Optical Networks [EENGM0003]

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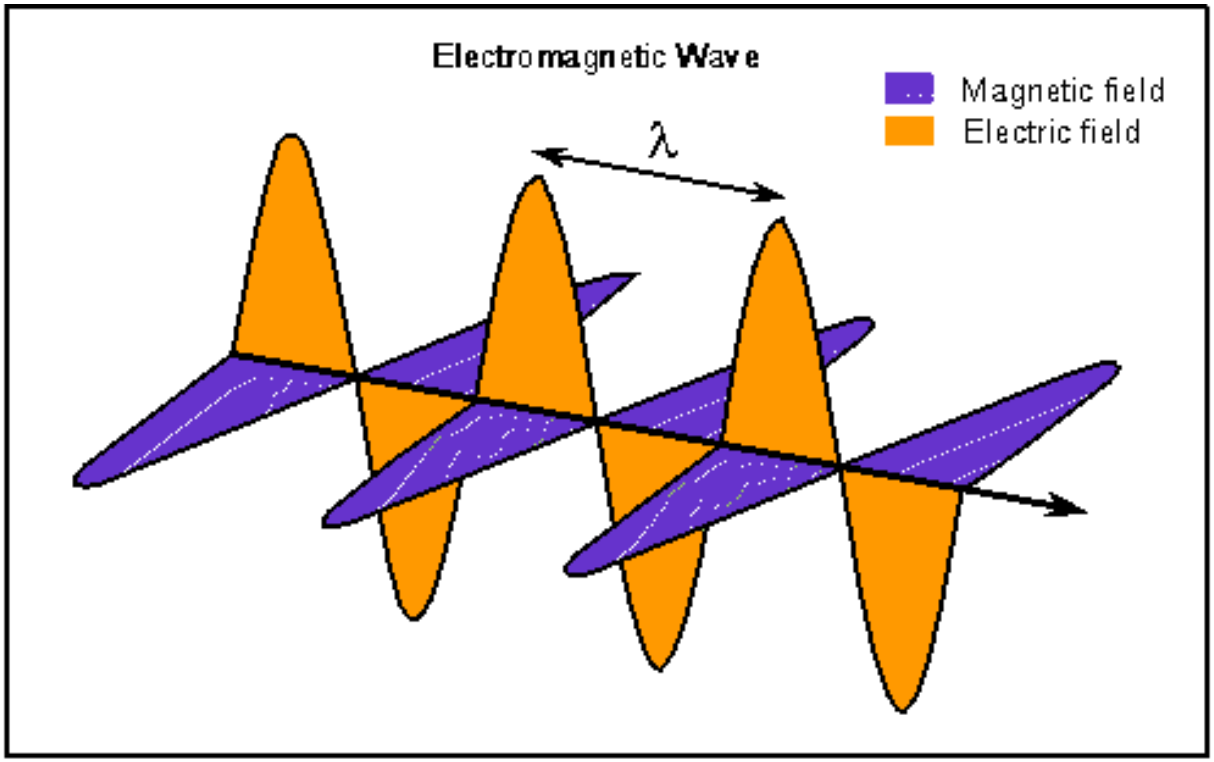
Session 2 outline

- Optical Modulation formats
- Optical multiplexing techniques
- Optical network topologies
- Layers of optical networks

Properties of lightwaves

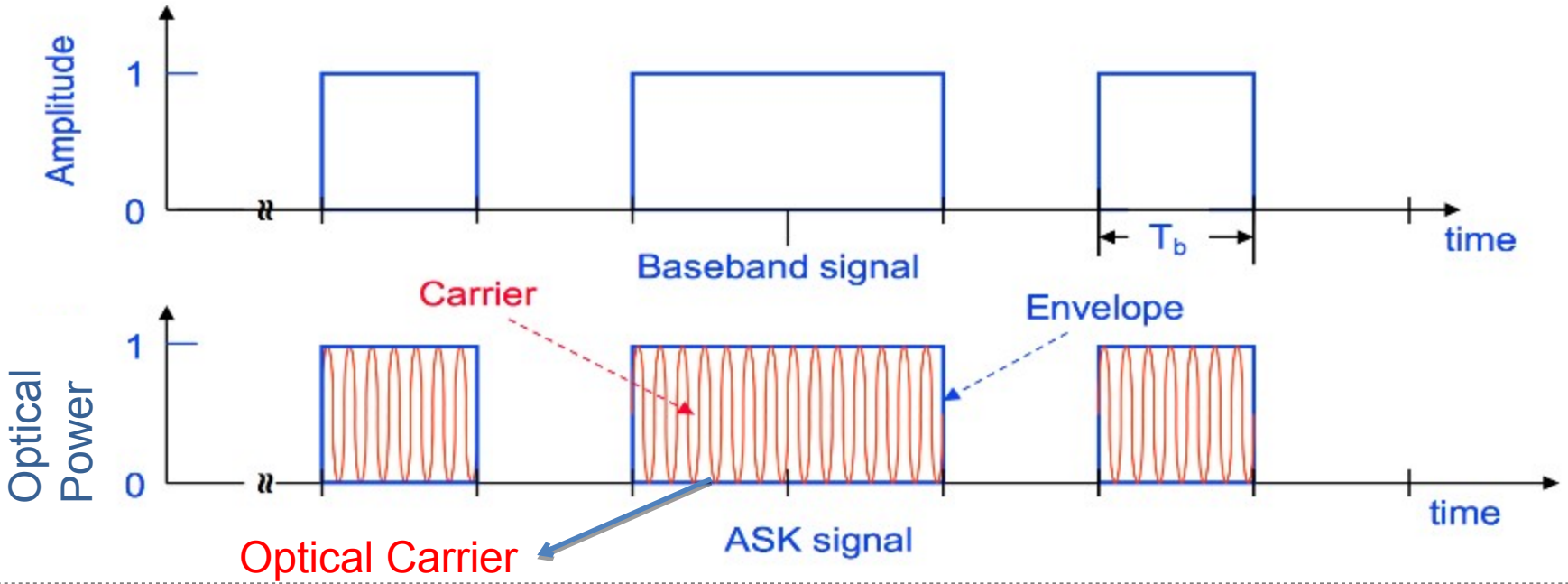
$$E(t) = A(t) \cdot \cos\left[\omega(t)t + \varphi(t)\right]$$

- Amplitude
- wavelength
- Phase
- Polarization
- Direction



Optical modulation [intensity modulation]

- Modulating the intensity of the optical carrier is called “intensity modulation”
  - If the information is digital then the format is known as “ amplitude shift keying” or ASK.
  - The format is also known in optical communications as “on off keying”, (OOK).



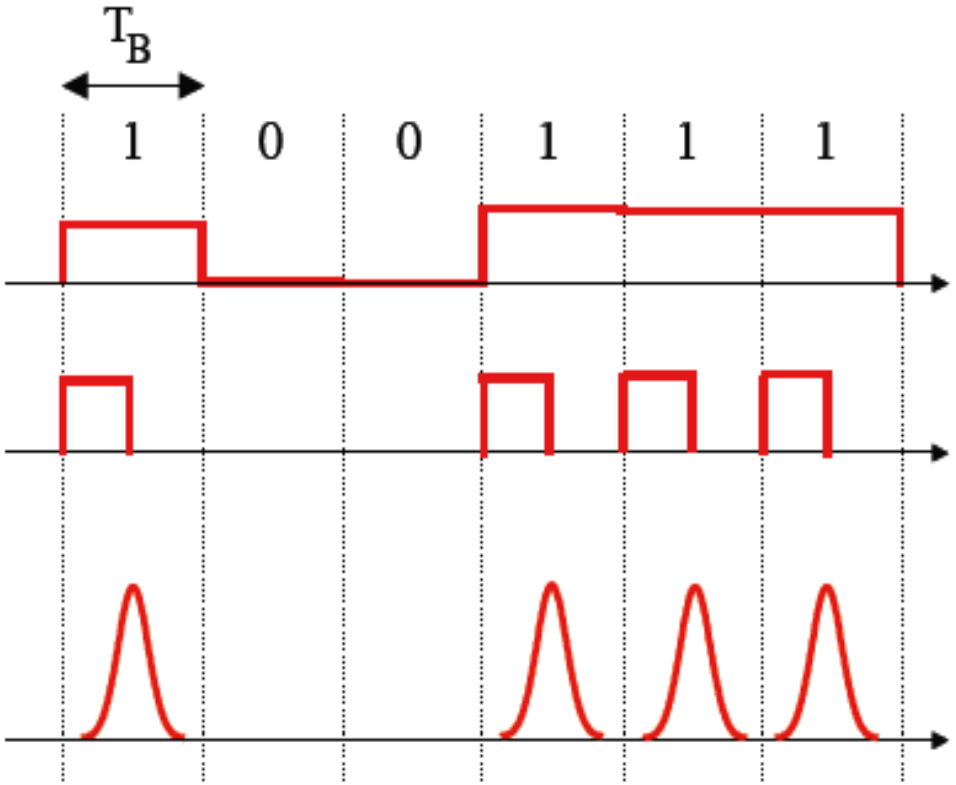
Optical modulation [intensity modulation]

