OPTICAL NETWORKS

Dramatic changes in the telecommunications industry

- First and foremost is the continuing, relentless need for more capacity in the network. This demand is fueled by many factors such as Internet, WWW, no. of users, amount of time, and thus bandwidth taken by each user.

- Businesses today rely on high-speed networks to conduct their businesses.

- Bandwidth cost is reduced due to Technological advances resulting in the development of a new set of applications that make use of more bandwidth and affects behavioral patterns.

- Another factor causing major changes in the industry is the deregulation of the telephone industry private players.

- Also, traffic in a network is dominated by data as opposed to traditional voice traffic. Today, data transport services are pervasive and are capable of providing quality of service to carry performance sensitive applications such as real-time voice and video.

These factors have driven the development of high-capacity optical networks

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

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

Due to all these advantages

- Optical fiber Networks have high capacity

- Can be used for providing the high bandwidth services

Provides an easy and flexible way to deliver bandwidth on demand where and when it is needed

All the networks using optical fiber as transmission medium - optical networks

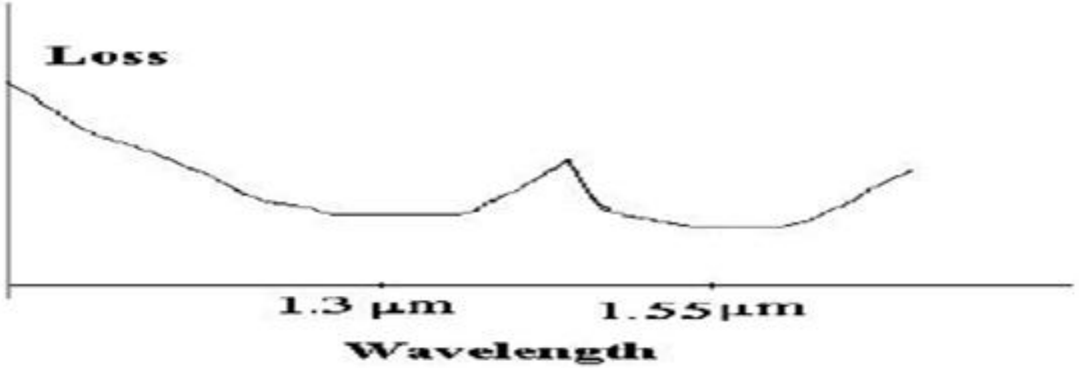
When - transmitted signal remains in optical form till its arrival at destination - *All-optical network*

Optical fiber uses ·· carrier frequency of the order of 10^{15} Hz.

- Bandwidth generally a smaller fraction of carrier frequency

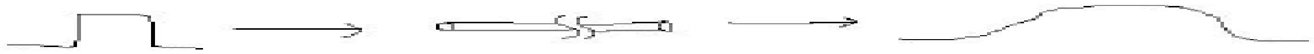
  Large BW is available (of the order of 40 THz)

Optical fiber has low loss in 1.3 μm and 1.55 μm bands



Degradation of signal in optical fiber

- Dispersion



Minimum dispersion at 1.3μm

- Attenuation

Minimum attenuation at 1.55μm

A and B communicate with each other via switch/router (exchange in conventional terminalogy)

These are Switched Networks.

When the links are optical fiber - optical network

But the signal might go through E/O and O/E conversion many times before reaching destination

Commonly deployed networks with fiber as point-to-point link

FDDI, DQDB, SONET/SDH, ATM, IEEE802.3

Telecommunications Network Architecture

- The telecommunications network may be owned and operated by different carriers. The carrier owns the facilities (like fiber links) and equipment deployed inside the network.
- Some times the carriers may lease certain facilities from other carriers and in turn offer value-added services to customers. There are also virtual carriers.

- A *local-exchange* carrier (LEC) offers local services in metropolitan areas, and an *interexchange* carrier (IXC) offers long-distance services.
- In contrast to public networks, *private* networks are networks owned and operated by corporations for their internal use. Many of these corporations in turn rely on capacity provided by public networks to implement their private networks, particularly if these networks cross public land.

LAN: Networks within buildings spanning at most a few kilometers.
MAN: Networks that span a campus or metropolitan area, typically tens to a few hundred kilometers.
WAN: Networks that span even longer distances, ranging from several hundred to thousands of kilometers.

Public Network:

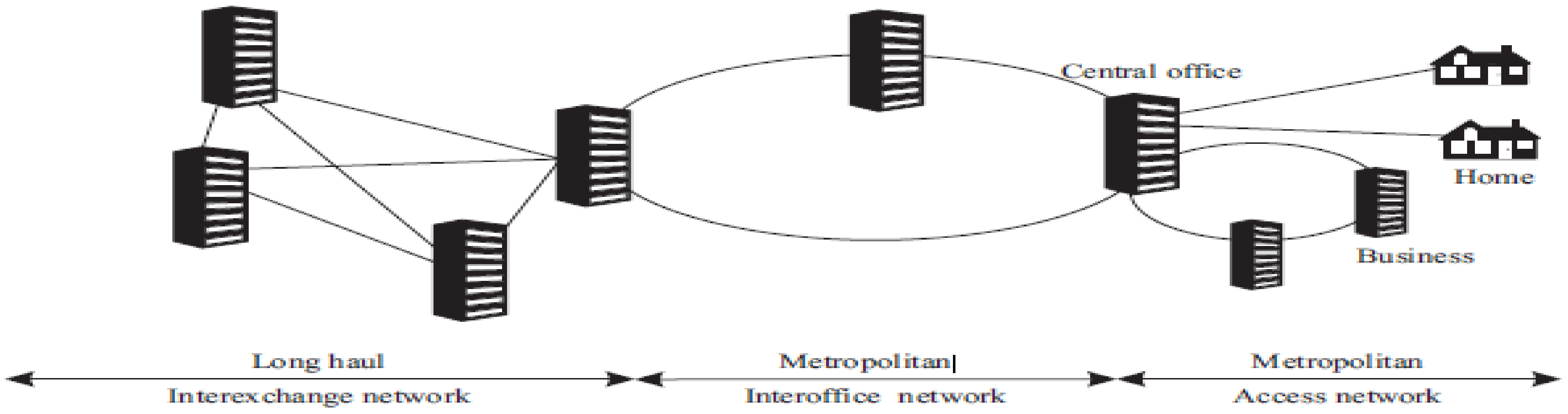


Figure 1.1 Different parts of a public network.

The nodes in the network are ***central offices.*** They are also called as–***POPs*** *–point of presence*- when nodes present a small size, or –***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

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)

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

The public network shown above is a terrestrial network.

Optical fiber is also extensively used in undersea networks. Undersea networks can range from a few hundred kilometers in distance to several thousands of kilometers for routes that cross the Atlantic and Pacific oceans.

