

Fiber Optics Communications

Week 13

Fiber Optic Communication Networks

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Topics of Previous Lecture (Week-12)

Optical Fiber transmission system design -2

- Amplified Optical Fiber transmission system
- EDFA Gain and Noise Model
- ASE Noise and Polarization
- ASE Noise Power Spectral Density (PSD)
- Filtered Optical Signal
- Optical Signal to Noise Ratio (OSNR)
- Bit Error Probability
- ASE Limited Maximum Reachable Distance

Week-13: Lecture Learning Outcomes

1. Explain the fundamental concepts and advantages of fiber optic communication networks over traditional communication networks
2. Define and compare different optical network topologies, including bus, ring, star, and mesh topologies
3. Distinguish between different generations of optical networks based on functionality and technology advancement
4. Describe the multiplexing hierarchy and operation of SONET and SDH standards
5. Define wavelength routing and its importance in second-generation optical networks.
6. Explain different types of principle of WDM networks
7. Explain the concept and architecture of PONs.

Week-13: Fiber Optic Communication Networks

Outline

- Introduction: Fiber Optic Communication Networks
- Optical Network Topologies
- Generation of Optical Networks
- First Generation: SONET/SDH Basics
- Second Generation: Wavelength Routing Networks
- WDM Networks
- Passive Optical Networks (PON)

Fiber Optic Communication Networks

- **Fiber Optic Communication Networks** are communication systems that use light signals transmitted through optical fibers to transfer data with high speed, large capacity, and low loss over short to long distances.
- Optical networks form the foundation of global connectivity, powering internet backbones, cloud services, and next-generation communication systems like 5G and beyond
- Fiber Optic Communication Networks comprises of different telecommunication segments such as:

❖ **Long-Haul Optical Systems:** Terrestrial optical back bone networks, Submarine Optical networks

❖ **Medium-Haul Optical Systems:** Metropolitan optical networks

❖ **Short-Haul Optical Systems:** Optical Access Networks, mobile back-hauls and front-hauls etc.

Fiber Optic Communication Networks

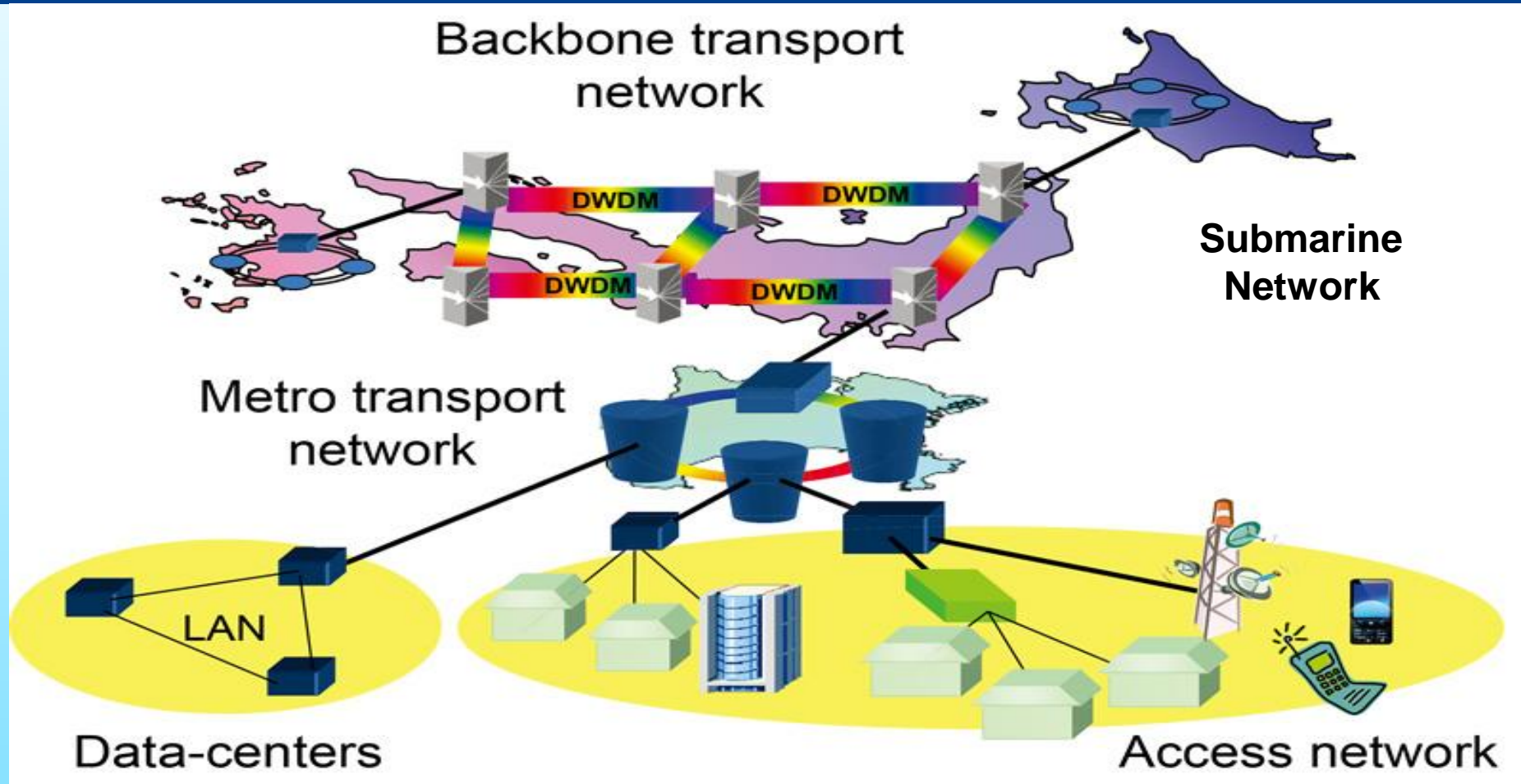


Figure 1: Fiber optic networks

Source: S. Akihida, "Optical fiber communications technology and its application," Ritsumeikan University. <https://en.ritsumeikan.ac.jp/image.jsp?id=554641&version=English>

Optical Network Topologies

- **Topology** is the logical/Physical manner in which **nodes** are linked together by information transmitting channels to form a network
- **A node** is a point where one or more communication lines terminate
- **A network** is a collection of interconnected stations
- **Stations or Users:** are devices that network subscribers use to communicate
- Common Optical Network Topologies [1]:

❖ Bus

❖ Ring

❖ Star

❖ Mesh

Optical Network Topologies

Bus Topology

- ❖ Uses an optical trunk or optical backbone to which all of the workstations on the network connect.
- ❖ Advantages:
 - ✓ Cheap and easy to implement
 - ✓ Require less fiber cable
 - ✓ Does not use any specialized optical network equipment
- ❖ Disadvantages:
 - ✓ A break in the fiber cable will prevent all systems from accessing the network.

