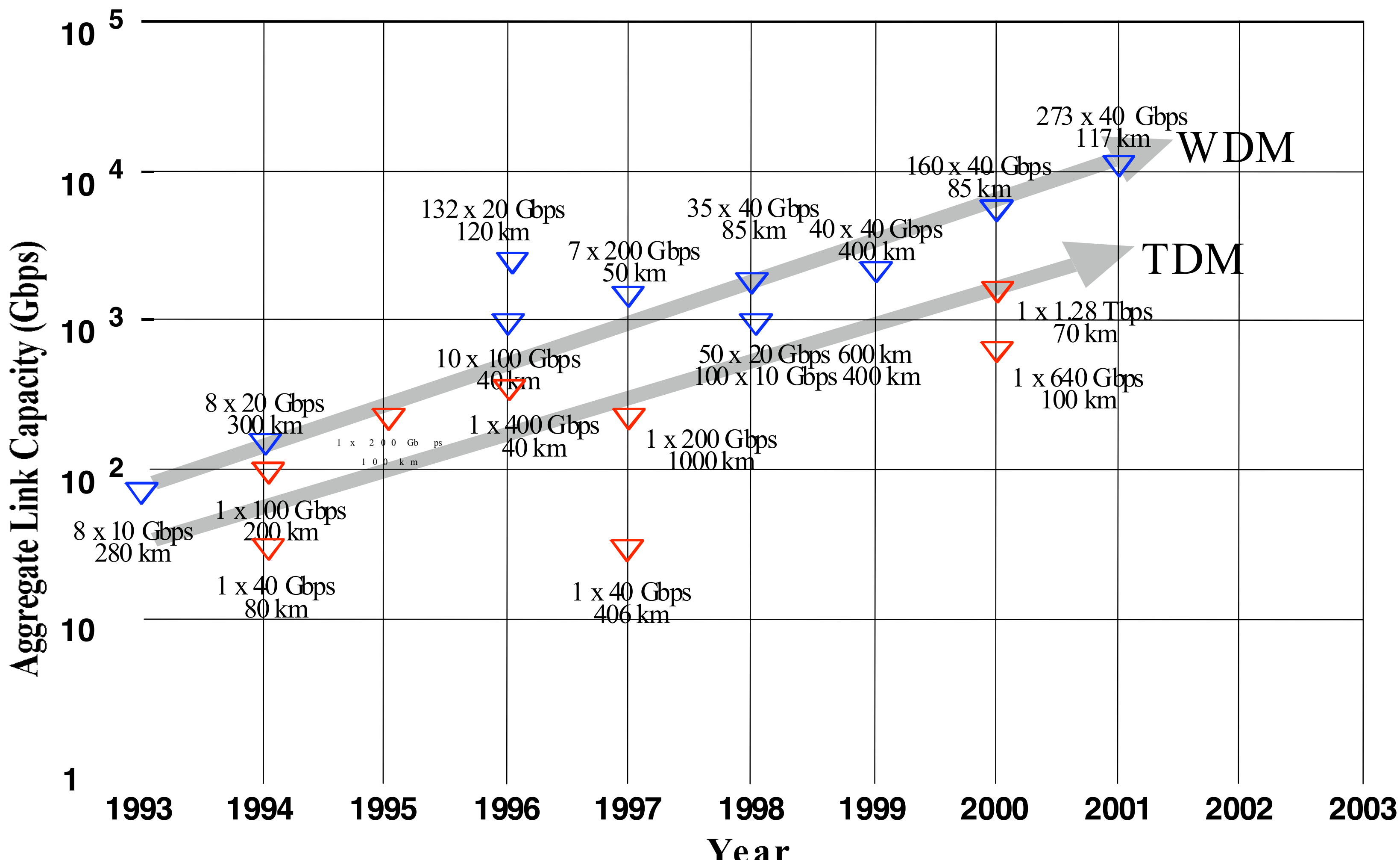
Multichannel WDM @1550 nm. Number of channels and channel spacing limited by fiber four-wave mixing (FWM)