- The simplest modulation format used for commercially deployed optical systems are intensity modulation (optical power modulation)

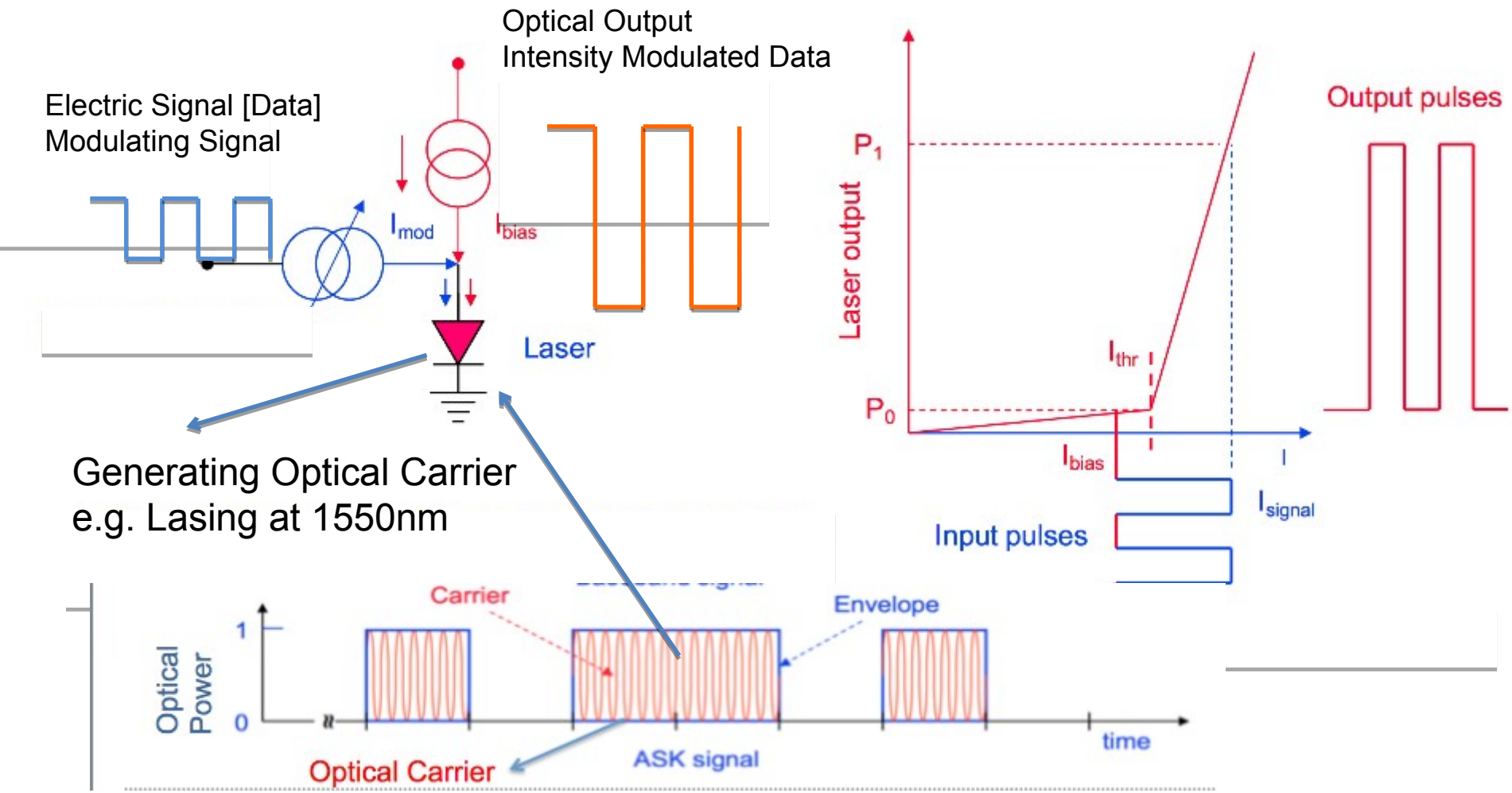
Non Return to Zero
NRZ

Return to Zero
RZ (50 % dc)

Pulsed
RZ (gaussian-like or soliton-like pulses, can be less than 50% dc)

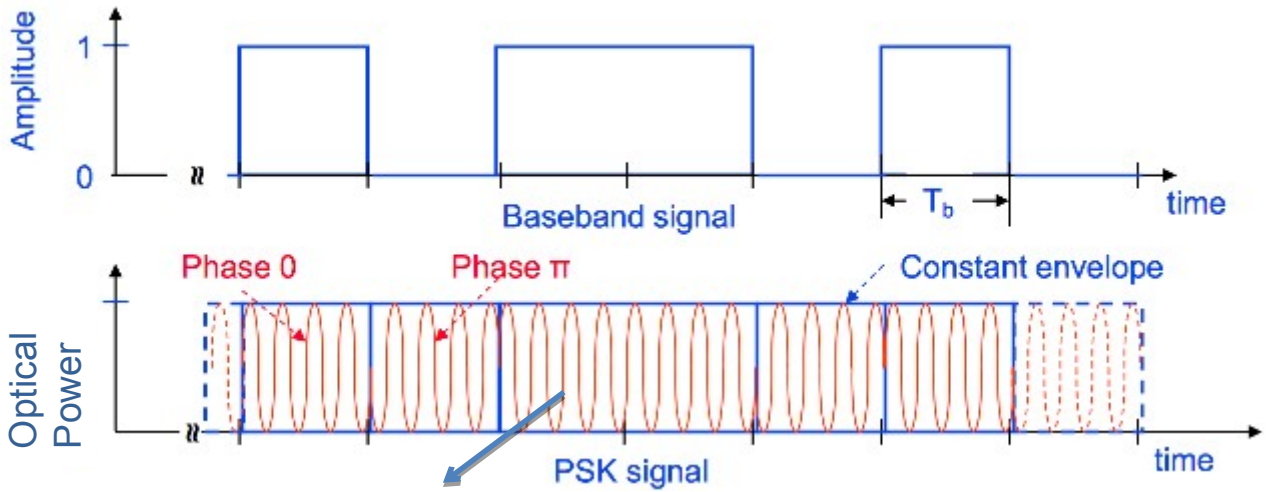


Optical modulation [intensity modulation, direct modulation]



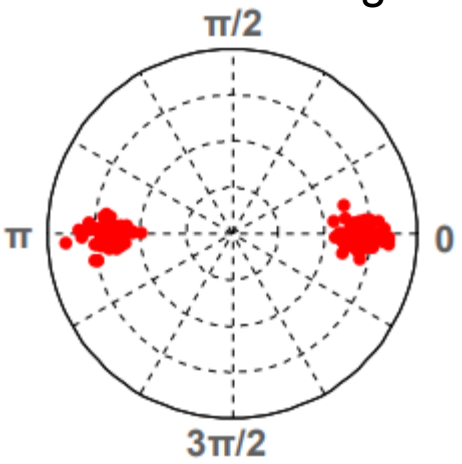
Optical modulation [phase modulation]

