5. Introduction to Optical Networks

Optical Communication Systems and Networks

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Fiber optic properties

Main goal: to take advantage of optical fibers properties

- Great product bandwidth x distance (B x L)
- Transparent to signal format / service
- Low loss (0.18 dB / km, constant with the optical carrier frequency)
- Low cost (raw material abundant - SiO_2 -)
- Low weight and volume
- Strength and flexibility
- Immunity to electromagnetic interference
- Security and Privacy
- Corrosion Resistance
- Need to exploit/take advantage of fiber bandwidth
  - development of new optical communications systems to satisfy traffic demands

What is an optical network?

- An optical network is a communications network in which transmission **links are made up optical fibers**, and its architecture is designed to exploit the optical fiber advantages

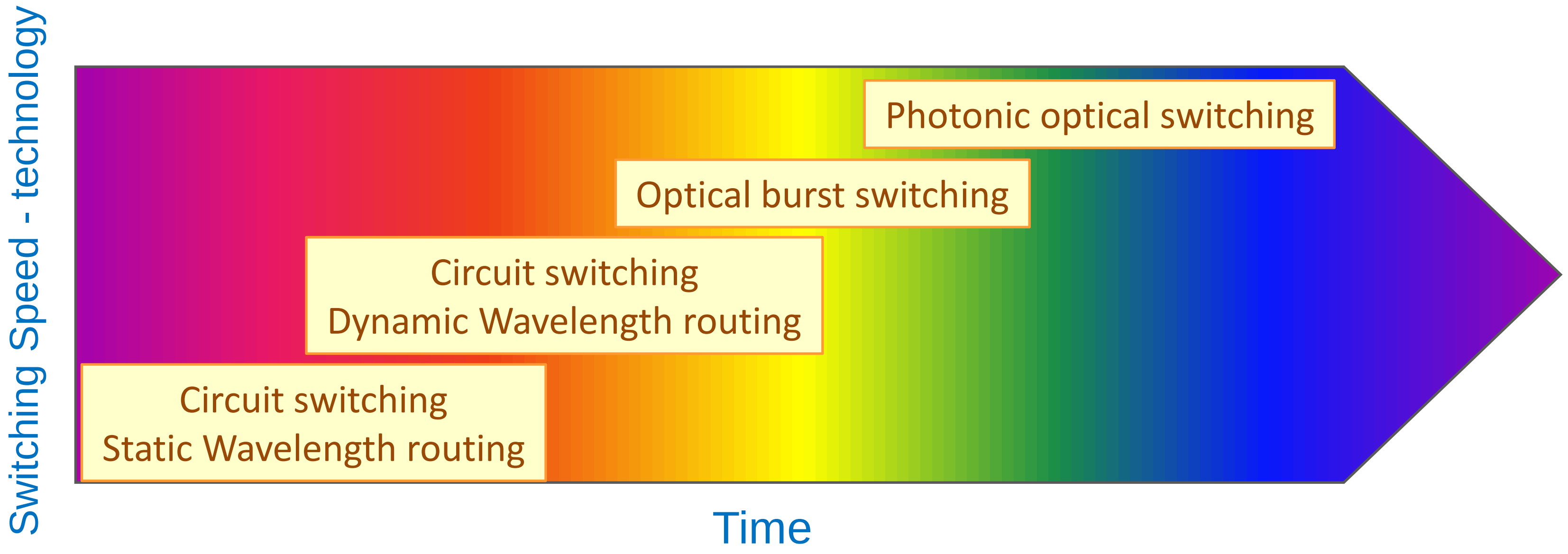
- First-generation optical networks were composed by optical fiber point-to-point transmission links substituting copper-based lines maintaining the terminating electronic equipment

- Second-generation optical networks have also routing, switching, and **intelligence in the optical layer**

Introduction to Optical Networking

- **Objetives:** to provide a huge capacity in communication networks, a common infraestructure over which a variety of services can be delivered
- In comparison with copper cables, optical networks offer much higher bandwidth free of electromagnetic interferences and other undiserable effects
- Provides an easy and flexible way to deliver bandwidth on demand where and when it is needed
- Type of service:
  - **Circuit-switched**
    - A guaranteed bandwidth is allocated to each connection being available all the time the connection lasts
  - **Packet-switched**
    - Data streams are broken up into small packets of data
    - Packets are multiplexed together with packets from other data streams inside the network
    - Packets are switched inside the network based on their destination

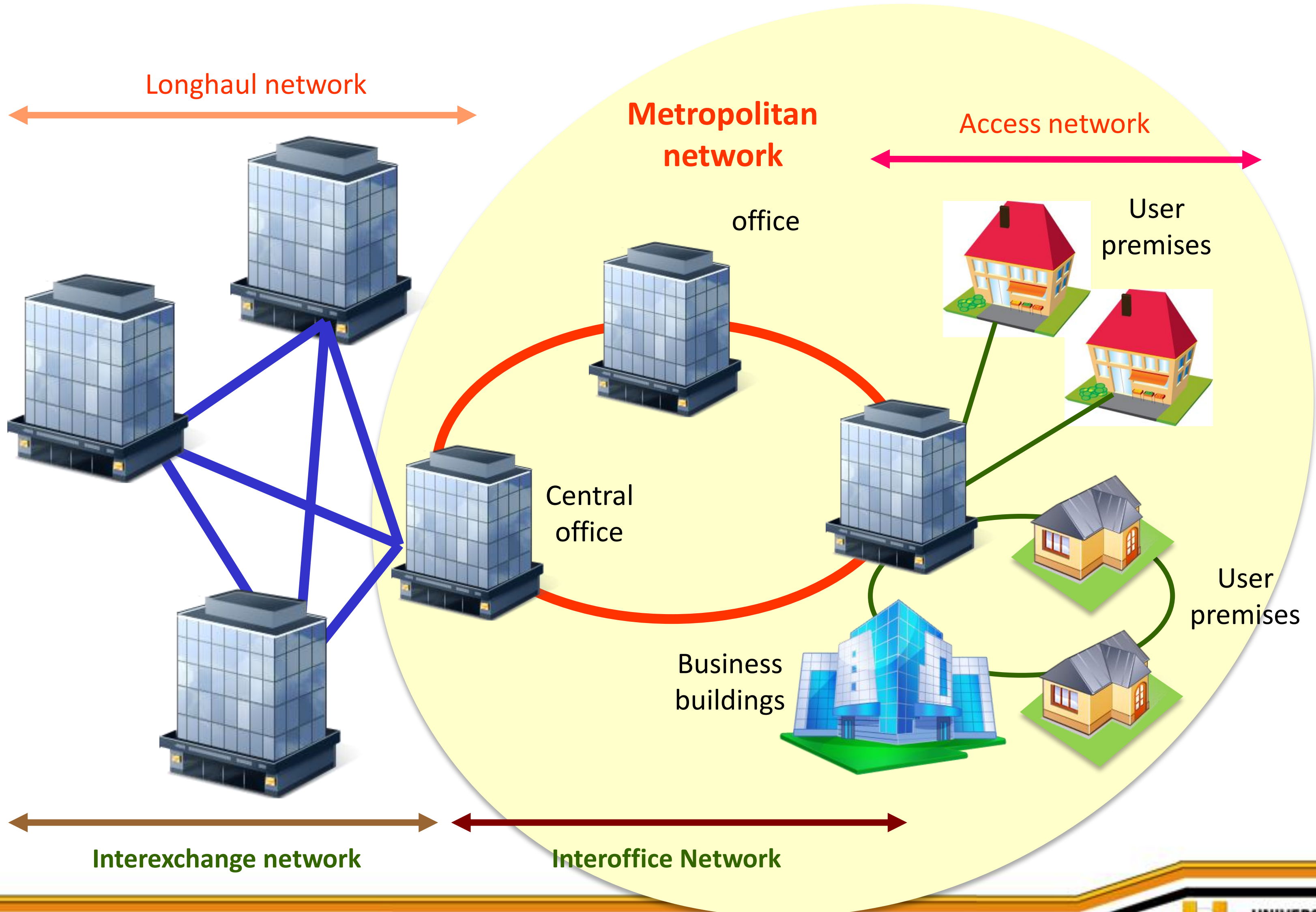
Overview of optical networking evolution



