ROEVER ENGINEERNING COLLEGE

ELAMBALUR- PERAMBALUR-621212

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

EC1401-OPTICAL COMMUNICATION AND NETWORKS

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QUESTION BANK

Prepared By

K.SAKTHIVEL

HOD/ECE

EC1401-OPTICAL COMMUNICATION AND NETWORKS

UNIT I OPTICAL NETWORKING COMPONENTS
First and second generation optical networks – Components – Couplers – Isolators – circulators – Multiplexers – Filters – Amplifiers – Switches and wavelength converters

UNIT II SONET AND SDH NETWORKS
Integration of TDM signals – Layers – Framing – Transport overhead – Alarms – multiplexing – Network elements – Topologies – Protection architectures – Ring architectures – Network management

UNIT III BROADCAST AND SELECT NETWORKS
Topologies – Single-hop – Multi-hop – and Shufflenet multi-hop network – Media – Access control protocols – Test beds.

UNIT IV WAVELENGTH ROUTING NETWORKS
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UNIT V HIGH CAPACITY NETWORKS
SDM – TDM and WDM approaches – Application areas – Optical TDM networks – Multiplexing and demultiplexing – Synchronization – Broadcast networks – Switch based networks – OTDM test beds

TEXT BOOKS

1. Rajiv, Ramaswami and Kumar Sivarajan, "Optical Networks: A practical perspective", 2nd Edition, Morgan Kaufmann, 2001.
2. Keiser G., "Optical fiber communication systems", McGraw-Hill, 2000
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1. Vivek Alwayn, "Optical Network Design and Implementation", Pearson Education, 2004.
2. Hussein T. Mouftab and Pin-Han Ho, "Optical Networks: Architecture and Survivability", Kluwer Academic Publishers, 2002

UNIT I OPTICAL NETWORKING COMPONENTS

First and second generation optical networks – Components – Couplers – Isolators – circulators – Multiplexers – Filters – Amplifiers – Switches and wavelength converters

UNIT I
OPTICAL NETWORKING COMPONENTS
PART-A

1. Define Optical Network

Optical networks are high-capacity telecommunications networks based on optical technologies and components that provide routing, grooming, and restoration at the wavelength level as well as wavelength-based services

2. Define LAN, MAN, WAN

Networks within buildings spanning at most a few kilometers are called local-area networks (LANs); those that span a campus or metropolitan area, typically tens to a few hundred kilometers, are called metropolitan-area networks (MANs); and networks that span even longer distances, ranging from several hundred to thousands of kilometers, are called wide-area networks (WANs).

3. What are the two fundamental types of network infrastructure?

There are two fundamental types of underlying network infrastructures based on how traffic is multiplexed and switched inside the network: circuit-switched and packet-switched

4. Give the example of first generation network

Examples of first-generation optical networks are SONET (synchronous optical network) and the essentially similar 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 Fiber Channel.

5. Define WDM

To increase the capacity is by a technique called wavelength division multiplexing (WDM). WDM is essentially the same as frequency division multiplexing (FDM), which has been used in radio systems for more than a century. For some reason, the term FDM is used widely in radio communication, but WDM is used in
the context of optical communication, perhaps because FDM was studied first by communications engineers and WDM by physicist

6. What are the key network elements in optical network?

The key network elements that enable optical networking are optical line terminals (OLTs), optical add/drop multiplexers (OADMs), and optical cross connects (OXCs),

7. List out optical components.

The components used in modern optical networks include couplers, lasers, photo detectors, optical amplifiers, optical switches, and filters and multiplexers

8. Define couplers.

A directional coupler is used to combine and split signals in an optical network. A 2 × 2 coupler consists of two input ports and two output ports, the most commonly used couplers are made by fusing two fibers together in the middle—these are called fused fiber couplers

9. Define isolators.

Its main function is to allow transmission in one direction through it but block all transmission in the other direction. Isolators are used in systems at the output of optical amplifiers and lasers primarily to prevent reflections from entering these devices, which would otherwise degrade their performance

10. What are the two key parameters of an isolator?

Two key parameters of an isolator are its insertion loss, which is the loss in the forward direction and which should be as small as possible, and its isolation, which is the loss in the reverse direction and which should be as large as possible. The typical insertion loss is around 1 dB, and the isolation is around 40–50 dB.

11. List out the key characteristics of optical filter.

1. Good optical filters should have low insertion losses. The insertion loss is the input-to-output loss of the filter.

2. The loss should be independent of the state of polarization of the input signals. The state of polarization varies randomly with time in most systems, and if the filter has a polarization-dependent loss, the output power will vary with time as well—an undesirable feature.

3. The pass band of a filter should be insensitive to variations in ambient temperature. The temperature coefficient is measured by the amount of wavelength shift per unit degree change in temperature. The system requirement is that over the entire operating temperature range (about 100◦C typically), the wavelength shift should be much less than the wavelength spacing between adjacent channels in a WDM system.

4. As more and more filters are cascaded in a WDM system, the pass band becomes progressively narrower. To ensure reasonably broad pass bands at the end of the cascade, the individual filters should have very flat pass bands, so as to accommodate small changes in operating wavelengths of the lasers over time. This is measured by the 1 dB bandwidth,

5. At the same time, the pass band skirts should be sharp to reduce the amount of energy passed through from adjacent channels. This energy is seen as crosstalk and degrades the system performance. The crosstalk suppression, or isolation of the filter, which is defined as the relative power passed through from the adjacent channels, is an important parameter as well.

12. Define grating.

The term grating is used to describe almost any device whose operation involves interference among multiple optical signals originating from the same source but with different relative phase shifts

13. Define Bragg Gratings.

Bragg gratings are widely used in fiber optic communication systems. In general, any periodic perturbation in the propagating medium serves as a Bragg grating. This perturbation is usually a periodic variation of the refractive index of the medium.

14. Define Fabry-Perot Filters.

A Fabry-Perot filter consists of the cavity formed by two highly reflective mirrors placed parallel to each other. This filter is also called a Fabry-Perot interferometer or etalon. The input light beam to the filter enters the first mirror at right angles to its surface. The output of the filter is the light beam leaving the second mirror.

15. What is Mach-Zehnder Interferometers?

A Mach-Zehnder interferometer (MZI) is an inter ferometric device that makes use of two interfering paths of different lengths to resolve different wavelengths. Devices constructed on this principle have been around for some decades. Today, Mach- Zehnder interferometers are typically constructed in integrated optics and consist of two 3 dB directional couplers interconnected through two paths of differing lengths

16. What is Erbium-Doped Fiber Amplifiers?

An erbium-doped fiber amplifier (EDFA) consists of a length of silica fiber whose core is doped with ionized atoms (ions), Er3+, of the rare-earth element erbium. This fiber is pumped using a pump signal from a laser, typically at a wavelength of 980 nm or 1480 nm. In order to combine the output of the pump laser with the input signal, the doped fiber is preceded by a wavelength-selective coupler.

17. Define thermalization.

Within each energy band, the erbium ions are distributed in the various levels within that band in a no uniform manner by a process known as thermalization.

18. Define pumping.

The energy difference between the E1 and E3 levels corresponds to a wavelength of 980 nm. So if optical power at 980 nm—called the pump power—is injected into the amplifier, it will cause transitions from E1 to E3 and vice versa. Since N1 > N3, there will be a net absorption of the 980 nm power. This process is called pumping.

19. Define Extinction ratio?

The extinction ratio of an on-off switch is the ratio of the output power in the on state to the output power in the off state. This ratio should be as large as possible and is particularly important in external modulators. Whereas simple mechanical switches have extinction ratios of 40–50 dB, high-speed external modulators tend to have extinction ratios of 10–25 dB

20. Define Wavelength Converters?

A wavelength converter is a device that converts data from one incoming wavelength to another outgoing wavelength. Wavelength converters are useful components in WDM networks for three major reasons. First, data may enter the network at a wavelength that is not suitable for use within the network.

PART-B

1. Explain in detail the generation of optical networks

Optical Networks

Optical networks offer the promise to solve many of the problems we have discussed.In addition to providing enormous capacities in the network, an optical network provides a common infrastructure over which a variety of services can be delivered.These networks are also increasingly becoming capable of delivering bandwidth ina flexible manner where and when needed.Optical fiber offers much higher bandwidth than copper cables and 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 of realizing short-distance (a few meters to hundredsof meters), high-speed (gigabits per second and above) interconnections inside large systems.

Optical fibers are widely deployed today in all kinds of telecommunications networks. 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 many fiber cables. For example, a 10-mile-long route using three fiber cables is said to have 10 route miles and 30 sheath (cable) miles. Each cable contains many fibers. If each cable has 20 fibers, the same route is said to have 600 fiber miles. A city or telecommunications company may present its fiber deployment in sheath miles; for example, a metropolitan region may have 10,000 fiber sheath miles. This is one way to promote a location as suitable for businesses that develop or use information technology.When we talk about optical networks, we are really talking about two generations of optical networks. In the first generation, optics was essentially used for transmission and simply to provide capacity. Optical fiber provided lower bit error rates and higher capacities than copper cables. All the switching and other intelligent network functions were handled by electronics. Examples of first-generation optical networks are SONET (synchronous optical network) and the essentially similar 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 have routing, switching, and intelligence in the optical layer.

Second-Generation Optical Networks

Optics is clearly the preferred means of transmission, and WDM transmission is widely used in networks. Optical networks are capable of providing more functions than just point-to-point transmission. Major advantages are to be gained by incorporating some of the switching and routing functions that were performed byv electronics into the optical part of the network. For example, as data rates get higher and higher, it becomes more difficult for electronics to process data. Suppose the electronics must process data in blocks of 70 bytes each (e.g., a small Ethernet packet).
In a 100 Mb/s data stream, we have 5.6 μs to process a block, whereas at 10 Gb/s, the same block must be processed within 56 ns. In first-generation networks, the electronics at a node must handle not only all the data intended for that node but also all the data that is being passed through that node on to other nodes in the network. If the latter data could be routed through in the optical domain, the burde on the

underlying electronics at the node would be significantly reduced. This is one of the key drivers for second-generation optical networks

Optical networks based on this paradigm are now being deployed.. We call this network a wavelength routing network. The network provides lightpaths 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, the lightpaths are routed and switched from one link to another link. In some cases, lightpaths may be converted from one wavelength to another wavelength as well along their route. Different lightpaths 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 lightpath between B and C, the lightpath between D and E, and one of the lightpaths between E and F do not share any links in the network and can therefore be set up using the same wavelength $\lambda 1$. At the same time, the lightpath between A and F shares a link with the lightpath between B and C and must therefore use a different wavelength. The two lightpaths between E and F must also be assigned different wavelengths. Note that these lightpaths all use the same wavelength on every link in their path. We must deal with this constraint if we do not have wavelength conversion capabilities within the network. Suppose we had only two wavelengths available in the network and wanted to set up a new lightpath between nodes E and F. Without wavelength conversion, we would not be able to set up this lightpath. On the other hand, if the intermediate node X can perform wavelength conversion, then we can set up this lightpath using wavelength $\lambda 2$ on link EX and wavelength $\lambda 1$ on link XF The key network elements that enable optical networking are optical line terminals

2. Explain the operating principle of Couplers

Principle of Operation

When two waveguides are placed in proximity to each other, light “couples” from one waveguide to the other. This is because the propagation modes of the combined waveguide are quite different from the propagation modes of a single waveguide due to the presence of the other waveguide. When the two waveguides are identical, which is the only case we consider in this book, light launched into one waveguide couples to the other waveguide completely and then back to the first waveguide in a periodic manner. The net result of this analysis is that the electric fields, Eo1 and Eo2, at the outputs of a directional coupler may be expressed in terms of the electric fields at the inputs Ei1 and Ei2, as follows:
Eo1(f)
Eo2(f)= e?i?l cos(?l) i sin(?l) i sin(?l) cos(?l)__Ei1(f)Ei2(f)
Here, l denotes the coupling length and ? is the propagation constantbin each of the two waveguides of the directional coupler. The quantity ? is called the coupling coefficient and is a function o the width of the waveguides, the refractive indices of the waveguiding region (core) and the substrate, and the proximity of the two waveguides. Equation will prove useful in deriving the transfer functions of more complex devices built using directional couplers Although the directional coupler is a two-input, two-output device, it is often used with only one active input, say, input 1.
In this case, the power transfer function of the directional coupler is
T11(f)
T12(f)= cos2(?l)sin2(?l)

Here, Tij (f) represents the power transfer function from input i to output j and is defined by Tij (f) = |Eoj |2/|Eii |2. 3 dB coupler the coupling length must be chosen to satisfy ?l = (2k + 1)?/4, where k is a nonnegative integer

Conservation of Energy

The general form can be derived merely by assuming that the directional coupler is lossless. Assume that the input and output electric fields are related by a general equation of the form

Eo1

Eo2=s11 s12

s21 s22 Ei1 Ei2

The matrix

S =s11 s12

s21 s22

is the transfer function of the device relating the input and output electric fields and is called the scattering matrix. We use complex representations for the input and output electric fields, and thus the sij are also complex. It is understood that we must consider the real part of these complex fields in applications. This complex representation for the sij allows us to conveniently represent any induced phase shifts.

For convenience, we denote Eo = (Eo1,Eo2)T and Ei = (Ei1,Ei2)T, where the superscript T denotes the transpose of the vector/matrix. In this notation be written compactly as Eo = SEi .

The sum of the powers of the input fields is proportional to ET i E? I = |Ei1|2+|Ei2|2. Here, ? represents the complex conjugate. Similarly, the sum of the powers of the output fields is proportional to ETE?o = |Eo1|2 + |Eo2|2. If the directional coupler is lossless, the power in the output fields must equal the power in the input fields so that

ETo Eo = (SEi)T (SEi)?= ETi (ST S?)E?i= ETi E?i .Since this relationship must hold for arbitrary Ei , we must haveST S? = I where I is the identity matrix. Note that this relation follows merely from conservation of energy and can be readily generalized to a device with an arbitrary number of inputs and outputs.

For a 2 × 2 directional coupler, by the symmetry of the device

we can set s21 = s12 = a and s22 = s11 = b.

|a|2 + |b|2 = 1 and ab ? + ba ? = 0.

|a| = cos(x) and |b| = sin(x). If we write a = cos(x)ei?a and b = sin(x)ei?b

yields cos(?a ? ?b) = 0. Thus ?a and ?b must differ by an odd multiple of ?/2.

3. Describe in detail the working principle of isolators and circulators

Couplers and most other passive optical devices are reciprocal devices in that the devices work exactly the same way if their inputs and outputs are reversed. However, in many systems there is a need for a passive nonreciprocal device. An isolator is an example of such a device. Its main function is to allow transmission in one direction through it but block all transmission in the other direction. Isolators are used in systems at the output of optical amplifiers and lasers primarily to prevent reflections from entering these devices, which would otherwise degrade their performance.

The two key parameters of an isolator are its insertion loss, which is the loss in the forward direction and which should be as small as possible, and its isolation, which is the loss in the reverse direction and which should be as large as possible. The typical insertion loss is around 1 dB, and the isolation is around 40–50 dB.

A circulator is similar to an isolator, except that it has multiple ports, typically three or four, in. In a three-port circulator, an input signal on port 1 is sent out on port 2, an input signal on port 2 is sent out on port 3, and an input signal on port 3 is sent out on port 1. Circulators are useful to construct optical add/drop elements, Circulators operate on the same principles as isolators

Principle of Operation

In order to understand the operation of an isolator, we need to understand the notion of polarization. That the state of polarization (SOP) of light propagating in a single-mode fiber refers to the orientation of its electric field vector on a plane that is orthogonal to its direction of propagation. At any time, the electric field vector can be expressed as a linear combination of the two orthogonal linear polarizations supported by the fiber. We will call these two polarization modes the horizontal and vertical modes.

Assume that the input light signal has the vertical SOP shown in the figure. It is passed through a polarizer, which passes only light energy in the vertical SOP and blocks light energy in the horizontal SOP. Such polarizer can be realized using crystals, called dichroics which have the property of selectively absorbing light with one SOP. The polarizer is followed by a Faraday rotator. A Faraday rotator is a nonreciprocal device, made of a crystal that rotates the SOP, say, clockwise, by 45?, regardless of the direction of propagation.

The Faraday rotator is followed by another polarizer that passes only SOPs with this 45? Orientation. Thus the light signal from left to right is passed through the device without any loss. On the other hand, light entering the device from the right due to a reflection, with the same 45? SOP orientation, is rotated another 45? by the Faraday rotator, and thus blocked by the first polarizer. Note that the preceding explanation assumes a particular SOP for the input light signal. In practice we cannot control the SOP of the input, and so the isolator must work regardless of the input SOP.

This requires a more complicated design, and many different designs exist. The input signal with an arbitrary SOP is first sent through a spatial walk-off polarizer (SWP). The SWP splits the signal into its two orthogonally polarized components. Such an SWP can be realized using birefringent crystals whose refractive index is different for the two components.

When light with an arbitrary SOP is incident on such a crystal, the two orthogonally polarized components are refracted at different angles. Each component goes through a Faraday rotator, which rotates the SOPs by 45?. The Faraday rotator is followed by a half-wave plate. The half-wave plate (a reciprocal device) rotates the SOPs by 45? in the clockwise direction for signals propagating from left to right, and by 45? in the counterclockwise direction for signals propagating from right to left.