- Optical phase modulation is the modulation of the phase of the optical carrier
  - For digital baseband signals is known as “phase shift keying”, (PSK). In this
  - format the phase of the carrier switches between “1” and “0” shifts by, say, 180^{o}



Optical Carrier e.g. lasing at 1550nm

Constellation diagram



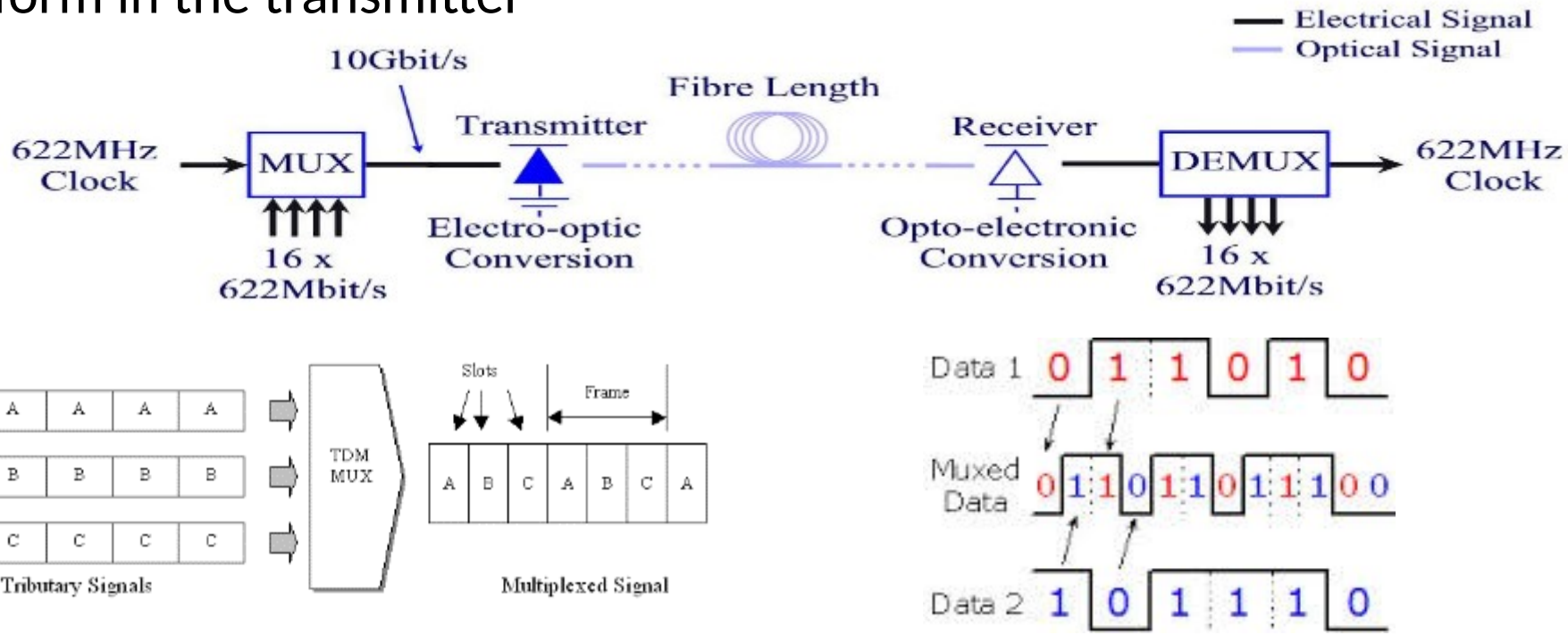
Signal has to be compared with LO

Multiplexing

- Transmitting several signals over a single communications channel
- Common multiplexing technologies used in optical domain
  - **Deterministic Multiplexing:**
    - Transmission medium is divided between a fixed number of communication channels
    - Frequency Division Multiplexing (modulating data into different sub-carrier frequencies)
    - Wavelength Division Multiplexing (multiplexing wavelengths into a single fibre)
    - Time division Multiplexing (dividing available time among various signals)
  - **Statistical Multiplexing (dynamic allocation of time and or frequecny** spaces depending on the traffic pattern)
    - Requires buffering resulting in variable delay
      - Information have to be delayed
      - Some information may be lost

Multiplexing in optical communication [Optical-ETDM]

- Number of lower speed (baseband) sub-channels multiplexed in time domain using electronics forming aggregate (total) signal
- This electrically multiplexed signal then converted into optical form in the transmitter



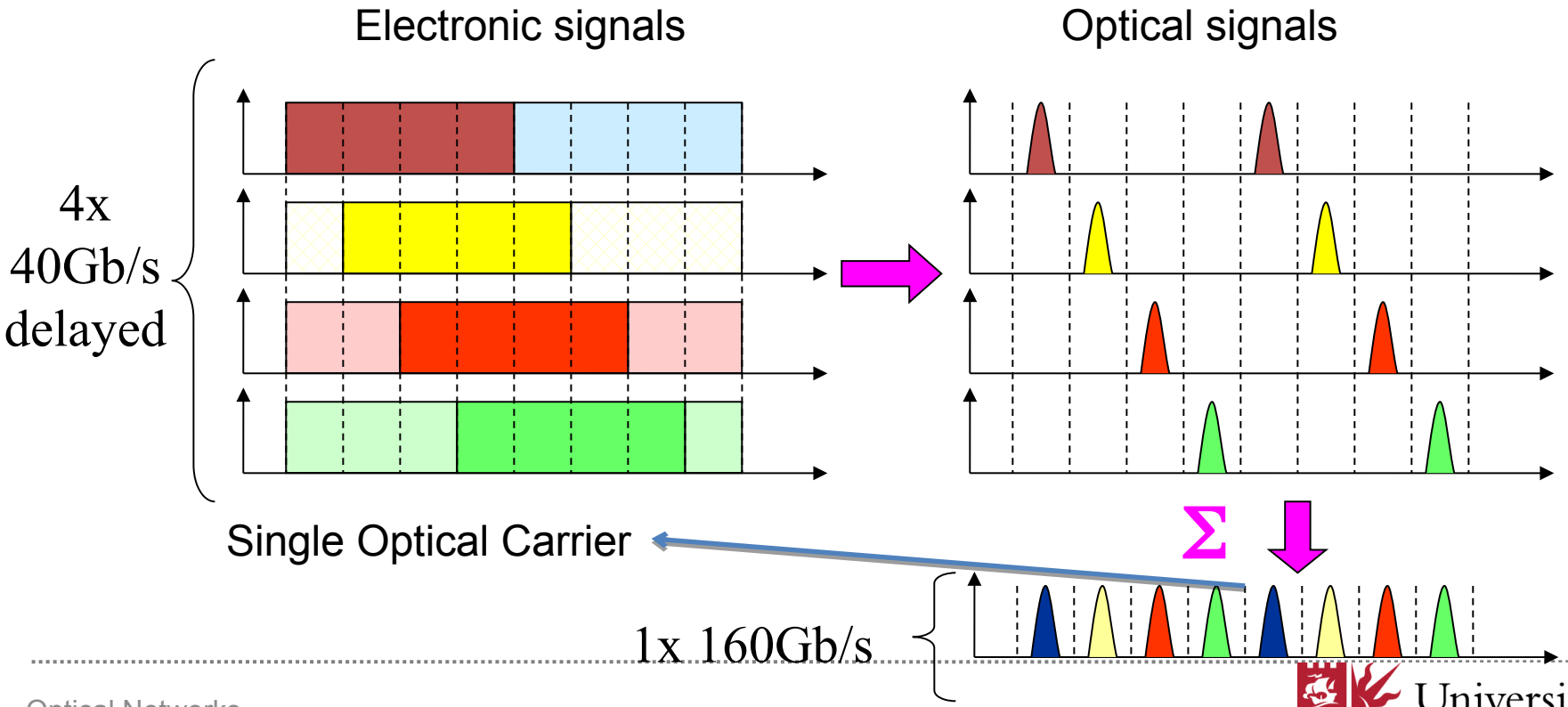
Multiplexing in optical communication [Optical-ETDM]