Services are offered by carriers to their customers.

- **Connection-Oriented**
- **Connectionless**

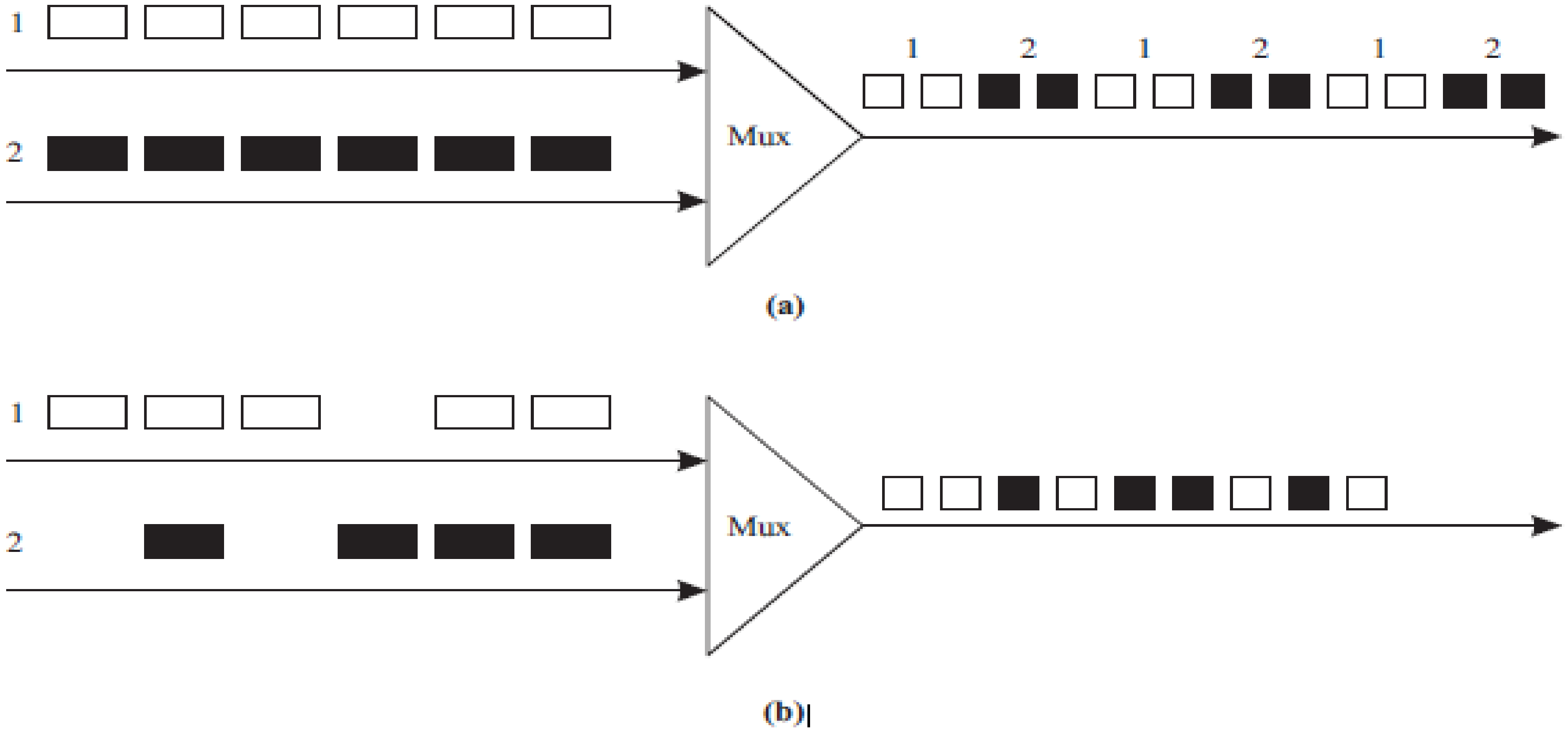
Switching Types

–Circuit-switched

- Involves call set up, data transfer and call termination.
- A guaranteed bandwidth is allocated to each connection, available till the connection lasts.
- The sum of the bandwidth of all the connections, on a link must be less than the link bandwidth.
- Not efficient at handling bursty data traffic.

–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, also called datagram circuit(service)



(a) Fixed Packet Switching

(b) Statistical Packet Switching

The Changing Services Landscape

The service model used by the carriers is changing rapidly as networks and technologies evolve and competition among carriers intensifies.

- Network characteristics
    - Full redundancy
    - Fast restoration
    - High availability (99.999 %)
    - Low latency
    - High bandwidth
    - Dynamic allocation and high bandwidth efficiency
    - Support various services
- More providers and equipment builders (due to deregulation of the telecom industry)
- Providers are expected to provide more services at higher capacity at lower prices!
    - A positive feedback business model!
    - Need for high capacity network
    - More users

The Changing Services Landscape

- The bandwidth delivered per connection is increasing, and it is becoming common to lease lines ranging in capacity from 155 Mb/s to 2.5 Gb/s and even 10 Gb/s.

- The duration for which bandwidth is leased is reduced to mins or hours rather than days or months.

- Availability: Typically, carriers provide 99.999% availability, which corresponds to a downtime of less than 5 minutes per year. This in turn requires the network to be designed to provide very fast restoration of service in the event of failures such as fiber cuts, today in about 50 ms. Very fast restoration is accomplished by providing full redundancy—half the bandwidth in the network is reserved for this purpose.

- The mix of services offered by carriers is expanding. Carriers would thus like to migrate to a single-network infrastructure that enables them to deliver both circuit switched and packet switched services.

Optical networks offer these solutions

Optical Network Capabilities

- An optical network provides a common infrastructure over which a variety of services can be delivered.