Public optical networks

- A public network may be owned and operated by different carriers
- The nodes in the network are ***central offices.*** They are also called:
  - ***POPs*** *–point of presence-* when nodes present a small size
  - ***hubs*** when nodes are featured by their large size
- Optical links consist of multiple fiber pairs grouped according to the geographic reach, topology, traffic patterns, restoration schemes,…
  - In most cases, **meshed networks** are based on interconnected **ring networks**
- These networks can be broken up into:
  - ***Metropolitan network***
    - Part of the network lying within a large city or a region
  - ***Long-haul network***
    - Part of the network interconnecting cities or different regions

Schematic of a public optical network



Public optical networks

1) Metropolitan network

- The metro network consists of a **metro access network** and a **metro interoffice network**
  - The **access network** extends from a central office to individual businesses or homes (typically, groups of homes rather than individual homes at this time)
    - Its reach is typically a few kilometers
    - Traffic is collected from customer premises and hubbed into the central office
  - The **interoffice network** connects groups of central offices within a city or region
    - It usually spans a few kilometers to several tens of kilometers between offices
    - Distances can vary significatively depending on geografic region (American links and distances are usually longer than European)

Public optical networks

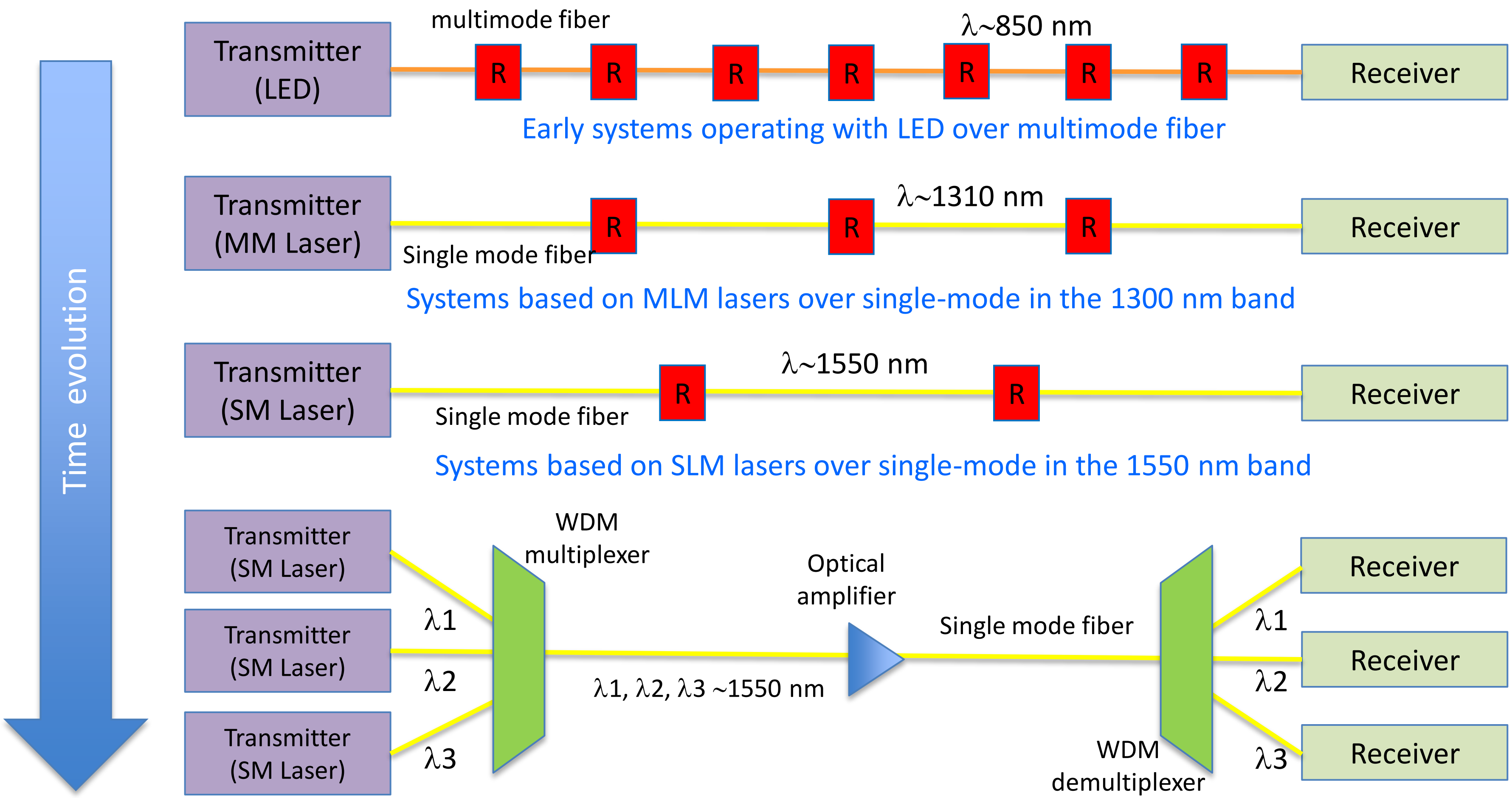
2) Long-haul network

- The long-haul network interconnects different cities or regions and spans hundreds to thousands of kilometers between nodes
- Sometimes, it provides the handoff between the metro network and the long-haul network (when they are operated by different carriers)
- Unlike access networks, the traffic distribution in the metro interoffice and long-haul networks is based on a meshed topology