- Bellcore came up with Synchronous Optical Network (SONET) while ITU in Europe came up with Synchronous Digital Hierarchy (SDH)
  - SDH based on 155.52Mbit/s
  - SONET based on 51.84Mbit/s

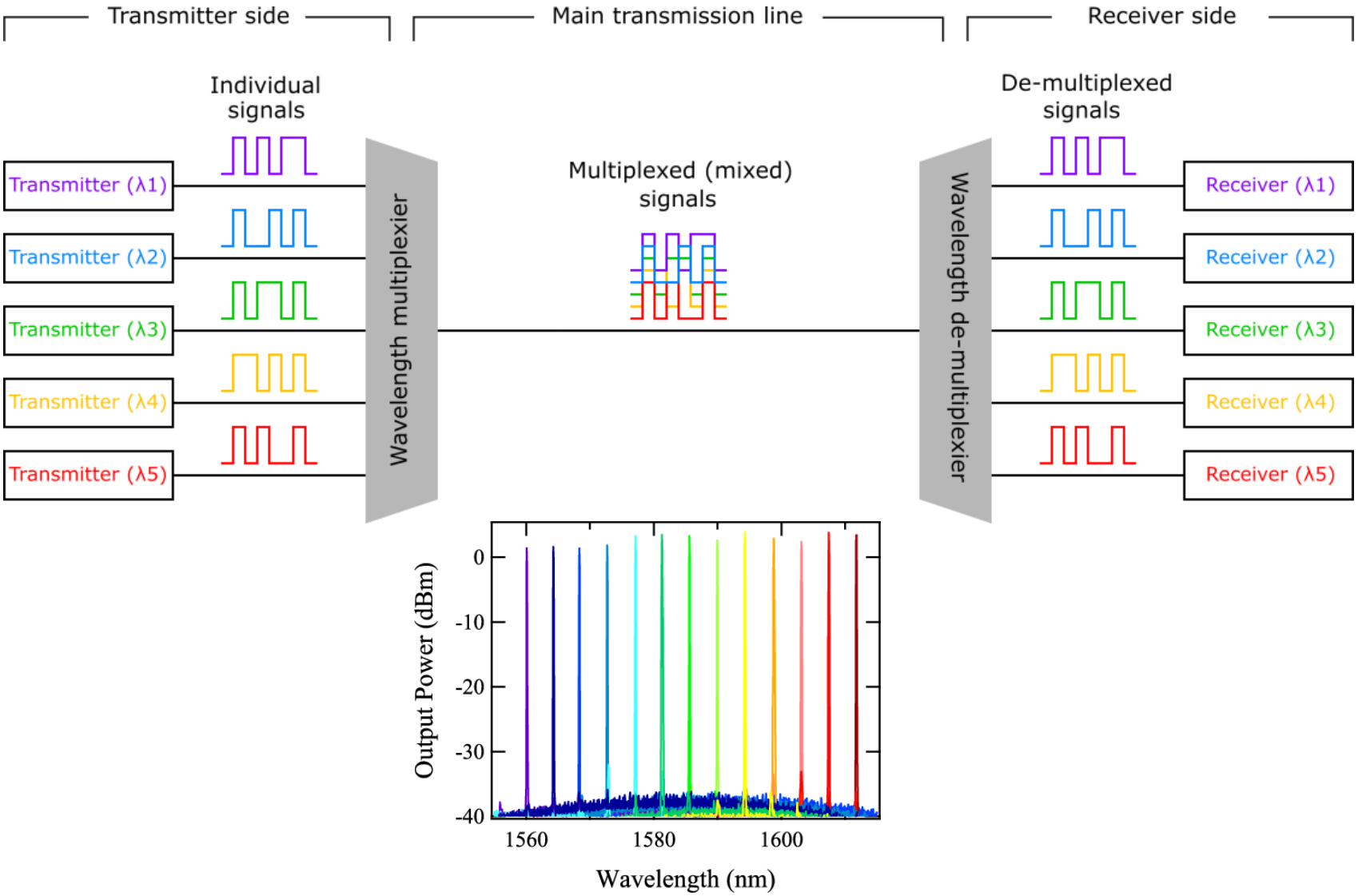
SONET	Optical	SDH	Ch. Data Rate (Mbit/s)
STS-1	OC-1	-	51.84
STS-3	OC-3	STM-1	155.52
STS-12	OC-12	STM-4	622.08
STS-48	OC-48	STM-16	2,488.32
STS-192	OC-192	STM-64	9,953.28
STS-768	OC-768	SMT-256	39,813.12

Multiplexing in optical communication [Optical-OTDM]

- In OTDM , electronic signals are converted to optical signal and time multiplexed optically
  - It is practically difficult to achieve
    - Requirements for Optical synchronization and High speed electro-optic
    - Sensitive to fibre nonlinearity

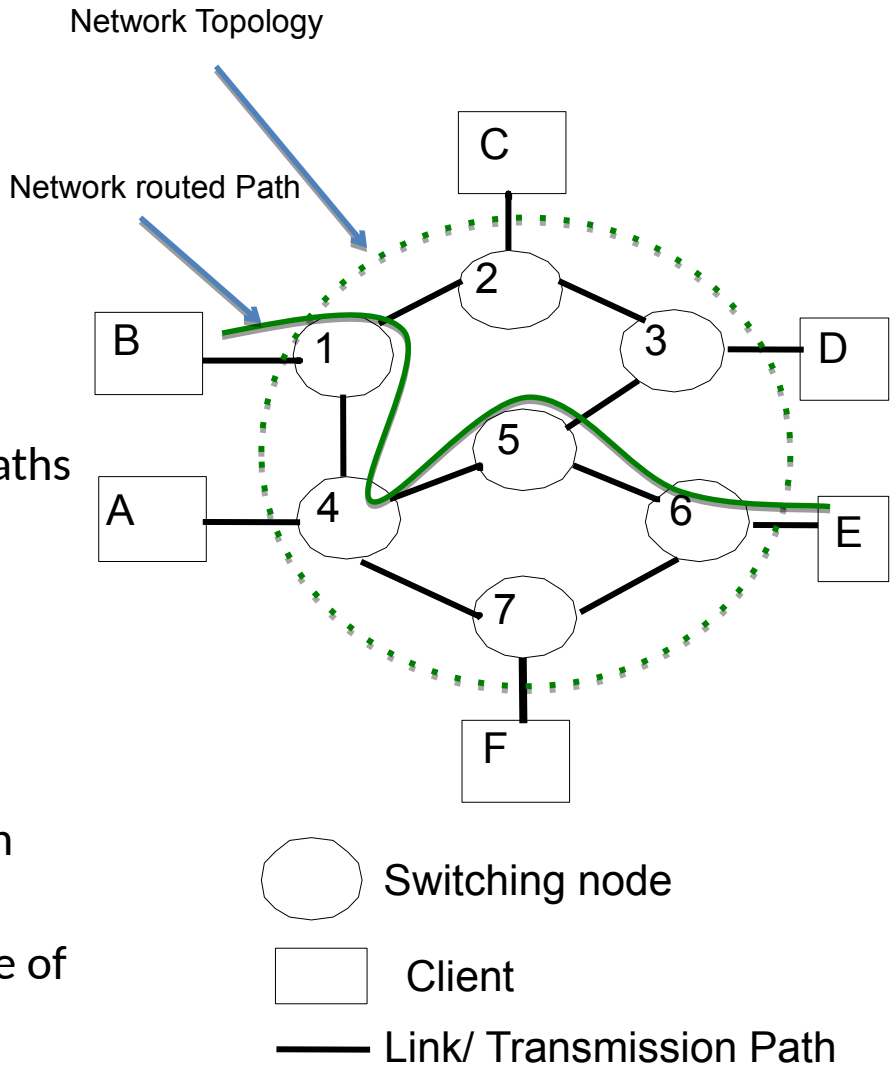


Wavelength Division Multiplexing (WDM)