Optical Network Topologies

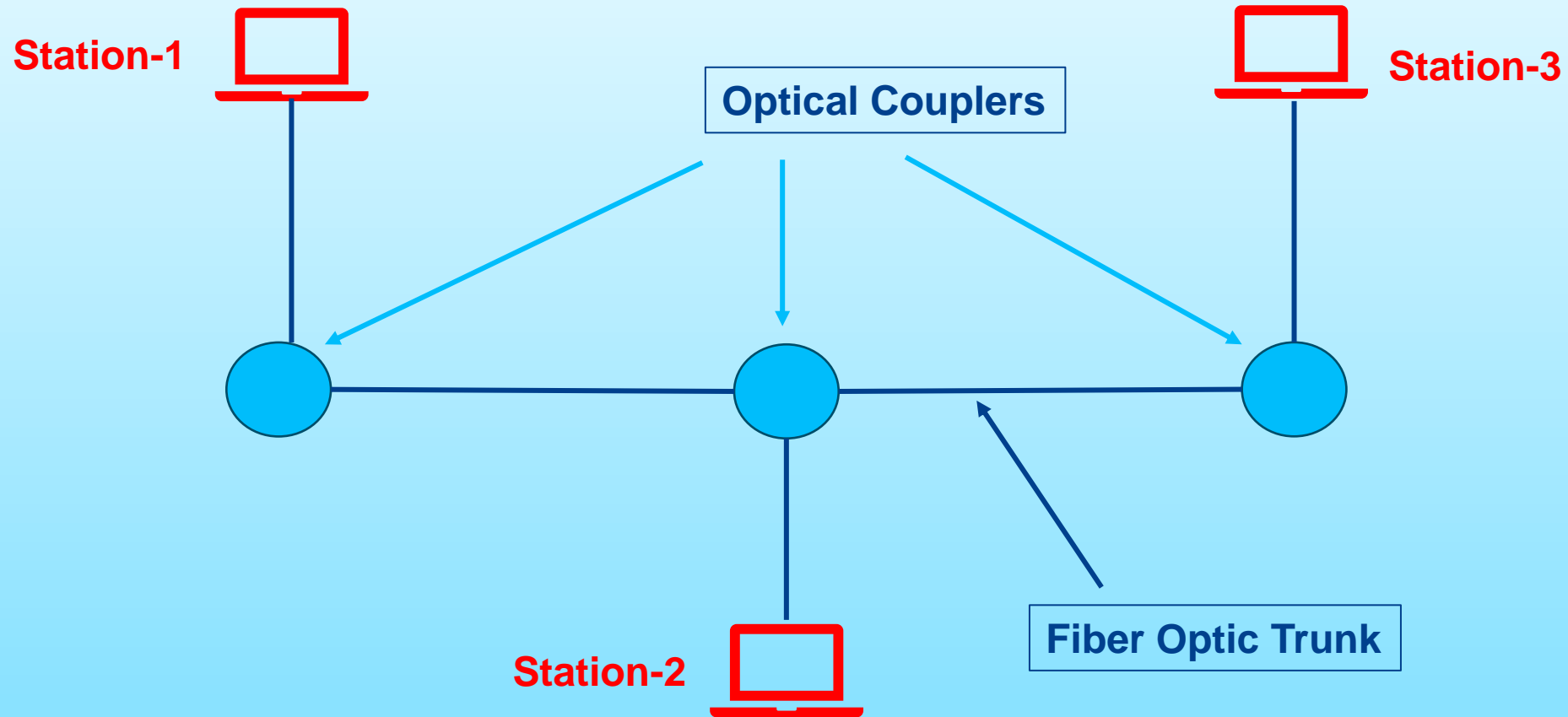


Figure 2: Bus Topology

Optical Network Topologies

Ring Topology

- ❖ Network devices are connected in closed loop optical fiber trunk
- ❖ Advantages:
 - ✓ Fiber cable faults are easily located
 - ✓ Ring networks are moderately easy to Install
- ❖ Disadvantages:
 - ✓ Expansion to the network can cause network disruption
 - ✓ A single break in the cable can disrupt the entire network.

Optical Network Topologies

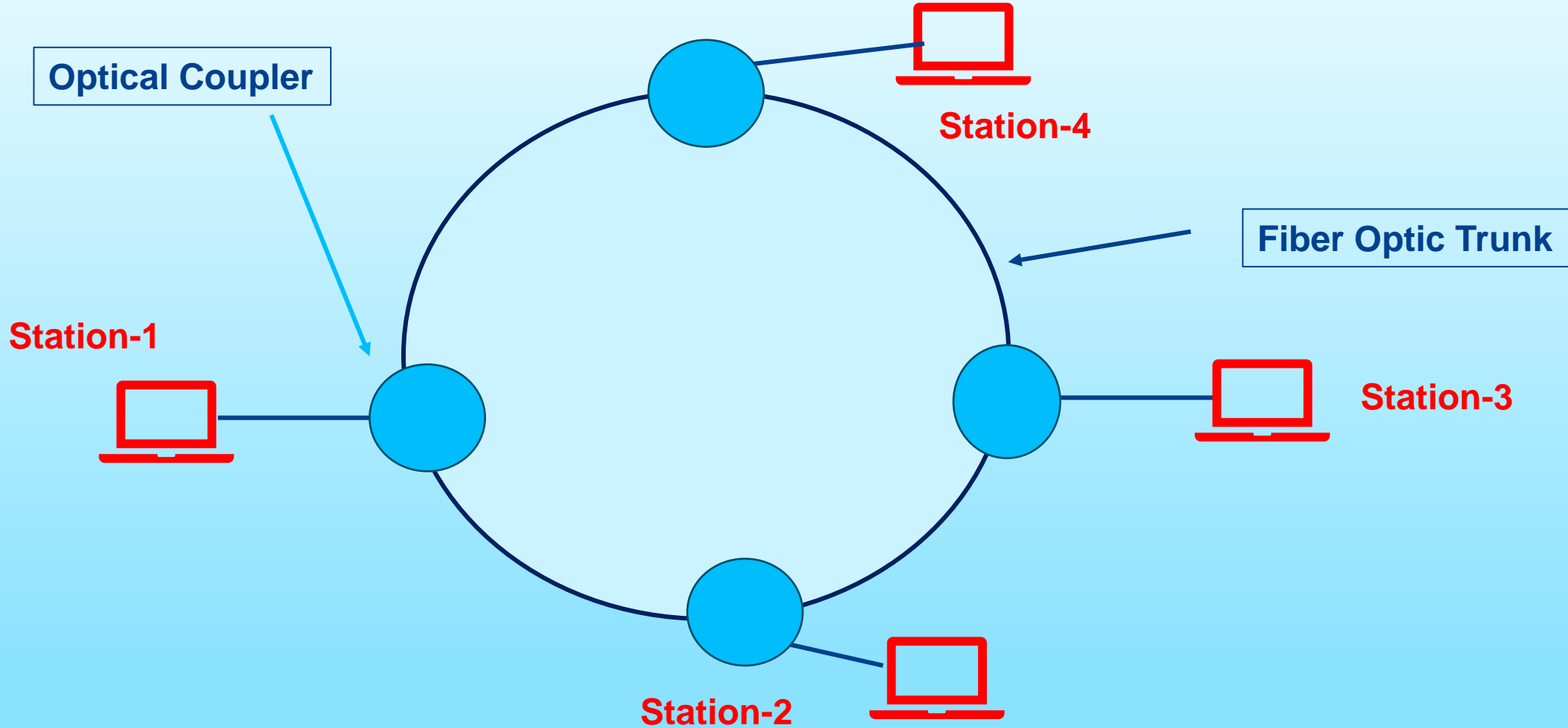


Figure 3: Ring topology

Optical Network Topologies

Star Topology

- ❖ All workstations are connected to central star couplers
- ❖ Each device requires a single trunk fiber cable
- ❖ point-to-point connection between the device and the star coupler
- ❖ Advantages:
 - ✓ Easily expanded without disruption to the network
 - ✓ Fiber cable failure affects only a single user
 - ✓ Easy to troubleshoot and isolate problem
- ❖ Disadvantages:
 - ✓ Requires more fiber cable
 - ✓ A central connecting device allows for a single point of failure