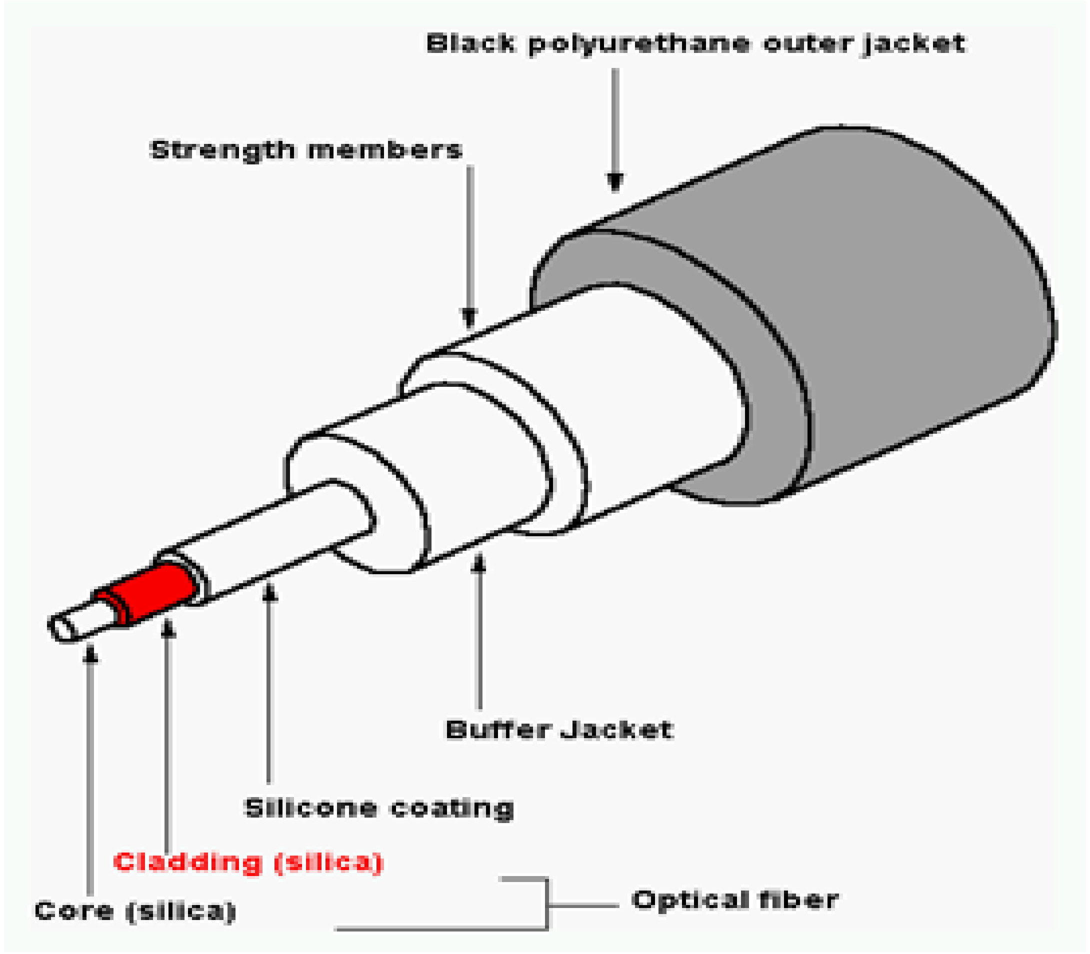
- It is capable of delivering bandwidth in a flexible manner where and when needed.

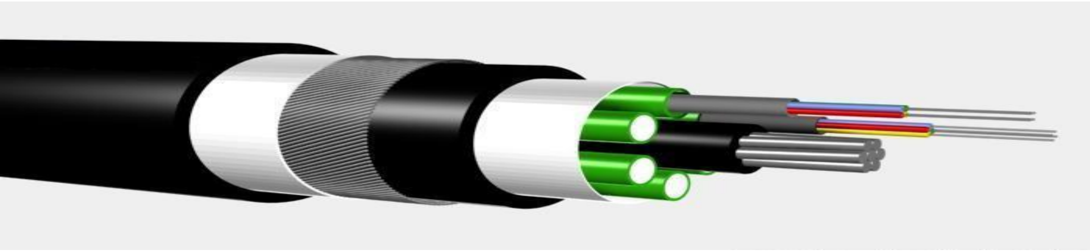
- It offers much higher bandwidth than copper cables.

- It is less susceptible to various kinds of electromagnetic interferences and other undesirable effects. As a result, it is the preferred medium for transmission of data at anything more than a few tens of megabits per second over any distance more than a kilometer.

- It is also the preferred means for realizing short-distance (a few meters to hundreds of meters), high-speed (gigabits per second and above) interconnections inside large systems.

Optical Fiber





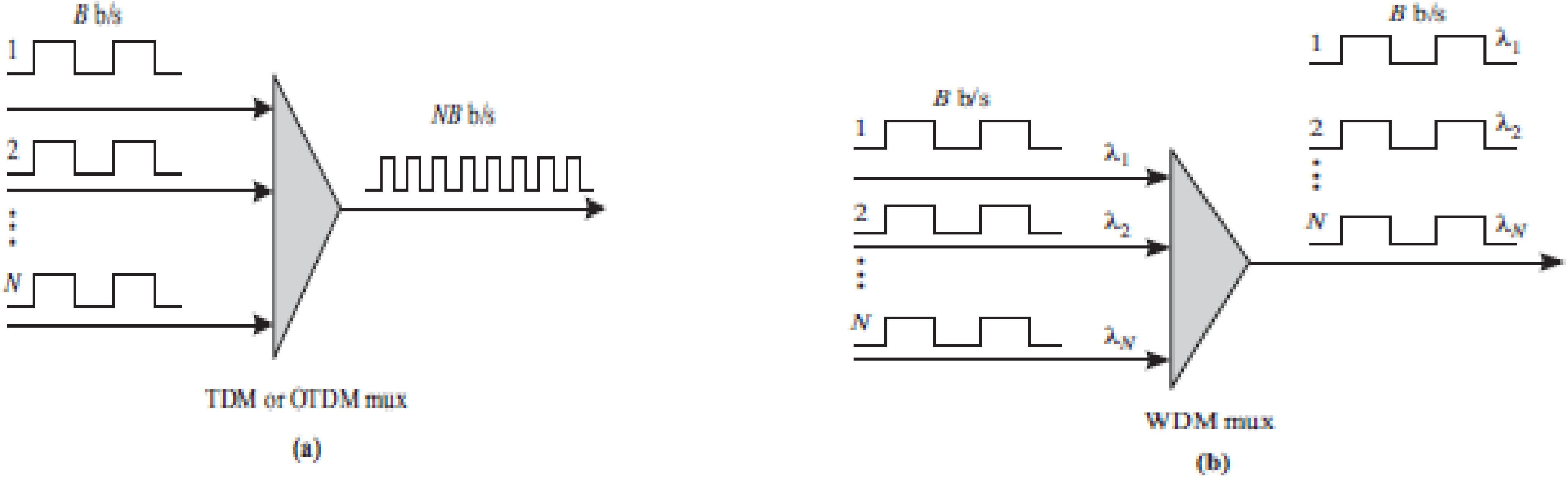
- The amount of deployment of fiber is often measured in *sheath* miles.
- Sheath miles is the total length of fiber cables, where each *route* in a network comprises of many fiber *cables*.
- For example, a 10-mile-long route using three fiber cables is said to have 30 *sheath* (cable) miles of fiber.
- Each cable may contain many *fibers*. If each cable has 20 fibers, the same route is said to have 600 fiber miles.
- Currently more than 1.5 billion kilometers of optical fiber is deployed around the world.
- The circumference of earth is 40,000 Km!

Generations of Optical Networks

First generation optical networks: Here optics was essentially used for transmission and simply to provide capacity. All the switching and other intelligent network functions were handled by electronics.