Properties of optical networks

- The performance of optical communication systems depends on several issues such as geographycal reach, network configuration and information features
- Generally, the format or nature of transmission is DIGITAL IN:
  - Point-to-point links
  - Distribution networks
- Although in very particular applications ANALOGICAL formats are still used
  - Distribution networks, CATV networks…
  - Keep the format due to economic reasons
  - Tend to disappear in a near future
- The most used kind of system is IM-DD due to its simplicity
- Digital signals offer advantages when they are transmitted and processed:
  - Higher noise inmunity
  - Easier processing
  - Simple multiplexing

Optical Networks Trends

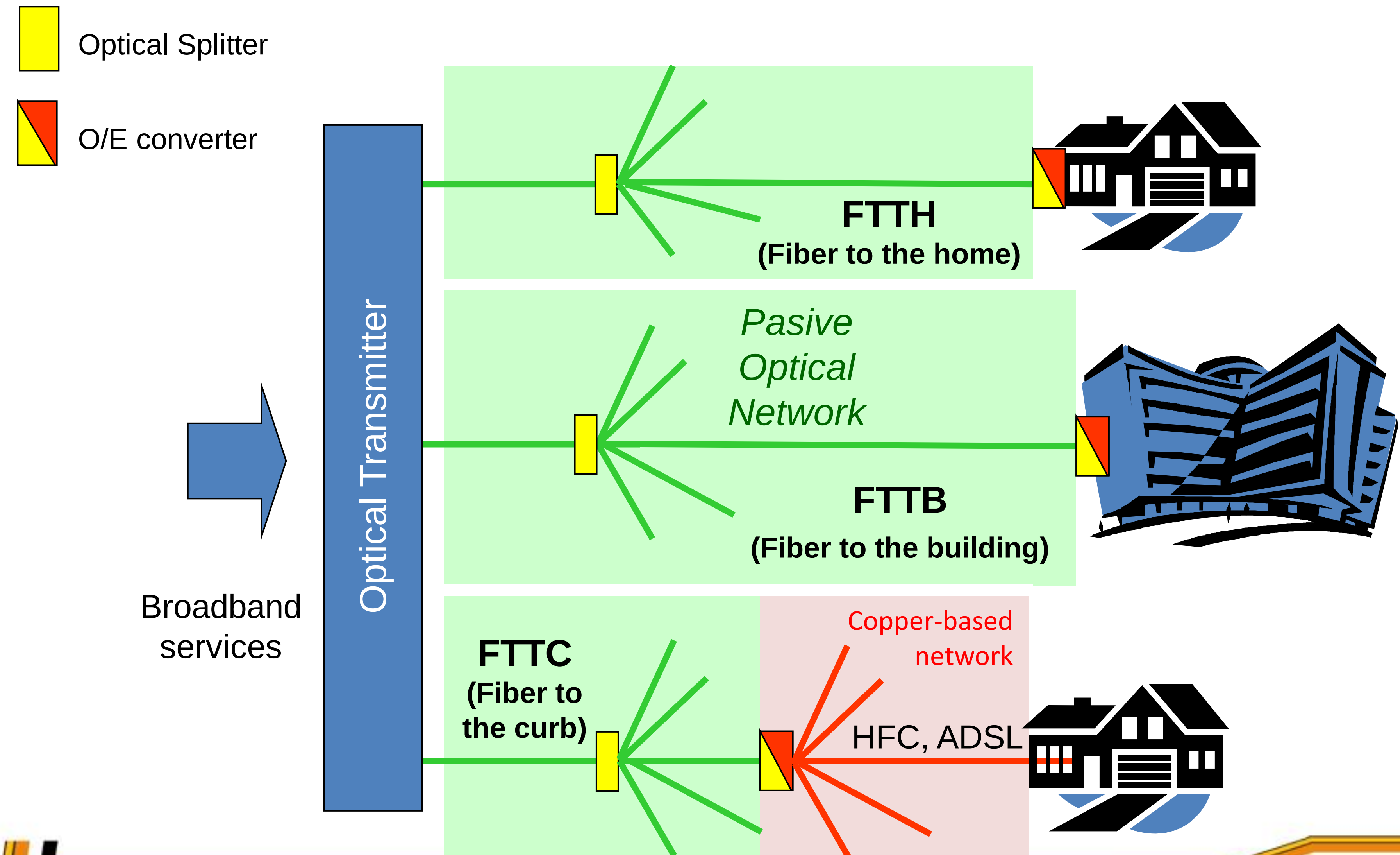


Current systems based ond WDM in 1550 nm over single mode fiber where regenerators are replaced by optical amplifiers