Optical Network Topologies

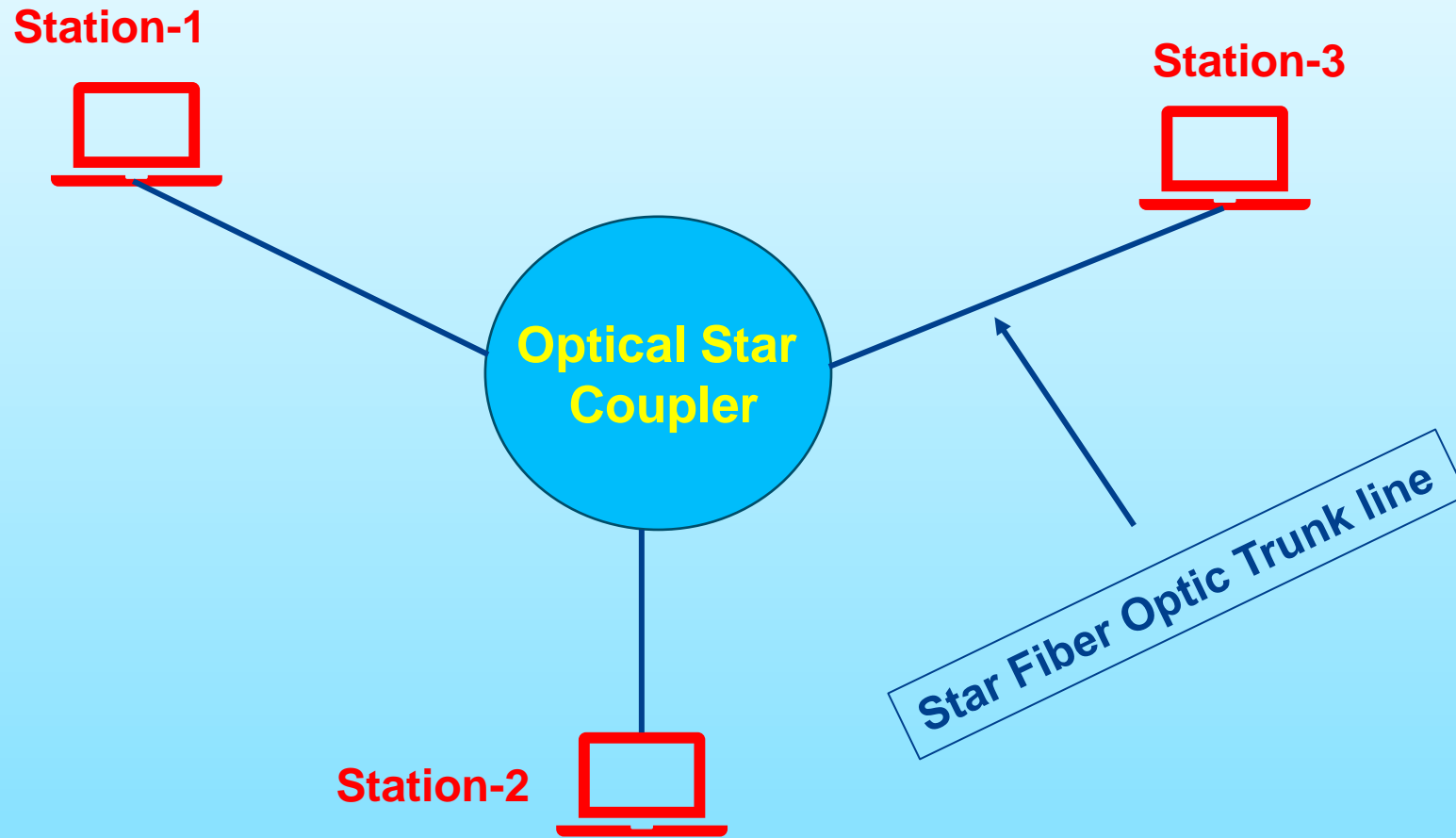


Figure 4: Star topology

Optical Network Topologies

Mesh Topology

- ❖ Each network nodes connected to each other
- ❖ High level of link redundancy
- ❖ Advantages:
 - ✓ Provides redundant paths between nodes
 - ✓ The network can be expanded without disruption
- ❖ Disadvantages:
 - ✓ Requires more cable than the other fiber optic network topologies
 - ✓ Complicated implementation and high cost

Optical Network Topologies

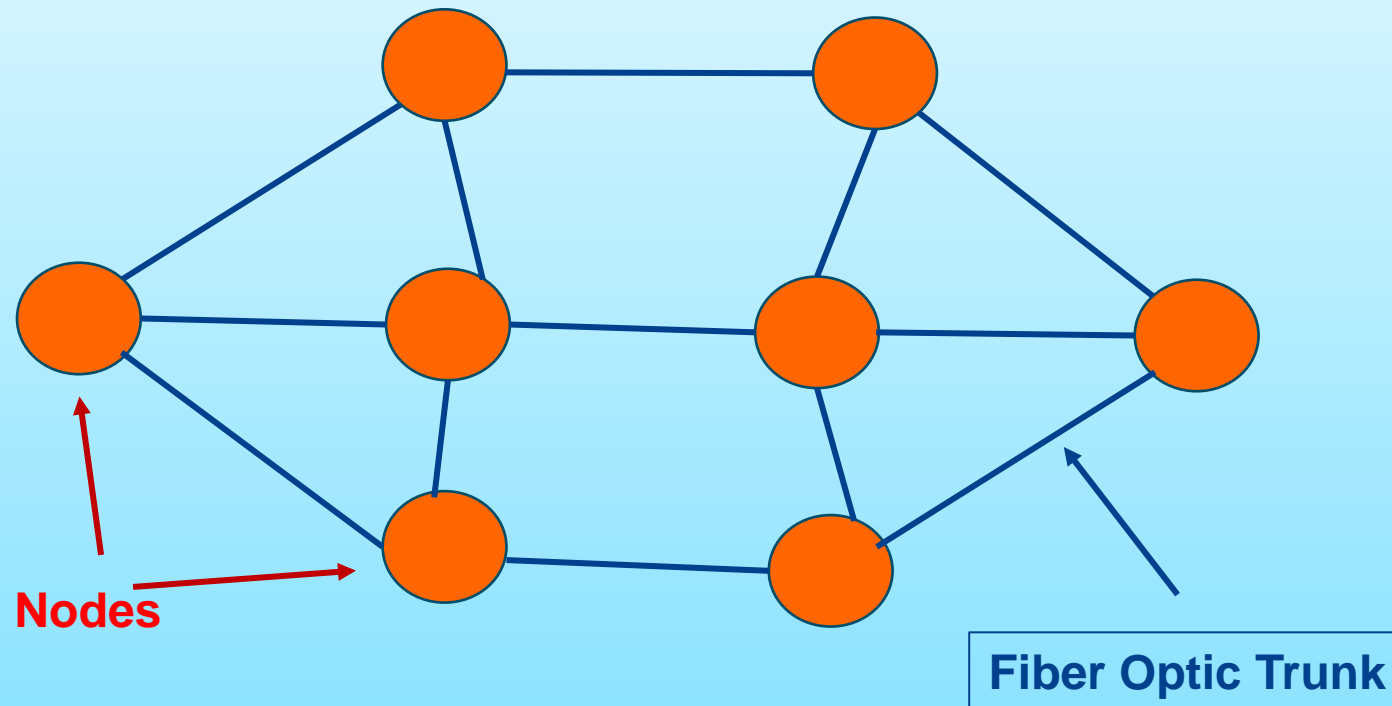


Figure 5: Mesh topology

Generation of Optical Networks

- The development of fiber optics communication network can be categorized in to two generations:

First-generation Optical networks

- ❖ Signal transmission in the optical domain to provide high capacity
- ❖ **Example:** SONET network (Synchronous Optical Network) and SDH network (Synchronous digital hierarchy network)

Second-generation Optical networks

- ❖ Wavelength routed network using Optical Circuit Switching (OCS)
- ❖ More functionality are handled in the optical domain (routing, switching)

First Generation of Optical Networks

- In first generation optical networks, optical signal transmission over optical fiber is used for point-to-point transmission
- Switching and routing handled electronically in electronic domain

Examples

- ❖ SONET/SDH
- ❖ Key Components: electronic cross-connects (EXC), Add and drop multiplexers (ADM)
- ❖ Hybrid solution:
 - ✓ coexistence of fiber optic and coaxial cable on the same architecture
 - ✓ coexistence of analog and digital formats on the same architecture