Mid 90s

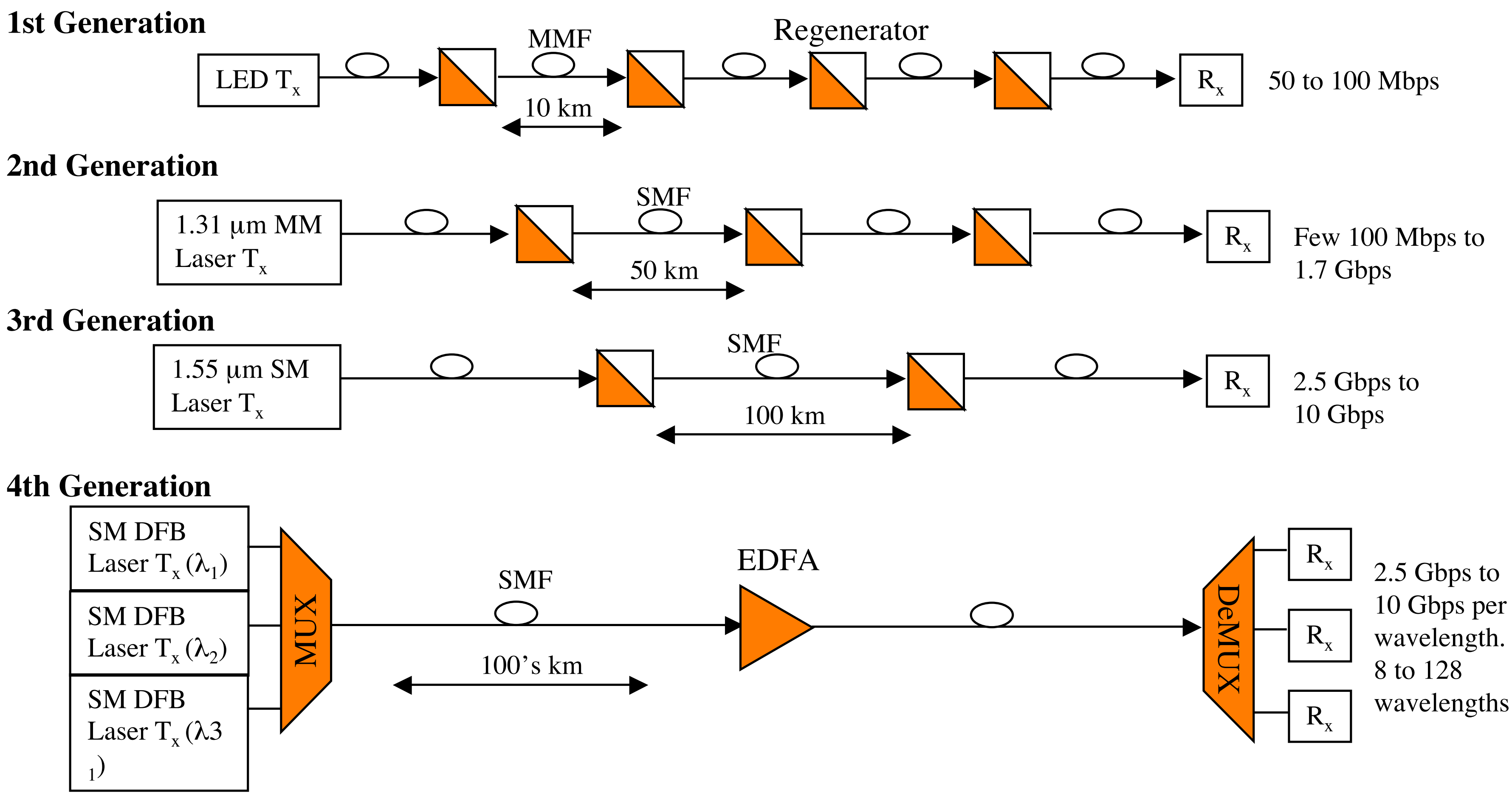
Optical Solitons, dispersion compensation

1st Generation | **2nd Generation** | **3rd Generation** | **4th Generation** | **5th Generation**