Optical Networks Trends

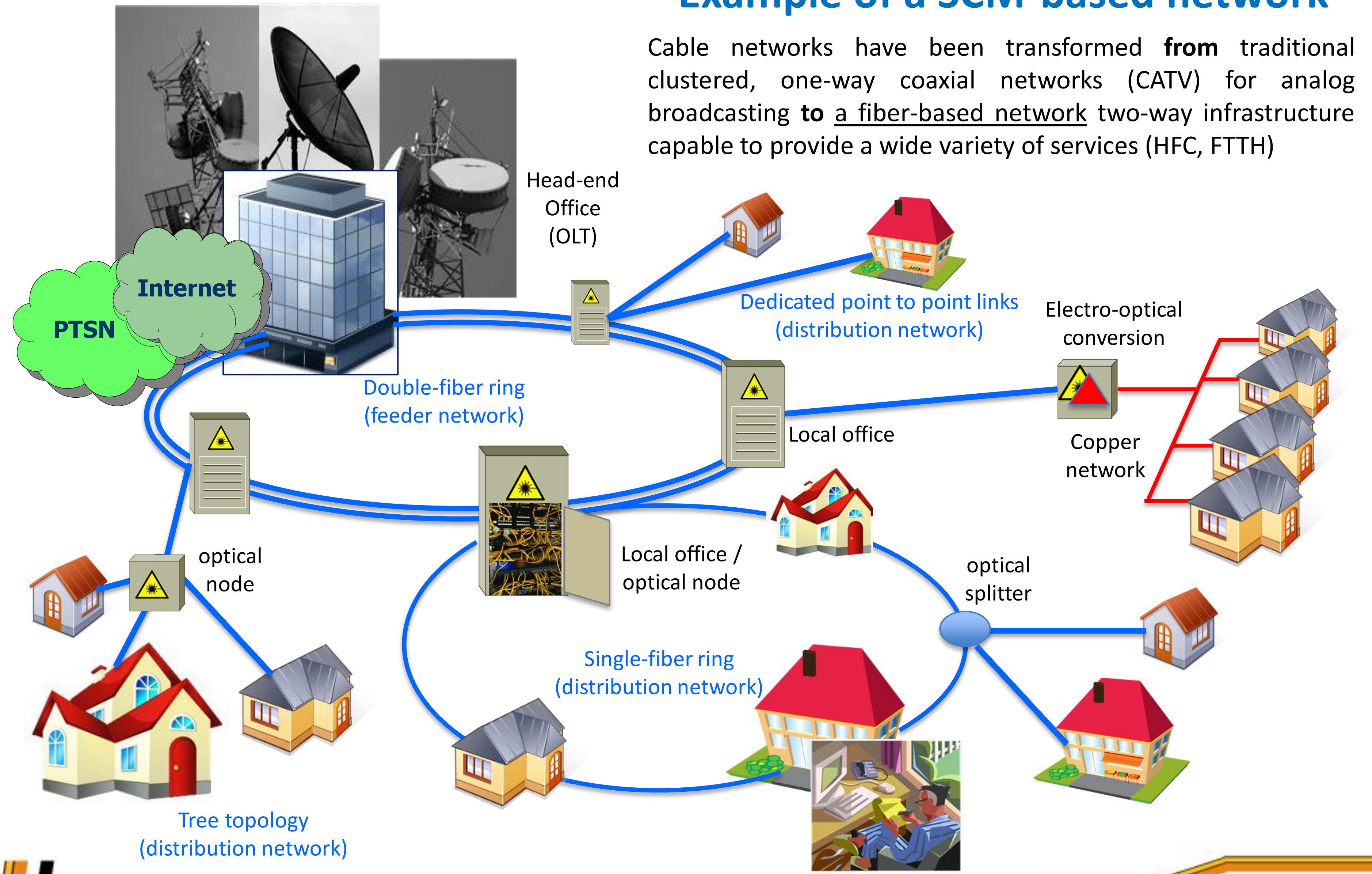
- The emergence of first-generation optical networks in late 80's provided deployement:
  - metropolitan-area networks: 100 Mb/s fiber distributed data interface (FDDI)
  - networks to interconnect mainframe computers: 200 Mb/s enterprise serial connection (ESCON)
- Nowadays, storage networks using the Fibre Channel are proliferating typically with data rates in the multiples of gigabits per second
- Standardization and deployment of SONET (USA) and SDH networks (Europe and Japan)
- High-speed optical interfaces on a variety of other devices such as IP routers and Ethernet switches.
- Wavelength-routing networks became a major focus area for several researchers since the early 1990s
- Optical add/drop multiplexers and cross-connects are now available commercially and are beginning to be introduced into the optical layer in telecommunications networks
- Research activity on optical packet-switched networks and local-area optical networks continues today

Geographic reach of optical networks



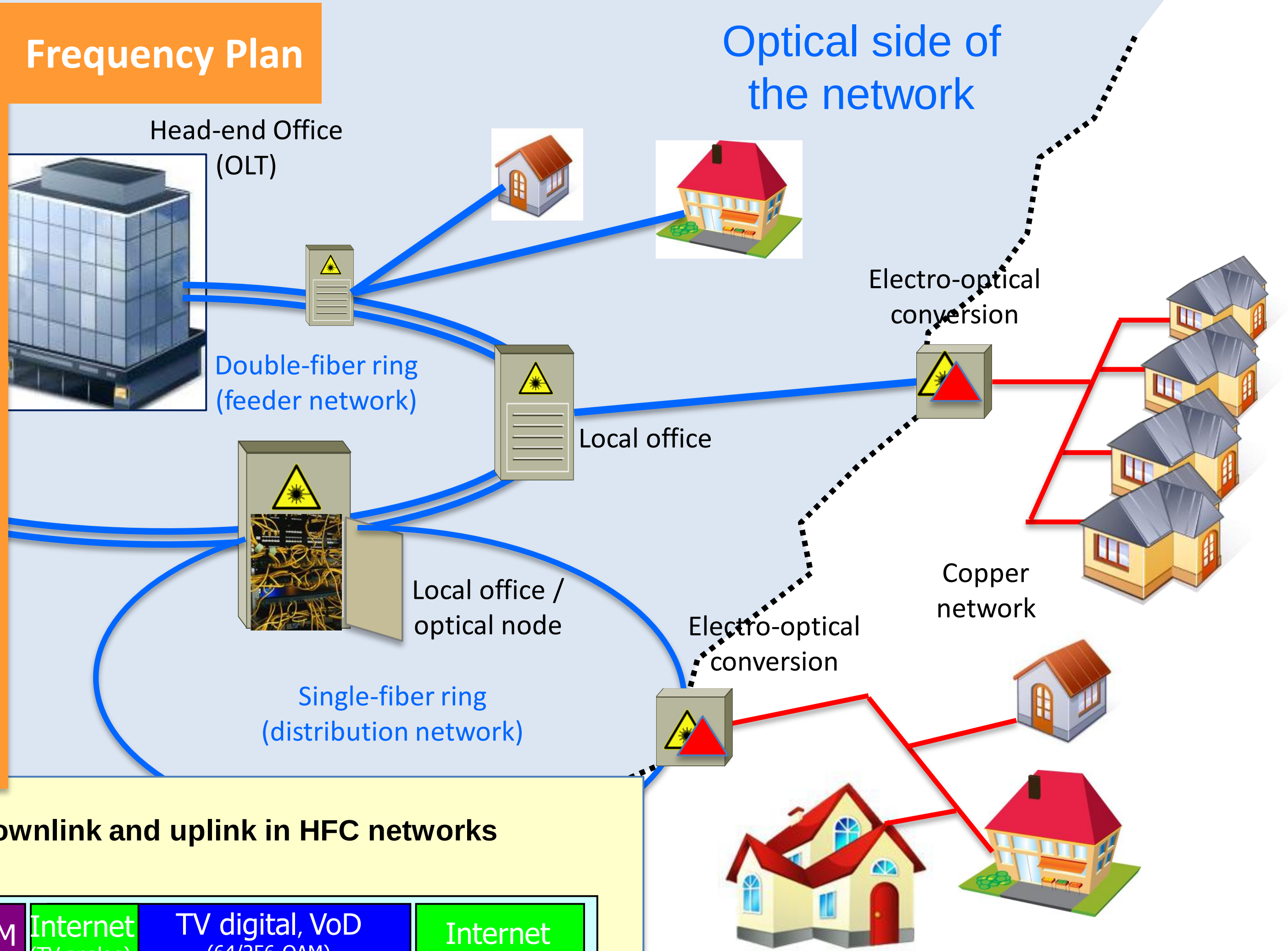
Example of a SCM-based network

Cable networks have been transformed **from** traditional clustered, one-way coaxial networks (CATV) for analog broadcasting **to** a fiber-based network two-way infrastructure capable to provide a wide variety of services (HFC, FTTH)