First Generation of Optical Networks

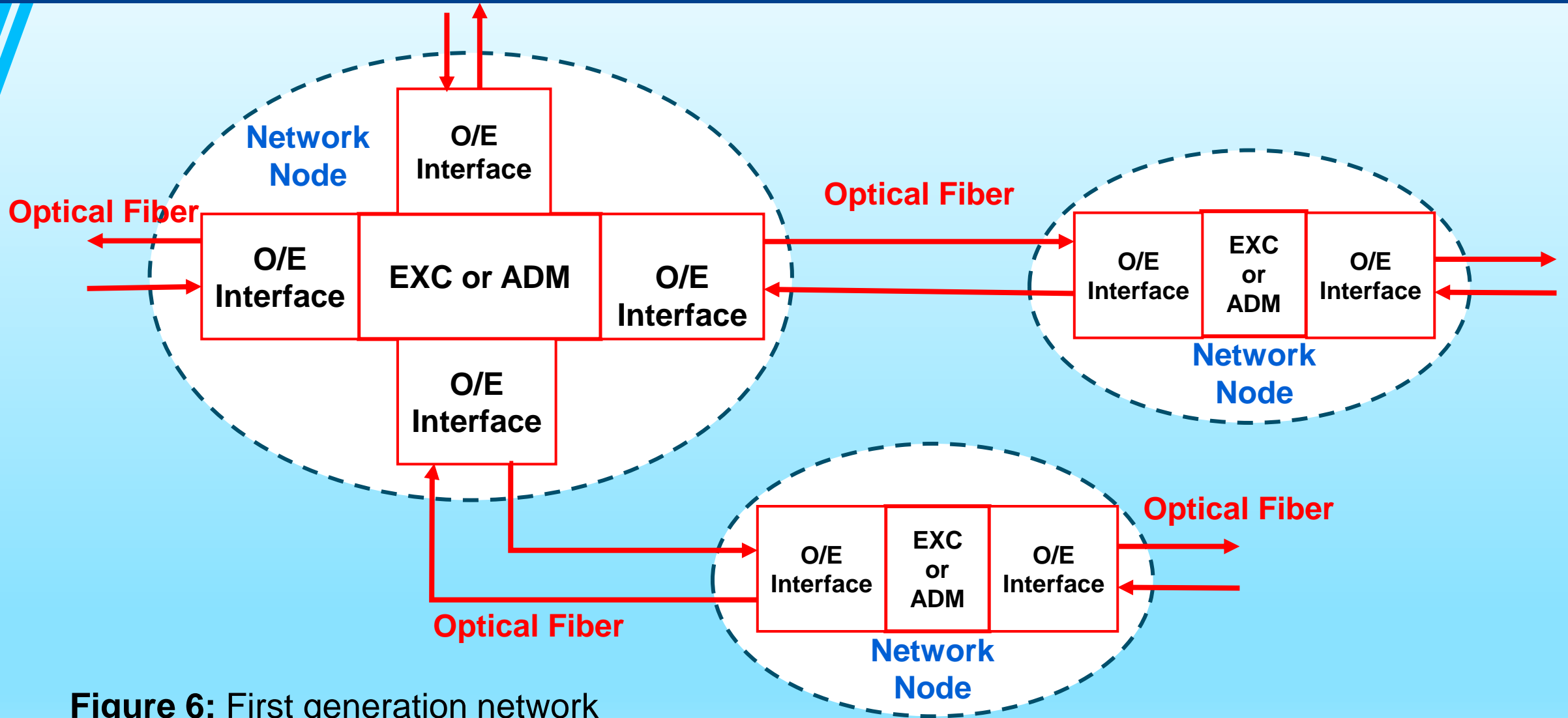


Figure 6: First generation network functions in electronic domain

SONET/SDH Basics

- **SONET (Synchronous Optical Network):** North American optical transmission and multiplexing standard
- Provide synchronous, reliable, and high-capacity transport of voice, data, and video over optical fibers

Key Features of SONET

- ❖ Synchronous transmission: All network elements operate on a common clock
- ❖ Standardized hierarchy: Defines multiplexing of lower-rate signals into higher-rate frames
- ❖ Transport Rates: OC-1 (51.84 Mbps), OC-3 (155 Mbps), OC-12 (622 Mbps), OC-48 (2.5 Gbps), OC-192 (10 Gbps)

SONET/SDH Basics

- **SDH (Synchronous Digital Hierarchy):** Europe and Japan optical transmission and multiplexing standard
- SDH and SONET are almost similar and both use synchronous transmission hierarchical multiplexing

SDH Transport Rate

- ❖ STM-1 (155 Mbps), STM-4 (622 Mbps), STM-16 (2.5 Gbps), STM-64 (10 Gbps)

Second Generation: Wavelength Routing Networks

- Second generation optical networks are wavelength routing networks
- Wavelength routing networks enable advanced functionalities beyond basic point-to-point links
- The wavelength routing network provides light-paths to its users such as :

❖ **SONET Terminals**

❖ **IP routers**

- A light-path is an end-to-end optical connection between a source node and a destination node
- It operates over a specific wavelength across all links along the route in most cases
- In some cases, wavelength conversion (from one wave length to another wavelength) may performed for light-paths
- At intermediate nodes, the light-path is optically routed or switched from one fiber link to another with out optical to electrical conversions

Wavelength Routing Networks

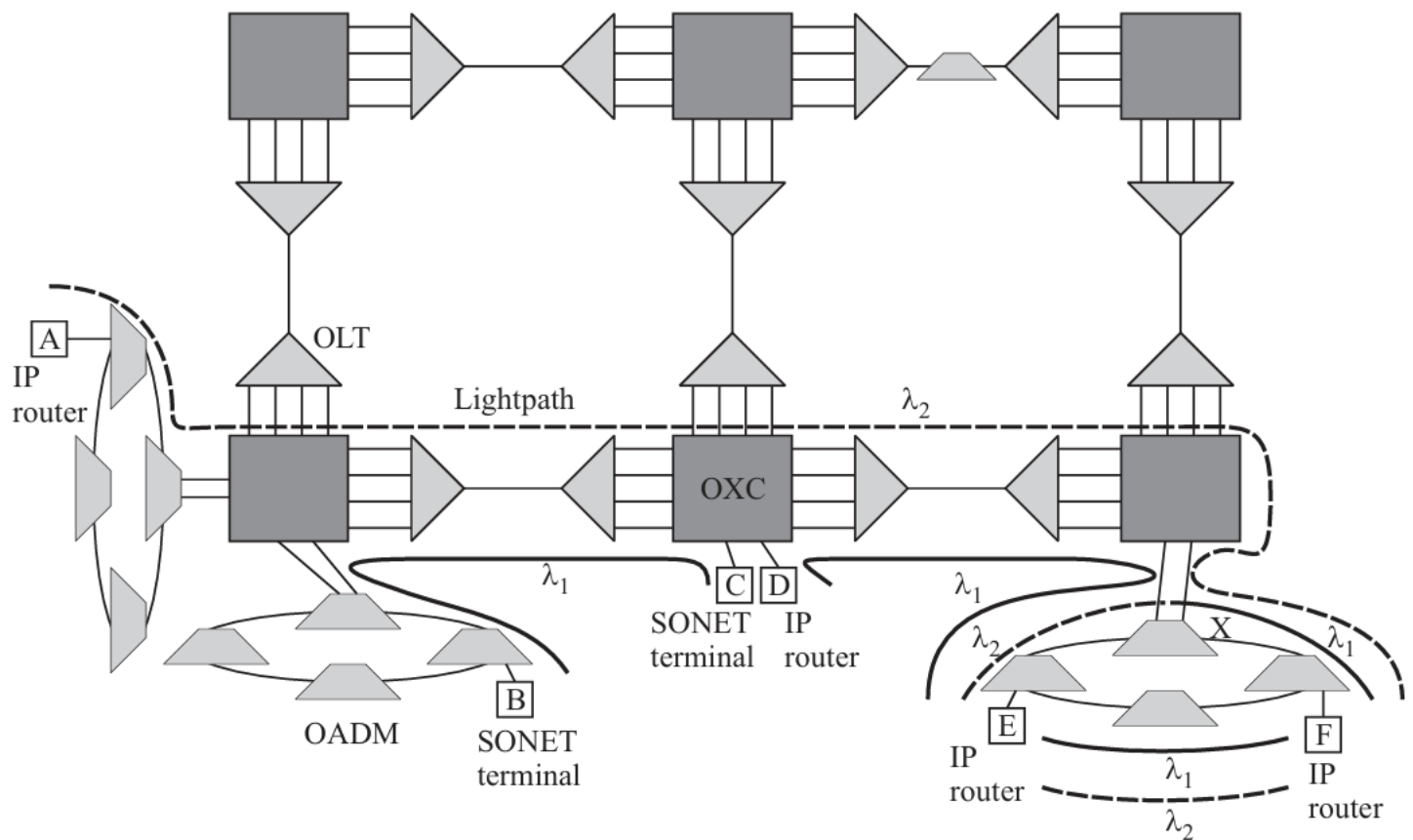


Figure 7: Wavelength routed network

Source: R. Ramaswami, K. Sivarajan, and G. H. Sasaki, "Optical Networks: A Practical Perspective," 3rd ed., Elsevier/Morgan Kaufmann, 2009.