Ex: SONET (synchronous optical network), SDH (synchronous digital hierarchy) networks, which form the core of the telecommunications infrastructure in North America and in Europe and Asia, respectively, as well as a variety of enterprise networks such as Fibre Channel.

Second-generation optical networks: They have routing, switching, and intelligence in the *optical layer.*



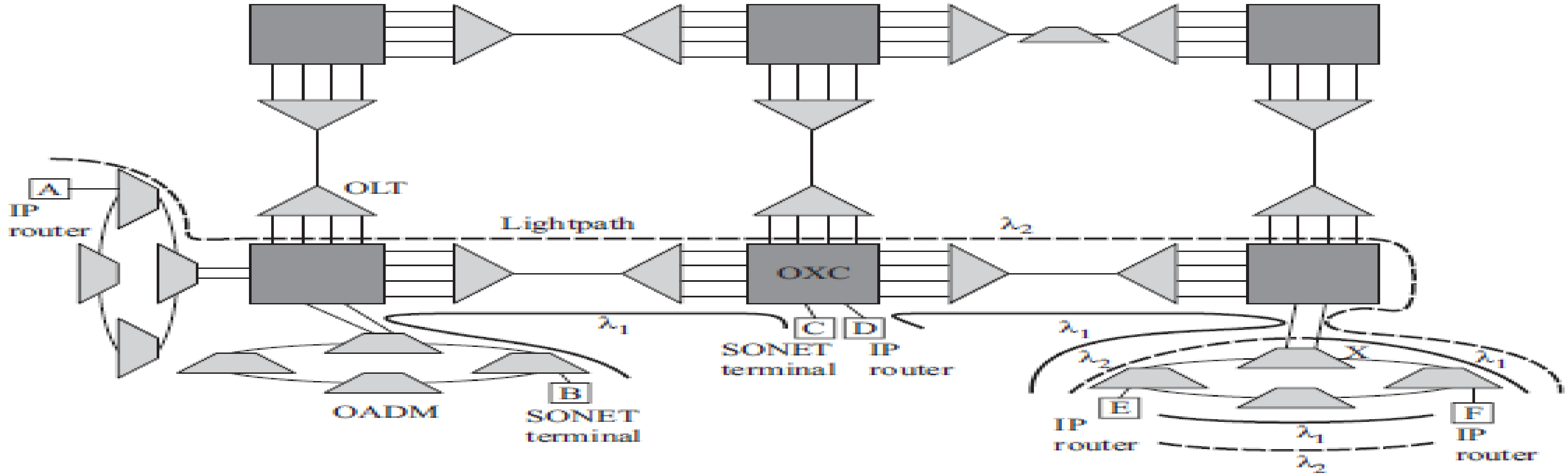


Figure A WDM wavelength-routing network, showing optical line terminals (OLTs), optical add/drop multiplexers (OADMs), and optical crossconnects (OXCs). The network provides lightpaths to its users, which are typically IP routers or SONET terminals.

- The optical network provides *light paths* to its users, such as SONET terminals or IP routers.
- Light paths are optical connections carried end to end from a source node to a destination node over a wavelength on each intermediate link.
- At intermediate nodes in the network, light paths are routed & switched from one link to another link.

In some cases, light paths may be converted from one wavelength to another wavelength as well along their route.

Different light paths in a wavelength-routing network can use the same wavelength as long as they do not share any common links.

This allows the same wavelength to be reused spatially in different parts of the network.

The architecture supports a variety of topologies, including ring and mesh topologies.

The network consists of optical line terminals (OLTs), optical add/drop multiplexers (OADMs), and optical cross connects (OXCs) interconnected via fiber links.

Features of WDM Architecture

Wavelength reuse: Multiple light paths in the network can use the same wavelength, as long as they do not overlap on any link. This spatial reuse capability allows the network to support a large number of light paths using a limited number of wavelengths.

Wavelength conversion. Light paths may undergo *wavelength conversion* along their route. Wavelength conversion can improve the utilization of wavelengths inside the network. Wavelength conversion is also needed at the boundaries of the network to adapt signals from outside the network into a suitable wavelength for use inside the network.

Transparency: The light paths can carry data at a variety of bit rates, protocols, and so forth and can, in effect, be made protocol insensitive.

Circuit switching: The light paths provided by the optical layer can be set up and taken down upon demand.

Survivability: The network can be configured such that, in the event of failures, light paths can be rerouted over alternative paths automatically. This provides a high degree of resilience in the network.

Light path topology: The light path topology is the graph consisting of the network nodes, with an edge between two nodes if there is a light path between them. The Light path topology thus refers to the topology seen by the higher layers using the optical layer. To an IP network residing above the optical layer, the light paths look like links between IP routers. The set of light paths can be tailored to meet the traffic requirements of the higher layers.

Optical Line Terminal(OLT)

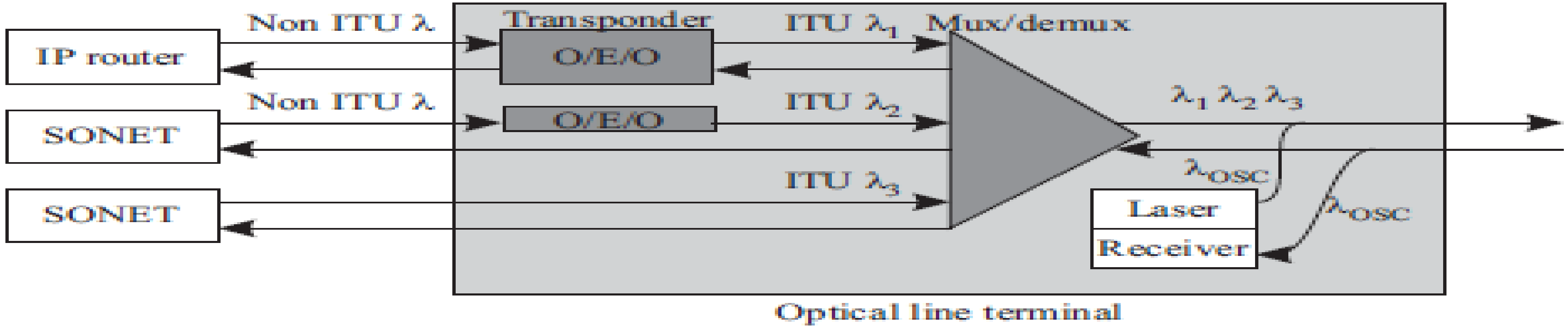


Figure Block diagram of an optical line terminal. The OLT has wavelength multiplexers and demultiplexers and adaptation devices called transponders. The transponders convert the incoming signal from the client to a signal suitable for transmission over the WDM link and an incoming signal from the WDM link to a suitable signal toward the client. Transponders are not needed if the client equipment can directly send and receive signals compatible with the WDM link. The OLT also terminates a separate optical supervisory channel (OSC) used on the fiber link.