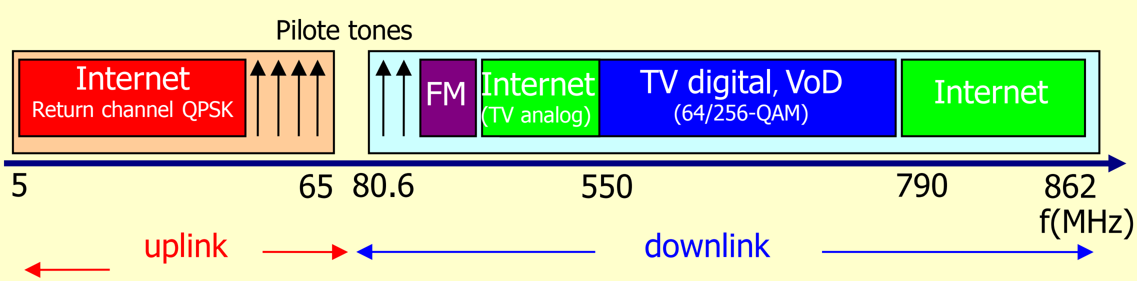


Frequency Plan

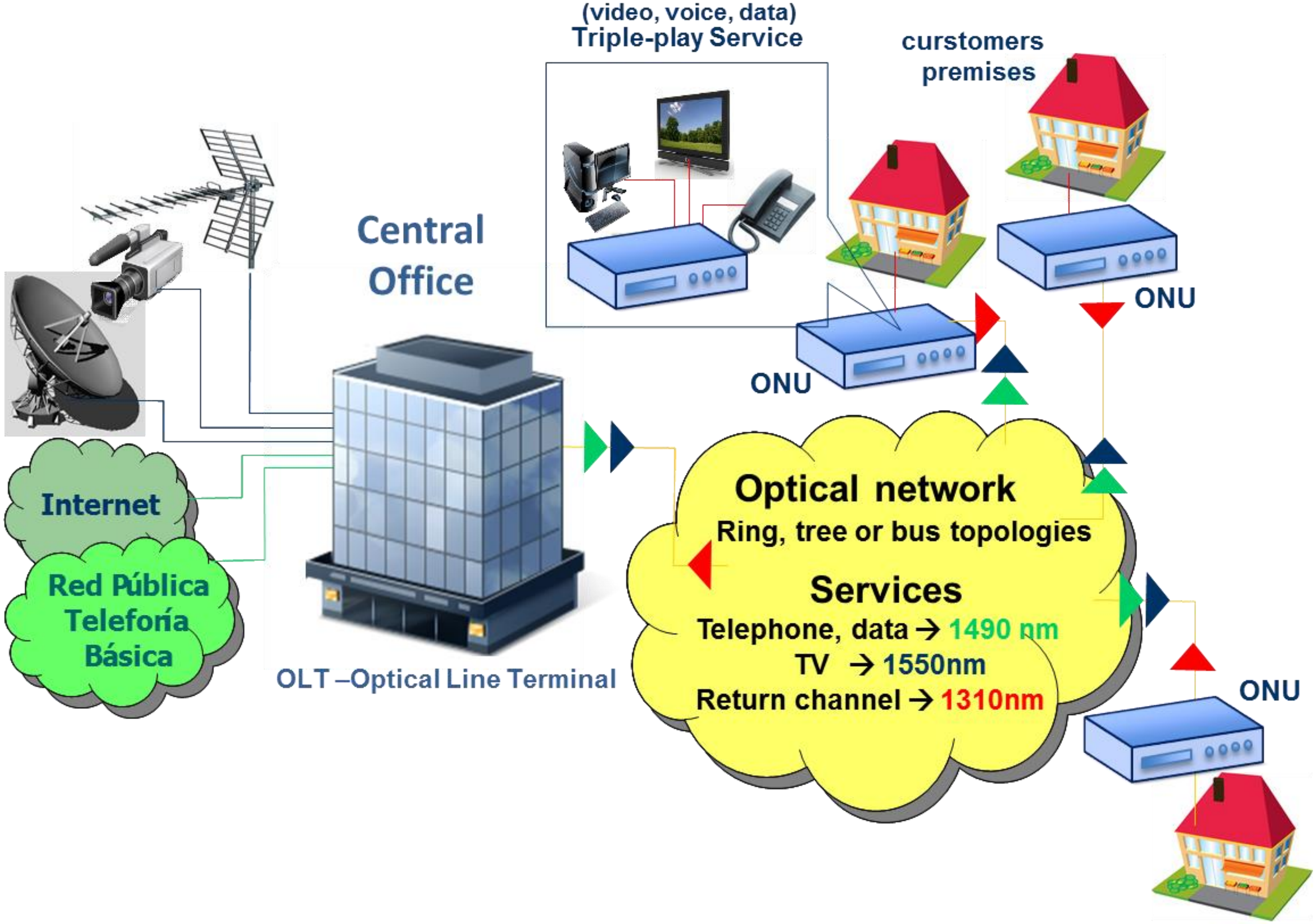
PAL B/G
Channels: 110 PAL **Band:** 48,25 – 855,25 MHz **Spacing**: 7/8 MHz
BK450
Channels: 48 PAL + 2 tones **Band:** 48,25 – 599,25 MHz **Spacing**: 7/8 MHz
BK600
Channels: 110 PAL **Band:** 48,25 – 855,25 MHz **Spacing**: 7/8 MHz
CENELEC
Channels: 42 PAL **Band:** 48,25 – 855,25 MHz **Spacing**: 7/8 MHz