<https://ars.els-cdn.com/content/image/3-s2.0-B9780123740922500096-f01-04-9780123740922.jpg>

Key Wavelength Routing Network Elements

- The key network elements that enable optical networking are:

Optical line terminals (OLTs):

- ❖ OLT combines (multiplexes) multiple wavelengths onto a single optical fiber for transmission.
- ❖ It also separates (demultiplexes) incoming wavelengths from a single fiber into individual output fibers

Optical Add/Drop Multiplexers (OADMs)

- ❖ An OADM receives multiple wavelength channels through a single optical fiber
- ❖ It selectively drops specific wavelengths for local access or processing
- ❖ The remaining wavelengths are allowed to pass through to the next node

Key Wavelength Routing Network Elements

Optical Cross-Connects (OXC)

- ❖ An OXC essentially performs a similar function as OADM but at much larger sizes
- ❖ OXCs have a large number of ports, from a few tens to several thousands
- ❖ They can switch wavelengths from any input port to any output port
- ❖ Both OADMs and OXCs may include wavelength conversion capabilities
- ❖ This allows signals to change wavelength at intermediate nodes, improving **network flexibility** and **reducing wavelength conflicts**

WDM Networks

- Second generation optical network Introduced multiple wavelengths (channels) per fiber to increase capacity.
- Optical amplifiers (like EDFAs) enabled long-distance multi-wavelength transmission
- Wave length division multiplexing (WDM) technology combines different carrier wavelengths to transmit on a single fiber and separates them on the other end [2]

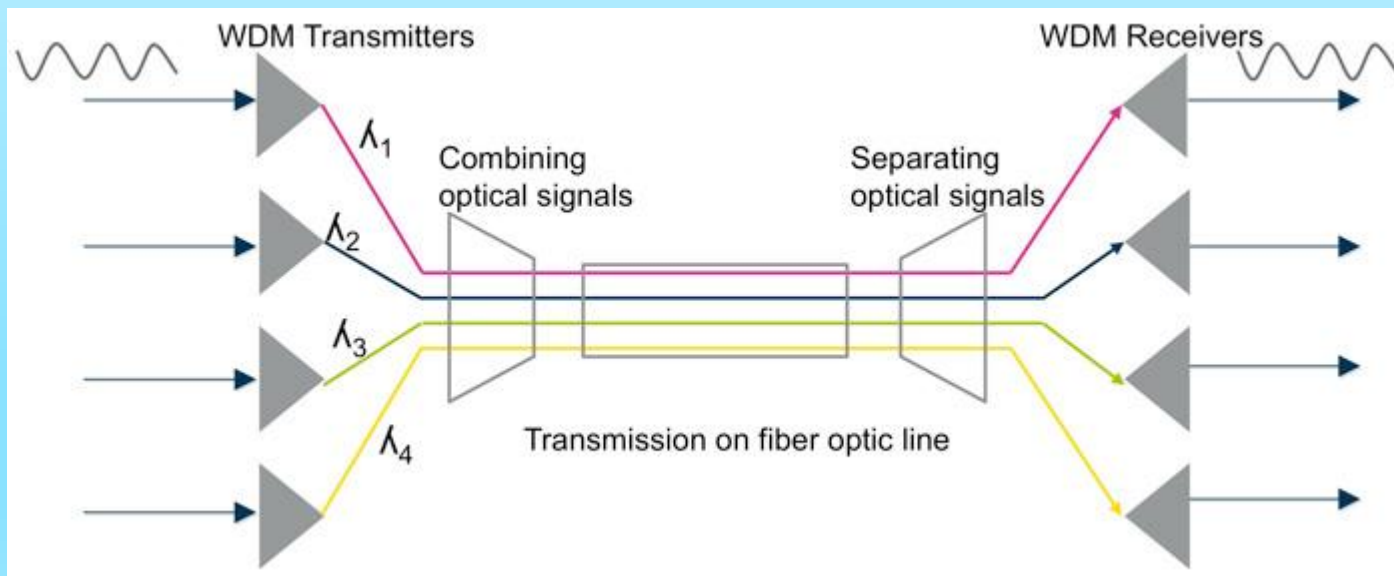


Figure 8: WDM systems

Source: A. Weissberger, "OFC 2024: Researchers achieve 12-spatial-channel WDM/SDM transmission over transoceanic distance," IEEE ComSoc Technology Blog, Jan. 16 2024. <https://img-en.fs.com/community/wp-content/uploads/2013/02/WDM-system.jpg>

WDM Networks

- WDM systems can be classified as Unidirectional and bidirectional WDM systems

Unidirectional WDM Systems

- ❖ Transmission of optical signal of all optical channels in one direction on a single fiber simultaneously
- ❖ Requires a separate fiber for the opposite direction
- ❖ Simpler design and reduced interference between channels
- ❖ Common in long-haul backbone links