Therefore, the combination of the Faraday rotator and the half-wave plate converts the horizontal polarization into a vertical polarization and vice versa, and the two signals are combined by another SWP at the output. For reflected signals in the reverse direction, the half-wave plate and Faraday rotator cancel each other's effects, and the SOPs remain unchanged as they pass through these two devices and are thus not recombined by the SWP at the input.

4. Explain the operation of Fabry-perot filters

A Fabry-Perot filter consists of the cavity formed by two highly reflective mirrors placed parallel to each other, as shown in Figure 3.16. This filter is also called a Fabry-Perot interferometer or etalon. The input light beam to the filter enters the first mirror at right angles to its surface. The output of the filter is the light beam leaving the second mirror.

This is a classical device that has been used widely in interferometric applications.Fabry-Perot filters have been used for WDM applications in several optical network test beds. There are better filters today, such as the thin-film resonant multifamily filter These latter filters can be viewed as Fabry-Perot filters with wavelength-dependent mirror reflectivities. Thus the fundamental principle of operation of these filters is the same as that of the Fabry-Perot filter. The Fabry-Perot cavity is also used in lasers Compact Fabry-Perot filters are commercially available components. Their main advantage over some of the other devices is that they can be tuned to select different channels in a WDM system

Principle of Operation

The input signal is incident on the left surface of the cavity. After one pass through the cavity, a part of the light leaves the cavity through the right facet and a part is reflected. A part of the reflected wave is again reflected by the left facet to the right facet. For those wavelengths for which the cavity length is an integral multiple of half the wavelength in the cavity—so that a round trip through the cavity is an integral multiple of the wavelength—all the light waves transmitted through the right facet add in phase. Such wavelengths are called the resonant wavelengths of the cavity.

The power transfer function of a filter is the fraction of input light power that is transmitted by the filter as a function of optical frequency f , or wavelength. For the
Fabry-Perot filter, this function is given by TFP (f) =1 ? A 1?R_2_
1 +_2?R1?R sin(2?f ?)_2
This can also be expressed in terms of the optical free-space wavelength ? as
TFP (?) =_1 ? A1?R_2_
1 +_2?R1?R sin(2?nl/?)_2_.
(By a slight abuse of notation, we use the same symbol for the power transfer function in both cases.) Here A denotes the absorption loss of each mirror, which is the fraction of incident light that is absorbed by the mirror. The quantity R denotes the reflectivity of each mirror (assumed to be identical), which is the fraction of incident light that is reflected by the mirror. The one-way propagation delay across the cavity is denoted by ? . The refractive index of the cavity is denoted by n and its length by l. Thus ? = nl/c, where c is the velocity of light in vacuum. This transfer function can be derived by considering the sum of the waves transmitted by the filter after an odd number of passes through the cavity. The power transfer function of the Fabry-Perot filter is plotted for A = 0 and R = 0.75, 0.9, and 0.99. Note that very high mirror reflectivities are required to obtain good isolation of adjacent channels.

The power transfer function TFP (f) is periodic in f , and the peaks, or passbands, of the transfer function occur at frequencies f that satisfy f ? = k/2 for some positive integer k. Thus in a WDM system, even if the wavelengths are spaced sufficiently far apart compared to the width of each passband of the filter transfer function, several frequencies (or wavelengths) may be transmitted by the filter if they coincide with different passbands. The spectral range between two successive passbands of the filter is called the free spectral range (FSR).

A measure of the width of each passband is its full width at the point where the transfer function is half of its maximum (FWHM). In WDM systems, the separation between two adjacentwavelengthsmust be at least a FWHMin order to minimize crosstalk. (More precisely, as the transfer function is periodic, adjacent wavelengths must be separated by a FWHM plus an integral multiple of the FSR.) Thus the ratio FSR/FWHM is an approximate (order-of-magnitude) measure of the number of wavelengths that can be accommodated by the system. This ratio is called the finesse, F,of the filter andis given byF = ??R 1 ? R

If the mirrors are highly reflective, won't virtually all the input light get reflected? Also, how does light get out of the cavity if the mirrors are highly reflective? To resolve this paradox, we must look at the light energy over all the frequencies. When we do this, we will see that only a small fraction of the input light is transmitted through the cavity because of the high reflectivities of the input and output facets, but at the right frequency, all the power is transmitted Tunability

A Fabry-Perot filter can be tuned to select different wavelengths in one of several ways. The simplest approach is to change the cavity length. The same effect can be achieved by varying the refractive index within the cavity. Consider aWDM system, all of whose wavelengths lie within one FSR of the Fabry-Perot filter. The frequency f0 that is selected by the filter satisfies f0? = k/2 for some positive integer k. Thus f0 can be changed by changing? , which is the one-way propagation time for the light beam across the cavity. If we denote the length of the cavity by l and its refractive index by n,? = ln/c, where c is the speed of light in vacuum. Thus? can be changed by changing either l or n. Mechanical tuning of the filter can be effected by moving one of the mirrors so that the cavity length changes. This permits tunability only in times of the order of a few milliseconds.

For a mechanically tuned Fabry-Perot filter, a precise mechanism is needed in order to keep the mirrors parallel to each other in spite of their relative movement. The reliability of mechanical tuning mechanisms is also relatively poor. Another approach to tuning is to use a piezoelectric material within the cavity. A piezoelectric filter undergoes compression on the application of a voltage. Thus the length of the cavity filled with such a material can be changed by the application of a voltage, thereby effecting a change in the resonant frequency of the cavity. The piezo material, however, introduces undesirable effects such as thermal instability and hysteresis, making such a filter difficult to use in practical systems.

5. Explain the operation of Mach-zehnder interferometer

A Mach-Zehnder interferometer (MZI) is an interferometric device that makes use of two interfering paths of different lengths to resolve different wavelengths. Devices constructed on this principle have been around for some decades. Today, Mach- Zehnder interferometers are typically constructed in integrated optics and consist of two 3 dB directional couplers interconnected through two paths of differing lengths, as shown in Figure 3.21(a). The substrate is usually silicon, and the waveguide and cladding regions are silica (SiO2) Mach-Zehnder interferometers are useful as both filters and (de)multiplexers. Even though there are better technologies for making narrow band filters, for example, dielectric multicavity thin-film filters, and MZIs are still useful in realizing wide band filters.

For example, MZIs can be used to separate the wavelengths in the 1.3? m and 1.55 ?m bands. Narrow band MZI filters are fabricated by cascading a number of stages, as we will see, and this leads to larger losses. In principle, very good crosstalk performance can be achieved using MZIs if the wavelengths are spaced such that the undesired wavelengths occur at, or close to, the nulls of the power transfer function. However, in practice, the wavelengths cannot be fixed precisely (for example, the wavelengths drift because of temperature variations or age). Moreover, the coupling ratio of the directional couplers is not 50:50 and could be wavelength dependent. As a result, the crosstalk performance is far from the ideal situation. Also the pass band of narrow bandMZIs is not flat.

In contrast, the dielectric multicavity thin-film filters can have flat pass bands and good stop bands. MZIs are useful as two-input, two-output multiplexers and demultiplexers. They can also be used as tunable filters, where the tuning is achieved by varying the temperature of one of the arms of the device. This causes the refractive index of that arm to change, which in turn affects the phase relationship between the two arms and causes a different wavelength to be coupled out. The tuning time required is of the order of several milliseconds. For higher channel-count multiplexers an multiplexers, better technologies are available today. One example is the arrayed waveguide grating (AWG) described in the next section. Since understanding the ZI is essential to understanding the AWG, we will now describe the principle of peration of MZIs.

Principle of Operation

Consider the operation of the MZI as a demultiplexer; so only one input, say, input 1, has a signal (see Figure 3.21(a)). After the first directional coupler, the input signal power is divided equally between the two arms of theMZI, but the signal in one arm has a phase shift of ?/2 with respect to the other. Specifically, the signal in the lower arm lags the one in the upper arm in phase by ?/2, as discussed in Section 3.1. This is best understood from (3.1). Since there is a length difference of _L between the two arms, there is a further phase lag of ?_L introduced in the signal in the lower arm

.In the second directional coupler, the signal from the lower arm undergoes anotherphase delay of ?/2 in going to the first output relative to the signal from the upper arm. Thus the total relative phase difference at the first or upper output between the two signals is ?/2 + ?_L + ?/2. At the output directional coupler, in going to the second output, the signal from the upper arm lags the signal from the lower arm in phase by ?/2. Thus the total relative phase difference at the second or lower output between the two signals is ?/2 + ?_L ? ?/2 = ?_L. If ?_L = k? and k is odd, the signals at the first output add in phase,

whereasthe signals at the second output add with opposite phases and thus cancel each other. Thus the wavelengths passed from the first input to the first output are those wavelengths for which ?_L = k? and k is odd. The wavelengths passed from the first input to the second output are those wavelengths for which ?_L = k? and k is even. Assume that the difference between these path lengths is _L and that only one input, say, input 1, is active. Then it can be shown (see Problem 3.14) that the power transfer function of the Mach-Zehnder interferometer is given by

T11(f)

T12(f)=sin2(?_L/2)

cos2(?_L/2)

Thus the path difference between the two arms, _L, is the key parameter characterizing the transfer function of the MZI. Now consider k MZIs interconnected, as shown in Figure 3.21(c) for k = 4. Such a device is termed a multistage Mach-Zehnder interferometer. The path length difference for the kth MZI in the cascade is assumed to be 2k?1_L. The transfer function of each MZI in this multistage MZI together with the power transfer function of the entire filter

6. Explain Acousto-optic tunable filter

Acousto-Optic Tunable Filter

The acousto-optic tunable filter is a versatile device. It is probably the only known tunable filter that is capable of selecting several wavelengths simultaneously. This capability can be used to construct a wavelength crossconnect.

The acousto-optic tunable filter (AOTF) is one example of several optical devices whose construction is based on the interaction of sound and light. Basically, an acoustic wave is used to create a Bragg grating in a waveguide, which is then used to perform the wavelength selection. Figure 3.27 shows a simple version of the AOTF. We will see that the operation of this AOTF is dependent on the state of polarization of the input signal. Figure 3.28 shows a more realistic polarization-independent implementation in integrated optics.

Principle of Operation

It consists of awaveguide constructed from a birefringent material and supporting only the lowest-order TE and TM modes (see Section 2.3.4). We assume that the input light energy is entirely in the TE mode. A polarizer, which selects only the light energy in the TM mode, is placed at the other end of the channel waveguide. If, somehow, the light energy in a narrow spectral range around the wavelength to be selected is converted to the TM mode, while the rest of the light energy remains in the TE mode, we have a wavelength-selective filter. This conversion is effected in an AOTF by launching an acoustic wave along, or opposite to, the direction of propagation of the light wave. As a result of the propagation of the acoustic wave, the density of the medium varies in a periodic manner. The period of this density variation is equal to the wavelength of the acoustic wave. This periodic density variation acts as a Bragg grating. From the discussion of such gratings in Section 3.3.3, it follows that if the refractive indices nTE and nTM of the TE and TM modes satisfy the Bragg condition

nTM?= nTE?± 1

then light couples from one mode to the other.

Thus light energy in a narrow spectral range around the wavelength ? that satisfies (3.17) undergoes TE to TM mode conversion. Thus the device acts as a narrow bandwidth filter when only light energy in the TE mode is input and only the light energy in the TM mode is selected at the output In LiNbO3, the TE and TM modes have refractive indices nTE and nTM that differ by about 0.07. If we denote this refractive index difference by (_n), the Bragg condition) can be written as? = _(_n). The wavelength that undergoes mode conversion and thus lies in the passband of the AOTF can be selected, or tuned, by suitably choosing the acoustic wavelength

In order to select a wavelength of 1.55 ?m, for (_n) = 0.07, using (3.18), the acoustic wavelength is about 22 ?m. Since the velocity of sound in LiNbO3 is about 3.75 km/s, the corresponding RF frequency is about 170 MHz. Since the RF frequency is easily tuned, the wavelength selected by the filter can also be easily tuned. The typical insertion loss is about 4 dB.

The AOTF considered here is a polarization-dependent device since the input light energy is assumed to be entirely in the TE mode. A polarization-independent AOTF, shown in Figure 3.28, can be realized in exactly the same manner as a polarization-independent isolator by decomposing the input light signal into its TE and TMconstituents and sending each constituent separately through the AOTF and recombining them at the output.

Transfer Function

Whereas the Bragg condition determines the wavelength that is selected, the width of the filter passband is determined by the length of the acousto-optic interaction. The longer this interaction, and hence the device, the narrower the passband. It can be shown that the wavelength dependence of the fraction of the power transmitted by the AOTF is given by

T (?) =sin2(?/2)1 + (2_?/_)21 + (2_?/_)2 .

. Here _? = ? ??0, where ?0 is the optical wavelength that satisfies the Bragg condition, and _ = ?20 /l_n is a measure of the filter passband width. Here, l is the length of the device (or, more correctly, the length of the acousto-optic interaction). It can be shown that the full width at half-maximum (FWHM) bandwidth of the filter is ? 0.8_ (Problem 3.20). This equation clearly shows that the longer the device, the narrower the passband. However, there is a trade-off here: the tuning speed is inversely proportional to l. This is because the tuning speed is essentially determined by the time it takes for a sound wave to travel the length of the filter.

The polarization-independent AOTF illustrated in can be used as a twoinput, two-output dynamic wavelength crossconnect. We studied the operation of this device as a filter earlier; in this case, only one of the inputs was active. We leave it as an exercise (Problem 3.21) to show that when the second input is also active, the energy at the wavelength ? satisfying the Bragg phase-matching condition (3.18) is exchanged between the two ports. This is illustrated in where the wavelength ?1 satisfies the Bragg condition and is exchanged between the ports. Now the AOTF has one remarkable property that is not shared by any other tunable filter structure we know. By launching multiple acoustic waves simultaneously, the Bragg condition (3.18) can be satisfied for multiple optical wavelengths simultaneously. Thus multiple wavelength exchanges can be accomplished simultaneously between two ports with a single device of the form shown in here the wavelengths ?1 and ?4 are exchanged between the ports.

Thus this device performs the same routing function as the static ncrossconnect of. However, the AOTF is a completely general two-input, two-output dynamic crossconnect since the routing pattern, or the set of wavelengths to be exchanged, can be changed easily by varying the frequencies of the acoustic waves launched in the device. In principle, larger dimensional dynamic crossconnects (with more input and output ports) can be built by suitably cascading 2 × 2 crossconnects. We will see in Section 3.7, however, that there are better ways of building large-scale crossconnects. As of this writing, the AOTF has not yet lived up to its promise either as a versatile tunable filter or a wavelength crossconnect. One reason for this is the high level of crosstalk that is present in the device the first side lobe in its power transfer function is not even 10 dB below the peak transmission. This problem can be alleviated to some extent by cascading two such filters. In fact, the cascade can even be built on a single substrate. But even then the first side lobe would be less than 20 dB below the peak transmission.

It is harder to cascade more such devices without facing other problems such as an unacceptably high transmission loss. Another reason for the comparative failure of the AOTF today is that the passband width is fairly large (100 GHz or more) even when the acousto-optic interaction length is around 1 inch (Problem 3.22). This makes it unsuitable for use in dense WDM systems where channel spacings are now down to 50 GHz.

7. Explain the operation of Erbium –Doped fiber Amplifier

Erbium-Doped Fiber Amplifiers

An erbium-doped fiber amplifier (EDFA) is shown in Figure 3.34. It consists of a length of silica fiber whose core is doped with ionized atoms (ions), Er3+, of the rare earth element erbium. This fiber is pumped using a pump signal from a laser, typically at a wavelength of 980 nm or 1480 nm. In order to combine the output of the pump laser with the input signal, the doped fiber is preceded by a wavelength-selective coupler. At the output, another wavelength-selective coupler may be used if needed to separate the amplified signal from any remaining pump signal power. Usually, an isolator is used at the input and/or output of any amplifier to prevent reflections into the amplifier.We will see in Section 3.5 that reflections can convert the amplifier into a laser, making it unusable as an amplifier.

A combination of several factors has made the EDFA the amplifier of choice in today's optical communication systems: (1) the availability of compact and reliable high-power semiconductor pump lasers, (2) the fact that it is an all-fiber device, making it polarization independent and easy to couple light in and out of it, (3) the simplicity of the device, and (4) the fact that it introduces no crosstalk when amplifying WDM signals. This last aspect is discussed later in the context of semiconductor optical amplifiers

Principle of Operation

Three of the energy levels of erbium ions in silica glass are shown in Figure 3.35 and are labeled E1, E2, and E3 in order of increasing energy. Several other levels in Er3+ are not shown. Each energy level that appears as a discrete line in an isolated case. If these levels are spread into bands, all frequencies that correspond to the energy difference between some energy in the E2 band and some energy in the E1 band can be amplified. In the case of erbium ions in silica glass, the set of frequencies that can be amplified by stimulated emission from the E2 band to the E1 band corresponds to the wavelength range 1525–1570 nm, a bandwidth of 50 nm, with a peak around 1532 nm. By a lucky coincidence, this is exactly one of the low-attenuation windows of standard optical fiber that optical communication systems use. Denote ionic population in level Ei by Ni , i = 1, 2, 3. In thermal equilibrium, N1 > N2 > N3. The population inversion condition for stimulated emission from E2 to E1 is N2 > N1 and can be achieved by a combination of absorption and spontaneous emission as follows. The energy difference between the E1 and E3 levels corresponds to a wavelength of 980 nm. So if optical power at 980 nm—called the pump power—is injected into the amplifier, it will cause transitions from E1 to E3 and vice versa. Since N1 > N3, there will be a net absorption of the 980 nm power. This process is called pumping.