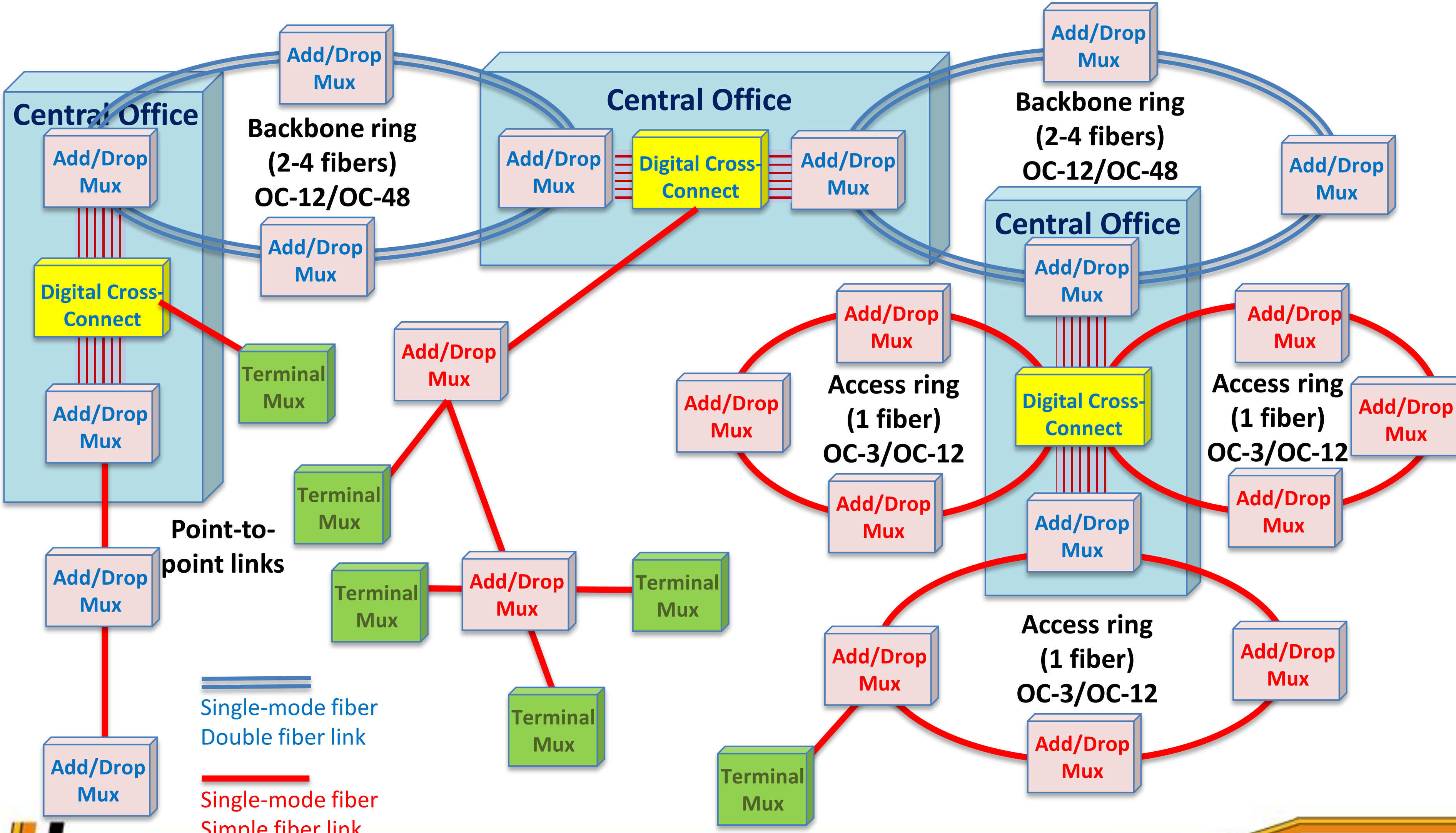
RF Spectrum of downlink and uplink in HFC networks



FTTH network based on an access network (PON standard)



1st Generation of Optical Networks



Optical Networks. 2nd Generation

- Unlike 1st generation networks, it is intended to perform additional functions point to point transmission in the optical domain:
  - **switching**
  - **Routing**

- The emergence of second generation networks considers the introduction of a new level in a layered network model: **the optical layer**

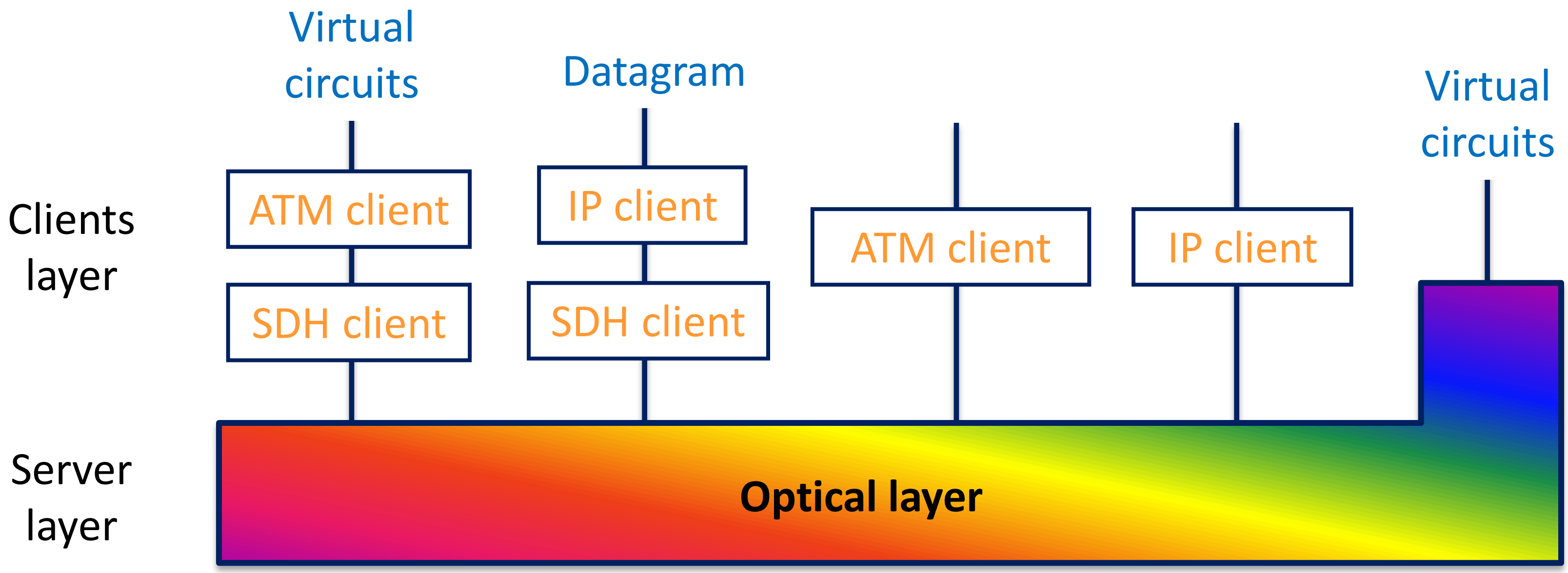
  This means:

  - A reduction of "bottlenecks":

    In the first generation of networks, the increase of the line speed complicates the header processing in the electronic domain