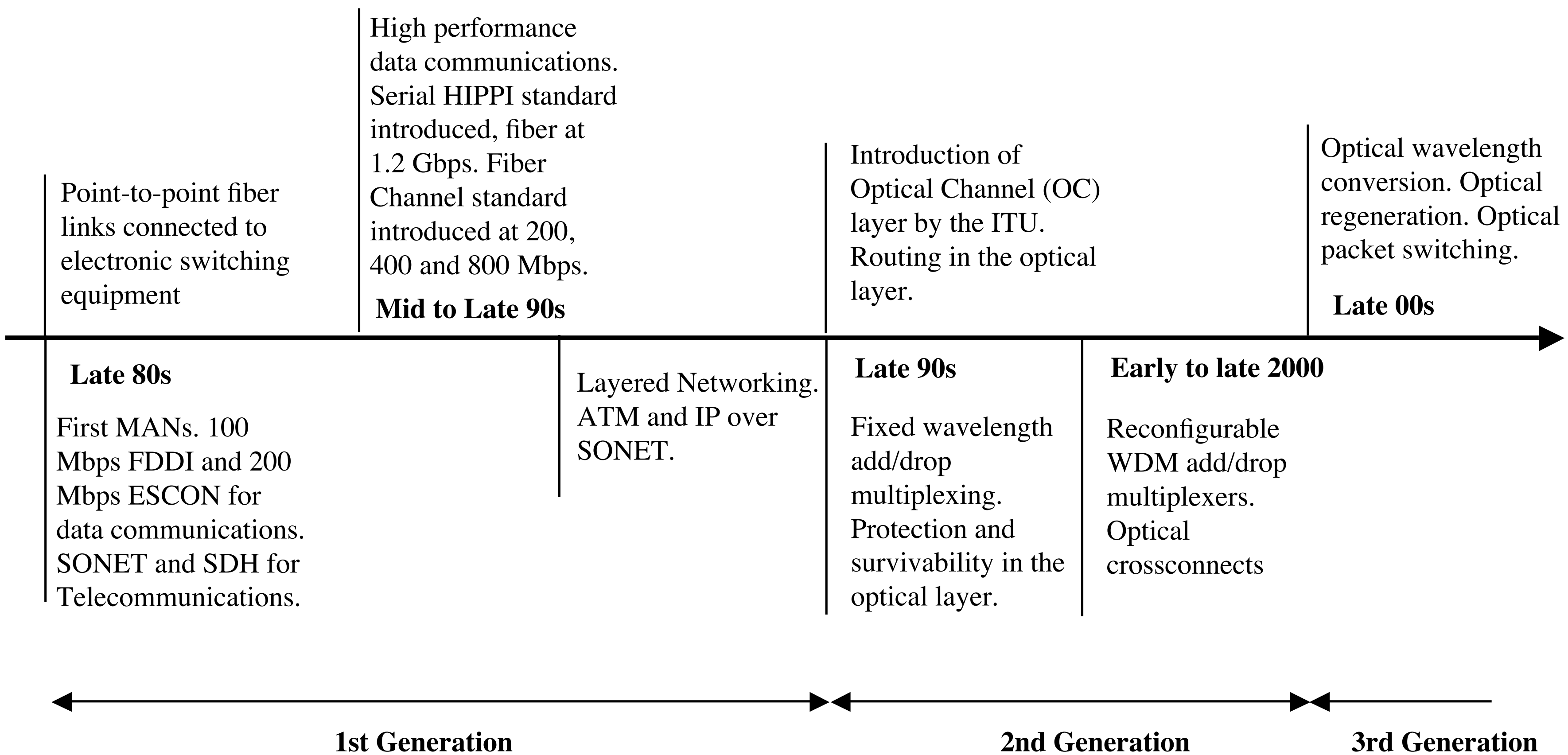
Transmission Bandwidth Evolution



Capacity and Repeater Spacing



Evolution of Fiber-Optic Networks



Networking Overview

Introduction

- This session briefly introduces some issues related to communication networks
  - The concept of network layers
  - Circuit and packet switching
  - The most important network protocols
  - Network management (survivability, restoration etc)
  - Transparency
  - Scalability
- It is meant to give a common terminology and framework for the next sessions
  - It is not strictly related to *optical* networking

Bibliography on Networking

- **On the OSI model:**
  - **Computer Networks**, 3rd edition, *A.S. Tanenbaum*, Prentice-Hall Inc, 1996, (one of the most famous texts in the field)
  - **Computer communications**, 2nd edition, *K.G. Beauchamp*, Chapmen & Hall, 1993 (a good overall view of networks)
- On SONET/SDH, ATM and high speed networking
  - **Broadband Networking**, M. Sexton, A. Reid, Artech House,1997
  - **High speed digital transmission networking**, G. Held, J. Wiley&S, 1999

Who's who in standards

- ISO: International Standard Organization
  - an international agency for the development of standards in many areas
  - currently 89 member countries including: Britain, France, USA
  - consists of several national standard bodies
- ITU: International Telecommunication Union (formed in 1993, ex- CCITT International Telegraph and Telephone Consultative Committee)
  - The ITU-T publishes standards (ITU-T Recommendations) covering all fields of telecommunications except radio aspects
- IEEE: Institute of Electrical and Electronic Engineers
  - the IEEE standards for local area networks have subsequently been used by ISO as the basis for its standards on LANs
- ANSI: American National Standard Institute
- IETF: Internet Engineering Telecommunications Forum
  - IP centric network based standards

The OSI model

- The Open System Interconnection (OSI) model developed by ISO is often taken as a reference in communication networking
- It is based on a seven *layer* structure

Layer	Name
7	**Application**
6	**Presentation**
5	**Session**
4	**Transport**
3	**Network**
2	**Data Link**
1	**Physical**

- It is mostly a theoretical model that describes how applications on any network maycommunicate with each other
  - Real protocols do not map *exactly* on OSI
    - TCP-IP has 6 layers
    - SONET/SDH has 4 layers
- Still, the OSI ideas and terminologies are common to *most* protocols

OSI layers

- OSI is mainly intended for data-centric networks (packets), i.e. for computer interconnects
- Basic idea:connecting computers, transmitters and receivers together in an open system
- Each layer:
  - Receives information from the layer above
  - Adds some functionality
  - Passes the information the the layer below
- OSI thus defines:
  - The functions of each layer
  - The interfaces between layers

Layer 1: Physical Layer

- Defines the physical and electrical and optical characteristics of the network
  - Concerned with the description of the physical circuits and the transmission of bits
  - Ensures that when one side sends a “1”, the other side of the “wire” receives a “1” with a high level of reliability
  - For example, defines:
    - Voltages or power levels used to represent a 1 and a 0
    - Bit rate, modulation format
    - Handshaking required for transmission to take place
    - Other physical parameters, such as connector types, cable type, etc