WDM Networks

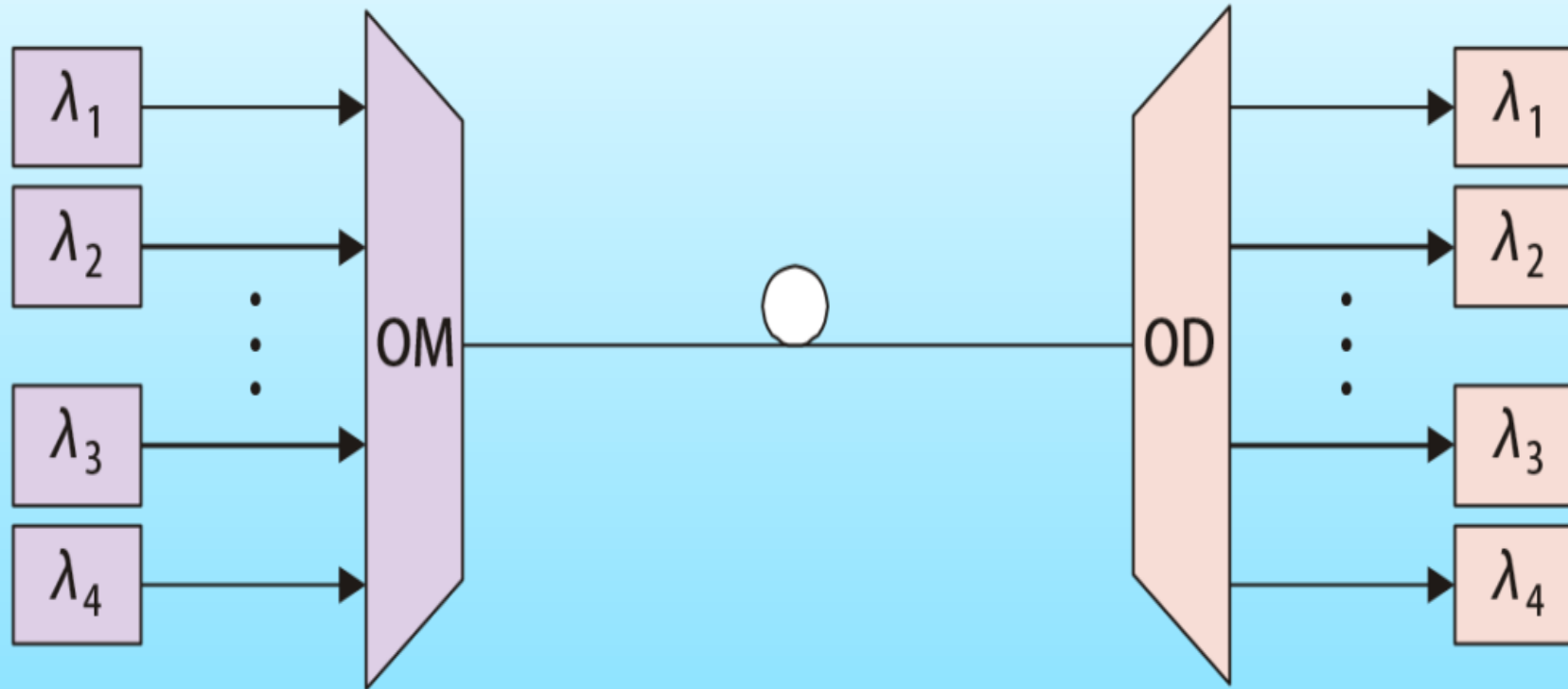


Figure 9: Unidirectional WDM systems

Source: "Unidirectional and Bidirectional WDM Systems," Lfiber, Mar. 8 2017. <https://www.lfiber.com/wp-content/uploads/unidirectional-wdm-1200x458.png>

WDM Networks

Bidirectional WDM Systems

- ❖ Transmission of optical signal of multiple optical channels in both direction on a single fiber simultaneously
- ❖ Fiber cost is reduced but system design becomes more complex
- ❖ Requires careful wavelength planning and isolation to prevent crosstalk

WDM Networks

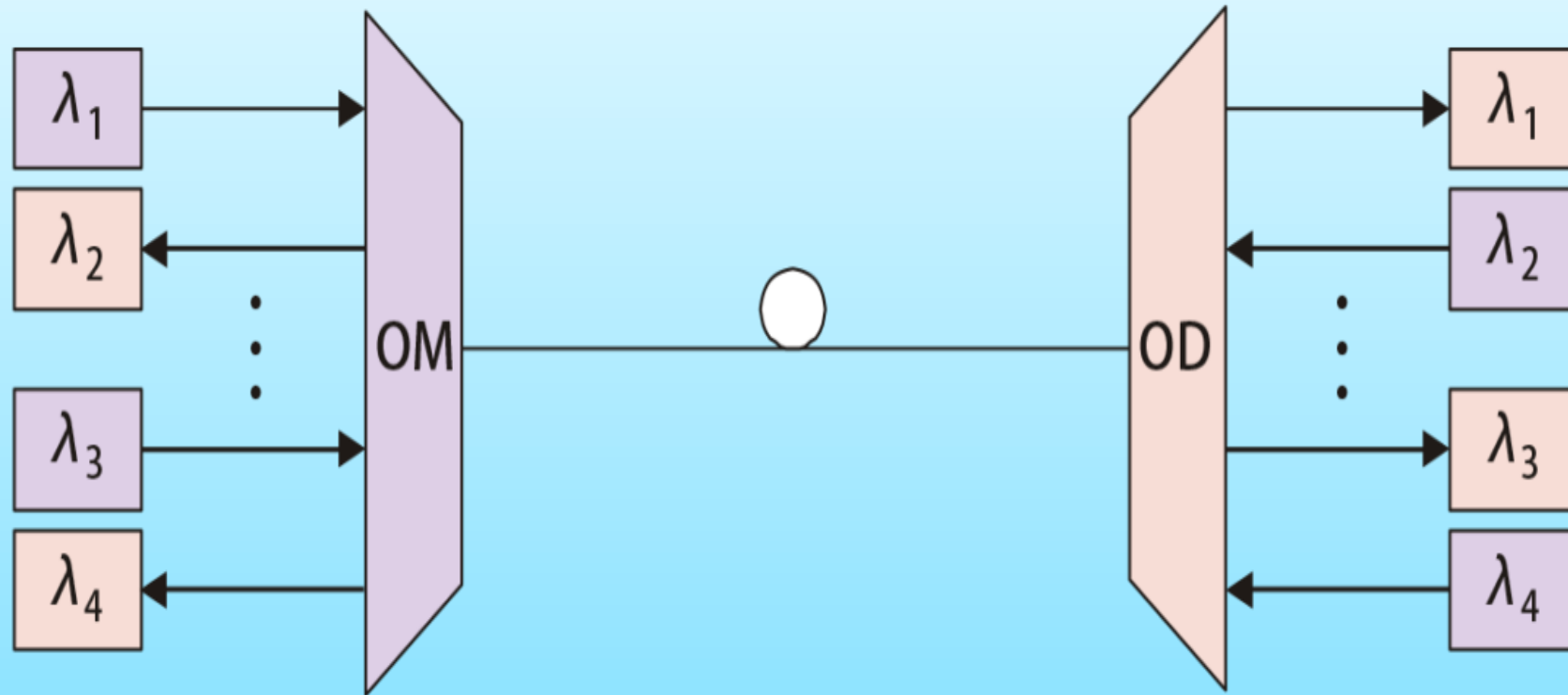


Figure 10: Bidirectional WDM systems

Source: "Unidirectional and Bidirectional WDM Systems," Lfiber, Mar. 8 2017. <https://www.lfiber.com/wp-content/uploads/bidirectional-wdm-1200x458.png>

WDM Networks

- Based on the WDM architecture, WDM networks can be classified as

Broadcast and select WDM network

- ❖ It's the architecture of WDM network that have a simple broadcast system
- ❖ Star topology is a popular topology used in this type of WDM networks
- ❖ Working Principle:
 - ✓ Multiple nodes transmit data on different wavelengths
 - ✓ The star coupler combines all transmitted signals
 - ✓ This combined signal is broadcasted to all nodes in the network
 - ✓ Each node tunes its receiver to the specific wavelength carrying its intended message