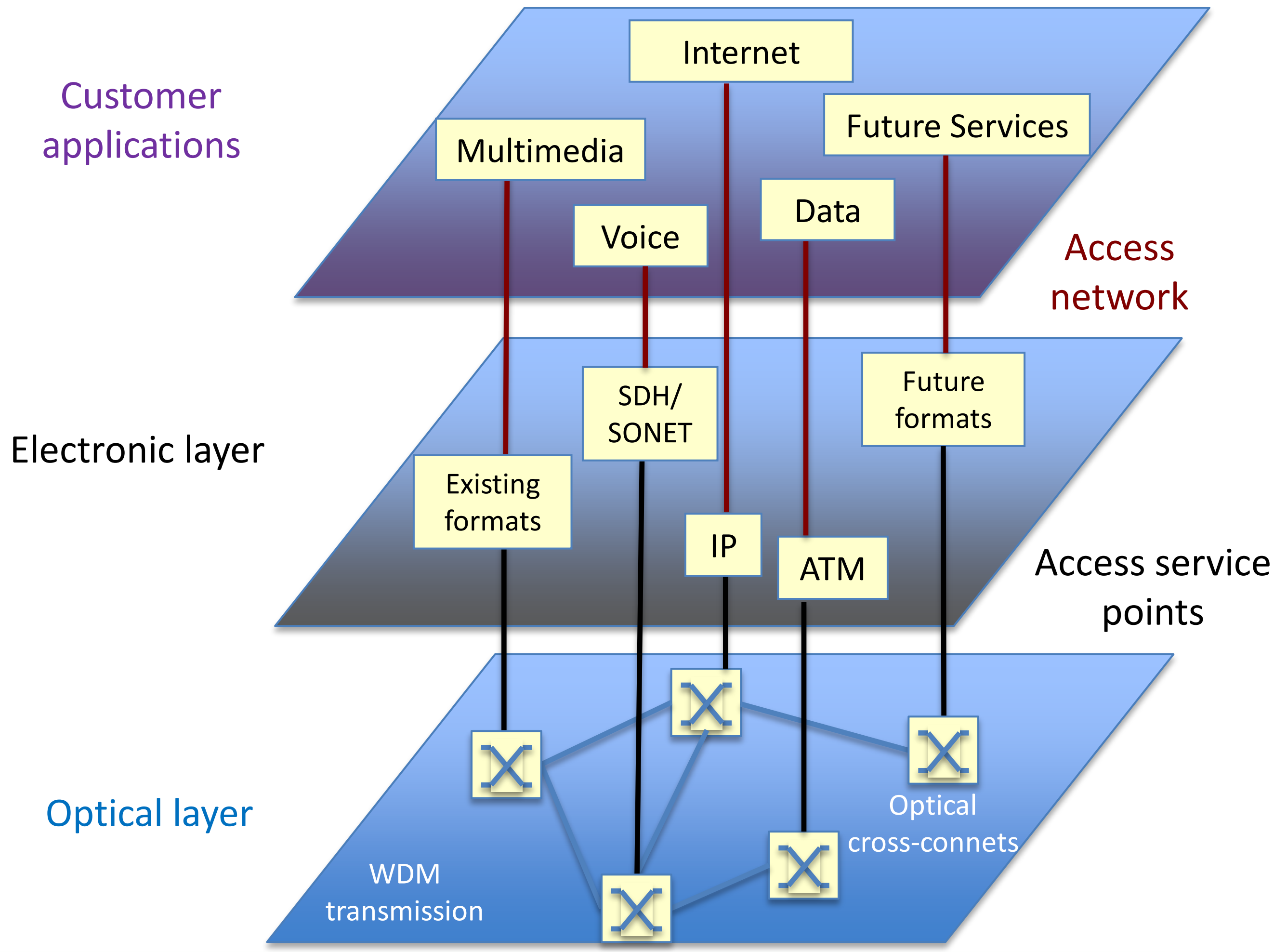
  - It is a service layer that provides "optical paths" to its users (other client layers: SDH, ATM, ESCON, 10GbE ...)

Optical Networks. 2nd Generation



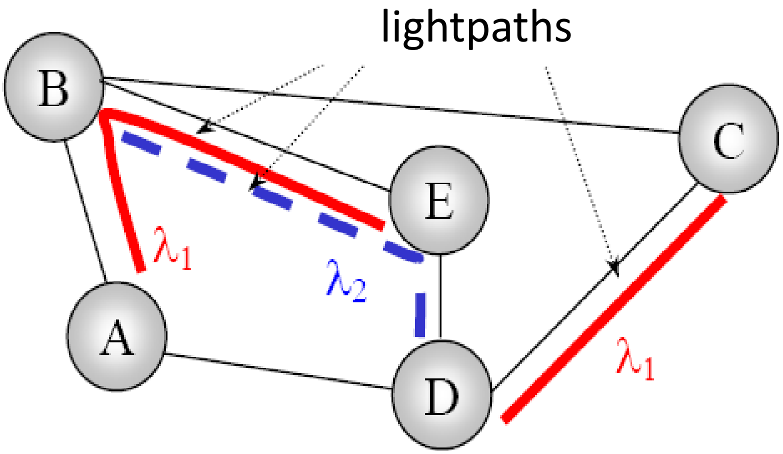
A **lightpath** is an **optical connection end-to-end** which takes place in the optical layer by using a specific wavelength along several optical links and throught different intermediate nodes.

Layered architecture in telecommunications networks



Optical Networks. 2nd Generation

Different lightpaths can use the same wavelength unless they do not share the same optical fiber link → **Optical continuity constraint**



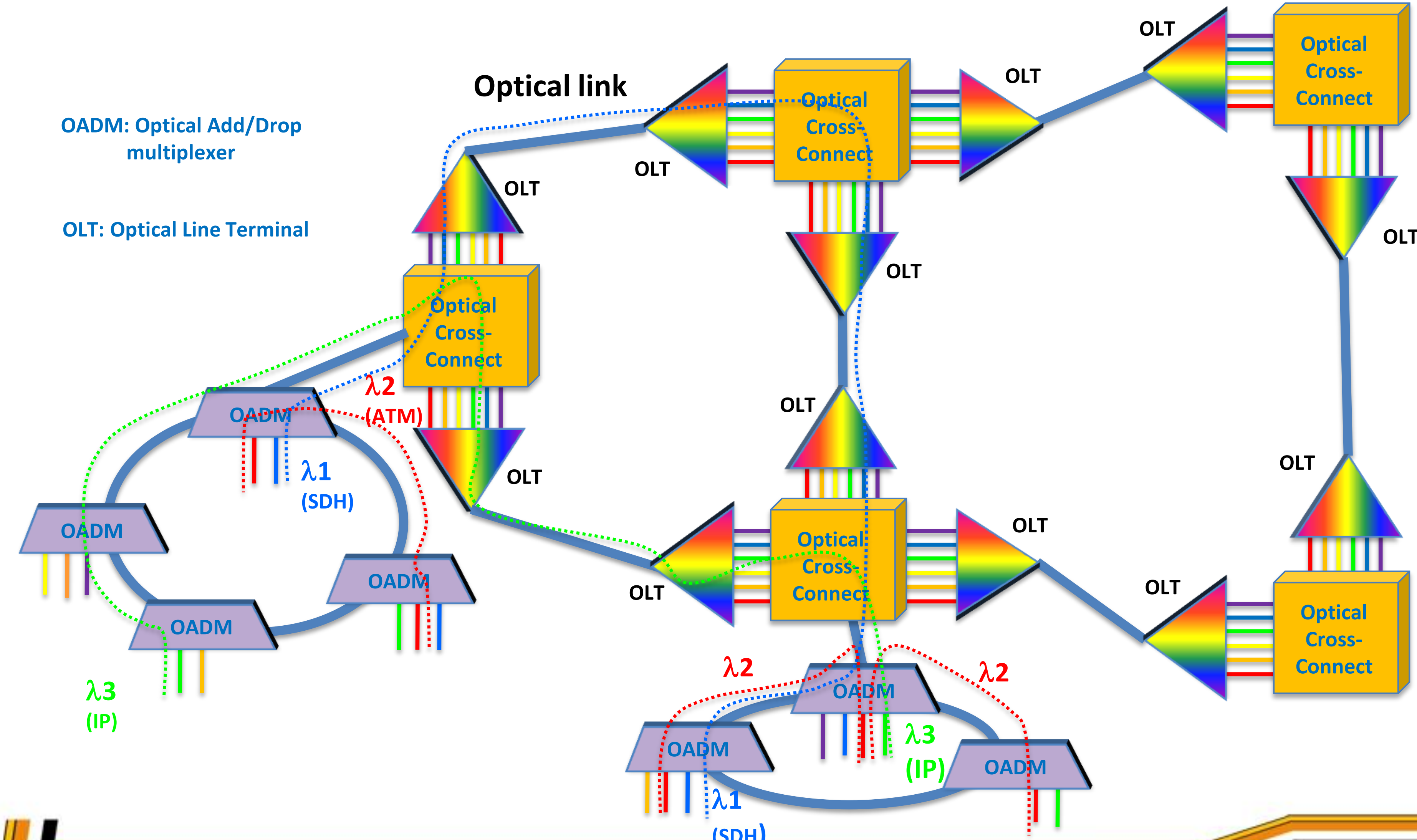
Lightpaths are routed at intermediate nodes towards other links, where wavelengths can be exchanged (wavelength-routing network)