The ions that have been raised to level E3 by this process will quickly transit to level E2 by the spontaneous emission process. The lifetime for this process, ?32, is about 1 ?s. Atoms from level E2 will also transit to level E1 by the spontaneous emission process, but the lifetime for this process, ?21, is about 10 ms, which is much larger than the E3 to E2 lifetime. Moreover, if the pump power is sufficiently large, ions that transit to the E1 level are rapidly raised again to the E3 level only to transit to the E2 level again. The net effect is that most of the ions are found in level E2, and thus we have population inversion between the E2 and E1 levels. Therefore, if simultaneously a signal in the 1525–1570 nm band is injected into the fiber, it will be amplified by stimulated emission from the E2 to the E1 level. Several levels other than E3 are higher than E2 and, in principle, can be used for pumping the amplifier. But the pumping process is more efficient, that is, uses less pump power for a given gain, at 980 nm than these other wavelengths. Another possible choice for the pump wavelength is 1480 nm. This choice corresponds to absorption from the bottom sublevel of the E1 band to the top sublevel of the E2 band itself. Pumping at 1480 nm is not as efficient as 980 nm pumping.Moreover, the degree of population inversion that can be achieved by 1480 nm pumping is lower. The higher the population inversion, the lower the noise figure of the amplifier. Thus 980 nm pumping is preferred to realize low-noise amplifiers. However, higher-power pump lasers are available at 1480 nm, compared to 980 nm, and thus 1480 nm pumps find applications in amplifiers designed to yield high output powers. Another advantage of the 1480 nm pump is that the pump power can also propagate with low loss in the silica fiber that is used to carry the signals. Therefore, the pump laser can be located remotely from the amplifier itself. This feature is used in some systems to avoid placing any active compo

Gain Flatness Since the population levels at the various levels within a band are different, the gain of an EDFA becomes a function of the wavelength.

One way to improve the flatness of the amplifier gain profile is to use fluoride glass fiber instead of silica fiber, doped with erbium [Cle94]. Such amplifiers are called erbium-doped fluoride fiber amplifiers (EDFFAs). The fluoride glass produces a naturally flatter gain spectrum compared to silica glass. However, there are a few drawbacks to using fluoride glass. The noise performance of EDFFAs is poorer than EDFAs. One reason is that they must be pumped at 1480 nm and cannot be pumped at 980 nm. This is because fluoride glass has an additional higher energy level E4 above the E3 level, as shown in Figure 3.35, with the difference in energies between these two levels corresponding to 980 nm. This causes the 980 nm pump power to be absorbed for transitions from the E3 to E4 level, which does not produce useful gain. This phenomenon is called excited state absorption.nents in the middle of the link In addition to this drawback, fluoride fiber itself is difficult to handle. It is brittle, difficult to splice with conventional fiber, and susceptible to moisture. Nevertheless, EDFFAs are now commercially available devices. Another approach to flatten the EDFA gain is to use a filter inside the amplifier.

The EDFA has a relatively high gain at 1532 nm, which can be reduced by using a notch filter in that wavelength region inside the amplifier. Some of the filters described in Section 3.3 can be used for this purpose. Long-period fiber gratings and dielectric thin-film filters are currently the leading candidates for this application.

Multistage Designs

In practice, most amplifiers deployed in real systems are more complicated than the simple structure shown in Figure 3.34. Figure 3.37 shows a more commonly used two-stage design. The two stages are optimized differently. The first stage is designed to provide high gain and low noise, and the second stage is designed to produce high output power. As we will see in Problem 4.5 in Chapter 4, the noise performance of the whole amplifier is determined primarily by the first stage. Thus this combination produces a high-performance amplifier with low noise and high output power. Another important consideration in the design is to provide redundancy in the event of the failure of a pump, the only active component of the amplifier. The amplifier shown in the figure uses two pumps and can be designed so that the failure of one pump has only a small impact on the system performance. Another feature of the two-stage design that we will address in Problem 4.5 is that a loss element can be placed between the two stages with negligible impact on the performance. This loss element may be a gain-flattening filter, a simple optical add/drop multiplexer, or a dispersion compensation module used to compensate for accumulated dispersion along the link. L-Band EDFAs

EDFAs operating in the C-band (1530–1565 nm). Erbium-doped fiber, however, has a relatively long tail to the gain shape extending well beyond this range to about 1605 nm. This has stimulated the development of systems in the so-called L-band from 1565 to 1625 nm. Note that current L-band EDFAs do not yet cover the top portion of this band from 1610 to 1625 nm. L-band EDFAs operate on the same principle as C-band EDFAs. However, there are significant differences in the design of L- and C-band EDFAs. The gain spectrum of erbium is much flatter intrinsically in the L-band than in the C-band. This makes it easier to design gain-flattening filters for the L-band. However, the erbium gain coefficient in the L-band is about three times smaller than in the C-band. This necessitates the use of either much longer doped fiber lengths or fiber with higher erbium doping concentrations. In either case, the pump powers required for L-band EDFAs are much higher than their C-band counterparts. Due to the smaller absorption cross sections in the L-band, these amplifiers also have higher amplified spontaneous emission

8. Explain the importance of optical switches in networks

Optical switches are used in optical networks for a variety of applications. The different applications require different switching times and number of switch ports,. One application of optical switches is in the provisioning of lightpaths. In this application, the switches are used inside wavelength crossconnects to reconfigure them to support new lightpaths. In this application, the switches are replacements for manual fiber patch panels, but with significant added software for end-to-end network management

Another important application is that of protection switching, the subject of Here the switches are used to switch the traffic stream from a primaryfiber onto another fiber in case the primary fiber fails. The entire operation must typically be completed in several tens of milliseconds, which includes the time to detect the failure, communicate the failure to the appropriate network elements handling the switching, and the actual switch time. Thus the switching time required is on the order of a few milliseconds. Different types of protection switching arepossible, and based on the scheme used, the number of switch ports needed may vary from two ports to several hundreds to thousands of ports when used in a wavelength crossconnect.

Switches are also important components in high-speed optical packet-switched networks. In these networks, switches are used to switch signals on a packet-bypacket basis. For this application, the switching time must be much smaller than a packet duration, and large switches will be needed. For example, a 53-byte packet (one cell in an ATM network) at 10 Gb/s is 42 ns long, so the switching time required for efficient operation is on the order of a few nanoseconds. Optical packet switching is still in its infancy and is the subject of Chapter 12.Yet another use for switches is as external modulators to turn on and off the data in front of a laser source. In this case, the switching time must be a small fraction of the bit duration. So an external modulator for a 10 Gb/s signal (with a bit duration of 100 ps) must have a switching time (or, equivalently, a rise and fall time) of about 10 ps. In addition to the switching time and the number of ports, the other importantparameters used to characterize the suitability of a switch for optical networking applications are the following:

1. The extinction ratio of an on-off switch is the ratio of the output power in the on state to the output power in the off state. This ratio should be as large as possible and is particularly important in external modulators. Whereas simple mechanical switches have extinction ratios of 40-50 dB, high-speed external modulators tend to have extinction ratios of 10-25 dB
.

2. The insertion loss of a switch is the fraction of power (usually expressed in decibels) that is lost because of the presence of the switch and must be as small as possible. Some switches have different losses for different input-output connections. This is an undesirable feature because it increases the dynamic range of the signals in the network. With such switches, we may need to include variable optical attenuators to equalize the loss across differentis determined primarily by the architecture used to build the switch, rather than the inherent technology itself, as we will see in several examples below
.

3. Switches are not ideal. Even if input x is nominally connected to output y, some power from input x may appear at the other outputs. For a given switching state or interconnection pattern, and output, the crosstalk is the ratio of the power at that output from the desired input to the power from all other inputs. Usually, the crosstalk of a switch is defined as the worst-case crosstalk over all outputs and interconnection patterns.

4. As with other components, switches should have a low polarization-dependent loss (PDL). When used as external modulators, polarization dependence can be tolerated since the switch is used immediately following the laser, and the laser's output state of polarization can be controlled by using a special polarization-preserving fiber to couple the light from the laser into the external modulator.

5. A latching switch maintains its switch state even if power is turned off to the switch. This is a somewhat desirable feature because it enables traffic to be passed through the switch even in the event of power failures.

6. The switch needs to have a readout capability wherein its current state can be monitored. This is important to verify that the right connections are made through the switch.
7. The reliability of the switch is an important factor in telecommunications applications. The common way of establishing reliability is to cycle the switch through its various states a large number of times, perhaps a few million cycles. However, in the provisioning and protection-switching applications discussed above, the switch remains in one state for a long period, say, even a few years, and is then activated to change state. The reliability issue here is whether the switch will actually switch after it has remained untouched for a long period. paths. This loss uniformity

9. Write the necessity of wavelength converters in optical networks?

Wavelength Converters

A wavelength converter is a device that converts data from one incoming wavelength to another outgoing wavelength. Wavelength converters are useful components in WDM networks for three major reasons. First, data may enter the network at a wavelength that is not suitable for use within the network. commonly transmit data in the 1310 nm wavelength window, using LEDs or Fabry-Perot lasers. Neither the wavelength nor the type of laser is compatible with WDMnetworks. So at the inputs and outputs of the network, data must be converted from these wavelengths to narrow-band WDM signals in the 1550 nm wavelength range. A wavelength converter used to perform this function is sometimes called a transponder. Second, wavelength converters may be needed within the network to improve the utilization of the available wavelengths on the network links..

Finally, wavelength converters may be needed at boundaries between different networks if the different networks are managed by different entities and these entities do not coordinate the allocation of wavelengths in their networks. Wavelength converters can be classified based on the range of wavelengths that they can handle at their inputs and outputs. A fixed-input, fixed-output device always takes in a fixed-input wavelength and converts it to a fixed-output wavelength. A variable-input, fixed-output device takes in a variety of wavelengths but always converts the input signal to a fixed-output wavelength.A fixed-input, variable-output device does the opposite function. Finally, a variable-input, variable-output device can convert any input wavelength to any output wavelength. In addition to the range of wavelengths at the input and output, we also need to consider the range of input optical powers that the converter can handle, whether the converter is transparent to the bit rate and modulation format of the input signals, and whether it introduces additional noise or phase jitter to the signal. We will see that the latter two characteristics depend on the type of regeneration used in the converter. For all-optical wavelength converters, polarization-dependent loss should also be kept to a minimum.

There are four fundamental ways of achieving wavelength conversion: (1) optoelectronic, (2) optical gating, (3) interferometric, and (4) wave mixing. The latter three approaches are all-optical but not yet mature enough for commercial use. Optoelectronic converters today offer substantially better performance at lower costthan comparable all-optical wavelength converters

UNIT II SONET AND SDH NETWORKS
Integration of TDM signals – Layers – Framing – Transport overhead – Alarms – Multiplexing – Network elements – Topologies – Protection architectures – Ring Architectures – Network management

UNIT-II
SONET AND SDH NETWORKS
PART-A

1. Define SONET/SDH
SONET (Synchronous Optical Network) is the current transmission and multiplexing standard for high-speed signals within the carrier infrastructure in North America. A closely related standard, SDH (Synchronous Digital Hierarchy), has been adopted in Europe and Japan and for most submarine links.

2. List out the benefits of SONET/SDH
   1. Multiplexing simplification
   2. Management
   3. Interoperability
   4. Network availability

3. Define Multiplexing
SONET and SDH employ a sophisticated multiplexing scheme, which can, however, be easily implemented in today's very large-scale integrated (VLSI) circuits. Although SONET and SDH are basically similar, the terms used in SONET and SDH are different, and we will use the SONET version in what follows and introduce the SDH version wherever appropriate.

4. What is the basic signal rate of SONET?
SONET, the basic signal rate is 51.84 Mb/s, called the synchronous transport signal level-1 (STS-1). Higher-rate signals (STS-N) are obtained by interleaving the bytes from N frame-aligned STS-1s.

5. Define SONET frame.
A SONET frame consists of some overhead bytes called the transport overhead and the payload bytes. The payload data is carried in the so-called synchronous payload envelope (SPE). The SPE includes a set of additional path overhead bytes that are inserted at the source node and remain with the data until it reaches its Destination node.

6. What is the basic signal rate of SDH?
SDH, the basic rate is 155 Mb/s and is called STM-1 (synchronous transport module-1). Note that this is higher than the basic SONET bit rate. The SONET bit rate was chosen to accommodate the commonly used asynchronous signals, which are DS1 and DS3 signals. The SDH bit rate was chosen to accommodate the commonly used PDH signals, which are E1, E3, and E4 signals. Higher-bit-rate signals are defined analogous to SONET

7. List out SONET layers

The SONET layer consists of four sublayers—the path, line, section, and physical layers.

8. Define path layer

The path layer in SONET (and SDH) is responsible for end-to-end connections between nodes and is terminated only at the ends of a SONET connection. It is possible that intermediate nodes may do performance monitoring of the path layer signals, but the path overhead itself is inserted at the source node of the connection and terminated at the destination node. Each connection traverses a set of links and intermediate nodes in the network.

9. What is the function of physical layer in SONET?

the physical layer is responsible for actual transmission of bits across the fiber.

10. List out the Elements of a SONET/SDH Infrastructure

SONET is deployed in three types of network configurations: rings, linear configurations, and point-to-point links. The early deployments were in the form of point-to-point links, and this topology is still used today for many applications

11. What are the two types of Ring architecture?

Two types of ring architectures are used: unidirectional path-switched rings (UPSRs) and bidirectional line-switched rings (BLSRs)

12. What is the use of Digital cross connect?

Another major component in the SONET infrastructure is a digital crossconnect (DCS). A DCS is used to manage all the transmission facilities in the central office. Before DCSs arrived, the individual DS1s and DS3s in a central office were manually patched together using a patch panel.

13. Define management

The SONET and SDH standards incorporate extensive management information for managing the network, including extensive performance monitoring, identification of connectivity and traffic type, identification and reporting of failures, and a data communication channel for transporting management information between the nodes. This is mostly lacking in the PDH standards

14. What are all the problems suffered by Plesiochronous digital hierarchy?

PDH suffered from several problems, which led carriers and vendors alike to seek a new transmission and multiplexing standard in the late 1980s. This resulted in the SONET/SDH standards, which solved many problems associated with PDH. We explain some of the benefits of SONET/SDH below and contrast it with PDH.

1. Multiplexing simplification: In asynchronous multiplexing, each terminal in the network runs its own clock, and while we can specify a nominal clock rate for the signal, there can be significant differences in the actual rates between different clocks

2. Management: The SONET and SDH standards incorporate extensive management information for managing the network, including extensive performance monitoring, identification of connectivity and traffic type, identification and reporting of failures, and a data communication channel for transporting management information between the nodes. This is mostly lacking in the PDHstandards.

3. Interoperability: Although PDH defined multiplexing methods, it did not define a standard format on the transmission link. Thus different vendors used different line coding, optical interfaces, and so forth to optimize their products, which made it very difficult to connect one vendor's equipment to another's via a transmission link. SONET and SDH avoid this problem by defining standard optical interfaces that enable interoperability between equipment from different vendors on the link. Unfortunately, certain aspects of SONET and SDH were only recently standardized, such as the data communication channel mentioned above. As a result, even today, it is not trivial to interconnect SONET equipment from different vendors.
4. Network availability: The SONET and SDH standards have evolved to incorporate specific network topologies and specific protection techniques and associated protocols to provide high-availability services. As a consequence, the service restoration time after a failure with SONET and SDH is much smallermless than 60 msmthan the restoration time in PDH networks, which typically took several seconds to minutes.

15. Define virtual tributary in SONET

The SPE container along with its path overhead is called a virtual tributary (VT)in SONET

16. List out the four sizes of virtual tributary

VT1.5, VT2, VT3, VT6

17. What is grooming?

Grooming is the term used to describe how different traffic streams are switched and packed in to higher speed streams

18. List the three important blocks of optical layer

1. Optical channel
2. Optical multiple section
3. Optical amplifier section

19. What is optical channel?

End –to-end routing of the light paths. Each light paths traverses a number of links in the network and each of these links carries multiple wavelengths

20. Define light path

A light path is an end—to –end connection established across the optical network and uses a wavelength on each link in a path between the source and destination

PART-B.

1. Discuss in detail about the problems suffered by Plesiochronous digital hierarchy?

PDH suffered from several problems, which led carriers and vendors alike to seek a new transmission and multiplexing standard in the late 1980s. This resulted in the SONET/SDH standards, which solved many problems associated with PDH. We explain some of the benefits of SONET/SDH below and contrast it with PDH.