Network terminology

- **Clients**: Devices that want to communicate with one another (computer, phone…)
- **Network**: Transmission paths connecting clients together (e.g. optical network)
- **Transmission paths**: are transmission lines that support transport of traffic loads (e.g. fibre)
- **Nodes**: connecting multiple transmission paths and clients together
- **Topology** : The way in which the nodes are linked together (bus, star, ring)
- **Switching nodes:** are nodes that switch information between transmissions path
- **Routing**: Selection of a suitable path though the network
- **Protocols**: Rules for the successful exchange of information across the network

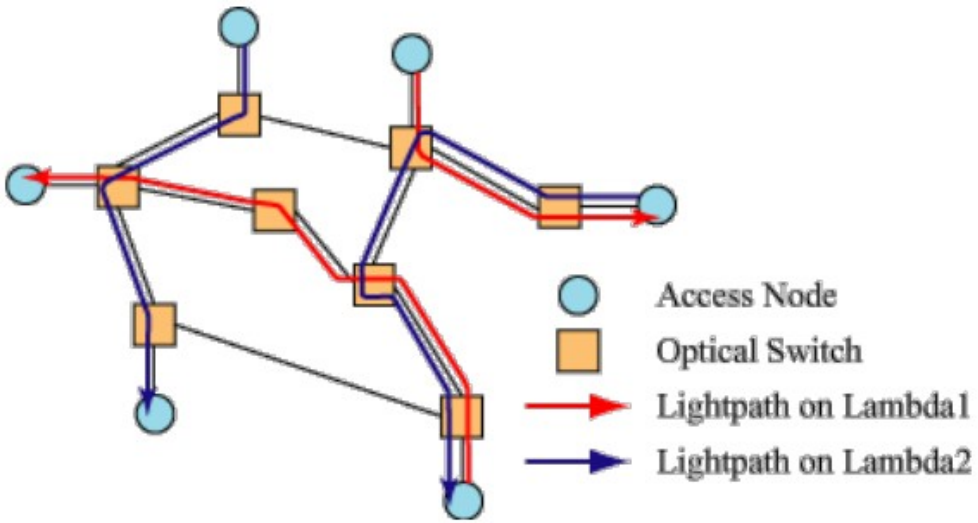


Optical network topology

- In a communications network the interconnection between clients can be achieved in a number of ways.

- The architecture used must satisfy economic and technical requirements.

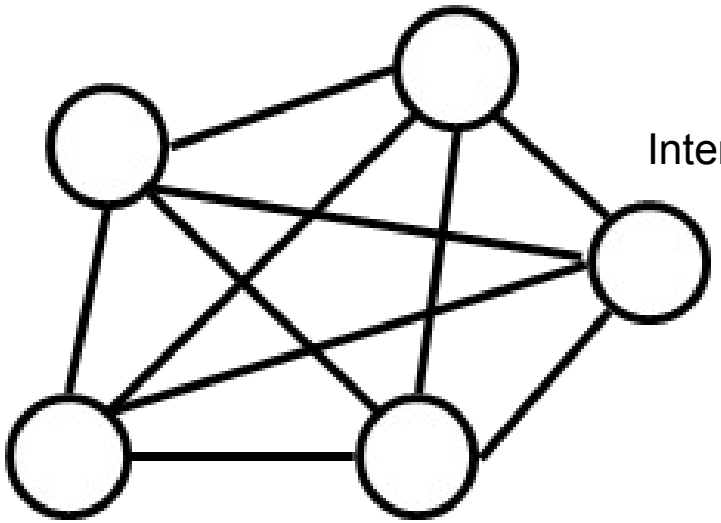
- The different types of architecture reflect different priorities on switching and transmission.



Optical network topology: mesh networks

- The diagram shows how a set of nodes might be connected using a fully interconnected mesh network.
  - In this arrangement a separate connection is provided between each pair of nodes.

n = 5 nodes



Interconnecting lines = ½ (n)(n-1) = 10

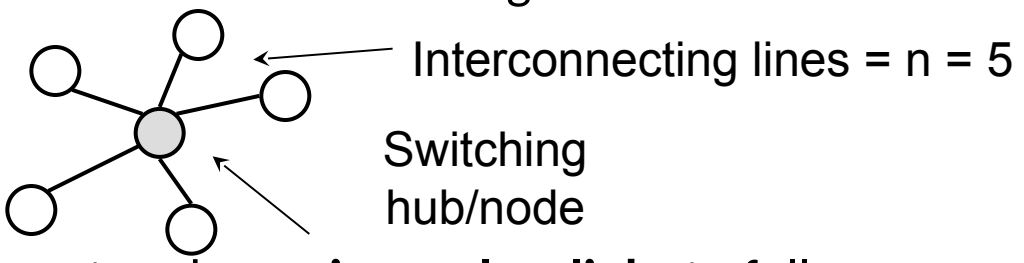
- For the case with widely dispersed clients , this network architecture would be clearly uneconomic.
  - The individual transmission systems required by each connection would be inefficiently used and would generate a very low traffic level.

Optical network topology : star networks (centralised switching)

- In star network, each client is connected via a **point-to-point link to a central node/switch.**
- The central node may be “passive”, “active”, or “intelligent”.
- A passive node simply connects the arms of a star, no signal regeneration is performed.
- An active hub is like a passive hub, except that it regenerates signals.
- Intelligent central nodes not only regenerate signals but also perform activities such as intelligent path selection and network management.

Star network

(centralized switching)

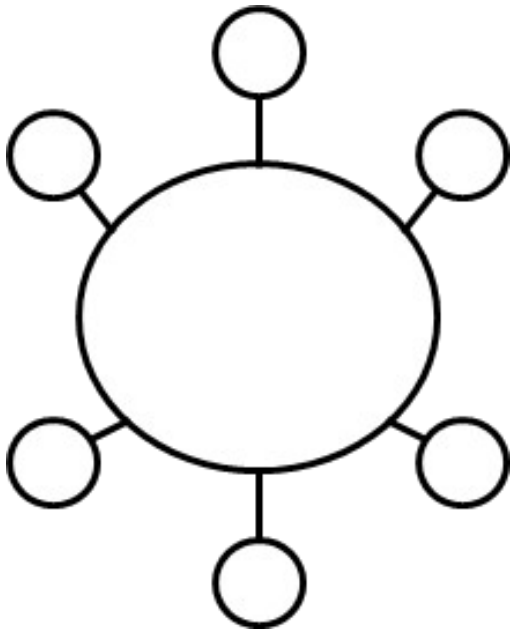


- The centralised switching star network **requires only n links** to fully interconnect the n nodes, but a more complex switching function is required.
  - Thus for the cost of centralised a substantial reduction in transmission costs can be achieved, e.g. n transmission paths instead of n(n-1)/2 for the fully interconnected mesh case.

Optical network topology: ring networks

- Ring network consists of nodes that are joined by point-to-point connection to form a closed loop or ring.
- The transmitted signal is regenerated at each node.
- It is a shared-access network and it has the capability of broadcasting messages.
- It needs some form of access control to determine which node will transmit when.