Layer 2: Data Link Layer

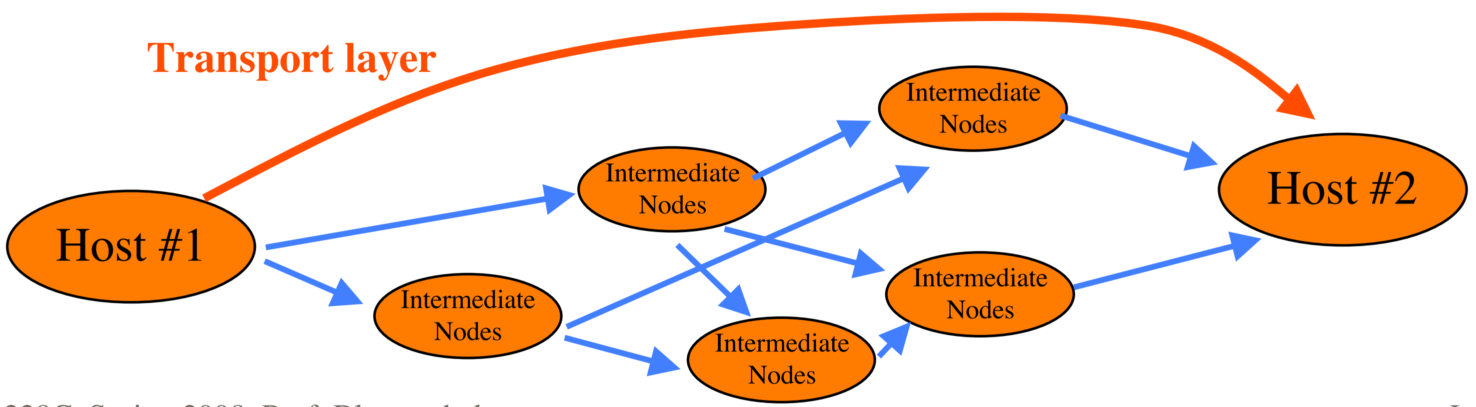
- Turns the raw transmission facility into an error free digital link
  - the data link layer breaks data into frames
  - provides error detection and correction mechanisms upon these frames
- To achieve this target, the Data link needs to:
  - recognize the boundaries of each frame
  - determine the correct sequence of frames
  - regulate how many frames arrive over a specific period
- When several transmitters share the same physical channel, the Data link layer has to define a Medium Access Control (MAC) protocol
- Layer 1 and 2 are not meant to take into account the network global structure
  - They mainly implement a reliable way to transmit packets between two points of the network connected by a “wire”

Layer 3: Network Layer

- It provides the transfer of data between two hosts on a given network topology
  - the simplest connection may be a direct link between two stations
  - alternatively, at the other extreme, the connection may be over many different networks which are linked together via gateways
- the Network Layer must therefore be responsible for
  - the establishment, maintenance and termination of the connection between two hosts across any intervening communications facility
  - it must deal with problems of addressing, routing and prevention of bottlenecks
  - some accounting - to detect bottlenecks before they arise!

Layer 4: Transport Layer

- Layer 4 primary task is to hide all the network dependent characteristics from the layers above it
  - Provides transparent data transfer
  - All the protocols defined for the transport layer will only need to be implemented on the host computers and not on any intermediate computers in the network
- The transport layer:
  - establishes and maintains a logical connection with the corresponding transport layer on a remote host
  - uses this connection to transfer data