1. Multiplexing simplification: In asynchronous multiplexing, each terminal in the network runs its own clock, and while we can specify a nominal clock rate for the signal, there can be significant differences in the actual rates between different clocks. For example, in a DS3 signal, a 20 ppm (parts per million) variationin clock rate between different clocks, which is not uncommon, can produce a difference in bit rate of 1.8 kb/s between two signals. So when lower-speed streams are multiplexed by interleaving their bits, extra bits may need to be stuffed in the multiplexed stream to account for differences between the clock rates of the individual streams. As a result, the bit rates in the asynchronous hierarchy are not integral multiples of the basic 64 kb/s rate, but rather slightly higher to account for this bit stuffing. For instance, a DS1 signal is designed to carry 24 64 kb/s signals, but its bit rate (1.544 Mb/s) is slightly higher than 24×64 kb/s. With asynchronous multiplexing, it is very difficult to pick out a low-bitrate stream, say, at 64 kb/s, from a higher-speed stream passing through, say, a DS3 stream, without completely demultiplexing the higher-speed stream down to its individual component streams. This results in the need for “multiplexer mountains,” or stacked-up multiplexers, each time a low-bit-rate stream needs to be extracted, as shown in Figure 6.1. This is a relatively expensive proposition and also compromises network reliability because of the large amount of electronics needed overall.
The synchronous multiplexing structure of SONET/SDH provides significant reduction in the cost of multiplexing and demultiplexing. All the clocks in the network are perfectly synchronized to a single master clock, and as a consequence, the rates defined in SONET/SDH are integral multiples of the basic rate and no bit stuffing is needed when multiplexing streams together. As a result, a lower-speed signal can be extracted from a multiplexed SONET/SDH stream in a single step by locating the appropriate positions of the corresponding bits in the multiplexed signal. This makes the design of SONET multiplexers and demultiplexers much easier than their asynchronous equivalents.

2. Management: The SONET and SDH standards incorporate extensive management information for managing the network, including extensive performance monitoring, identification of connectivity and traffic type, identification and reporting of failures, and a data communication channel for transporting management information between the nodes. This is mostly lacking in the PDH standards.

3. Interoperability: Although PDH defined multiplexing methods, it did not define a standard format on the transmission link. Thus different vendors used different line coding, optical interfaces, and so forth to optimize their products, which made it very difficult to connect one vendor’s equipment to another’s via a transmission link. SONET and SDH avoid this problem by defining standard opticalinterfaces that enable interoperability between equipment from different vendors on the link.

4. Network availability: The SONET and SDH standards have evolved to incorporate specific network topologies and specific protection techniques and associated protocols to provide high-availability services. As a consequence, the service restoration time after a failure with SONET and SDH is much smaller—less than 60 ms—than the restoration time in PDH networks, which typically took several seconds to minutes.

2. Explain the Multiplexing structure employed in SONET/SDH network?

Multiplexing

SONET and SDH employ a sophisticated multiplexing scheme, which can, however, be easily implemented in today's very large-scale integrated (VLSI) circuits. Although SONET and SDH are basically similar, the terms used in SONET and SDH are different, and we will use the SONET version in what follows and introduce the SDH version wherever appropriate

.

For SONET, the basic signal rate is 51.84 Mb/s, called the synchronous transport signal level-1 (STS-1). Higher-rate signals (STS-N) are obtained by interleaving the bytes from N frame-aligned STS-1s. Because the clocks of the individual signals are synchronized, no bit stuffing is required. For the same reason, a lower-speed stream

Transmission rates for SONET/SDH, adapted from [SS96].

SONET Signal SDH Signal Bit Rate (Mb/s)
STS-1 51.84
STS-3 STM-1 155.52
STS-12 STM-4 622.08
STS-24 1244.16
STS-48 STM-16 2488.32
STS-192 STM-64 9953.28
STS-768 STM-256 39, 814.32

can be extracted easily from a multiplexed stream without having to demultiplex the entire signal.

The currently defined SONET and SDH rates are shown in Table 6.2. Notethat an STS signal is an electrical signal and in many cases (particularly at the higher speeds) may exist only inside the SONET equipment. The interface to other equipment is usually optical and is essentially a scrambled version of the STS signal in optical form. Scrambling is used to prevent long runs of 0s or 1s in the data stream. (See Section 4.1.1 for a more detailed explanation of scrambling.) Each SONET transmitter scrambles the signal before it is transmitted over the fiber, and the next SONET receiver descrambles the signal. The optical interface corresponding to the STS-3 rate is called OC-3 (optical carrier-3), and similar optical interfaces have been defined for OC-12, OC-48, OC-192, and OC-768 corresponding to the STS-12, STS-48, STS-192, and STS-768 signals.

For SDH, the basic rate is 155 Mb/s and is called STM-1 (synchronous transport module-1). Note that this is higher than the basic SONET bit rate. The SONET bit rate was chosen to accommodate the commonly used asynchronous signals, which are DS1 and DS3 signals. The SDH bit rate was chosen to accommodate the commonly used PDH signals, which are E1, E3, and E4 signals. Higher-bit-rate signals are defined analogous to SONET,

A SONET frame consists of some overhead bytes called the transport overhead and the payload bytes. The payload data is carried in the so-called synchronous payload envelope (SPE). The SPE includes a set of additional path overhead bytes that are inserted at the source node and remain with the data until it reaches its destination node. For instance, one of these bytes is the path trace, which identifies the SPE and can be used to verify connectivity in the network.

SONET and SDH make extensive use of pointers to indicate the location of multiplexed payload datawithin a frame. The SPE does not have a fixed starting point within a frame. Instead, its starting point is indicated by a pointer in the line overhead. Even though the clocks in SONET are all derived from a single source, there can be small transient variations in frequency between different signals. Such a difference between the incoming signal and the local clock used to generate an outgoing signal translates into accumulated phase differences between the two signals. This problem is easily solved by allowing the payload to be shifted earlier or later in a frame and indicating this by modifying the associated pointer. This avoids the need for bit stuffing or additional buffering. However, it does require a fair amount of pointer processing, which can be performed easily in today's integrated circuits.Lower-speed non-SONET streams below the STS-1 rate are mapped into virtual tributaries (VTs). Each VT is designed to have sufficient bandwidth to carry its payload. In SONET, VTs have been defined in four sizes: VT1.5, VT2, VT3, and VT6. These VTs are designed to carry 1.5, 2, 3, and 6 Mb/s asynchronous/plesiochronous streams,Of these, the VT1.5 signal is the most common, as it holds the popular DS1 asynchronous signal. At the next level in the hierarchy, a VTgroup consists of either four VT1.5s, three VT2s, two VT3s, or a single VT6. Seven such VT groups are byte interleaved along with a set of path overheads to create a basic SONET SPE. Just as an SPE floats within a SONET frame, the VT payload (called VT SPE) can also float within the STS-1 SPE, and a VT pointer is used to point to the VT SPE. The pointer is located in two designated bytes within each VT group.

In many cases, it is necessary to map higher-speed non-SONET signals into an SPE for transport over SONET. The most common examples today are probably high-speed IP or Ethernet packet streams. For this purpose, an STS-Nc signal with a locked payload is also defined in the standards. The "c" stands for concatenated, and N is the number of STS-1 payloads. The concatenated or locked payload implies that this signal cannot be demultiplexed into lower-speed streams.

For example, a 150 Mb/s client signal can be mapped into an STS-3c signal. Mappings have been defined in the standards for a variety of signals, including IP. While SDH employs the same philosophy as SONET, there are some differences in terminology and in the multiplexing structure for sub-STM-1 signals. Analogous to SONET virtual tributaries, SDH uses virtual containers (VCs) to accommodate lower-speed non-SDH signals. VCs have been defined in five sizes: VC- 11, VC-12, VC-2, VC-3, and VC-4. These VCs are designed to carry 1.5 Mb/s (DS1), 2 Mb/s (E1), 6 Mb/s (E2), 45 Mb/s (E3 and DS3), and 140 Mb/s (E4) asynchronous/plesiochronous streams, respectively. However, a two-stage hierarchy is defined here, where VC-11s, VC-12s, and VC-2s can be multiplexed into VC-3s or VC-4s, and VC-3s and VC-4s are then multiplexed into an STM-1 signal. VCAT and LCAS

SONET has the option of locking or concatenating multiple STS-1 payloads to carry client signals. Commonly supported concatenations are STS-3c, STS-12c, STS-48c, and STS-192c, which correspond to the line rates. A drawback of concatenation is that the constituent payloads must be contiguous. Thus, if there are two STS-1s that are adjacent but a third STS-1 that is not, the three could not be concatenated together to form an STS-3c. This can leave stranded unused bandwidth. Another drawback is that since there are a limited number of concatenated connection rates, STS-3c, STS-12c, . . ., there can be a mismatch between the client signal rate and the available SONET/SDH connection rates.

Virtual Concatenation (VCAT) addresses these problems by allowing noncontiguous payloads to be combined as a single connection. Such a grouping is referred to as a virtual concatenation group (VCG). VCAT is an inverse multiplexing technique that combines multiple connections into a single connection at the aggregate bandwidth. For example, STS-1-12v is a SONET VCAT connection with the same data rate as an STS-12c and is composed of 12 STS-1 payloads, which are possibly noncontiguous. Here, the "v" in STS-1-12v means virtual concatenation. AnotherSONET VCAT connection with the same data rate is an STS-3c-4v, which is composed of four STS-3c connections.

The VCAT notation for SONET is STS-N-Mv, where N is the size of a member and M is the number of members in a VCG. The values of N are the standard concatenated payload sizes, and commonly STS-1 and STS-3c. The M values have fewer restrictions than contiguous concatenation, and as a result the right-sized bandwidth can be provisioned for a data application. Going back to our Gigabit Ethernet application, VCAT can provide a 1.05 Gb/s STS-3-7v connection, whichis an overprovisioning of only 5%. SDH also has virtual concatenation. The VCAT notation for SDH is VC-N-Mv, for example, VC-4-7v is composed of seven VC-4 connections, and VC-3-5v is composed of five VC-3 connections.
The Link Capacity Adjustment Scheme (LCAS) is a companion to VCAT that allows for hitless resizing of bandwidth in a VCAT connection when adding or removing members of a VCG. This can be useful for managing the capacity of a VCAT connection for applications such as using the connection as an IP link.

3. Write short notes on SONET/SDH layers.

The SONET layer consists of four sublayers—the path, line, section, and physical layers. Figure 6.4 shows the top three layers. Each layer, except for the physical layer, has a set of associated overhead bytes that are used for several purposes. These overhead bytes are added whenever the layer is introduced and removed whenever the layer is terminated in a network element. The functions of these layers will become clearer when we discuss the frame structure and overheads associated with each layer in the next section. The path layer in SONET (and SDH) is responsible for end-to-end connections between nodes and is terminated only at the ends of a SONET connection. It is possible that intermediate nodes may do performance monitoring of the path layer

SONET/SDH layers showing terminations of the path, line, and section layers for a sample connection passing through terminalmultiplexers (TMs) and add/drop multiplexers (ADMs). The physical layer is not shown. signals, but the path overhead itself is inserted at the source node of the connectionand terminated at the destination node.

Each connection traverses a set of links and intermediate nodes in the network. The line layer (multiplex section layer in SDH) multiplexes a number of path-layer connections onto a single link between two nodes. Thus the line layer is terminated at each intermediate line terminal multiplexer (TM) or add/drop multiplexer (ADM) along the route of a SONET connection. The line layer is also responsible for performing certain types of protection switching to restore service in the event of a line failure.

Each link consists of a number of sections, corresponding to link segments between regenerators. The section layer (regenerator-section layer in SDH) is terminated at each regenerator in the network. Finally, the physical layer is responsible for actual transmission of bits across the fiber.

4. Write short notes on SONET/SDH Frame.

. A frame is 125 μs in duration (which corresponds to a rate of 8000 frames/s), regardless of the bit rate of the SONET signal. This time is set by the 8 kHz sampling rate of a voice circuit. The frame is a specific sequence of 810 bytes, including specific bytes allocated to carry overhead information and other bytes carrying the payload. We can visualize this frame as consisting of 9 rows and 90 columns, with each cell holding an 8-bit byte. B denotes an 8-bit byte. The bytes are transmitted row by row, from left to right, with the most significant bit in each byte being transmitted first. The first three columns are reserved for section and line overhead bytes. The remaining bytes carry the STS-1 SPE. The STS-1 SPE itself includes one column of overhead bytes for carrying the path overhead.An STS-N frame is obtained by byte-interleaving N STS-1 frames,

The transport overheads are in the first 3N columns, and the remaining 87N columns contain the payload. The transport overheads need to be frame alignedbefore they are interleaved. However, because each STS-1 has an associated payloadpointer to indicate the location of its SPE, the payloads do not have to be frame aligned. An STS-Nc frame looks like an STS-N frame, except that the payload cannot be broken up into lower-speed signals in the SONET layer. The same 87N columns contain the payload, and special values in the STS-payload pointers areused to indicate that the payload is concatenated. the overhead bytes in an STS-1 frame or an STS-Nc frame. In an STS-N frame, there are N sets of overhead bytes, one for each STS-1. Each STS-1has its own set of section and line overheads.

An STS-Nc, on the other hand, has only a single set of overhead bytes, due to the fact that its payload has to be carried intact from its source to its destination with the SONET network. We cover the overhead bytes here because they provide some key managementfunctions that make SONET so attractive for network operators. In the following discussion, the actual locations and formatting of the bytes are not as important asunderstanding the functions they perform. We will look at these functions in more Figure 6.6 Structure of an STS-N frame, which is obtained by byte-interleaving N STS-1 frames.

. The section and line overheads in particular are of great interest to the optical layer. Some if not all these bytes are monitored by optical layer equipment. In addition, some of the overhead bytes are currently undefined, and these bytes are now being considered as possible candidates to carry optical layer overhead information.

Section Overhead Framing (A1/A2). These two bytes are used for delineating the frame and are set toprespecified values in each STS-1 within an STS-N. Network elements use these bytes to determine the start of a new frame. Section Trace(J0)/Section Growth(Z0). The J0 byte is present in the first STS-1 inan STS-N and is used to carry an identifier, which can be monitored to verify connectivity between adjacent section-terminating nodes in the network. The Z0 byte is present in the remaining STS-1s, and its use is still to be determined.

Section BIP-8 (B1). This byte is located in the first STS-1 in an STS-N and is used to monitor the bit error rate performance of each section. The byte locations in the remaining frames within an STS-N are currently undefined. The transmitter computes a bit interleaved parity (BIP) computed over all bytes in the previous STS-N frame after scrambling and places it in the B1 byte of the current frame .SONET overhead bytes. Entries of the form X/Y indicate that the first label X applies to the first STS-1 within an STS-N signal and the second label Y applies to the remaining STS-1's in the STS-N. before it is scrambled. An odd parity value indicates an error.

Orderwire (E1). This byte (located in the first STS-1 in a frame) is used to carry a voice channel between nodes, for use by maintainence personnel in the field. Section User Channel (F1). This byte (located in the first STS-1 in a frame) is made available to the user for inserting additional user-specific information. Section Data Communication Channel (D1, D2, D3). These bytes (located in the first STS-1 in a frame) are used to carry a data communication channel (DCC) for maintenance purposes such as alarms, monitoring, and control. Line Overhead Following is a brief outline of the functions of some of the line overhead bytes.

STS Payload Pointer (H1 and H2). The H1 and H2 bytes in the line overhead carry a two-byte pointer that specifies the location of the STS SPE. More precisely, these bytes carry a value corresponding to the offset in bytes between the pointer and the first byte of the STS SPE.

Line BIP-8 (B2). The B2 byte carries a bit interleaved parity check value for each STS-1 within the STS-N. It is computed by taking the parity over all bits of the line overhead and the envelope capacity of the previous STS-1 frame before it is scrambled. This byte is checked by line terminating equipment. The intermediate section terminating equipment checks and resets the B1 byte in the section overhead but does not alter the B2 byte.

APS channel (K1, K2). The K1 and K2 bytes are used to provide a channel for carrying signaling information during automatic protection switching (APS).We will study the different types of SONET APS schemes. The K2 byte is also used to detect a specific kind of a signal called a forward defect indicator and to carry a return defect indicator signal. These defect indicator signals are used for maintenance purposes in the network;

Line Data Communication Channel. BytesD4 throughD12 (located in the first STS- 1 in a frame) are used to carry a line data communication channel for maintenance purposes such as alarms, monitoring, and control

Path Overhead

STS Path trace (J1). Just as in the section overhead, the path overhead includes a byte (J1) to carry a path identifier that can be monitored to verify connectivity in the network.

STS Path BIP-8 (B3). The B3 byte provides bit error rate monitoring at the path layer. It carries a bit interleaved parity check value calculated over all bits of the previous STS SPE before scrambling.

STS Path Signal Label (C2). The C2 byte is used to indicate the content of the STS SPE. Specific labels are assigned to denote each type of signal mapped into a SONET STS-1.

Path Status (G1). The G1 byte is used to convey the performance of the path from the destination back to the source node. The destination inserts the current error count in the received signal into this byte, which is then monitored by the source node. Part of this byte is also used to carry a defect indicator signal back to the source.

5. Describe in detail about SONET/SDH Ring Architecture?

Two types of ring architectures are used: unidirectional path-switched rings (UPSRs) and bidirectional line-switched rings (BLSRs). The BLSRs can use either two fibers (BLSR/2) or four fibers (BLSR/4). We will discuss these architectures and the protection mechanisms that they incorporate in detail in Chapter 9. In general, UPSRs are used in the access part of the network to connect multiple nodes to a hub node residing in a central office, and BLSRs are used in the interoffice part of the Network to interconnect multiple central offices.

Another major component in the SONET infrastructure is a digital crossconnect (DCS). A DCS is used to manage all the transmission facilities in the central office. Before DCSs arrived, the individual DS1s and DS3s in a central office were manually patched together using a patch panel. Although this worked fine for a small number of traffic streams, it is quite impossible to manage today's central offices, which handle thousands of such streams, using this approach.