WDM Networks

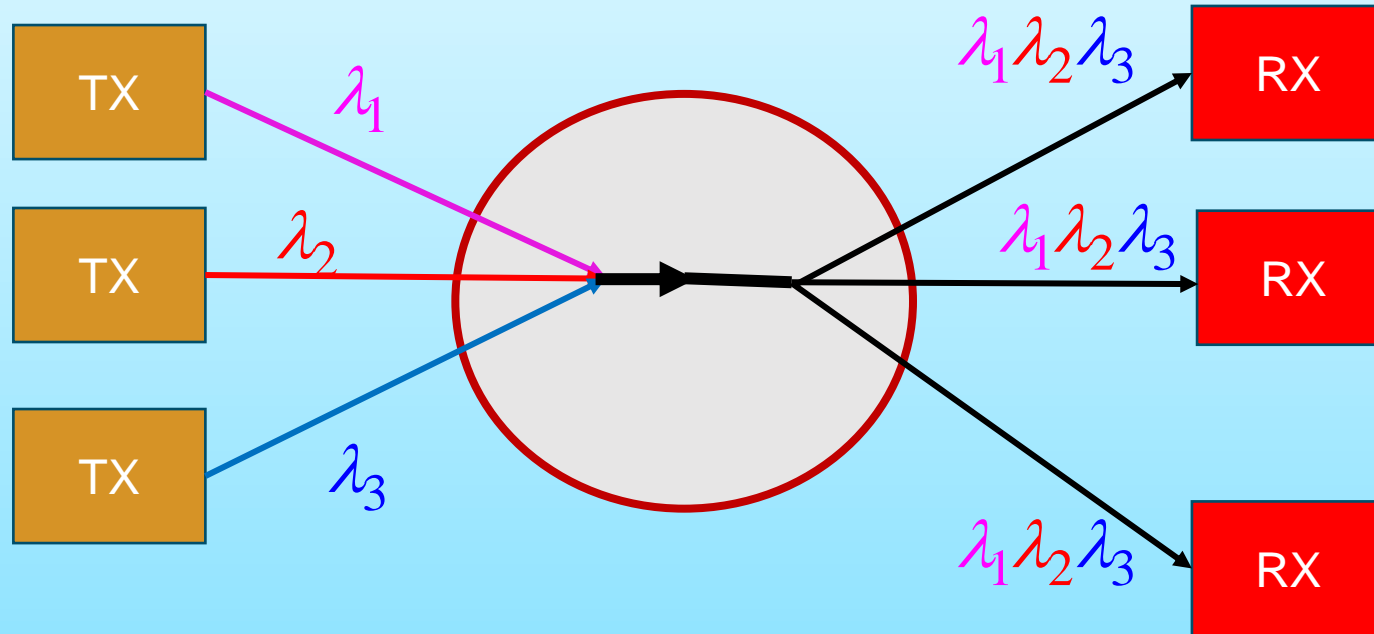


Figure 10: Broadcast and select WDM networks

WDM Networks

Wavelength Routed WDM Network

- ❖ **Main Components:**
 - ✓ Routing Node: Responsible for forwarding optical signals along the selected path
 - ✓ Access Nodes: Performs Optical–Electrical–Optical (O-E-O) conversion for signal processing or access
- ❖ Uses light-paths (end-to-end optical connections) established over specific
- ❖ **Use optical switching:** Data remains in the optical domain and no electronic conversion at intermediate nodes

WDM Networks

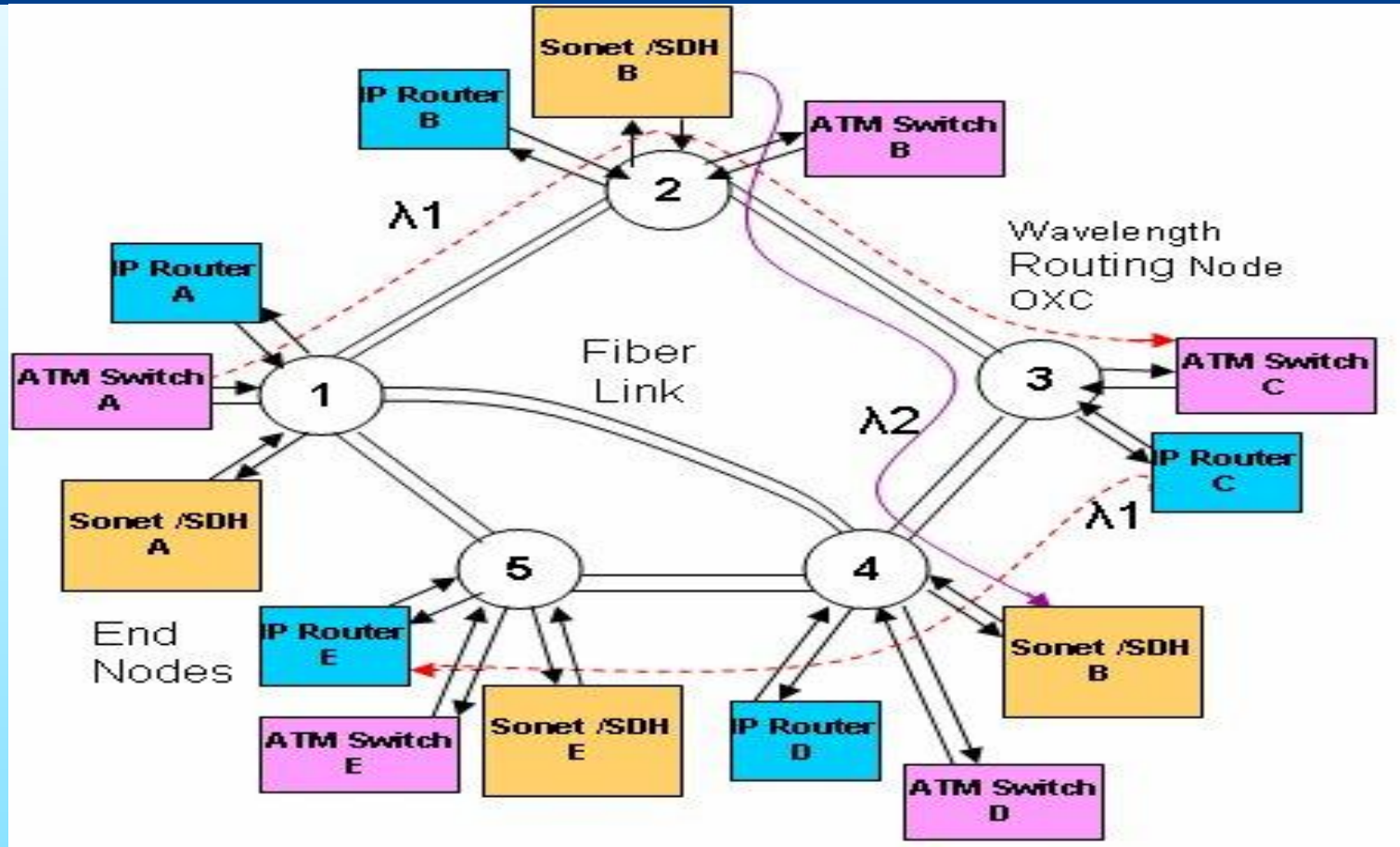


Figure 11: Wavelength routed WDM networks

Source: P. Goswami, S. K. Ghosh and D. Datta, "On Survivability of Dynamically Provisioned Wavelength-Routed Networks," Optical Society of India (OSI) Symposium, Dec. 2007. https://www.researchgate.net/profile/Partha-Goswami/publication/272792217/figure/fig1/AS:392012873388034@1470474560526/Wavelength-routed-optical-WDM-network_W640.jpg