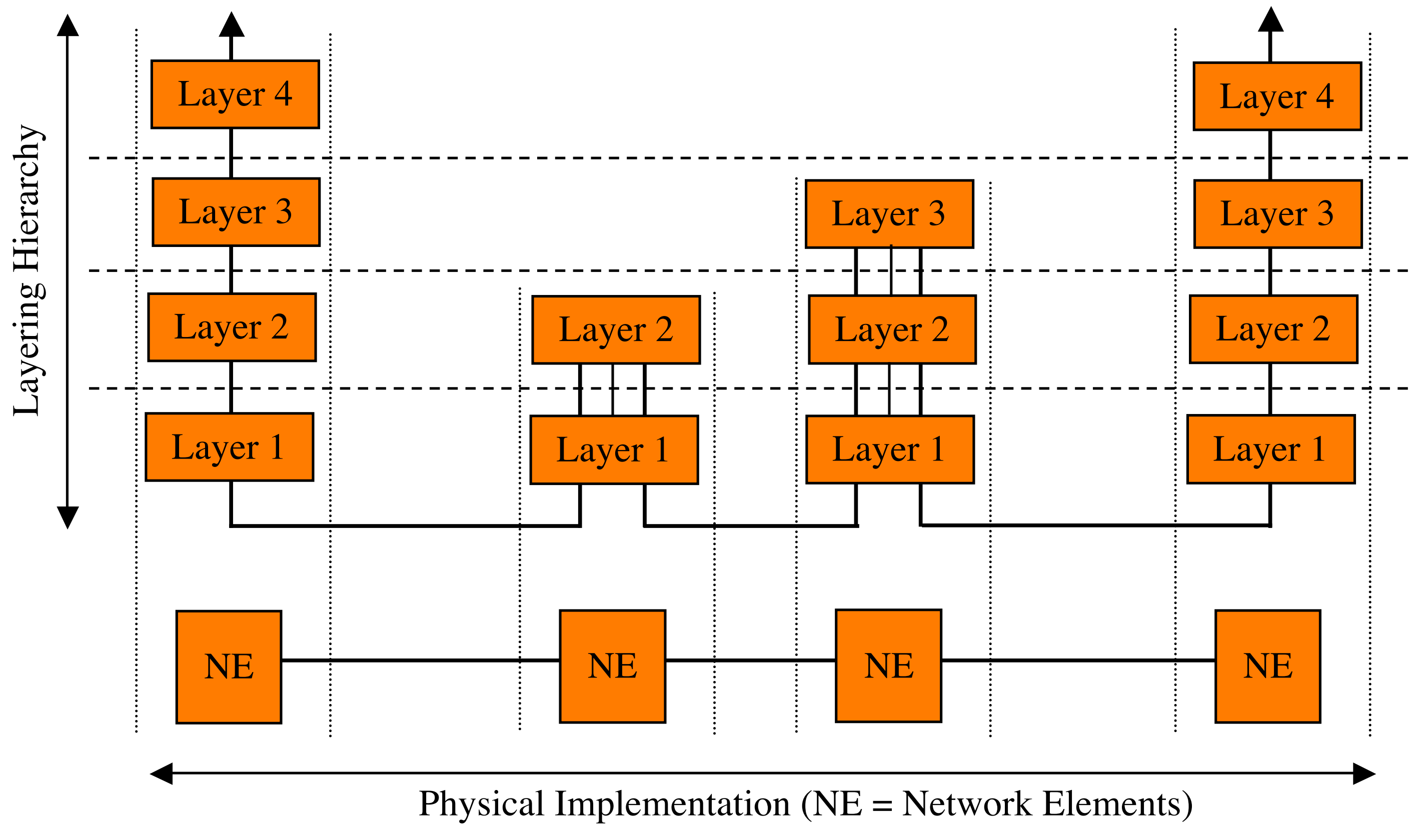


Layers above Layer 4

- Layers 5 to 7 (Session, Presentation and Application) are related to user interfaces, and are outside the scope of this course
  - Session layer
    - the period of time for which two users remain logically connected (even though not transmitting data continuously) is known as a session
    - purpose of the session layer is to provide a user-oriented connection service
    - a session protocol may provide a user interface by adding to the basic connection service
  - Presentation Layer
    - presentation layer is concerned with the format of the data being exchanged
    - it provides a set of data transformation services, typically including formatting and data translation
    - e.g.. if one user might use ASCII codes for character representation whereas another user might use EBCDIC
    - the presentation layer provides the code conversion
  - Application Layer
    - the highest layer in the reference model and is the environment in which user's programs operate and communicate
    - This layer therefore contains management functions and generally useful mechanisms to support distributed applications
    - protocols are provided for functions such as file transfer and electronic mail (ftp, mail, telnet)

Layered Network Architectures

- Note that at the two ends of the connection, the layering goes up to the highest OSI layers, while intermediate nodes may implement just 2 or 3 levels



Circuit and Packet switching

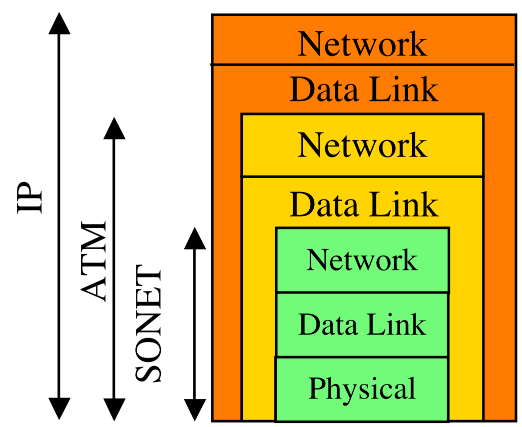
- Circuit switching
  - Typical of traditional voice applications (standard telephony)
  - A given communication is set up on a given path along the network, then it is available (apart from failure) till the end of the connection
  - A given bandwidth is totally and always available for all the duration of the connection
  - Example: SONET/SDH
- Packet switching
  - Typical of data-centric applications (networks of computers)
  - A packet (organized group of bits) is sent along the network, in a connectionless way
  - Subsequent packets may be routed differently along a mesh network (datagram)
  - Some packets may be lost along the link
  - The available bandwidth depends on the network load
  - Examples: TCP-IP, Ethernet, *postal service*

Comments on the OSI model

- The OSI layering concept is at the basis of all modern communication networks
- Even though OSI was mainly studied for packet-switched computer networks, it anyway maps quite well on other kind of networks, such as
  - Connection-oriented, circuit switches networks, based on SONET/SDH
  - Virtual circuits (packets in a Connection-oriented approach), based on ATM
  - Simpler protocols, such as Ethernet, FDDI, etc