A DCS automatesthis process and replaces a patch panel by crossconnecting these individual streams under software control. It also does performance monitoring and has grown to incorporate multiplexing as well. DCSs started out handling only PDH streams but have evolved to handle SONET streams as well. Although the overall network topology including the DCSs is a mesh, note that only rings have been standardizedso far. A variety of DCSs are available today, as shown in Figure 6.9. Typically, these DCSs have hundreds to thousands of ports.

The term grooming refers to the grouping together of traffic with similar destinations, quality of service, or traffic type. It includes multiplexing of lower-speed streams into high-speed streams, as well as extracting lower-speed streams from different higher-speed streams and combining them based on specific attributes. In this context, the type of grooming that a DCS performs is directly related to the granularity at which it switches traffic. If a DCSis switching traffic at granularities of DS1 rates.

Different types of crossconnect systems. traffic at the DS1 level. At the bottom of the hierarchy is a narrowband DCS, which grooms traffic at the DS0 level. Next up is a wideband DCS, which grooms traffic at DS1 rates, and then a broadband DCS, which grooms traffic at DS3/STS-1 rates. These DCSs typically have interfaces ranging from the grooming rate to much higherspeed interfaces. For instance, a wideband DCS will have interfaces ranging from DS1 to OC-12, while a broadband DCS will have interfaces ranging from DS3 to OC-768. There are also DCSs that groom at DS3 rates and above, with primarily high-speed optical interfaces.While such a box could be called broadband DCS, it is more commonly called an optical crossconnect. However, we also have other types of optical crossconnects that groom traffic at STS-48 rates, and yet others that usepurely optical switch fabrics and groom traffic in units of wavelengths or more.

Instead of having this hierarchy of crossconnect systems, why not have a single DCS with high-speed interfaces, which grooms at the lowest desired rate, say, DS0? This is not possible due to practical considerations of scalability, cost, and footprint. For instance, it is difficult to imagine building a crossconnect with hundreds to thousands of 10 Gb/s OC-192 ports that grooms down to the DS1 level. In general, the higher the speed of the desired interfaces on the crossconnect, the higher up it will reside in the grooming hierarchy .

6. Explain the elements of SONET/SDH infrastructure?

SONET is deployed in three types of network configurations: rings, linear configurations, and point-to-point links. The early deployments were in the form of point-to-point links, and this topology is still used today for many applications. In this case, the nodes at the ends of the link are called terminal multiplexers (TMs).

Elements of a SONET infrastructure. Several different SONET configurations are shown, including point-to-point, linear add/drop, and ring configurations. Both access and interoffice (backbone) rings are shown. The figure also explains the role of a DCS in the SONET infrastructure, to crossconnect lower-speed streams, to interconnect multiple rings, and to serve as a node on rings by itself. TMs are also sometimes called line terminating equipment (LTE).

In many cases, it isnecessary to pick out one or more low-speed streams from a high-speed stream and,likewise, add one or more low-speed streams to a high-speed stream. This function is performed by an add/drop multiplexer (ADM). For example, an OC-48 ADM can drop and add OC-12 or OC-3 streams from/to an OC-48 stream. Similarly, an OC-3 ADM can drop/add DS3 streams from/to an OC-3 stream. ADMs are now widely used in the SONET infrastructure. ADMs can be inserted in the middle of apoint-to-point link between TMs to yield a linear configuration.

Maintaining service availability in the presence of failures has become a key driver for SONET deployment. The most common topology used for this purpose is a ring. Rings provide an alternate path to reroute traffic in the event of link or node failures, while being topologically simple. The rings are made up of ADMs, which in addition to performing the multiplexing and demultiplexing operations, incorporate the protection mechanisms needed to handle failures.

Usually, SONET equipment can be configured to work in any of these three configurations: ring ADM, linear ADM, or as a terminal multiplexer. Rings are used both in the access part of the network and in the backbone (interoffice) part of the network to interconnect central offices..

7. Discuss in detail the Network management systems

1. Performance management deals with monitoring and managing the various parameters that measure the performance of the network. Performance management is an essential function that enables a service provider to provide quality-of-service guarantees to their clients and to ensure that clients comply with the requirements imposed by the service provider. It is also needed to provide input to other network management functions, in particular, fault management, when anomalous conditions are detected in the network.

2. Fault management is the function responsible for detecting failures when they happen and isolating the failed component. The network also needs to restore traffic that may be disrupted due to the failure, but this is usually considered a separate function.

3. Configuration management deals with the set of functions associated with managingOrderly changes in a network. The basic function of managing the equipmentin the network belongs to this category. This includes tracking the equipment in the network and managing the addition/removal of equipment, including anyrerouting of traffic this may involve and the management of software versions on the equipment. Another aspect of configuration management is connection management, which deals with setting up, taking down, and keeping track of connections in a network. This function can be performed by a centralized management system. Alternatively, it can also be performed by a distributed network control entity. Distributed network control becomes necessary when connection setup/take-down events occur very frequently or when the network is very largeand complex. Finally, the network needs to convert external client signals entering the optical layer into appropriate signals inside the optical layer. This function is adaptation management

4. Security management includes administrative functions such as authenticating users and setting attributes such as read and write permissions on a per-user basis. From a security perspective, the network is usually partitioned into domains, both horizontally and vertically. Vertical partitioning implies that some users may be allowed to access only certain network elements and not other network elements. For example, a local craftsperson may be allowed to access only the network elements he is responsible for and not other network elements. Horizontal partitioning implies that some users may be allowed to access some parameters associated with all the network elements across the network. For example, a user leasing a lightpath may be provided access to all the performance parameters associated with that lightpath across all the nodes that the lightpath
traverses. Security also involves protecting data belonging to network users from being tapped or corrupted by unauthorized entities. This part of the problem needs to be handled by encrypting the data before transmission and providing the decrypting capability to legitimate users.

5. Accountingmanagement is the function responsible for billing and for developing lifetime histories of the network components.

UNIT III BROADCAST AND SELECT NETWORKS
Topologies – Single-hop – Multi-hop – and Shufflenet multi-hop network – Media – Access control protocols – Test beds.

UNIT III
BROADCAST AND SELECT NETWORKS
PART-A

1. Define stations

Collections of devices that users employ to communicate are called stations. These may be computers, terminals, telephones, or other equipment for communicating. Stations are also referred to as data terminal equipment (DTE) in the networking world.

2. Define network

To establish connections between these stations, one deploys transmission paths running between them to form a collection of interconnected stations called a network.

3. Define node

. Within this network, a node is a point where one or more communication lines terminate and/or where stations are connected. Stations also can connect directly to a transmission line.

4. Define trunk

The term trunk normally refers to a transmission line that runs between nodes or networks and that supports large traffic loads

5. Define topology

The topology is the logical manner in which nodes are linked together by information transmission channels to form a network.

6. What is meant by switching and routing

. The transfer of information from source to destination through a series of intermediate nodes is called switching, and the selection of a suitable path through a network is referred to as routing. Thus a switched communication network consists of an interconnected collection of nodes, in which information streams that enter the network from a station are routed to the destination by being switched from one transmission path to another at a node.

7. Define router

When two networks that use different information-exchange rules (protocols) are interconnected, a device called a router is used at the interconnection point to translate the control information from one protocol to another.

8. Define Wavelength conversion

Lightpaths may undergo wavelength conversion along their route. one such lightpath that uses wavelength $\lambda 2$ on link EX, gets converted to $\lambda 1$ at node X, and uses that wavelength on link XF.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.

9. Define 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

10. Define transparency.

Transparency refers to the fact that the light paths can carry data at a variety of bit rates, protocols, and so forth and can, in effect, be made protocol insensitive. This enables the optical layer to support a variety of higher layers concurrently

11. What are the types of topology?

1. Bus topology
2. Star topology

12. Define bus topology

In bus topology a no .of nodes connected to a bus through 2*2 couplers by WDM fiber links

13. Define star topology

In star topology a no. of nodes connected a passive star coupler

14. Define central node or hub.

All nodes are joined at a single point called the central node or hub

15. Classified the categories of broad cast and selected network

1. Single hop network
2. Multi hop network

16. What is draw back of single hop network?

A draw back of single hop networks is the need for rapidly tunable lasers or receiver optical filters. In this case of multi hop networks generally do not have direct paths between each node pair. Each node has a small number of fixed-runed optical transmitters and receivers

17. Define broad cast and selected network

Broadcast-and-select networks are based on a passive star coupler device connected to several stations in a star topology. This device is a piece of glass that splits the signal it receives on any of its ports to all the ports. As a result it offers an optical equivalent of radio systems: each transmitter broadcasts its signal on a different wavelength, and the receivers can tune to receive the desired signal

18. Give short notes on media access control

The Media Access Control (MAC) data communication protocol sub-layer, also known as the Medium Access Control, is a sublayer of the Data Link Layer specified in the seven-layer OSI model (layer 2). It provides addressing and channel access control mechanisms that make it possible for several terminals or network nodes to communicate within a multi-point network, typically a local area network (LAN) or metropolitan area network (MAN). The hardware that implements the MAC is referred to as a Medium Access Controller.

19. List the various kinds of broadcast and select test beds.

1. Lambda net

2. NTT's tested

3. Rainbow

4. STARNET

5. BBC television studio test bed

6. Lightning

7. Super computer super net test bed

20. Give the bit rate per wavelength for the following test beds 1. 1. Lambda net 2. NTT's test bed 3.rainbow 4.STARNET 5.BBC television studio test bed

1. Lambda net -------- 1.5Gb/s

2. NTT's test bed -------622Mb/s

3. Rainbow ---------300Mb/s

4. STARNET ---------1.25/2.5 Gb/s

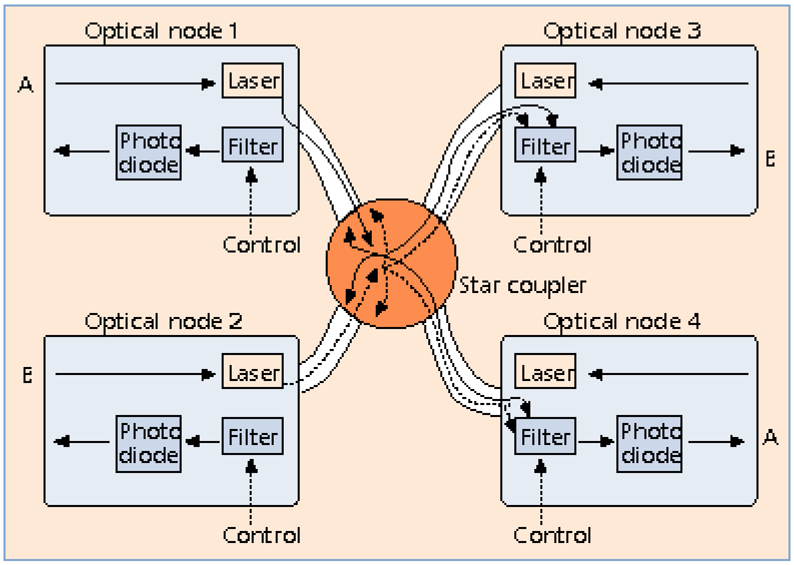
5. BBC television studio testbed ---- 2.5Gb/s

PART-B.

1. Explain the broadcast and select networks

Broadcast-and-Select Networks

Broadcast-and-select networks are based on a passive star coupler device connected to several stations in a star topology. This device is a piece of glass that splits the signal it receives on any of its ports to all the ports. As a result it offers an optical equivalent of radio systems: each transmitter broadcasts its signal on a different wavelength, and the receivers can tune to receive the desired signal (see Fig. 5 for a schematic drawing of such a system).



The main networking challenge in such networks pertains to the coordination of a pair of stations in order to agree and tune their systems to transmit and receive on the same wavelength. One design issue that must be determined before deciding on these protocols is the tuneable part of the system. It is possible to either have the transmitters each fixed on a different wavelength and have tuneable receivers, have fixed receivers and tuneable transmitters, or have tuning abilities in both components. It has been shown that it is more advantageous to have tuneable receivers and fixed transmitters than the other way around. The advantage of these networks is in their simplicity and natural multicasting capability. However, they have severe limitations since they do not enable reuse of wavelengths and are thus not scalable beyond the number of supported wavelengths.

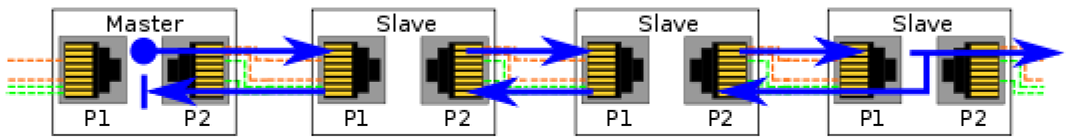
Another factor that hinders the scalability of this solution and disables it from spanning long distances is the splitting of the transmitted energy to all the ports. For these reasons the main application for broadcast-and-select is high-speed local and metropolitan area networks. However, the relatively high costs of WDM transmitters and receivers compared to the low costs of other technologies (e.g., ATM and switched Ethernet) do not enable broadcast-and-select networks to be competitive in this arena currently. Due to these reasons we will ignore broadcast-and-select networks for the rest of the discussion.

2. Explain the various topologies for broadcast networks

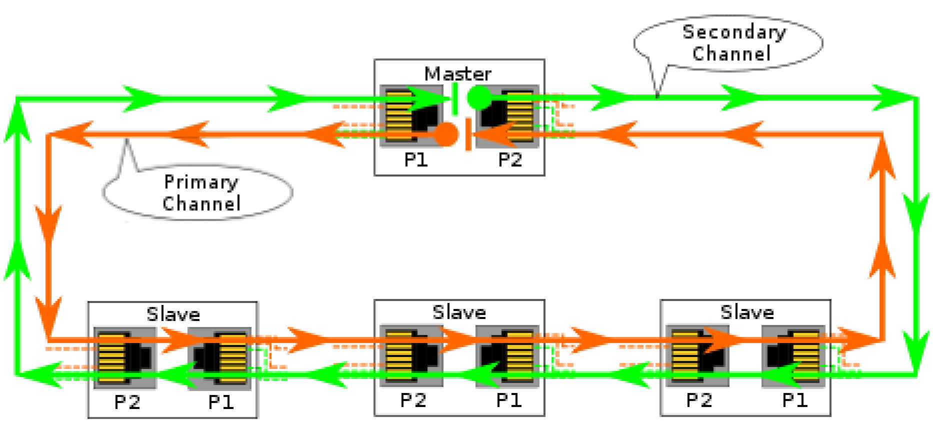
Network topologies

The sercos III specification defines two possible network topologies; Ring and Line. To those familiar with other networks, they may appear to both be configured as a Ring. All telegrams begin and end at the Master. The Full Duplex feature of the physical layer is used to achieve this.

Line topology



A line topology is the simpler of the two possible arrangements, and provides no redundancy. However, this configuration saves the cost of one cable. In it, only one of the two interfaces on the Master is used. Telegrams are issued out of the transmit PMA on the Master's active port. Either port on the Master may be the active one. sercos III determines this during phase-up (initialization). The first Slave receives the telegrams on the connected interface's receive PMA, modifies them as required, and issues them out on the transmit PMA of the second interface. Each cascading Slave does likewise until the last Slave in the Line is reached. That Slave, detecting no sercos III connection on its second port, folds the telegram back on the receiving interface's transmit port. The telegram then makes it way through each Slave back to the Master. Note the last Slave also emits all sercos III telegrams on its second port, even though no sercos III connection is detected. This is for snooping, ring closures (see below), as well as hot-plugging. Keep in mind that since the Ethernet destination field in all sercos III telegrams is the broadcast address of 0xFFFF FFFF FFFF (all 1s), all telegrams issued from this open port will be seen by other devices as broadcast telegrams. This behavior is by design, and cannot be disabled. To avoid taxing networks attached to an open sercos port, an NRT-Plug can be used, or alternately a managed Ethernet switch programmed to block broadcast telegrams received from the sercos port can be used.



Ring topology

A ring topology simply closes the network by attaching the unused port on the last device in a ring back to the unused port on the Master. When the sercos III Master senses that a ring exists, it sets up two counter-rotating telegrams. The same data is issued simultaneously out of the transmit PMAs of both ports on the Master. From there both telegrams are managed essentially identically as they make their way through each Slave, ending back at the opposite port on the Master they were emitted from. Advantages to this topology include tighter synchronization, as well as automatic infrastructure redundancy (see below).

Other network topologies

With both the line or ring structure, sercos III operates in a “circular” approach. All telegrams leave the Master, and return there. As with any network that operates in this manner, modified structures can be constructed to appear as a tree or star network, utilizing hardware that manages the branches, but the structure is still circular in nature.

3. Explain in detail About the MDEIA ACCESS PROTOCOL.

The Media Access Control (MAC) data communication protocol sub-layer, also known as the Medium Access Control, is a sublayer of the Data Link Layer specified in the seven-layer OSI model (layer 2). It provides addressing and channel access control mechanisms that make it possible for several terminals or network nodes to communicate within a multi-point network, typically a local area network (LAN) or metropolitan area network (MAN). The hardware that implements the MAC is referred to as a Medium Access Controller.

The MAC sub-layer acts as an interface between the Logical Link Control (LLC) sublayer and the network's physical layer. The MAC layer emulates a full-duplex logical communication channel in a multi-point network. This channel may provide unicast, multicast or broadcast communication service.