OLTs multiplex multiple wavelengths into a single fiber and also demultiplex a composite WDM signal into individual wavelengths. OLTs are used at either end of a point-to-point link.

It uses a transponder that adapts the signal coming in from a client of the optical network into a signal suitable for use inside the optical network. It monitors the bit error rate of the signal at the ingress and egress points in the network.

OLT also terminates an *optical supervisory channel* (OSC). The OSC is carried on a separate wavelength, different from the wavelengths carrying the actual traffic. It is used to monitor the performance of amplifiers along the link as well as for a variety of other management functions.

Optical Add/Drop Multiplexer(OADM)

Optical Add/Drop Multiplexers

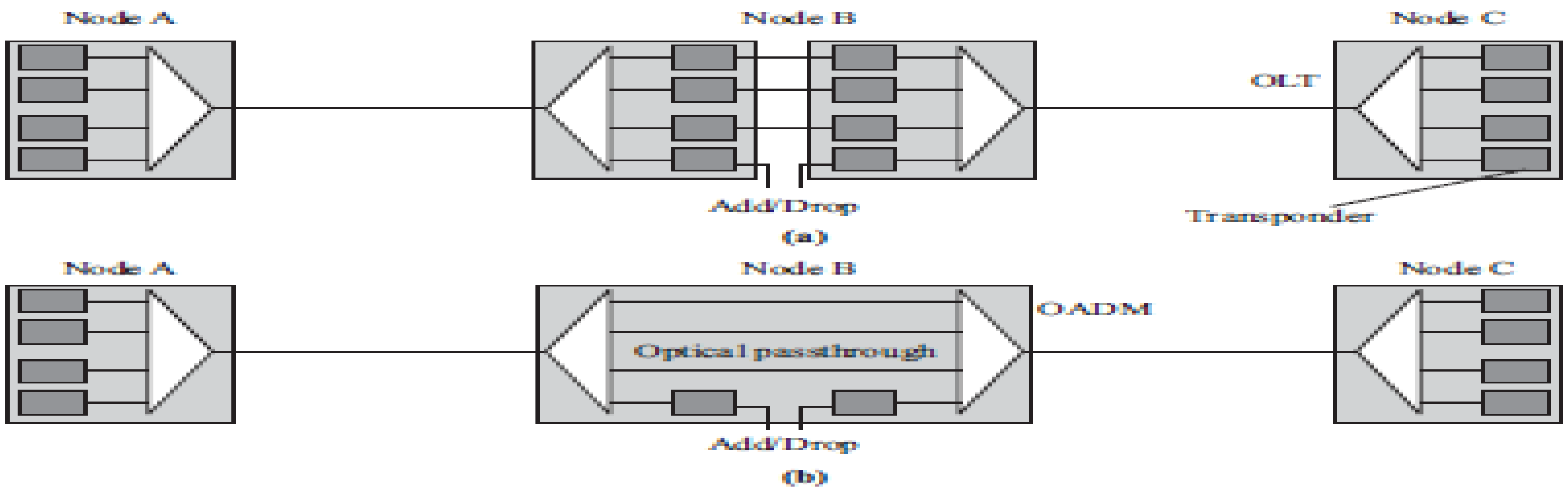
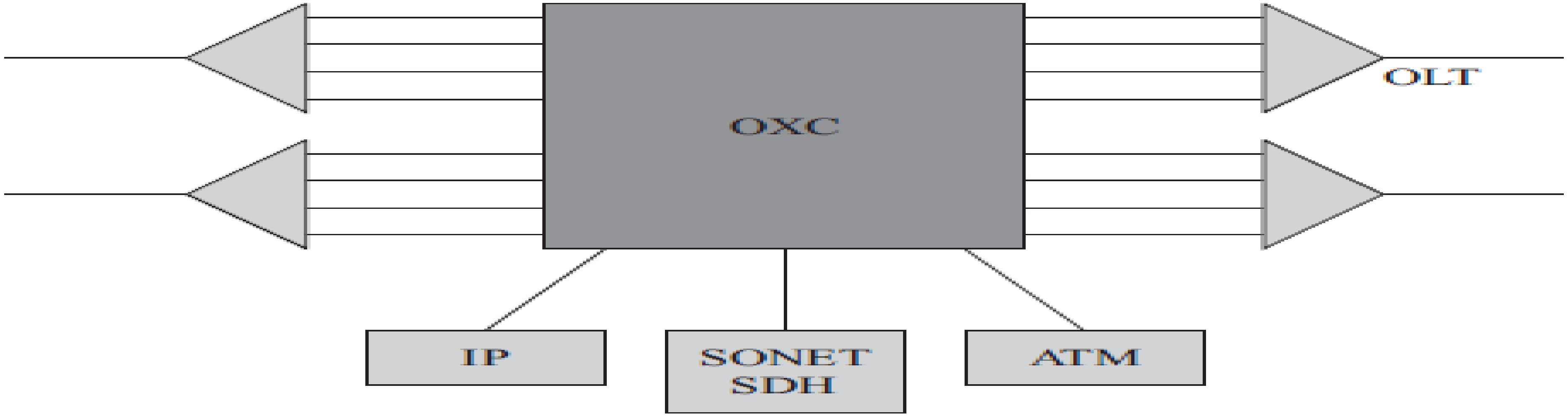


Figure A three-node linear network example to illustrate the role of optical add/drop multiplexers. Three wavelengths are needed between nodes A and C, and one wavelength each between nodes A and B and between nodes B and C. (a) A solution using point-to-point WDM systems. (b) A solution using an optical add/drop multiplexer at node B.

An OADM has two *line* ports where the composite WDM signals are present, and a number of *local* ports where individual wavelengths are dropped and added.



Optical Cross Connect (OXC)

OADMs are useful network elements to handle simple network topologies, such as the linear topology or ring topologies, and a relatively modest number of wavelengths.

An additional network element is required to handle more complex mesh topologies and large numbers of wavelengths, particularly at hub locations handling a large amount of traffic. This element is the optical cross connect (OXC).

OXCs have a large number of ports (ranging from a few tens to thousands) and are able to switch wavelengths from one input port to another.

Both OADMs and OXCs may incorporate wavelength conversion capabilities.

Key Functions of OXC

A. Service provisioning: An OXC can be used to provision light paths in a large network in an automated manner, without having to resort to performing manual patch panel connections.

This capability becomes important when we deal with large numbers of wavelengths in a node or with a large number of nodes in the network. It also becomes important when light paths in the network need to be reconfigured to respond to traffic changes.

The manual operation of sending a person to each office to implement a patch panel connection is expensive and error prone. Remotely configurable OXCs take care of this function.