Stack of protocols

- In most cases, several protocols are used in a layered approach
  - For example, in backbone networks, IP is typically carried over ATM, which in turn is carried on SONET
- Each of the protocols then has its own layering, which is always somehow mapped on the OSI standard
  - SONET has its own three layers, approx. corresponding (even though with different names) to the OSI Physical, Data and Network layers
  - The SONET network layer gives to ATM a point-to-point network, over which the ATM data layer is based
  - Again, the procedure is iterated for the IP over the ATM network layer



Stack of protocols

- Each layer of each protocols must give to whatever reside above it a reliable service, with respect to given specifications
- The interfaces among layers have to be defined in detail
  - In the interfaces between layers of a given protocol, the packet is partially modified, by adding some information, coding, etc
  - In the interfaces between different protocols, packets may be completely reorganized
- The interworking among different protocols (and different vendors) is a very important and difficult issue
  - Moreover, particularly in backbone transport network, a extremely high degree of reliability is required

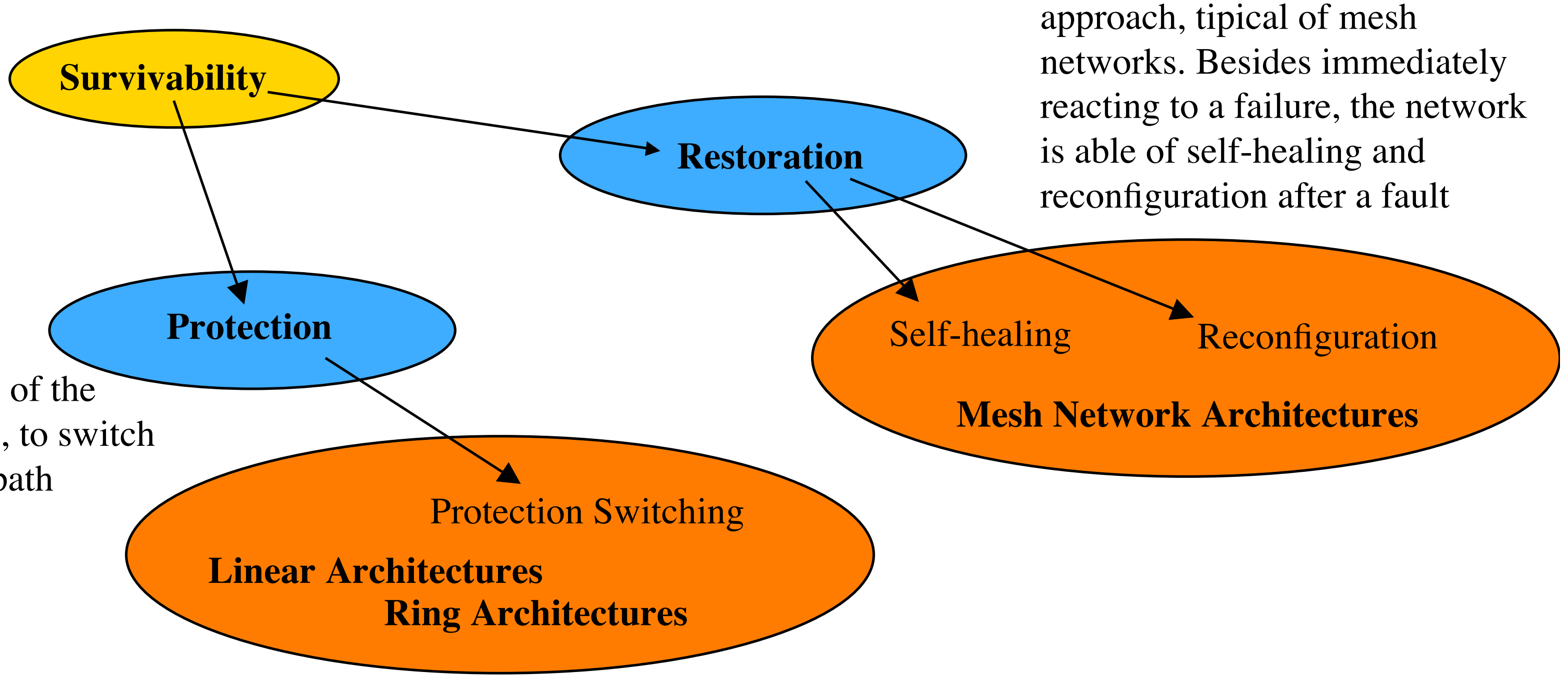
Network Operation and Management

- A communication network is not only a "raw transport" network, but should implement several other functions, such as:
  - Configuration Management
    - Manage the setting up and taking down of connections. Dynamic allocation of network bandwidth and provisioning.
  - Performance Management
    - Manage monitoring of channel, link, node and network performance.
  - Fault Management
    - Responsible for detecting failures and restoring traffic.
  - Security Management
    - Manage data protection, encryption, coding
  - Accounting Management
    - Manage billing and other record keeping functions

Network Survivability/Fault Management

- Survivability: The network’s ability to continue to provide services on spare network capacity in the presence of failures
- It is a fundamental requirement in backbone network, whose failure rate should be extremely low