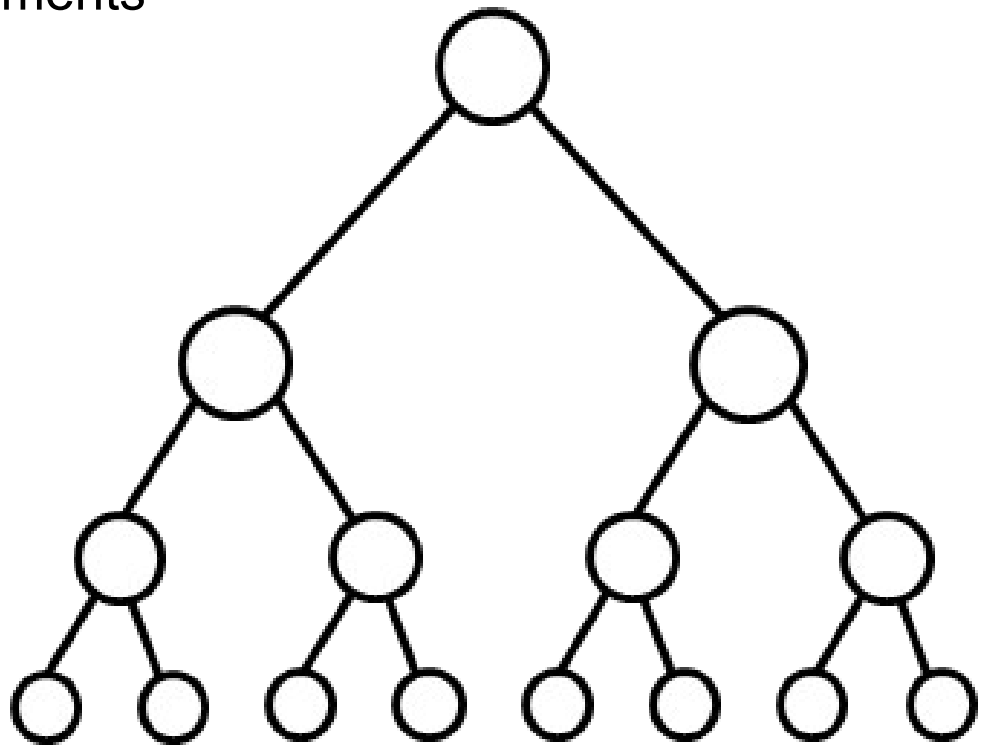
Ring network



Network architectures: tree Networks

- In a tree network, the optical links that are used to connect different nodes are collapsed into a central unit, called branch node/switch.

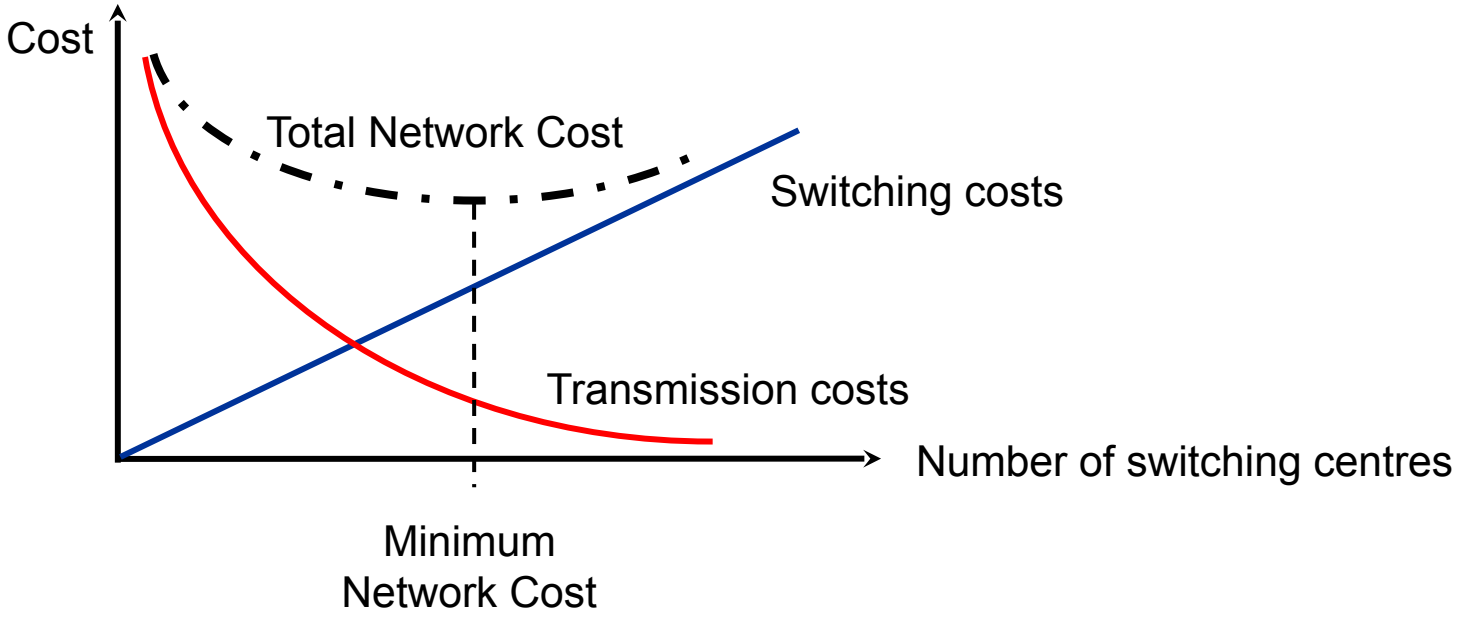
- Networking and switching is performed at different level of hierarchy based on requirements



Tree network

Network topology: minimum cost network

- Although centralised switching reduces the number of transmission links it may still be the case that the individual links are very long and carry little traffic.
- In large networks therefore the least cost solution may well require that more than one local centralised switching centre is provided.
- The more switching centres, the shorter the transmission paths per terminal but the greater the switching cost. Thus for any given distribution of terminals there is a minimum cost network.



Optical network topology

- Mesh Topology
  - Very high redundancy, fault tolerant, flexible for traffic engineering
  - Complex, expensive due to number of links and switches
  - No direct point-to-point connections for all possible source destination pairs

- Star Topology
  - Single point of failure (i.e. central node)
  - Can be more economical than mesh (depends on distance see earlier slide)
  - Simpler management

- Tree topology
  - An intermediate between star and mesh approach
  - Better fault tolerance on failure of links and nodes
  - Difficult access control and management

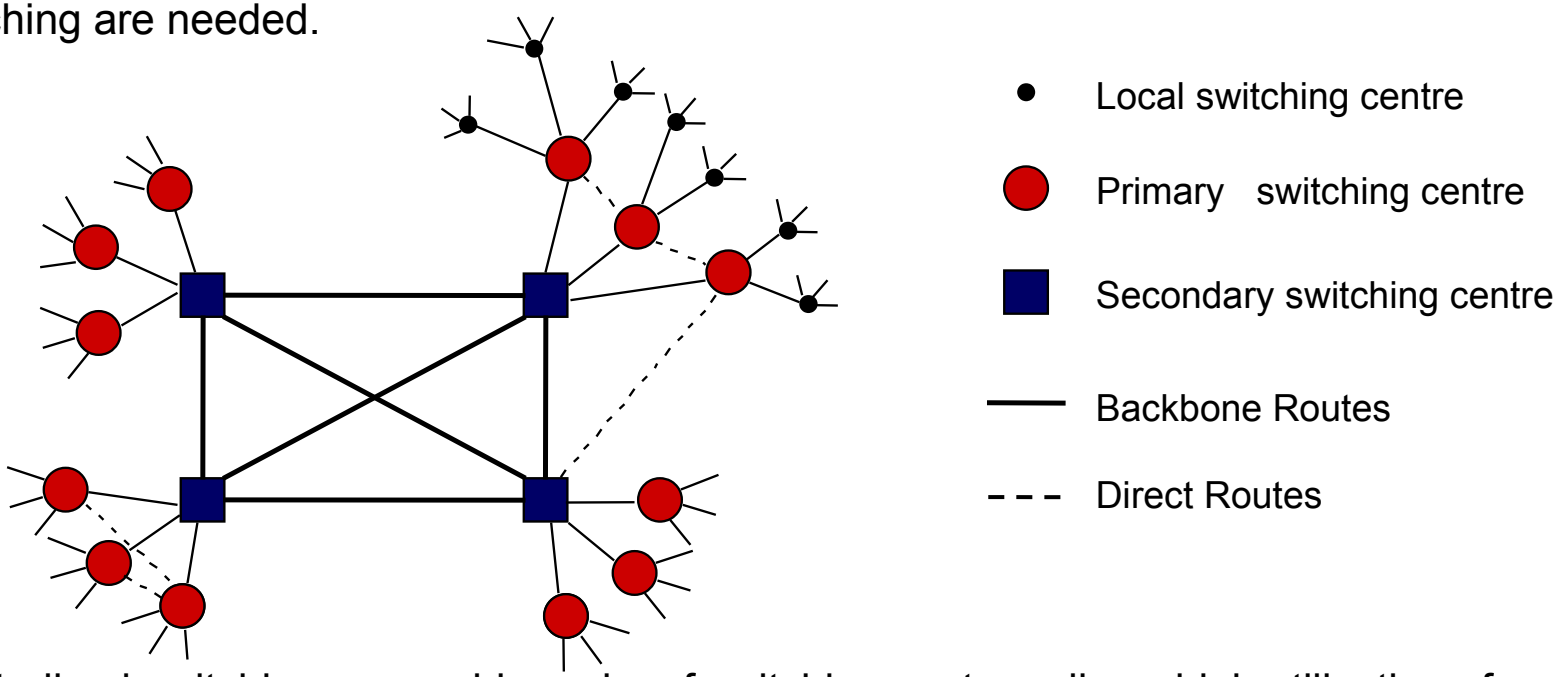
Optical network topology

- Ring topology
  - Complex access protocol
  - Simple structure , easy to manage
  - Shared direct Point-to-point connections for all possible source destination pairs
  - Single point of failure (ring Link)
  - large network needs large diameter (long links and large number of nodes sharing same link)