Addressing mechanism

The MAC layer's addressing mechanism is called physical address or MAC address. A MAC address is a unique serial number. Once a MAC address has been assigned to a particular network interface (typically at time of manufacture), that device should be uniquely identifiable amongst all other network devices in the world. This guarantees that each device in a network will have a different MAC address (analogous to a street address). This makes it possible for data packets to be delivered to a destination within a subnetwork, i.e. a physical network consisting of several network segments interconnected by repeaters, hubs, bridges and switches, but not by IP routers. An IP router may interconnect several subnets.

An example of a physical network is an Ethernet network, perhaps extended by wireless local area network (WLAN) access points and WLAN network adapters, since these share the same 48-bit MAC address hierarchy as Ethernet.

A MAC layer is not required in full-duplex point-to-point communication, but address fields are included in some point-to-point protocols for compatibility reasons.

Channel access control mechanism

The channel access control mechanisms provided by the MAC layer are also known as a multiple access protocol. This makes it possible for several stations connected to the same physical medium to share it. Examples of shared physical media are bus networks, ring networks, hub networks, wireless networks and half-duplex point-to-point links. The multiple access protocol may detect or avoid data packet collisions if a packet mode contention based channel access method is used, or reserve resources to establish a logical channel if a circuit switched or channelization based channel access method is used. The channel access control mechanism relies on a physical layer multiplex scheme.

The most widespread multiple access protocol is the contention based CSMA/CD protocol used in Ethernet networks. This mechanism is only utilized within a network collision domain, for example an Ethernet bus network or a hub network. An Ethernet network may be divided into several collision domains, interconnected by bridges and switches.

A multiple access protocol is not required in a switched full-duplex network, such as today's switched Ethernet networks, but is often available in the equipment for compatibility reasons.

Common multiple access protocols

Examples of common packet mode multiple access protocols for wired multi-drop networks are:

- CSMA/CD (used in Ethernet and IEEE 802.3)
- Token bus (IEEE 802.4)
- Token ring (IEEE 802.5)
- Token passing (used in FDDI)

Examples of common multiple access protocols that may be used in packet radio wireless networks are:

- CSMA/CA (used in IEEE 802.11/WiFi WLANs)
- Slotted ALOHA
- Dynamic TDMA
- Reservation ALOHA (R-ALOHA)
- Mobile Slotted ALOHA (MS-ALOHA)
- CDMA
- OFDMA

UNIT IV WAVELENGTH ROUTING NETWORKS
Node design – Issues in network design and operation – Optical layer cost tradeoffs – Routing and wavelength assignment – Wavelength routing test beds

UNIT IV
WAVELENGTH ROUTING NETWORKS
PART-A

1. When a node is called as add/drop multiplexer node?

There are exactly two trunk ports (excluding any protection fibers) the node is called a add/drop multiplexer node

2. List the various conversions involved in wavelength add/drop multiplexer

With fixed wavelength conversion
With full wavelength conversion
With limited wavelength conversion

3. Define online and off line light path

In the online case the demands for light paths arise one at a time and each light path must be provided on demand without waiting for further light path demands become known

In the off line case we are given the entire light path that are to be routed up front

4. What are the two types of wavelength routing network?

1. Static network
2. Reconfigurable network

5. Give the design parameters for cost of the networks

Router ports. Clearly, we would like to use the minimum possible number of IP router ports to support the given traffic. Note that since a lightpath is established between two router ports, minimizing the number of ports is the same as minimizing the number of lightpaths that must be set up to support the traffic.

Wavelengths. At the same time, we would also like to use the minimum possible number of wavelengths since using more wavelengths incurs additional equipment cost in the optical layer.

Hops. This parameter refers to the maximum number of hops taken up by a lightpath. For the PWDM ring, each lightpath takes up exactly one hop. This parameter becomes important because it gets more difficult to design the transmission system as the number of hops increases (see Chapter 5), which again increases the cost of optical layer equipment

6. Define RWA

Routing and wavelength assignment (RWA) problem, which is defined as follows. Given a network topology and a set of end-to-end light path requests (which could be obtained, for example, by solving the LTD problem), determine a route and wavelength(s) for the requests, using the minimum possible number of wavelengths.

7. List out the wavelength routing test beds

1. Africa ONE/sea me we-3
2. AON
3. NTT ring
4. MWTN
5. ONTC
6. Alcatels WDM ring
7. MONET

8. Give the topology for the following test beds 1.MWTN 2. AON

1. MWTN------ring/mesh
2. AON---------star

9. Define virtual topology

The virtual topology is the graph consisting of the network nodes with an edge between two nodes if there is a light path between them

10. Compare optical and electronic WXCs

	optical WXCs	electronic WXCs
Transparency	Yes	Difficult
Wavelength conversion	Difficult	Easier
Bit rate	>10Gb/s	<2.5Gb/s
Cross connect size	Small	large

11. List out the traffic models in optical networks

1. Fixed traffic matrix
2. Permutations
3. Maximum load
4. Statistical model

PART-B

1. Explain Cost Trade-Offs wave length routing network

In this section, we will study the cost trade-offs in designing networks in different ways to meet the same traffic demand by varying the light path topology. We will consider the trade-offs between the cost of the higher-layer equipment and the optical layer equipment. We measure the higher-layer equipment cost by the number of IP router ports (or SONET line terminals). The number of IP router ports required is equal to twice the number of light paths that need to be established since each light path connects a pair of IP router ports. An important component of the optical layer cost is the number of transponders required in the OLTs and OADMs.

Since every light path requires a pair of transponders, we club the cost of the transponders with that of the higher-layer equipment. This also covers the case where the transponders are present within the higher-layer equipment (see Figure 7.2). We measure the remainder of the cost of the optical layer equipment by the number of wavelengths used on a link.

Network topologies are usually designed to be 2-connected, that is, to have two node-wise disjoint routes between every pair of nodes in the network. While fiber mesh topologies that are arbitrary, but 2-connected, are more cost-efficient for largenetworks than fiber ring topologies, the latter have been widely deployed and are good for a network that does not have a wide geographic spread. For this reason we will consider fiber ring topologies in this section. There is a wide deployment of rings in part because a ring connecting N nodes has the minimum possible number of links (only N) for a network that is 2-connected, and thus tends to have a low fiber deployment cost.

We will consider a traffic matrix where t units of traffic are to be routed from one IP router to all other IP routers in the network. We denote the number of nodes in the network by N and assume the traffic is uniform; that is, $t/(N-1)$ units of traffic are to be routed between every pair of IP routers. For normalization purposes, the capacity of a wavelength is assumed to be one unit. As in the three-node linear topology above, we divide the network design problem into two: the LTD and RWA problems. We will consider three different lightpath topologies, all of which are capable of meeting the traffic requirements.

The first lightpath topology, shown in Figure 10.3(a), is a ring, which we call a point-to-point WDM (PWDM) ring. In this case, the lightpath topology is also a ring, just like the fiber topology, except that we can have multiple lightpaths between adjacent nodes in the ring, in order to provide the required capacity between the IP routers.

The second lightpath topology, shown in Figure 10.3(b), is a hub design. All routers are connected to a central (hub) router by one or more lightpaths. Thus all packets traverse two lightpaths: from the source router to the hub, and from the hub to the destination router.

The third, and final, lightpath topology, shown in Figure 10.3(c), is an all-optical design. In this case, we establish direct lightpaths between all pairs of routers. Thus, packets traverse only one lightpath to get from the source router to the destination router.

We next consider how to realize these lightpath topologies on the fiber network; that is, we solve the RWA problem for these three designs. The RWA problem is to find a route for each lightpath and to assign it a wavelength on every link of the route. We assume that a lightpath must be assigned the same wavelength on all the links it traverses; that is, the optical layer provides no wavelength conversion capability.

2. Explain the various routing and wavelength assignment methods

Routing and Wavelength Assignment

Design problem involves a trade-off between optical layer equipment (essentially, number of wavelengths) and higher-layer equipment for example, IP router ports or SONET line terminals). In the previous section, we studied the LTD problem. Here we study the routing and wavelength assignment (RWA) problem, which is defined as follows.

Given a network topology and a set of end-to-end lightpath requests (which could be obtained, for example, by solving the LTD problem), determine a route and wavelength(s) for the requests, using the minimum possible number of wavelengths. The RWA problem can be formulated as an ILP, but the ILP may take too much to solve except for networks with small numbers of nodes. The RWA problem can be simplified by dividing it into a lightpath routing (LR) problem and a wavelength assignment (WA) problem.

The LR problem is to find routes for a collection of lightpaths, perhaps the result of an LTD problem. The objective of the LR problem is to minimize the maximum, over all fiber links, of the number of lightpaths using a fiber link. An alternative objective of the LR problem is to minimize some network cost such as bandwidth, ports, switching, or regenerator cost.

The WA problem is, given a collection of lightpaths and their routes, to assign wavelengths to the lightpaths. The objective is to minimize, over all fiber links, the maximumwavelength used on a fiber link.

A simple method to solve the LR problem is to route the lightpaths one at a time in some order. Routes can be computed by using shortest path routing algorithms on the network topology, such as [Dij59]. The network topology has weights assigned to each link, so that the shortest path is the least-weight path. The link weights are chosen so that the resulting lightpath routes meet the objective of the LR problem.

A simple example of link weights is to have them all equal to one. Then the routes have the shortest number of hops, which minimizes the total use of links. Another example is to have a link weight equal to 1 + L, where L is the number of lightpaths routed through the link so far. The method will route lightpaths so that they avoid highly used links. This will balance the number of lightpaths over all links and minimize the number of wavelengths needed on a link. For the WA problem, the assignments must obey the following constraints:

1. Two lightpaths must not be assigned the same wavelength on a given link.
2. If no wavelength conversion is available through a switch, then a lightpath must be assigned the samewavelength on the links through the switch. If nowavelength conversion is available in the network, then a lightpath must be assigned the same wavelength all along its route.

If no wavelength conversion is available, a WA algorithm is needed to assign wavelengths. A simple and effective algorithm is first fit. It assumes that the wavelengths are numbered (e.g., 0, 1, ...), and it chooses the smallest numbered wavelength that is available. This tends to pack lightpaths into lower-numbered wavelengths and keeps higher-numbered wavelengths free for future lightpaths.

Another consideration for the RWA problem is network survivability when there are faults. As mentioned in, lightpaths can be protected from faults by a number of methods including 1+1, 1 : 1 and shared protection. Then lightpaths have working and protection paths. A lightpath's working and protection paths should be disjoint so that they cannot fail together. Typically, it is assumed that single fiber link faults and single-node faults are the most likely faults to occur. Therefore, they are considered when computing paths.

In general, multiple fiber links may fail together, and this is referred to as a shared risk link group (SRLG). A node fault leads to an SRLG because it causes all its incident links to fail. Another case of an SRLG is a collection of fiber links that share a conduit. If the conduit is cut, all the fiber links could fail.

To survive single fiber link cuts, the working and protection paths must have disjoint links. Similarly, to survive single-node failures, the working and protection paths avoid a common intermediate node, and to survive SRLGs, the paths must avoid traversing a common SRLG. There are two common methods to compute disjoint link paths. The first simply computes the paths one at a time. The first path is the shortest path, and the second path is another shortest but one that avoids the links of the first path.

This method of computing disjoint paths can be extended to single-node faults and SRLGs in a straightforward way. In particular, the second path avoids all nodes or SRLGs that the first path traverses. The second method to compute disjoint paths is to compute them together by using algorithms that solve the minimum disjoint paths problem. The minimum disjoint path problem assumes links have weights and finds disjoint paths with minimum total weight. This method is more complicated but can be extended to single-node faults and some cases of SRLGs.

The amount of bandwidth needed for the protection paths depends on the protection mechanism. In the case of 1+1 of its links. In the case of shared protection, protection bandwidth of a pair of light paths may be shared if their working paths cannot fail together. These considerations should be taken into account when wavelengths are assigned to working and protection paths.

In the rest of this chapter, we assume that the network as well as the lightpaths is bidirectional. Then a fiber link in the network is composed of two unidirectional fibers in opposite directions. From an operational viewpoint, most light paths will be full duplex, as the higher-level traffic streams that they carry (for example, SONET streams) are full duplex. Moreover, network operators would prefer to assign the same route and wavelength to both directions for operational simplicity.

Note, however, that it is possible to reduce the number of wavelengths needed in some cases by assigning different wavelengths to different directions of the lightpath.and 1:1 protection, the protection bandwidth is dedicated. Then a protection path will have a wavelength dedicated to it on each

3. Describe Node design for wavelength routing networks

Node graph architecture is a type of software design which builds around modular node components which can be connected together to form a graph. Often the software's underlying node graph architecture is also exposed to the end user as a 2 dimensional visualization of the node graph. The node graph architecture is popular in the film and computer games industry.

There are often many different node types participating in the node graph. For example in the Nuke Manual they list hundreds of nodes. Each node type performs one specific task. For example Nuke's Merge node produces an output image in which a number of input images have been layered. By connecting many different node types together complex image effects can be produced.

The node graph architecture often allows grouping of nodes inside other group nodes. This hides complexity inside of the group nodes, and limits their coupling with other nodes outside the group. This leads to a hierarchy where smaller graphs are embedded in group nodes. In Nuke the group node is simply called the Group node.

In the paper Hierarchical Small Worlds in Software Architecture they argue that most large software systems are built in a modular and hierarchical fashion, and they use node graphs to analyze large software systems. In fact a large number of software analysis papers often use node graphs to analyze large software systems suggesting that node graphs are good models of the internal structure and operation of the software.

Many commercial and non-commercial software systems allow users to visualize and interact with internal components via the node graph. Below are a number of node graph based software applications from the film and games industry.

Commercial applications

Nuke is a compositing application for film made by The Foundry. The nodes in its graph can be connected together to produce complex 2D image processing effects.

- Nuke Node Graph Basics
- Nuke Manual

Shake is a discontinued compositing application for film made by Apple. The nodes in its graph can be connected together to produce complex 2D image processing effects.

- Shake Screenshot
- Shake Manual

Maya is a modeling, animation, and rendering application made by Autodesk. The nodes in its graph are more general and produce 3D geometry and various other attributes.

- Maya Screenshot
- Maya Nodes

Houdini is a procedural modelling, animation, and rendering application made by Side Effects Software. The nodes in its graph produce procedural geometry. Side Effects Software refers to their node graphs as networks.

- Houdini Nodes and Networks
- Houdini Nodes

Valve's Source SDK allows players to create custom maps for all of their games. The nodes in its graphs are used in AI path planning and also in sending signals between game entities.

- Valve Nodes for Path Planning
- Entity Inputs and Outputs

Open source applications

Blender is a modelling, animation, compositing, and rendering application. The nodes in its graph produce images, 3D geometry, and various other attriutes.

- Blender Node Graph Screen Shot
- Blender Node System

NodeBox is procedural image creation application. The nodes in its graph produce vector based images.

- NodeBox Screen Shot
- NodeBox Node Reference

In-house studio applications

Many large movie studios are rumored to be using the node graph architecture to design many of their in-house software tools. Sony Pictures Imageworks uses an in-house compositing and lighting tool called Katana. In a recent press release (November 2009) it was announced that the Sony Pictures Imageworks' Katana software would be integrated into The Foundry's Nuke software.

- Katana and Nuke FAQ

4. Explain wavelength Routing Test Beds

Wavelength Routing Testbeds

Testbeds are essentially laboratory scale demonstrations and field trials. Several testbeds have demonstrated circuit switching in optical broadcast and select networks. One such example is the IBM's Rainbow which was designed to support 32 wavelengths separated by 1 nm in a star configuration. The testbeds could achieve bit rates of 1 Gb/s wavelength. The testbed Rainbow II successfully demonstrated support of four wavelengths at this speed. Wavelength routing has been successfully demonstrated in several testbeds, like AON, NTT Ring etc. In the following we briefly describe the All--Optical Network Consortium's testbed, which has been deployed in the Boston metropolitan area

AON
(Application-Oriented Networking) Using network devices to help with integration. Application-oriented networking has arisen in response to increasing use of XML messaging (combined with related standards such as XSLT, XPath and XQuery) to link miscellaneous applications, data sources and other computing assets. Many of the operations required to mediate between these different participants, or to monitor their exchanges, can be built into network devices that are optimized for the purpose. The rules and policies for performing these operations, also expressed in XML, are specified separately and downloaded as required. Network equipment vendor Cisco has adopted the AON acronym as the name of a family of products that function in this way.

UNIT V HIGH CAPACITY NETWORKS
SDM – TDM and WDM approaches – Application areas – Optical TDM networks – Multiplexing and demultiplexing – Synchronization – Broadcast networks – Switch based networks – OTDM test beds

UNIT V
HIGH CAPACITY NETWORKS
PART-A

1. Give the goal of PPS network

Packet-switched services are provided today using electronic switches by many networks, such as IP and Ethernet networks. Here, we are interested in networks where the packet-switching functions are performed optically. The goal of PPS networks is to provide the same services that electronic packet-switched networks provide, but at much higher speeds

2. Define Routing.

Routers maintain up-to-date information of the network topology. This information is maintained in the form of a routing table stored at each node.

3. Define Forwarding.

For each incoming packet, a router processes the packet header and looks up its routing table to determine the output port for that packet. It may also make some changes to the header itself and reinsert the header at the output.