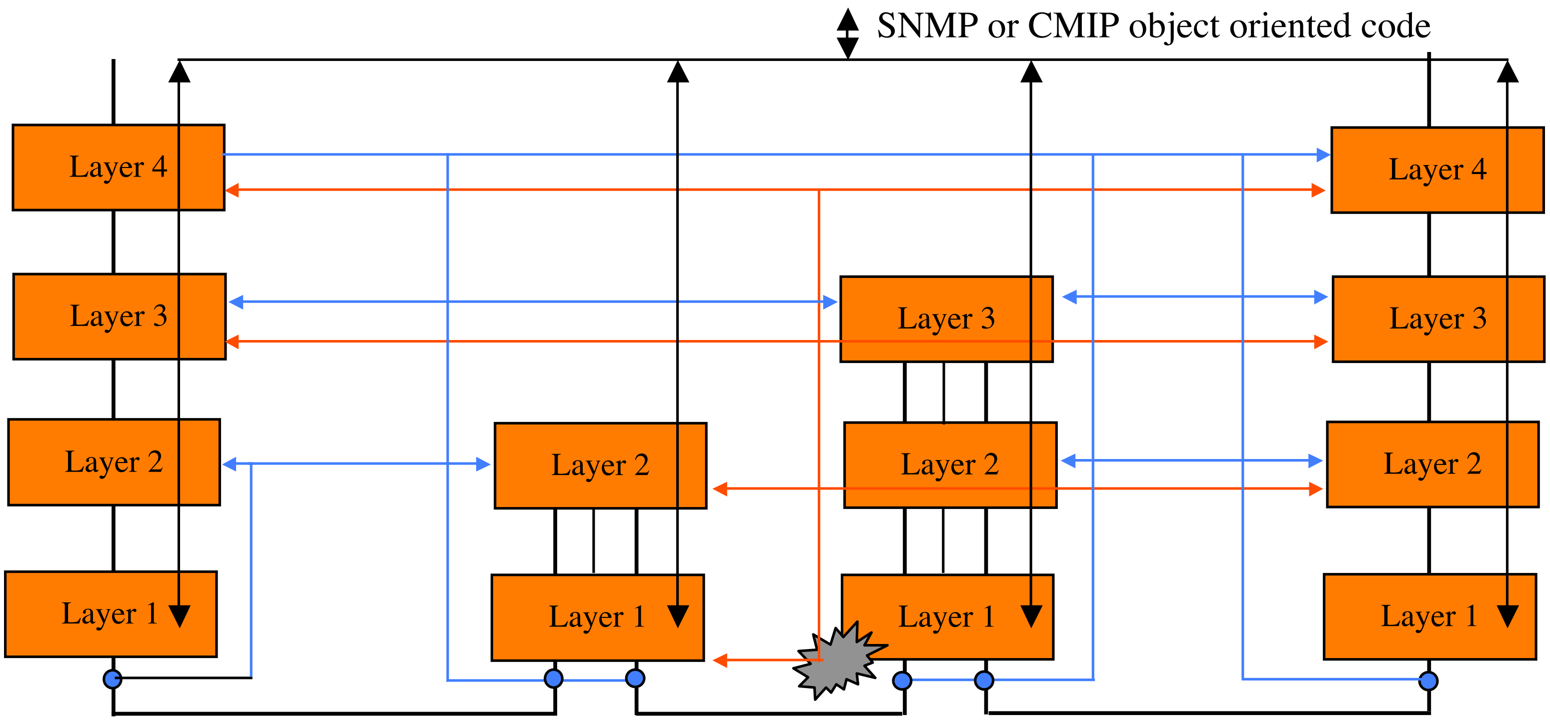
Restoration: a more complex approach, tipical of mesh networks. Besides immediately reacting to a failure, the network is able of self-healing and reconfiguration after a fault



Protection:
“immediate” response of the network after a failure, to switch the traffic on another path

Network Operation and Management

- On complex, mesh network, one of the most difficult task is how to efficiently disseminate link, node and network state information
- Several network element must be "network-aware"



SNMP Simple Network Management Protocol
CMIP Common Management Information Protocol