B. Protection: Protecting light paths against fiber cuts and equipment failures in the network is emerging as one of the most important functions expected from a cross connect. The cross connect is an intelligent network element that can detect failures in the network and rapidly reroute light paths around the failure. Cross connects enable true mesh networks to be deployed. These networks can provide particularly efficient use of network bandwidth, compared to the SONET/SDH rings .

C. Bit rate transparency: The ability to switch signals with arbitrary bit rates and frame formats is a desirable attribute of OXCs.

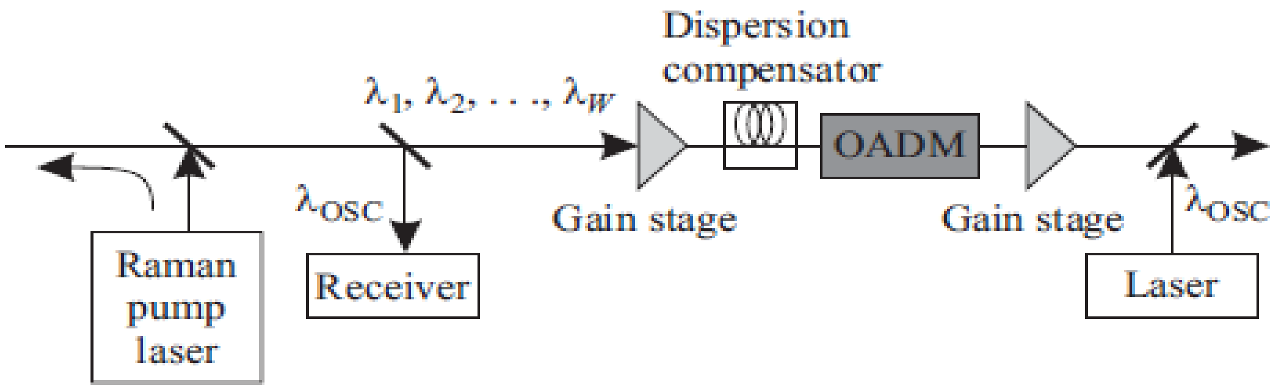
D. Performance monitoring, test access, and fault localization: OXCs provide visibility to the performance parameters of a signal at intermediate nodes. They usually allow test equipment to be hooked up to a dedicated test port where the signals passing through the OXC can be monitored in a nonintrusive manner.

Nonintrusive test access requires *bridging* of the input signal. In bridging, the input signal is split into two parts. One part is sent to the core, and the other part is made available at the test access port. OXCs also provide loopback capabilities. This allows a light path to be looped back at intermediate nodes for diagnostic purposes.

E. Wavelength conversion: In addition to switching a signal from one port to another port, OXCs may also incorporate wavelength conversion capabilities.

F. Multiplexing and Grooming: OXCs typically handle input and output signals at optical line rates. However, they can incorporate multiplexing and grooming(grouping together of traffic with similar destinations/QoS/traffic type) capabilities to switch traffic internally at much finer granularities.

Optical Line Amplifiers



Erbium doped optical line amplifiers are introduced at periodic intervals of 80-120 km. They provide automatic gain control and performance monitoring of the signal. They are also called as ***Raman*** amplifiers.

OADM Architectures

Several architectures have been proposed for building OADMs. These architectures typically use one or more of the multiplexers/filters.

Most practical OADMs use either fiber Bragg gratings, dielectric thin-film filters, or arrayed waveguide gratings. Here, we view an OADM as a black box with two line ports carrying the aggregate set of wavelengths and a number of local ports, each dropping and adding a specific wavelength.

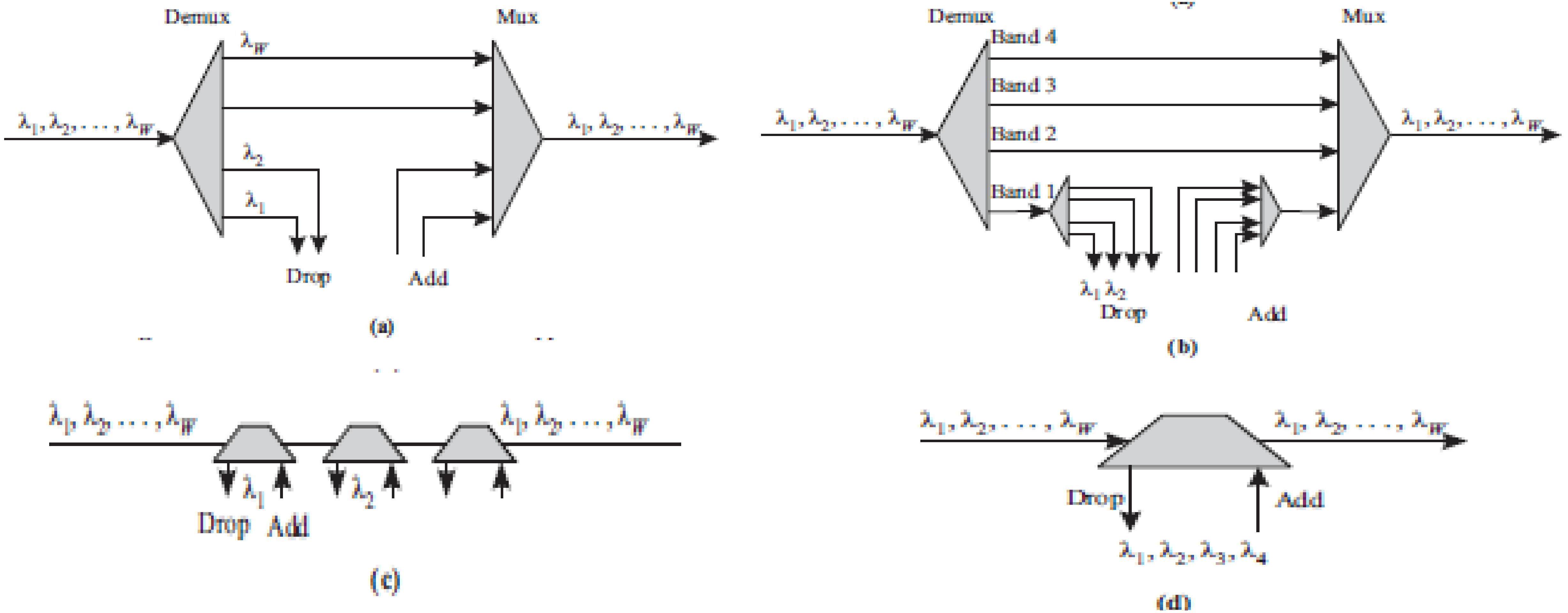


Figure Different OADM architectures. (a) Parallel, where all the wavelengths are separated and multiplexed back; (b) modular version of the parallel architecture; (c) serial, where wavelengths are dropped and added one at a time; and (d) band drop, where a band of wavelengths are dropped and added together. W denotes the total number of wavelengths.