Type of Application, traffic distribution , geography and economical factors dictate the type of network topologies deployed

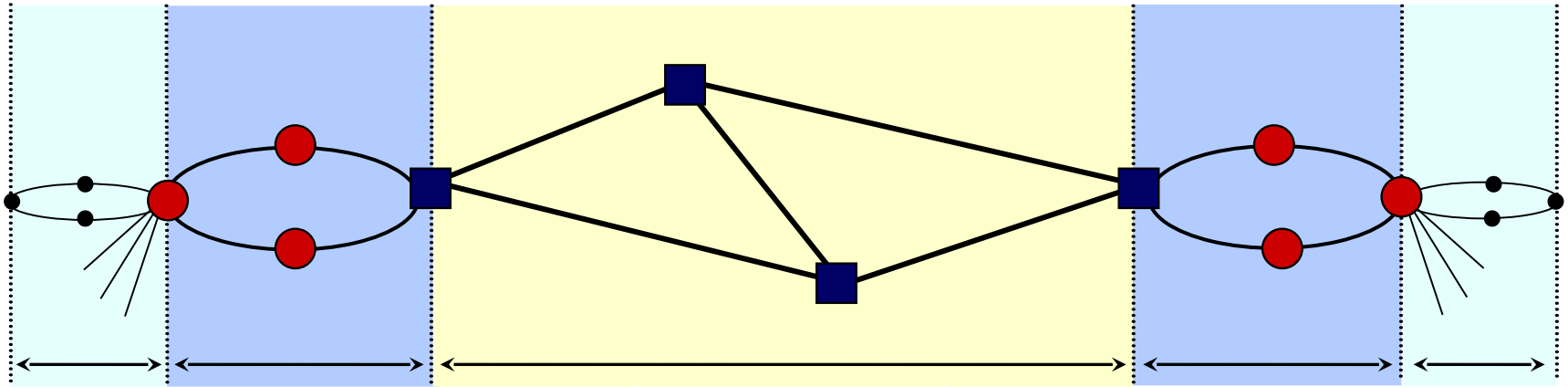
Network architectures: hierarchical (layered) networks

- For very large networks with many local switching centres further levels of centralised switching are needed.



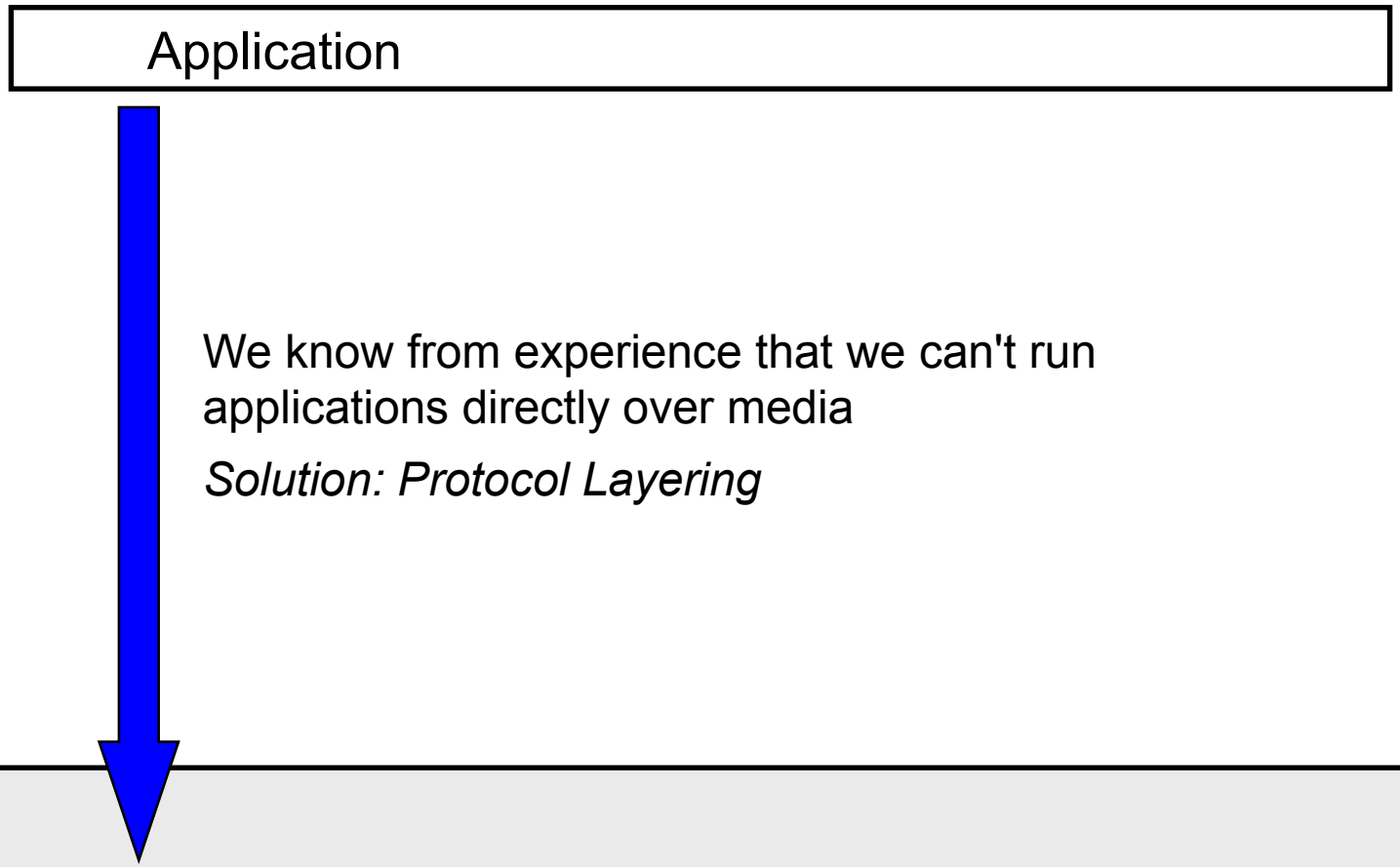
- Centralised switching upon a hierarchy of switching centres allows high utilisation of both transmission and switching resources.
- Switching centre equipment and the transmission routes between switching centres are shared between many terminals.
- Practically all public and private network structures (except for military networks) use a hierarchical structure with direct routes by-passing the hierarchical back-bone where high traffic demand justifies this.