Network and Connection Transparency

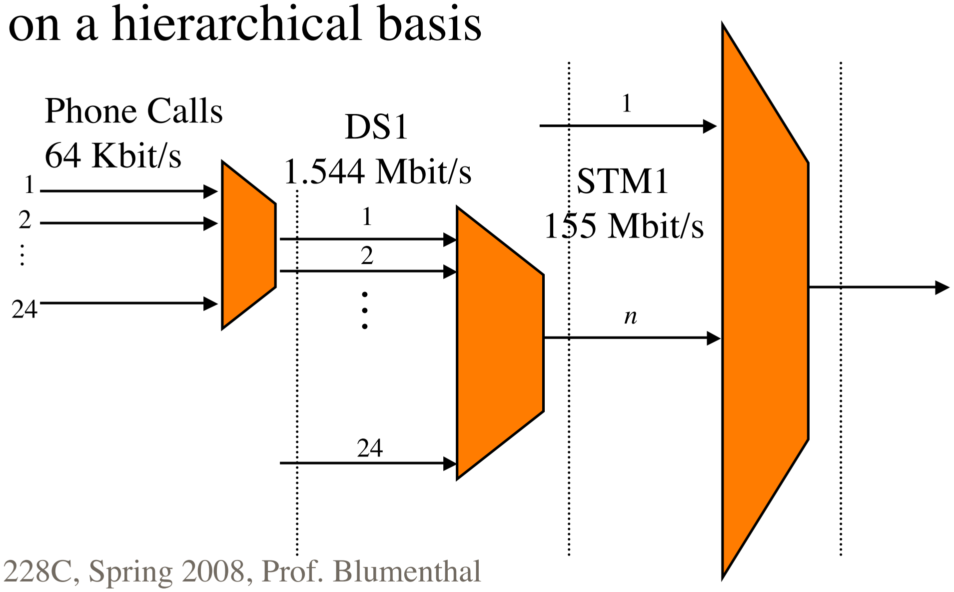
- There is often some ambiguity on the concept of transparency
- When applied to level 2 and 3, we should talk about the "degree of network transparency"
  - Support different network/link/physical layer types (SONET, ATM, IP, etc.)
  - Support traffic with different characteristics (bursty, non bursty, connection, connectionless, different quality)
- When applied to level 1 (physical layer) i.e., to raw physical transmission, we should talk about the "degree of physical transparency"
  - Support different bit-rates
  - Support different modulation formats
  - Support different power levels
- One of the main advantages of second generation optical networks it their potential to give some form of physical transparency, and to give to the higher layers a total network transparency

Network Scalability

- Scalability is another important concept in communication networks
- A successful network architecture MUST be reasonably scalable, i.e.:
  - It should be able to grow (i.e., to cope with increasing traffic demand) without requiring to completely re-design the network
- The scalability strategies should work in such a way that a network upgrade can be implemented while the rest of the network is operating (i.e. without requiring out-of-service in the rest of the network)
- One of the main advantages of second generation optical networks it their potential high degree of scalability

Multiplexing & Grooming

- Multiplexing (or traffic grooming) is the set of techniques that aggregate traffic generated from different sources over the same physical medium
- In transport networks, efficient multiplexing/demultiplexing is one of the key issues
  - Note that a phone call requires 64 Kbit/s, meaning that approx. 156,000 phone calls may travel simultaneously on a single channel at 10 Gbit/s
- In order to simplify the multiplexing problem, usually multiplexing is done on a hierarchical basis



Hierarchical Multiplexing

- In a hierarchical multiplexing, each multiplexing level has, at its input, a set of tributaries at a given bit rate
  - The bit rate of each of the tributaries increases going up in the multiplexing hierarchy
  - Again, like in network layering, the basic idea is to "iterate" the same process
- Hierarchical multiplexing allows to:
  - Maintain a reasonable multiplexing/demultiplexing complexity (due to the "iteration" idea)
  - To use, at each level, the proper protocols and transmission formats most suitable for that particular level of data grooming
  - To allow, by proper interfaces, multiplexing of traffic at potentially very different data rates (multi-service)

Multiplexing and Transport Networks

- A transport network, from a very general point of view, has to carry an extremely heterogeneous variety of data traffics, ranging from:
  - Voice channels at 64 Kb/s
  - Dedicated channel at extremely high bit rate, up to hundreds of Mbit/s and more (usually leased lines)
- The "edges" of the network tends to carry a very high number of tributaries at fairly low bit rate (which tends anyway to increase with the diffusion of new services for the final user)
- The "core" of the network has to carry a relative lower number of tributaries at very high bit rates
- Different levels of grooming may require different approaches, in terms of:
  - Protocols
  - Physical transmission
  - Multiplexing devices/techniques (TDM, WDM, SDM)

Multiplexing and Optical Networks

- In most of today transport network, all multiplexing functions are performed by electronic equipment (hubs, switches, routers, etc)
  - These equipments are extremely complex
  - Protocols are implemented in software (or firmware)
  - They can be thought as huge workstations whose task is the multiplexing, demultiplexing and routing of data (besides may other higher layers functions)
- As soon as, in the multiplexing hierarchy, the aggregate bit rate is sufficiently high, fibers are used as the preferred transmission medium
- Transport networks are today nearly completely based on optical transmission

⮑ *First Generation Optical Networks*

- When the traffic grooming has reached the “wavelength level”, then it is possible to use the photonic domain also for multiplexing-routing functions

⮑ *Second Generation Optical Networks*

On the Definition of Optical Networks

- The term "Optical Networks" is used in different ways
  - In some scenario, a network is said to be "optical" provided that fiber is used "somewhere" along the network links
- Some authors uses the following convention:
  - Optical networks *(= first generation optical networks)*
    - Fiber is used for transmission, the rest is electronic
  - All-Optical networks *(= second generation optical networks)*
    - Fiber is used for both transmission and some form of routing functions
- More ambiguity in the terminology arises in those solutions where a mix of optical and electrical routing is performed
- Mostly, even when talking about all-optical networking, the typical functions implemented in optics are circuit-switching functions
  - Usually, if packet-switching is performed (like in some advanced research testbeds), the used term is "all-optical packet switching"