The optical layer provides lightpaths to the higher layers through SAPs (service access point)

Optical Networks. 2nd Generation

OADM: Optical Add/Drop multiplexer

OLT: Optical Line Terminal



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Optical Networks. 2nd Generation

- **OLT** (Optical Line Terminals)
  - It multiplexes multiple wavelengths into a single fiber
  - It also demultiplexes a set of wavelengths on a single fiber into separate fibers
  - OLTs are used at the ends of a point-to-point WDM links
- **OADM** (Optical Add / Drop Multiplexers)
  - It takes a WDM signal from its input port and selectively drops some wavelengths locally while letting others pass through
  - It also selectively adds wavelengths to the WDM signal
  - OADMs are being used now in long-haul and metro networks
- **OXC** (Optical Cross-connects or optical switching matrix)
  - They perform a similar function to digital cross-connects but in the optical domain and presenting larger sizes.
  - They have a large number of ports and are able to switch wavelengths from one input port to another
  - OXCs are beginning to be deployed in long-haul networks because of the required higher capacities

Both **OADMs** and **OXCs** may incorporate **wavelength conversion** capabilities

Next Generation of Optical Networks
Optical Packet Switching

- Unlike transmission of ligthpaths based on circuit-switched networks, optical networks are investigated to perform **packet switching in the optical domain**

- These networks may require a form of optical time division multiplexing (OTDM): ***fixed*** or ***statistical***.
  - Statistical multiplexing are called optical packet-switched networks.
  - Fixed OTDM is based on a subset of optical packet switching where the multiplexing is fixed.

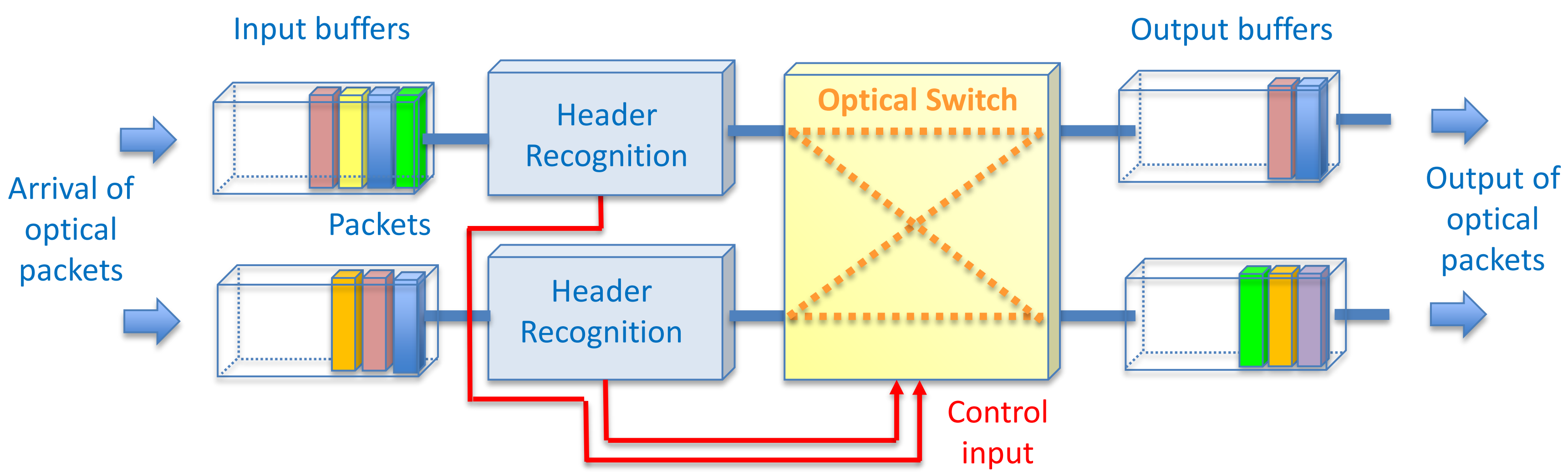
- There are **several limitations** with respect to processing signals in the optical domain:
  - The **lack of optical random access** memory for buffering
  - Optical **buffers are delay lines** based on length of fiber

- Packet switches use intelligent real-time software and dedicated hardware to control the network and provide quality-of-service guarantees → difficult in the optical domain

- Primitive state of the fast optical-switching technology compared to electronics.

Next Generation of Optical Networks

Optical Packet Switching



Optical packet-switching node

Next Generation of Optical Networks
Optical Packet Switching

- **Optical packet-switching node performance**
  - Packet-switching node takes a packet coming in → reads its header → switches it to the proper output port
  - The optical node:
    - may impose a new header on the packet
    - must also solve *contention* for output ports

      (when two packets coming in on different ports need to go out on the same output port: one of the packets must be buffered or sent out on another port)
  - Ideally, all the functions would be performed in the optical domain
    - In practice, functions such as header processing and switch controlling are still being done in the electronic domain
  - This is a result of the limited processing capabilities in the optical domain