Generic network hierarchy



- Networks are usually constructed in layers or tiers:
  - CORE - High capacity inter-city links with few intermediate nodes – mesh networks - long reach (>100Km)
  - METRO - Transports traffic between urban areas within a city – ring networks - intermediate reach (10-100km)
  - ACCESS - Collects traffic from local access points – ring or star - short reach (<10km)
- Each layer/tier has different traffic distributions (uniform, adjacent, hubbed), various bit-rates and subsequently, different architectures (linear, ring or mesh)

Protocol Layering



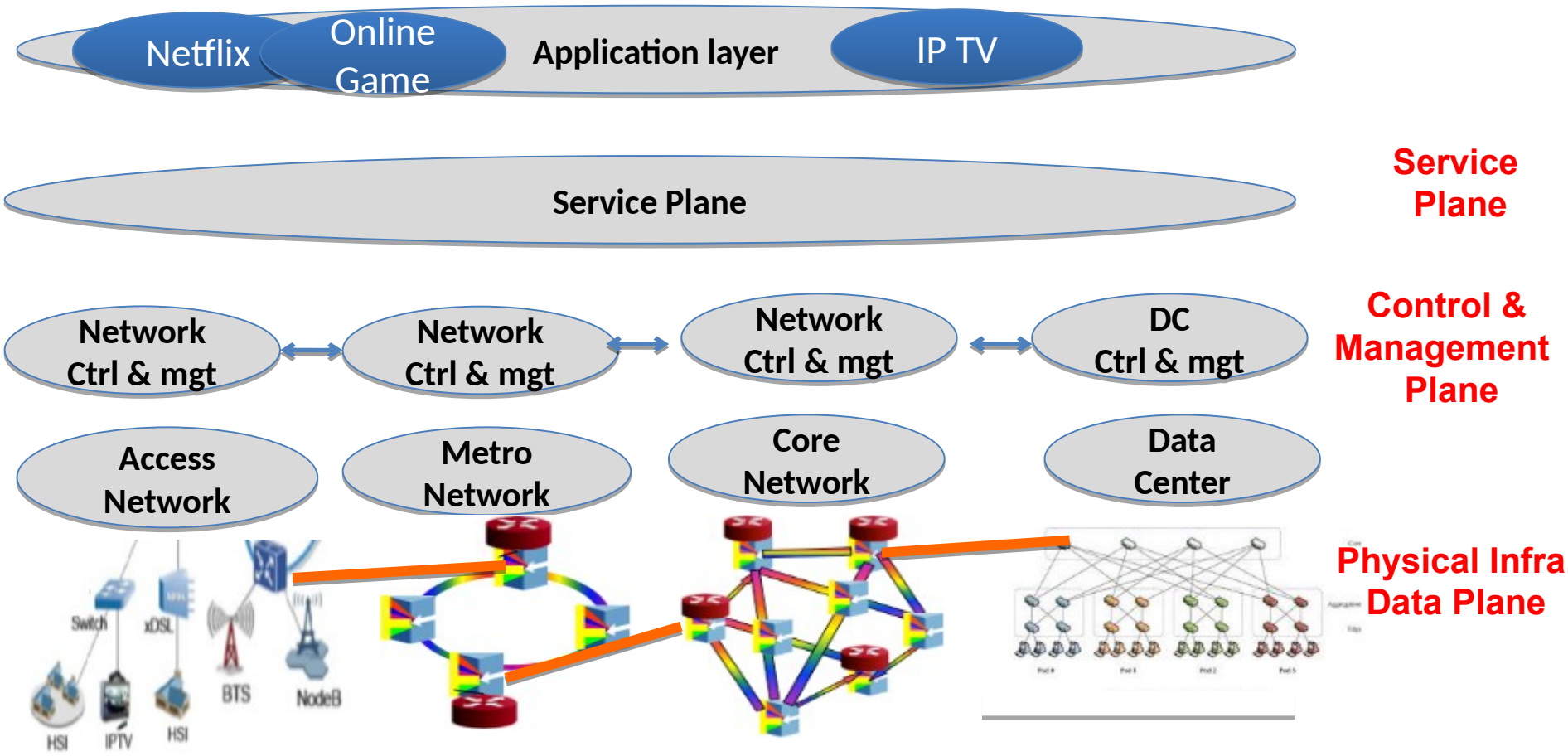
We know from experience that we can't run applications directly over media

Solution: Protocol Layering

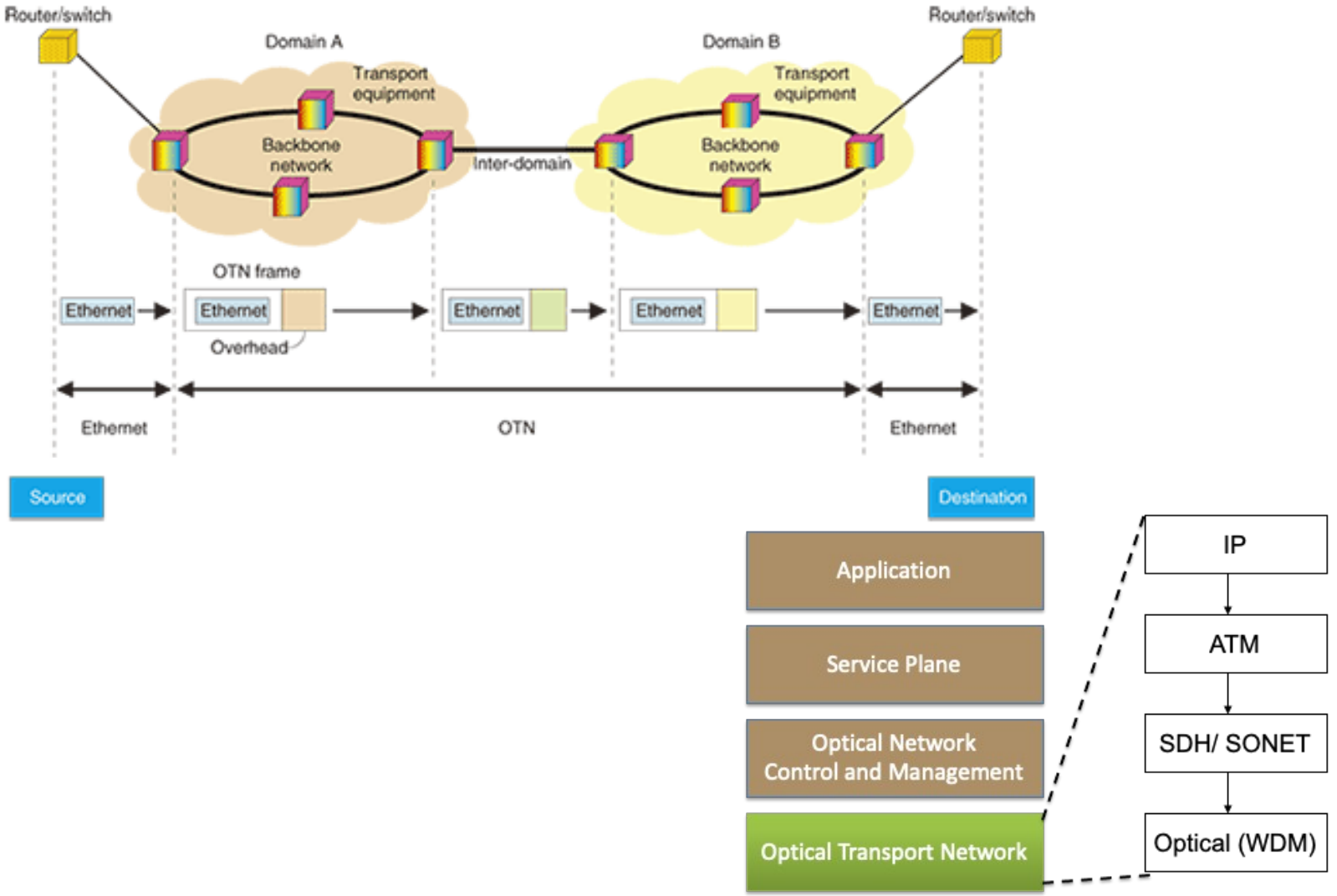
The OSI model

Layer	Function	Example
Application (7)	Services that are used with end user applications	SMTP,
Presentation (6)	Formats the data so that it can be viewed by the user Encrypt and decrypt	JPG, GIF, HTTPS, SSL, TLS
Session (5)	Establishes/ends connections between two hosts	NetBIOS, PPTP
Transport (4)	Responsible for the transport protocol and error handling	TCP, UDP
Network (3)	Reads the IP address form the packet.	Routers, Layer 3 Switches
Data Link (2)	Reads the MAC address from the data packet	Switches
Physical (1)	Send data on to the physical wire.	Hubs, NICS, Cable

Internet architecture



Classical Optical transport layer



End of Session2

- End of Part 1