4. Define Switching.

Switching is the actual process of switching the incoming packet to the appropriate output port determined by the forwarding process

5. Define Buffering.

Buffering is needed in a router for many reasons. Perhaps the most important one in this context is to deal with destination conflicts. Multiple packets arrive simultaneously at different inputs of a router. Several of these may have to be switched to the same output port. However, at any given time, only one packet can be switched to any given output port. Thus the router will have to buffer the other packets until they get their turn. Buffers are also used to separate packets based on their priorities or class of service.

6. Write short notes on Synchronization.

Synchronization can be broadly defined as the process of aligning two signal streams in time. In PPS networks, it refers either to the alignment of an incoming pulse stream and a locally available clock pulse stream or to the relative alignment of two incoming pulse streams. The first situation occurs during multiplexing and de multiplexing, and the second occurs at the inputs of the router where the different packet streams need to be aligned to obtain good switching performance.

7. Define Optical Time Division Multiplexing

At the inputs to the network, lower-speed data streams are multiplexed optically into a higher-speed stream, and at the outputs of the network, the lower-speed streams must be extracted from the higher-speed stream optically by means of a demultiplexing function. Functionally, optical TDM

(OTDM) is identical to electronic TDM. The only difference is that the multiplexing and demultiplexing operations are performed entirely optically at high speeds. The typical aggregate rate in OTDM systems is on the order of 100 Gb/s,

8. Write short notes on Optical AND Gates

The logical AND operations are performed optically at very high speeds. A number of mechanisms have been devised for this purpose. We describes two of them here. Note that the logical AND operation between two signals can be performed by an on-off switch if one of the signals is input to the switch and the other is used to control it.

9. Define Nonlinear Optical Loop Mirror

The nonlinear optical loop mirror (NOLM) consists of a 3 dB directional coupler, a fiber loop connecting both outputs of the coupler, and a nonlinear element (NLE) located asymmetrically in the fiber loop,

10. What is soliton trapping?

The two pulses undergo wavelength shifts in opposite directions so that the group velocity difference due to the wavelength shift exactly compensates the group velocity difference due to birefringence! Since the two soliton pulses travel together (they do not walk off), this phenomenon is called soliton trapping

11. Define Synchronization

Synchronization is the process of aligning two pulse streams in time. In PPS networks, it can refer clock pulse stream or to the relative alignment of two incoming pulse streams. Recall our assumption of fixed-size packetsither to the alignment of an incoming pulse streamed a locally available

12. Write down the Test beds of high capacity networks

Several PPS test beds have been built over the years. The main focus of most of these test beds is the demonstration of certain key PPS functions such as multiplexing and demultiplexing, routing/switching, header recognition, optical clock recovery (synchronization or bit-phase alignment), pulse generation, pulse compression, and pulse storage

13. Define KEOPS

KEOPS (Keys to Optical Packet Switching) [Gam98, Gui98, RMGB97] was a significant project undertaken by a group of research laboratories and universities in Europe. Its predecessor was the ATMOS (ATM optical switching) project [Mas96, RMGB97]. KEOPS demonstrated several of the building blocks for PPS and put together two separate demonstrators illustrating different switch architectures. The building blocks demonstrated include all-optical wavelength converters

14. Define BT Labs Testbeds

Researchers at British Telecom (BT) Laboratories demonstrated several aspects of PPS networks [CLM97] that we discussed in this chapter. Multiplexing and demultiplexing of high speed signals in the optical domains were demonstrated in a prototype broadcast local-area network based on a bus topology called Synchrolan [LGM+97, Gun97b]. Bit interleaving was used with each of the multiplexed channels operating at a bit rate of 2.5 Gb/s. The aggregate bit rate transmitted on the bus was 40 Gb/s. The clock signal (akin to a framing pulse) was distributed along with the bit-interleaved data channels.

15. Define AON

This test bed was developed by the All-Optical Network (AON) consortium consisting of AT&T Bell Laboratories, Digital Equipment Corporation, and the Massachusetts Institute of Technology [Bar96]. The aim was to develop an optical TDM LAN/MAN operating at an aggregate rate of 100 Gb/s using packet interleaving. Different classes of service, specifically guaranteed bandwidth service and bandwidth-on-demand service, were proposed to be supported

PART-B

1. Explain space division multiplexing approach, time division multiplexing approach, and Wave length division multiplexing approach

Using SDM

Using additional fibers is a straightforward upgrade alternative. The viability of this approach depends on a few factors. First, are additional fibers available on the route? If so, then the next consideration is the route length. If the route length is short (typically a few tens of kilometers) and no regenerators or amplifiers are required along the route, then this is a good alternative. However, if amplifiers or regenerators are required, then this becomes an expensive proposition because each fiber requires a separate set of amplifiers or regenerators.

However, it may be worth paying the price to light up a new fiber if the new equipment to be deployed over that fiber provides significantly reduced transmission costs compared to existing equipment on the already-lit fiber. If no fibers are available on the route, then we need to look at the cost associated with laying new fiber. This varies widely. If there is space in existing conduits, fiber can be pulled through relatively inexpensively and quickly.

However, if new conduits must be laid, the cost can be very expensive, even over short distances if the route is in a dense metropolitan area. If new conduits are to be laid, then the link can be populated with a large-count fiber cable. Today's fiber bundles come with hundreds of fibers.The other aspect of this problem is the time it takes to lay new fiber. Constructing new fiber links takes months to years and requires right-of-way permits from municipalities where the new link is laid.

These permits may not be easy to obtain in dense metropolitan areas, due to the widespread impact caused by digging up the streets. In contrast, upgrading an existing fiber link using either TDM or WDM can be done within days to weeks. Although it is necessary in some circumstances to lay new fibers, this is not a good mechanism for rapid response to service requests. Note that carriers are not likely to wait until the last fiber is exhausted before they consider an upgrade process.

For example, an upgrade process may be triggered when it is time to light up the last few fibers on a route. This might result in installing additional fibers along the router. Alternatively, the carrier may deploy a highercapacity TDM or WDM system on the last few fibers, and transfer the traffic from the lower-capacity fibers onto the new system deployed to free up existing fibers along the route.

Using TDM

Clearly, TDM is required for grooming traffic at the lower bit rates where optics is not cost-effective. The question is, to what bit rate should traffic be time division multiplexed before it is transmitted over the fiber (perhaps on a wavelength over the fiber)? Today's long-haul links operate mostly at rates of 2.5 Gb/s, 10 Gb/s, or 40 Gb/s. We will see in Section 13.2.5 that the choice of bit rate here is dictated primarily by the type of fiber available. Metropolitan interoffice links operate mostly at 2.5 Gb/s, and access links operate at even lower speeds.

Here the situation is somewhat more complicated, as we will explore in Section 13.2.8. Electronic TDM technology is already delivering the capability to reach 40 Gb/s transmission rates and may well push this out to 100 Gb/s in the future. Beyond these rates, it is likely that we will need some form of optical TDM. At the higher bit rates, we have to deal with more severe transmission impairments over the fiber, specifically chromatic dispersion, polarization-mode dispersion (PMD), and fiber nonlinearities. With standard single-mode fiber.

the chromatic dispersion limit is about 60 km at 10 Gb/s and about 1000 km at 2.5 Gb/s, assuming transmission around 1550 nm. With practical transmitters, the distances are even smaller. The

10 Gb/s limit can be further reduced in the presence of self-phase modulation. Beyond these distances, the signal must be electronically regenerated, or some form of chromatic dispersion compensation must be employed. Practical 10 Gb/s systems being deployed today commonly use some form of chromatic dispersion compensation. This is usually cheaper than using regeneration, particularly when combined with WDM.

the distance limit due to PMD at 10 Gb/s is 16 times less than that at 2.5 Gb/s. On old fiber links, the PMD value can be as high as 2 ps/√km. For this value, assuming a 1 dB penalty requirement, the distance limit calculated from (5.23) is about 25 km at 10 Gb/s. Electronic regeneration or PMD compensation is required for longer distances. The PMD-induced distance limit may be even lower because of additional PMD caused by splices, connectors, and other components along the transmission path. PMD does not pose a problem in newly constructed links where the PMD value can be kept as low as 0.1 ps/ √ km.

Finally, nonlinear effects such as self-phase modulation limit the maximum transmission power per channel, resulting in a need for closer amplifier spacing, and thus more amplifiers in the link, leading to somewhat higher costs. At 10 Gb/s, transmission powers are usually limited to under 5 dBm per channel. Today 10 Gb/s TDMsystems are widely deployed in long-haul networks, mostly in conjunction with WDM, and 40 Gb/s TDM systems will soon become commercially available.

Using WDM

It may be preferable to maintain a modest transmission bit rate, say, 10 Gb/s, and havemultiple wavelengths over the fiber, than to go to a higher bit rate and have fewer wavelengths. Keeping the bit rate low makes the system less vulnerable to chromatic dispersion, polarization-mode dispersion, and some types of nonlinearities, such as self-phase modulation.

On the other hand, WDM systems are generally not suitable for deployment over dispersion-shifted fiber because of the limitations imposed by four-wave mixing (see Chapter 5). WDM systems can be designed to be transparent systems. This allows different wavelengths to carry data at different bit rates and protocol formats. This can be a major advantage in some cases. Finally, WDM provides great flexibility in building networks.

For example, if there is a network node at which most of the traffic is to be passed through and a small fraction is to be dropped and added, it may be more cost-effective to use Figure 13.7 (a) Unidirectional and (b) bidirectional transmission systems. a WDM optical add/drop element than terminating all the traffic and doing the add/drop in the electrical domain. Today's state-of-the-art long-haul systems carry about 100 channels at 10 Gb/s each and have regenerator spacings of 600 to 1500 km. The ultra-long-haul systems expand spacing between regenerators to about 4000 km but have somewhat lower capacities than the long-haul systems.

2. Write short notes on OTDM

Optical Time Division Multiplexing

At the inputs to the network, lower-speed data streams are multiplexed optically into a higher-speed stream, and at the outputs of the network, the lower-speed streams must be extracted from the higher-speed stream optically by means of a demultiplexing function. Functionally, optical TDM (OTDM) is identical to electronic TDM. The only difference is that the multiplexing and demultiplexing operations are performed entirely optically at high speeds. The typical aggregate rate in OTDMsystems is on the order of 100 Gb/s,.

Optical signals representing data streams nfrom multiple sources are interleaved in time to produce a single data stream. The interleaving can be done on a bit-by-bit basis Assuming the data is sent in the form of packets, it can also be done on a packet-by-packet basis If the packets are of fixed length, the recognition of packet boundaries is much simpler. In what follows, we will assume that fixed-length packets are used. In both the bit-interleaved and the packet-interleaved case, framing pulses can be used. In the packet-interleaved case, framing pulses mark the boundary between packets.

In the bit-interleaved case, if n input data streams are to be multiplexed,a framing pulse is used every n bits. As we will see later, these framing pulses will turn out to be very useful for demultiplexing individual packets from a multiplexed stream of packets.Note from Figure 12.4 that very short pulses—much shorter than the bit interval of each multiplexed stream—must be used in OTDM systems. Given that we are interested in achieving overall bit rates of several tens to hundreds of gigabits per second, the desired pulse widths are on the order of a few picoseconds.

A periodic train of such short pulses can be generated using a mode-locked laser, as described in Section 3.5.1, or by using a continuous-wave laser along with an external modulator,
as described in Section 3.5.4. Since the pulses are very short, their frequency Figure 12.4 (a) Function of a bit-interleaved optical multiplexer. (b) Function of a packet-interleaved optical multiplexer. The same four data streams are multiplexed in both cases. In (b), the packet size is shown as 3 bits for illustration purposes only; in practice, packets are much larger and vary in size. Note that in both cases, the data must be compressed in time.

spectrum will be large. Therefore, unless some special care is taken, there will be significant pulse broadening due to the effects of chromatic dispersion. For this purpose,
many OTDM experiments use suitably shaped return-to-zero (RZ) pulses, which we studied in Sections 2.6 and 4.1. Assume that n data streams are to be multiplexed and the bit period of each of
these streams is T . Also assume that framing pulses are used. Then the interpulse width is $\tau = T/(n + 1)$ because n + 1 pulses (including the framing pulse) must be transmitted in each bit period. Thus the temporal width τp of each pulse must satisfy $\tau p \leq \tau$. Note that usually $\tau p < \tau$, so that there is some guard time between successive pulses. One purpose of this guard time is to provide for some tolerance in the multiplexing and demultiplexing operations. Another reason is to prevent the undesirable interaction between adjacent pulses that we discussed earlier

3. Explain about Multiplexing & Demultiplexing of OTDM

Bit Interleaving

We will first study how the bit-interleaved multiplexing illustrated in Figure 12.4(a) can be performed optically. This operation is illustrated in Figure 12.5. The periodic pulse train generated by a mode-locked laser is split, and one copy is created for each data streamto be multiplexed. The pulse train for the ith data stream, i = 1, 2, . . . ,n, is delayed by $i\tau$. This delay can be achieved by passing the pulse train through the appropriate length of optical fiber. Since the velocity of light in silica fiber is about
2 × 108 m/s, 1 meter of fiber provides a delay of about 5 ns. Thus the delayed pulse streams are nonoverlapping in time

. The undelayed pulse stream is used for the framing pulses. Each data stream is used to externally modulate the appropriately delayed periodic pulse stream. The outputs of the external modulator and the framing pulse stream are combined to obtain the bit-interleaved optical TDM stream. The power level of the framing pulses is chosen to be distinctly higher than that of the data pulses. This will turn out to be useful in demultiplexing, as we will see. In the case of broadcast networks with a star topology, the combining operation is naturally performed by the star coupler.

The corresponding demultiplexing operation is illustrated in Figure 12.6. The multiplexed input is split into two streams using, say, a 3 dB coupler. If the jth streamfrom the multiplexed streamis to be extracted, one of these streams is delayed by jτ. A thresholding operation is performed on the delayed stream to extract the framing pulses. The framing pulses were multiplexed with higher power than the other pulses in order to facilitate this thresholding operation.

Note that because of the induced delay, the extracted framing pulses coincide with the pulses in the undelayed stream that correspond to the data stream to be demultiplexed. A logical AND operation between the framing pulse stream and the multiplexed pulse stream is used to extract the j th stream. The output of the logical AND gate is a pulse during a pulse interval, both inputs have pulses; the output has no pulse otherwise. a nonlinear optical loop mirror and a soliton-trapping gate.

Packet Interleaving

As in the case of bit interleaving, a periodic stream of narrow pulses is externally modulated by the data stream. If the bit interval is T, the separation between successive pulses is also T. We must somehow devise a scheme to reduce the interval between successive pulses to τ , corresponding to the higher-rate multiplexed signal. This can done by passing the output of the external modulator through a series of compression stages. If the size An optical demultiplexer to extract one of the multiplexed channels from a bit-interleaved TDM stream (after [Mid93, Chapter 6]). of each packet is l bits, the output goes through k = _log2 l_ compression stages.

In the first compression stage, bits 1, 3, 5, 7, . . . are delayed by T − τ . In the second compression stage, the pairs of bits (1, 2), (5, 6), (9, 10), . . . are delayed by 2(T − τ). In the third compression stage, the bits (1, 2, 3, 4), (9, 10, 11, 12), . . . are delayed by 4(T − τ). The j th compression stage is shown in Figure 12.7(b). Each compression stage consists of a pair of 3 dB couplers, two semiconductor optical amplifiers (SOAs) used as on-off switches, and a delay line. The j th compression stage has a delay line of value 2j−1(T − τ). It is left as an exercise (Problem 12.1) to show that the delay encountered by pulse i, i = 1, 2, . . . , l, on passing through the kth compression stage is (2k −i)(T −τ). Combined with the fact that the input pulses are separated by time T , this implies that pulse i occurs at the output at time (2k − 1)(T − τ) + (i − 1)τ .

Thus the output pulses are separated by a time interval of τ . The demultiplexing operation is equivalent to “decompressing” the packet. In principle, this can be accomplished by passing the compressed packet through a set of decompression stages that are similar to the compression stage.. Again, the number of stages required would be k = log_l_, where l is the packet length in bits. However, the on-off switches required in this approach must have switching times on the order Figure 12.7 An optical multiplexer to create a packet-interleaved TDMstream. (a) The packet passes through k compression stages, where 2k is the smallest power of two that is not smaller than the packet length l in bits.

A more practical approach is to use a bank of AND gates and convert the single (serial) high-speed data stream into multiple (parallel) lower-speed data streams that can then be processed electronically. This approach is illustrated in Figure 12.8. In this figure, a bank of five AND gates is used to break up the incoming high-speed stream into five parallel streams each with five times the pulse spacing of the multiplexed stream. This procedure is identical to what would be used to receive five bit-interleaved data streams. One input to each AND gate is the incoming data stream, and the other input is a control pulse stream where the pulses are spaced five times apart. The control pulse streams to each AND gate are appropriately offset from each other so that they select different pulses. Thus the first parallel stream would contain bits 1, 6, 11, . . . of the packet, the second would contain bits 2, 7, 12, . . ., and so on. This approach can also be used to demultiplex a portion of the packet, for example, the packet header, in a photonic packet switch.