Parallel Architecture: In the parallel architecture all incoming channels are demultiplexed. Some of the demultiplexed channels can be dropped locally, and others are passed through. An arbitrary subset of channels can be dropped and the remaining passed through. So there are no constraints on what channels can be dropped and added.

As a consequence, this architecture imposes minimal constraints on planning light paths in the network. In addition, the loss through the OADM is fixed, independent of how many channels are dropped and added. Unfortunately, this architecture is not very cost-effective for handling a small number of dropped channels because, regardless of how many channels are dropped, all channels need to be demultiplexed and multiplexed back together.

Therefore we need to pay for all the demultiplexing and multiplexing needed for all channels, even if we need to drop only a single channel. This also results in incurring a higher loss through the OADM. However, the architecture becomes cost-effective if a large fraction of the total number of channels is to be dropped, or if complete flexibility is desired with respect to adding and dropping any channel.

Modular Parallel Architecture: Some cost improvements can be made by making the design modular as shown in Figure 7.5(b). Here, the multiplexing and demultiplexing are done in two stages.

The first stage of demultiplexing separates the wavelengths into bands, and the second stage separates the bands into individual channels. For example, a 16-channel system might be implemented using four bands, each having 4 channels. If only 4 channels are to be dropped at a location, the remaining 12 channels can be expressed through at the band level, instead of being demultiplexed down to the individual channel level.

In addition to the cost savings in the multiplexers and demultiplexers realized, the use of bands allows signals to be passed through with lower optical loss and better loss uniformity.

Several commercially available OADMs use this approach. Moreover, as the number of channels becomes large, a modular multistage multiplexing approach becomes essential.

In the serial architecture (Figure 7.5(c)), a single channel is dropped and added from an incoming set of channels. We call this device a single-channel OADM (SCOADM).

These can be realized using fiber Bragg gratings or dielectric thin-film filters. In order to drop and add multiple channels, several SC-OADMs are cascaded. This architecture in many ways complements the parallel architecture described above.

Adding and dropping additional channels disrupts existing channels. Therefore it is desirable to plan what set of wavelengths needs to get dropped at each location ahead of time to minimize such disruptions. The architecture is highly modular in that the cost is proportional to the number of channels dropped. Therefore the cost is low if only a small number of channels are to be dropped. However, if a large number of channels are to be dropped, the cost can be quite significant since a number of individual devices must be cascaded.

There is also an indirect impact on the cost because the loss increases as more channels are dropped, requiring the use of additional amplification.

In the band drop architecture (Figure 7.5(d)), a fixed group of channels is dropped and added from the aggregate set of channels. The dropped channels then typically go through a further level of demultiplexing where they are separated out. The added channels are usually combined with simple couplers and added to the passthrough channels. A typical implementation could drop, say, 4 adjacent channels out of 32 channels using a band filter.

This architecture tries to make a compromise between the parallel architecture and the serial architecture. The maximum number of channels that can be dropped is determined by the type of band filter used. Within this group of channels, adding/dropping additional channels does not affect other light paths in the network as the passthrough loss for all the other channels not in this group is fixed.

Table Comparison of different OADM architectures. W is the total number of channels and D represents the maximum number of channels that can be dropped by a single OADM.

Attribute	Parallel	Serial	Band Drop
D	$= W$	1	$\ll W$
Channel constraints	None	Decide on channels at planning stage	Fixed set of channels
Traffic changes	Hitless	Requires hit	Partially hitless
Wavelength planning	Minimal	Required	Highly constrained
Loss	Fixed	Varies	Fixed up to D
Cost (small drops)	High	Low	Medium
Cost (large drops)	Low	High	Medium

Transparency and All-Optical Networks

A major feature of the light path service provided by second-generation networks is that this type of service can be *transparent* to the actual data being sent over the Light path once it is set up.

For instance, a certain maximum and minimum bit rate might be specified, and the service may accept data at any bit rate and any protocol format within these limits. It may also be able to carry analog data.

Transparency in the network provides several advantages:

- An operator can provide a variety of different services using a single infrastructure. We can think of this as *service transparency.*

- The infrastructure is future-proof in that if protocols or bit rates change, the equipment deployed in the network is still likely to be able to support the new protocols and/or bit rates without requiring a complete overhaul of the entire network. This allows new services to be deployed efficiently and rapidly, while allowing legacy services to be carried as well.

In an ideal world, *all-optical network* would be *fully transparent.*

Table 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
Wavelength planning	Minimal	Required	Highly constrained
Loss	Fixed	Varies	Fixed up to *D*
Cost (small drops)	High	Low	Medium
Cost (large drops)	Low	High	Medium

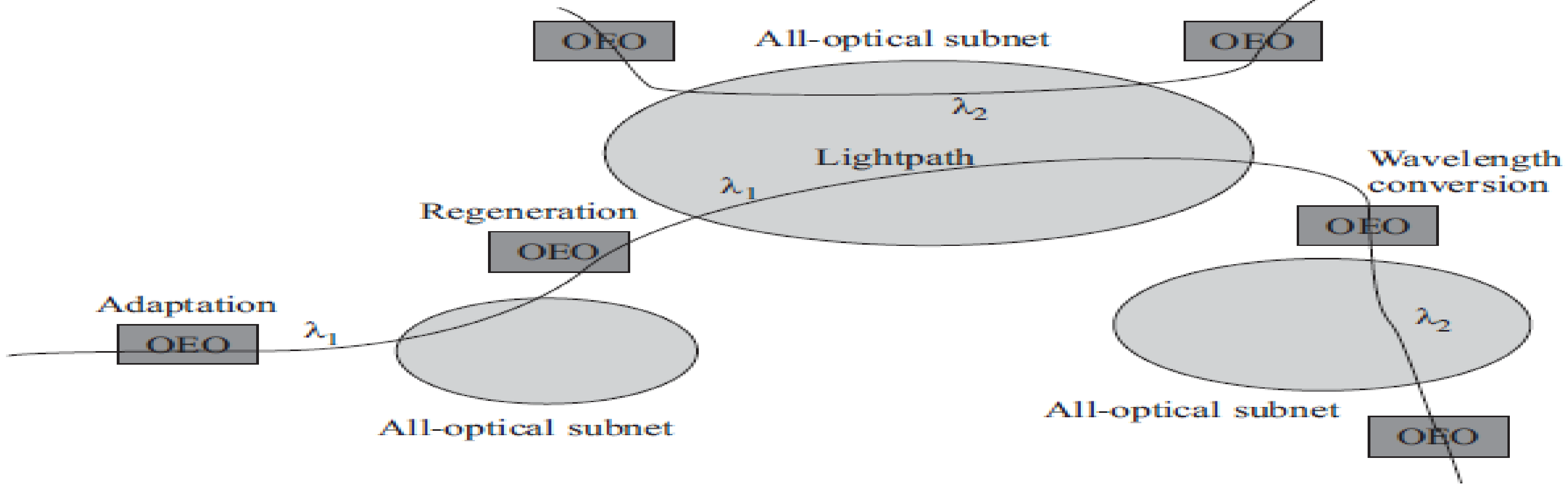


Figure 1.10 An optical network consisting of all-optical subnetworks interconnected by optical-to-electrical-to-optical (OEO) converters. OEO converters are used in the network for adapting external signals to the optical network, for regeneration, and for wavelength conversion.