WDM Networks

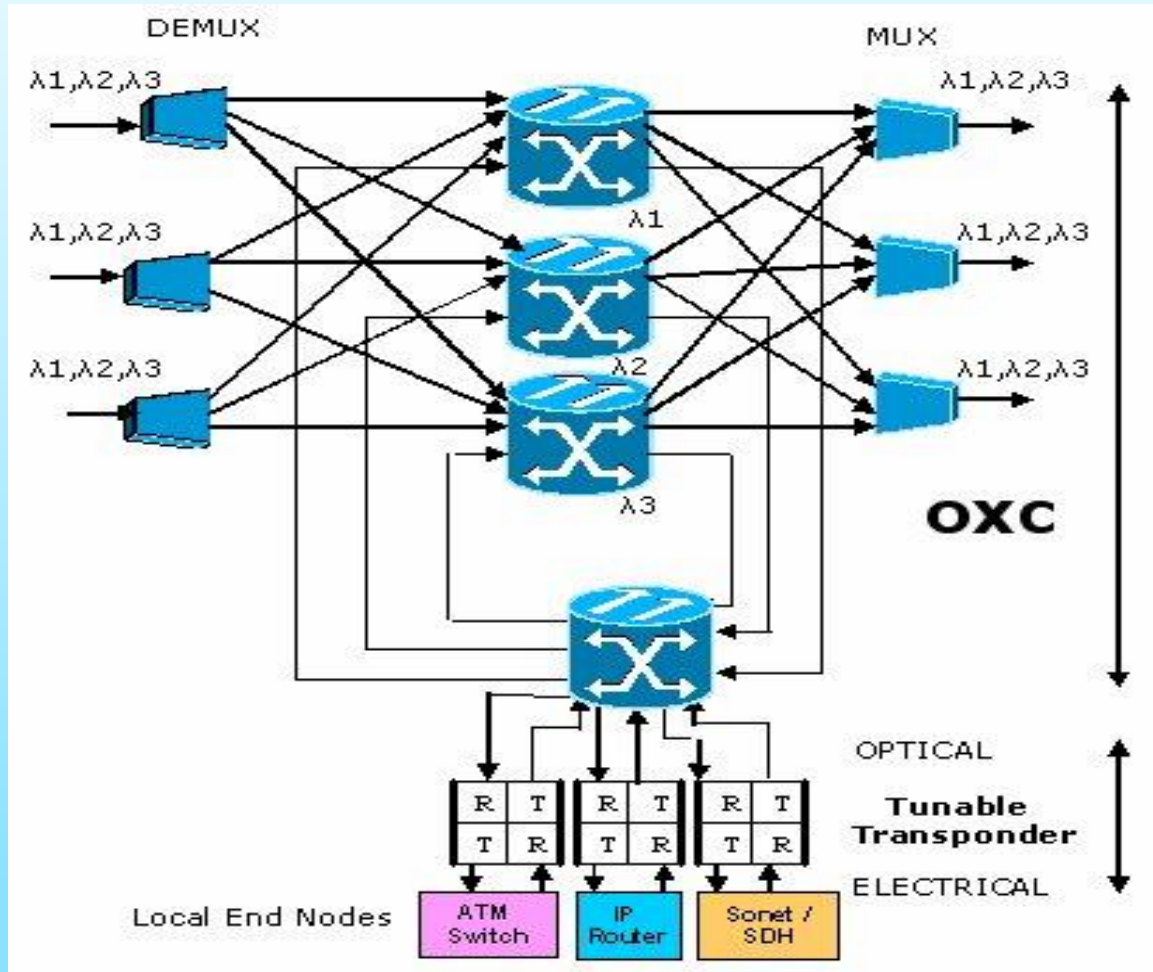


Figure 12: WDM-based OXC architecture in wavelength routed WDM network

Source: P. Goswami, S. K. Ghosh and D. Datta, "On Survivability of Dynamically Provisioned Wavelength-Routed Networks," Optical Society of India (OSI) Symposium, Dec. 2007.

https://www.researchgate.net/profile/Partha-Goswami/publication/272792217/figure/fig2/AS:392012873388036@1470474561007/WDM-based-OXC-architecture_W640.jpg



Passive Optical Networks (PON)

Passive Optical Networks (PON)

- A Passive Optical Network (PON) is a fiber-optic network architecture that uses passive optical splitters
- PON key components are as follows:

Optical line terminals (OLT):

- ❖ is the service provider's endpoint in a PON, typically located at the central office (CO)

Optical Network Unit (ONU):

- ❖ A device in a PON that connects multiple end users to the network
- ❖ Can serve several homes or offices in a building or neighborhood
- ❖ Converts optical signals from the OLT into electrical signals for users

Optical Network Termina(ONT): A type of ONU installed at the customer's premises and serve a household

Passive Optical Networks (PON)

- PON delivers data from a single Optical Line Terminal (OLT) to multiple Optical Network Units (ONUs).
- It uses no active components between OLT and ONUs
- PON represent one of the most attractive optical access-network solutions.
- PON Advantages:

- ❖ Low operational cost (no active components)
- ❖ High bandwidth efficiency
- ❖ Simplified fiber infrastructure
- ❖ Scalable for multiple users

Passive Optical Networks (PON)

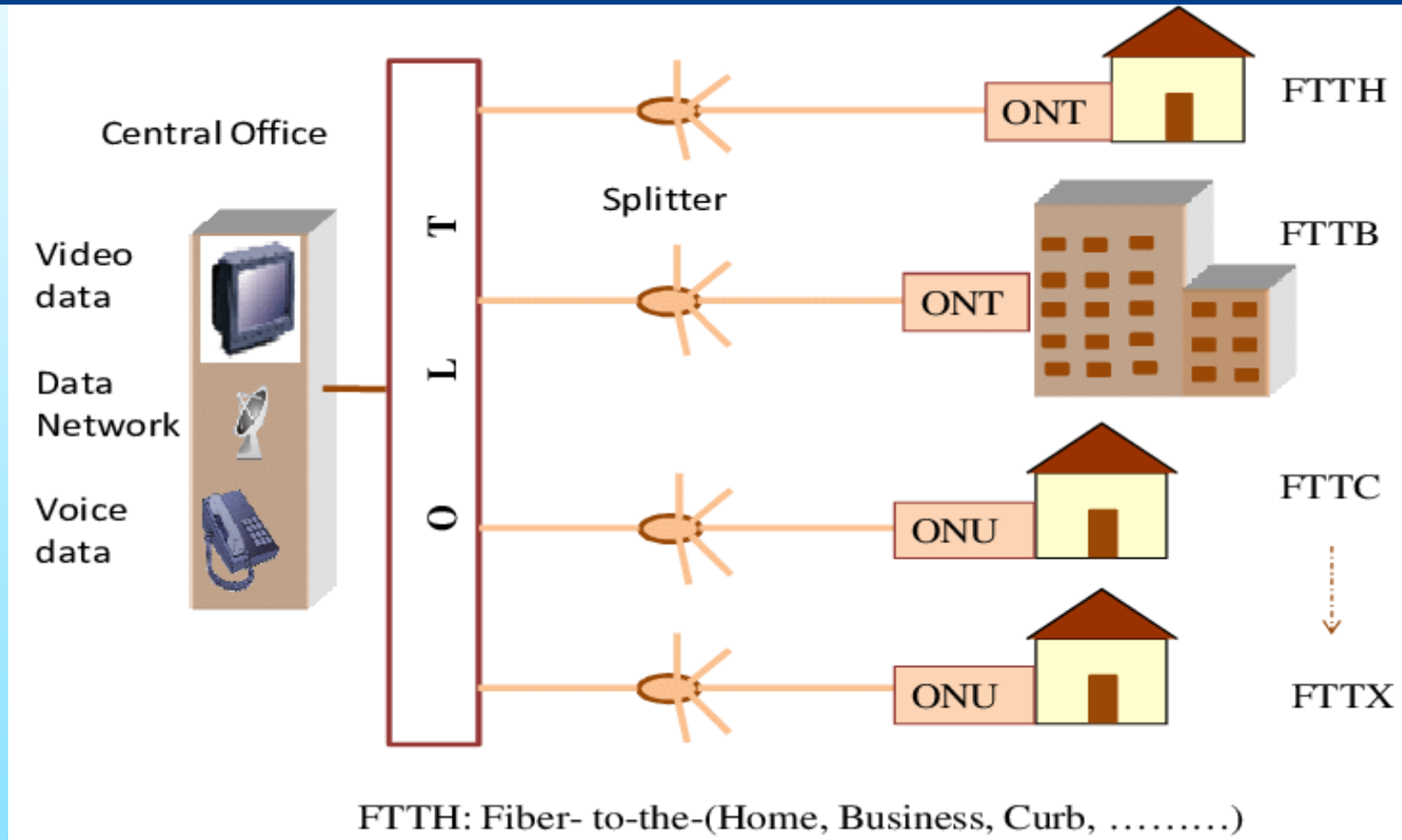


Figure 13: PON networks

Source: H. A. B. Mustafa, F. Xiao and K. Alameh, "A 1x2 adaptive optical splitter based on Opto-VLSI processor," 7th International Symposium on High-capacity Optical Networks and Enabling Technologies, Cairo, Egypt, 2010. <https://www.researchgate.net/profile/Haithem-Mustafa/publication/224219727/figure/fig1/AS:669083339075596@1536533307714/Schematic-architecture-of-a-passive-optical-network-PON-employing-1N-passive-optical.png>

Summary

- **Advantage of Fiber optic communication Networks:**
 - ✓ High speed communication
- **Usage Scenario:**
 - ✓ Backbone, metropolitan, and last mile access network
- **Generations**
 - ✓ **First Generation:** SONET/SDH, switching in electronic domain
 - ✓ **Second Generation:** all optical network, wavelength routing
- **Passive Optical Network (PON)**
 - ✓ Key last mile optical access network
 - ✓ **Key components:** OLT, ONU/ONT, optical splitter

References

- [1] Gerd Keiser, "*Fiber Optic Communications*", Springer, Pp.514, 2021.
- [2] Govind P. Agrawal, "Fiber-Optic Communication Systems", John Wiley & Sons, Pp.330-331, 2002.



Thank You!