Having electronic regenerators in the path of the signal reduces the transparency of that path. There are three types of electronic regeneration techniques for digital data. The standard one is called regeneration *with* retiming and reshaping, also known as 3R.

Here the bit clock is extracted from the signal, & the signal is re clocked. This technique essentially produces a "fresh" copy of the signal at each regeneration step, allowing the signal to go through a very large number of regenerators.

However, it eliminates transparency to bit rates and the framing protocols, since acquiring the clock usually requires knowledge of both of these. Some limited form of bit rate transparency is possible by making use of programmable clock recovery chips that can work at a set of bit rates that are multiples of one another.

An implementation using regeneration of the optical signal *without* retiming, also called 2R, offers transparency to bit rates, without supporting analog data or different modulation formats. However, this approach limits the number of regeneration steps allowed, particularly at higher bit rates, over a few hundred megabits per second. The limitation is due to the jitter, which accumulates at each regeneration step.

The final form of electronic regeneration is 1R, where the signal is simply received and retransmitted without retiming or reshaping. This form of regeneration can handle analog data as well, but its performance is significantly poorer than the other two forms of regeneration. For this reason, the networks being deployed today use 2R or 3R electronic regeneration.

Resilient Packet Ring

Resilient Packet Ring (RPR) is a packet-switched ring network that transports data packets such as IP packets. It has application as a metropolitan- or wide-area network.

RPR provides different services. It has guaranteed bandwidth, low delay service, and it has fair access for best-effort service.

The ring network topology is resilient to failures, and in particular it remains connected after single-link or single-node failures. RPR is at the link layer just like Ethernet. It has its own frames. The ring network is bidirectional formed by two counter-rotating rings called Ringlets 0 and 1, as shown in Figure below, where the links have the same capacities.

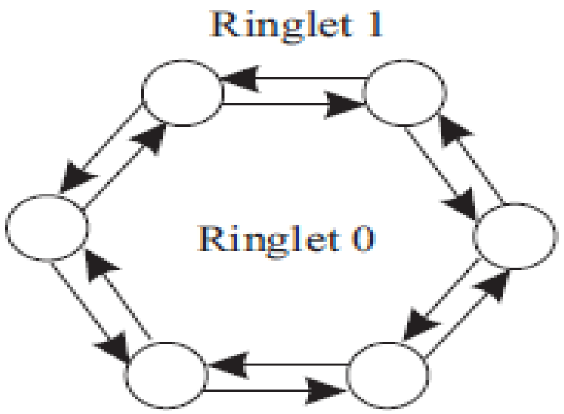


Figure Ringlets 0 and 1 of a Resilient Packet Ring.

A source node sends an RPR frame to its destination by inserting it into one of ringlets. The frame is then forwarded by intermediate nodes until it reaches its destination node, where it is switched out of the ringlet.

Note that there are two types of frames: *transit frames*, which have accessed a ringlet, and *ingress frames*, which are new frames that are waiting to be added into a ringlet.

Quality of Service

RPR supports three classes of traffic.

Class A: This class has low latency and jitter. When accessing a ringlet, it has high priority. It is divided into Classes A0 and A1, where both have pre allocated network bandwidth to ensure their latency and jitter. The pre allocated bandwidth for Class A0 traffic is called reserved and can only be used by the node's A0 traffic.

If the node does not have enough A0 traffic, the pre allocated bandwidth is left unused. On the other hand, pre allocated bandwidth for Class A1 is called reclaimable because the unused bandwidth may be used by other classes of traffic.

Class B. This class has predictable latency and jitter. When accessing a ringlet, this class has medium priority. Class B traffic is divided into Classes B-CIR(committed information rate) and B-EIR (excess information rate). Class B-CIR is similar to Class A1 because it has pre allocated network bandwidth to ensure its latency and jitter, and the bandwidth is reclaimable. Class B-EIR packets are called *fairness eligible* (FE) because they can access unused, unreserved bandwidth according to RBR's fairness mechanisms.

Class C. This class has best-effort transport. When accessing a ringlet, this class has low priority. Class C traffic is also fairness eligible because it can access unused, unreserved bandwidth according to the RPR's fairness mechanisms.

Self-Healing Rings

Ring networks have become very popular in the carrier world as well as in enterprise networks. A ring is the simplest topology that is *2-connected*, that is, provides two separate paths between any pair of nodes that do not have any nodes or links in common except the source and destination nodes. This allows a ring network to be resilient to failures. Rings are also efficient from a fiber layout perspective—multiple sites can be interconnected with a single physical ring. In contrast, a hubbed approach would require fibers to be laid between each site and a hub node, and would require two disjoint routes between each site and the hub, which is a more expensive proposition.

Much of the carrier infrastructure today uses SONET/SDH rings. These rings are called *self-healing* because they incorporate protection mechanisms that automatically detect failures and reroute traffic away from failed links and nodes onto other routes rapidly. The rings are implemented using SONET/SDH add/drop multiplexers.

Service Classes Based on Protection

Optical layer can provide multiple classes of service based on the type of protection provided. The main differences in these classes lie in the level of connection availability provided and the restoration time for a connection. These different classes will likely be supported using different protection schemes. Costs to both the customer and service provider will also depend on the service availability.

A possible set of services is as follows:

Platinum. This provides the highest level of availability and the fastest restoration times, comparable to SONET/SDH protection schemes, typically around 60 ms.

For example, a dedicated 1 + 1 protection scheme could be used to provide this class of service. This class may be viewed as a premium service and is accordingly priced.

Gold. This provides high availability and fast restoration times, typically in the range of hundreds of milliseconds. For example, a shared mesh protection scheme can provide this class of service.

Silver. This class sits below gold in terms of availability and restoration time. For example, a protection scheme that provides “best-effort” restoration may fit into this category. Another example would be a scheme wherein a connection is reattempted from scratch in case of a failure.

Bronze. Here, the optical layer provides unprotected light paths. In the event of a failure of the working path, the connection is lost.

Lead. This class of service would have the lowest availability and the lowest priority among all the classes. For instance, we may support this class by using protection bandwidth reserved for other classes of service. If that bandwidth is needed to protect other higher-priority traffic, connections in this class are preempted.

Thank You