Optical AND Gates

The logical AND operations shown in Figures 12.6 and 12.8 are performed optically at very high speeds. A number of mechanisms have been devised for this purpose.We describe two of them here. Note that the logical AND operation between two signals can be performed by an on-off switch if one of the signals is input to the switch and the other is used to control it

Nonlinear Optical Loop Mirror

The nonlinear optical loop mirror (NOLM) consists of a 3 dB directional coupler, a fiber loop connecting both outputs of the coupler, and a nonlinear element (NLE) located asymmetrically in the fiber loop, as shown in Figure 12.9(a). First, ignore the nonlinear element, and assume that a signal (pulse) is present at one of the inputs, shown as arm A of the directional coupler in Figure 12.9(a). Then, the two output signals are equal and undergo exactly the same phase shift on traversing the fiber loop. (Note that here we are talking about the phase shift of the optical carrier and not pulse delays.) We have seen in Problem 3.1 that in this case both the clockwise and the counterclockwise signals from the loop are completely reflected onto input A; specifically, no output pulse emerges from arm B in Figure 12.9(a). Hence thename fiber loop mirror is given for this configuration. However, if one of the signals were to undergo a different phase shift compared to the other, then an output pulse emerges from arm B in Figure 12.9(a). It is left as an exercise to show that the difference in the phase shifts should be π in order for all the energy to emerge from arm B

In many early experiments with the NOLM for the purpose of switching, here was no separate NLE. Rather, the intensity-dependent phase (or refractive index) change induced by the silica fiber was itself used as the nonlinearity. This intensity-dependent refractive index change is described by (2.23) and is the basis for the cancellation of group velocity dispersion effects in the case of soliton pulses..

The principle of operation for TOAD is as follows. The TOAD has another directional coupler spliced into the fiber loop for the purpose of injecting the contro pulses. The control pulses carry sufficiently high power and energy so that the optical properties of the NLE are significantly altered by the control pulse for a short time interval after the control pulse passes through it. In particular, the phase shift undergone by another pulse passing through the NLE during this interval is altered.

An example of a suitable NLE for this purpose is a semiconductor optical amplifier (SOA) that is driven into saturation by the control pulse. For proper operation of the TOAD as a demultiplexer, the timing between the control and signal pulses is critical. Assuming the NLE is located such that the clockwise signal pulse reaches it first, the control pulse must pass through the NLE after the clockwise signal pulse but before the counterclockwise signal pulse. If this happens, the clockwise signal pulse experiences the unsaturated gain of the amplifier, whereas the counterclockwise pulse sees the saturated gain. The latter also experiences an additional phase shift that arises due to gain saturation. Because of this asymmetry, the two halves of the signal pulse do not completely destructively interfere with each other, and a part of the signal pulse emerges from arm B of the input coupler.

Note that along with the signal pulse, the control pulse will also be present at the output. The control pulse can be eliminated by using different wavelengths for the signal and control pulses and placing an optical filter at the output to select only the signal pulse. But both wavelengths must lie within the optical bandwidth of the SOA. Another option is to use orthogonal polarization states for the signal and control pulses, and discriminate between the pulses on this basis. Whether or not this is done, the polarization state of the signal pulse must be maintained while traversing the fiber loop; otherwise, the two halves of the pulse will not interfere at the directional coupler in the desired manner after traversing the fiber loop.

Another advantage of the TOAD is that because of the short length of the fiber loop, the polarization state of the pulses is maintained even if standard single-mode fiber (nonpolarization-maintaining) is used. If the fiber loop is long, it must be constructed using polarization-maintaining fiber.

Soliton-Trapping AND Gate

The soliton-trapping AND gate uses some properties of soliton pulses propagating in a birefringent fiber. In Chapter 2, we saw that in a normal fiber, the two orthogonally polarized degeneratemodes propagate with the same group velocity.We also saw that in a birefringent fiber, these two modes propagate with different group velocities. As a result, if two pulses at the same wavelength but with orthogonal polarizations are launched in a birefringent fiber, they will walk off, or spread apart in time, because of this difference in group velocities.

However, soliton pulses are an exception to this walk-off phenomenon. Just as soliton pulses propagate in nonbirefringent silica fiber without pulse spreading due Figure 12.11 Block diagram of a soliton-trapping logical AND gate. to group velocity dispersion (Section 2.6), a pair of orthogonally polarized soliton pulses propagate in birefringent fiber without walk-off. The quantitative analysis of this phenomenon is beyond the scope of this book, but qualitatively what occurs is that the two pulses undergo wavelength shifts in opposite directions so that the group velocity difference due to the wavelength shift exactly compensates the group velocity difference due to birefringence! Since the two soliton pulses travel together (they do not walk off), this phenomenon is called soliton trapping.

The logical AND operation between two pulse streams can be achieved using this phenomenon if the two pulse streams correspond to orthogonally polarized soliton pulses. Most high-speed TDM systems use soliton pulses to minimize the effects of group velocity dispersion so that the soliton pulse shape requirement is not a problem. The orthogonal polarization of the two pulse streams can be achieved by appropriately using polarizers (see Section 3.2.1). The logical AND operation is achieved by using an optical filter at the output of the birefringent fiber.

Itconsists of a piece of birefringent fiber followed by an optical filter. Figure 12.12 illustrates the operation of this gate. When pulses of both polarizations are present at the wavelength λ, one of them gets shifted in wavelength to $\lambda + \delta\lambda$, and the other to $\lambda - \delta\lambda$. The filter is chosen so that it passes the signal at $\lambda + \delta\lambda$ and rejects the signal at λ. Thus the passband of the filter is such that one of the wavelength-shifted pulses lies within it. But the same pulse, if it does not undergo a wavelength shift, will not be selected by the filter. Thus the filter output has a pulse (logical one) only if both pulses are present at the input, and no pulse (logical zero) otherwise.

4. Explain the synchronization techniques involved in broadcast optical network

Synchronization

Synchronization is the process of aligning two pulse streams in time. In PPS networks, it can refer either to the alignment of an incoming pulse streamand a locally available Figure 12.12 Illustration of the operation of a soliton-trapping logical AND gate. (a) Only one pulse is present, and very little energy passes through to the filter output. This state corresponds to a logical zero. (b) Both pulses are present, undergo wavelength shiftsdue to the soliton-trapping phenomenon, and most of the energy from one pulse passes through to the filter output. This state corresponds to a logical one. clock pulse stream or to the relative alignment of two incoming pulse streams.

Thus if framing pulses are used to mark the packet boundaries, the framing pulses must occur periodically. The function of a synchronizer can be understood from Figure 12.13. The two periodic pulse streams, with period T, shown in Figure 12.13(a) are not synchronized because the top stream is ahead in time by _T. In Figure 12.13(b), the two pulse streams are synchronized. Thus, to achieve synchronization, the top stream must be delayed by _T with respect to the bottom stream. The delays we have hitherto considered, for example, while studying optical multiplexers and demultiplexers, have Been fixed delays. A fixed delay can be achieved by using a fiber of the appropriate length. However, in the case of a synchronizer, and in some other applications in photonic packet-switching networks, a tunable delay element is required since the amount of delay that has to be introduced is not known a priori.

The function of a synchronizer. (a) The two periodic pulse streams with period T are out of synchronization; the top stream is ahead by _T. (b) The two periodic streams have been synchronized by introducing a delay _T in the top stream relative to the bottom stream.

Tunable Delays

A tunable optical delay line capable of realizing any delay, in excess of a reference delay, from 0 to T − T/2k−1, in steps of T/2k−1, is shown in Figure 12.14. The parameter k controls the resolution of the delay achievable. The delay line consists of k − 1 fixed delays with values T/2, T/4, . . . ,T/2k−1 interconnected by k 2 × 2 optical switches, as shown. By appropriately setting the switches in the cross or bar state, an input pulse stream can be made to encounter or avoid each of these fixed delays. If all the fixed delays are encountered, the total delay suffered by the input pulse stream is T/2 + T/4 + . . . + T/2k−1 = T − T/2k−1. This structure can be viewed as consisting of k − 1 stages followed by an output switch. The output switch is used to ensure that the output pulse stream always exits the same output of this switch. The derivation of the control inputs c1, c2, . . . , ck to the k switches.

Two pulse streams can be synchronized to within a time interval of T/2k. The value k, and thus the number of fixed delays and optical switches, must be chosen such that 2−kT τ ,
Figure 12.14 A tunable delay line capable of realizing any delay from 0 to T −T/2k−1,
in steps of T/2k−1..

Optical Phase Lock Loop

Consider an NOLM that does not use a separate nonlinear element but rather uses the intensity-dependent refractive index of silica fiber itself as the nonlinearity. Thus, if a low-power pulse stream, say, stream 1, is injected into the loop—from arm A of the directional coupler in Figure 12.9(a)—the fiber nonlinearity is not excited, and both the clockwise and the counterclockwise propagating pulses undergo the same phase shift in traversing the loop. As a consequence, no power emerges from the output (arm B) in this case. If a high-power pulse stream, say, stream 2, is injected in phase (no relative delay) with, say, the clockwise propagating pulse stream, because of the intensity dependence of the refractive index of silica fiber, the refractive index seen by the clockwise pulse, and hence the phase shift undergone by it, is different from that of the counterclockwise pulse.

This mismatch in the phase shift causes an output to emerge from arm B in Figure 12.9(a). Note that if the high-power pulse stream is not in phase (has a nonzero relative delay) with the clockwise propagating pulse stream, the clockwise and counterclockwise pulses undergo the same phase shift, and no output emerges from arm B of the directional coupler. To achieve synchronization between pulse streams 1 and 2, a tunable delay element can be used to adjust their relative delays till there is no output of stream 1 from the NOLM.

5. Discuss in detail the various OTDM test beds

Testbeds

Several PPS testbeds have been built over the years. The main focus of most of these testbeds is the demonstration of certain key PPS functions such as multiplexing and demultiplexing, routing/switching, header recognition, optical clock recovery (synchronization or bit-phase alignment), pulse generation, pulse compression, and pulse storage.We will discuss some of these testbeds in the remainder of this section. The key features of these testbeds are summarized in Table 12.2

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KEOPS

KEOPS (Keys to Optical Packet Switching) [Gam98, Gui98, RMGB97] was a significant project undertaken by a group of research laboratories and universities in Europe. Its predecessor was the ATMOS (ATM optical switching) project [Mas96, RMGB97]. KEOPS demonstrated several of the building blocks for PPS and put together two separate demonstrators illustrating different switch architectures.

The building blocks demonstrated include all-optical wavelength converters using cross-phase modulation in semiconductor optical amplifiers (see Section 3.8) up to 40 GHz, a packet sychronizer at 2.5 Gb/s using a tunable delay line, tunable lasers, and low-loss integrated indium phosphide Mach-Zehnder–type electro-optic switches.

The demonstrations of network functionality were performed at a data rate of 2.5 Gb/s and 10 Gb/s, with the packet header being transmitted at 622 Mb/s. The KEOPS switches used wavelengths internal to the switch as a key tool in performing the switching and buffering, instead of using large optical space switches. In this sense, the KEOPS demonstrators are variations of the architecture of Figure 12.20.

The first demonstrator, shown in Figure 12.24, used a two-stage switching approach with wavelength routing. Here, the first stage routes the input signal to the appropriate delay line by converting it to a suitable wavelength and passing it through a wavelength demultiplexer. The second stage routes the packet to the correct output, again by using a tunable wavelength converter and a combination of wavelength demultiplexers and multiplexers. Each input has access to at least one delay line in each set of delay lines. Since the delay line in turn has access to all the output ports, the switch may be viewed as implementing a form of shared output buffering. The switch controller (not shown in the figure) schedules the incoming packets

Each input packet is scheduled with the minimum possible delay, d, such that (1) no other packet is scheduled in the same time slot to the same output port, (2) no other packet is scheduled in the same time slot on any of the delay lines leading to the same second-stage TWC as the desired packet, and (3) in order to deliver packets in sequence of their arrival, no previouspacket from the same input is scheduled to the same output port with a delay largerthan d.

Another demonstrator used a broadcast-and-select approach as shown in Figure 12.25. Here packets arriving at different inputs are assigned different wavelengths. Each packet is then broadcast into an array of delay lines providing different delays. Each delay line can store multiple packets simultaneously at different wavelengths. Thus each input packet is made available at the output over several slots. Of these, one particular slot is selected using a combination of wavelength demultiplexers, optical switches, and wavelength multiplexers.

NTT's Optical Packet Switches

Researchers at NTT have demonstrated photonic packet switches using an approach somewhat similar to KEOPS [Yam98, HMY98]. Like the KEOPS switches, these switches also use wavelengths internal to the switch as a key element in performing the switching function. The FRONTIERNET switch [Yam98], shown in Figure 12.26, uses tunable wavelength converters in conjunction with an arrayed waveguide grating to perform the switching function, followed by delay line buffers. This is again an output-buffered switch, with two stages of selection. For each output, the first stage selects the time slot, and the second stage the desired wavelength within that time slot. In the experiment, the tunable converter assumes that the incoming data is electrical and uses a tunable laser and external modulator to provide a tunable optical input into an arrayed waveguide grating

A 16 × 16 switch operating at 2.5 Gb/s with optical delay line buffering was demonstrated. In separate experiments [HMY98], the switching was accomplished by broadcasting a wavelength-encoded signal to a shared array of delay lines and selecting the appropriate time slot at the output, again like the KEOPS approach. A 4 × 4 switch at a 10 Gb/s data rate was demonstrated. The key technologies demonstrated included tunable lasers and optical delay line buffering. Figure 12.25 The broadcast-and-select packet switch used in KEOPS. Figure 12.26 The FRONTIERNET architecture

BT Labs Testbeds

Researchers at British Telecom (BT) Laboratories demonstrated several aspects of PPS networks [CLM97] that we discussed in this chapter. Multiplexing and demultiplexing of high-speed signals in the optical domains were demonstrated in a prototype broadcast local-area network based on a bus topology called Synchrolan [LGM+97, Gun97b]. Bit interleaving was used with each of the multiplexed channels operating at a bit rate of 2.5 Gb/s.

The aggregate bit rate transmitted on the bus was 40 Gb/s. The clock signal (akin to a framing pulse) was distributed along with the bit-interleaved data channels. The availability of the clock signal meant that there was no need for optical clock recovery techniques. A separate time slot was not used for the clock signal, but rather it was transmitted with a polarization orthogonal to that of the data signals. This enabled the clock signal to be separated easily from the data. In a more recent demonstration [Gun97a], the data and clock signals were transmitted over two separate standard single-mode (nonpolarization-preserving) fibers, avoiding the need for expensive polarization-maintaining components.

A PPS node was also demonstrated separately at BT Labs [Cot95]. The optical header from an incoming packet was compared with the header—local address— corresponding to the PPS node, using an optical AND gate (but of a different type than the ones we discussed). The rest of the packet was stored in a fiber delay line while the comparison was performed. The output of the AND gate was used to set a 1 × 2 switch so that the packet was delivered to one of two outputs based on a match, or lack of it, between the incoming packet header and the local address.

Princeton University Testbed

This testbed was developed in the Lightwave Communications Laboratory at Princeton University, funded by DARPA [Tol98, SBP96]. The goal was to demonstrate a single routing node in a network operating at a transmission rate of 100 Gb/s. Packet interleaving was used, and packets from electronic sources at 100 Mb/s were optically compressed to the 100 Gb/s rate using the techniques

The limitations of the semiconductor optical amplifiers used in the packetcompression process (Figure 12.7) require a 0.5 ns (50 bits at 100 Gb/s) guard band between successive packets. Optical demultiplexing of the compressed packet header was accomplished by a bank of AND gates, as described in Section 12.1. The TOAD architecture described in Section 12.1.3 was used for the AND gates. The number of TOADs to be used is equal to the length of the packet header. Thus the optically encoded serial packet header was converted to a parallel, electronic header by a bank of TOADs. The helical LAN topology proposed to be used in the AONTDMtestbed.

AON

This testbed was developed by the All-Optical Network (AON) consortium consisting of AT&T Bell Laboratories, Digital Equipment Corporation, and the Massachusetts Institute of Technology [Bar96]. The aim was to develop an optical TDM LAN/MAN operating at an aggregate rate of 100 Gb/s using packet interleaving. Different classes of service, specifically guaranteed bandwidth service and bandwidth-on-demand service, were proposed to be supported. The topology used is shown in Figure 12.27. This is essentially a bus topology where users transmit in the top half of the bus and receive from the bottom half. One difference, however, is that each user is attached for transmission to two points on the bus such that the guaranteed bandwidth transmissions are always upstream from the bandwidthon- demand transmissions.

Thus the topology can be viewed as having the helical shape shown in Figure 12.27—hence the name helical LAN (HLAN) for this network. Experiments demonstrating an optical phase lock loop were carried out. In these experiments, the frequency and phase of a 10 Gb/s electrically controlled modelocked laser were locked to those of an incoming 40 Gb/s stream. (Every fourth pulse in the 40 Gb/s stream coincides with a pulse from the 10 Gb/s stream.) Other demonstrated technologies include short pulse generation, pulse compression, pulse storage, and wavelength conversion.

CORD

The Contention Resolution by Delay Lines (CORD) testbed was developed by a consortium consisting of the University ofMassachusetts, Stanford University, and GTE Laboratories [Chl96]. A block diagram of the testbed is shown in Figure 12.28. The testbed consisted of two nodes transmitting ATM-sized packets (ATM has packets Figure 12.28 A block diagram of the CORD testbed. with size 53 bytes) at 2.488 Gb/s using different transmit wavelengths (1310 nm and 1320 nm). A 3 dB coupler broadcasts all the packets to both the nodes.

Each node generates packets destined to both itself and the other node. This gives rise to contentions at both the receivers. The headers of the packets from each node werecarried on distinct subcarrier frequencies (3 GHz and 3.5 GHz) located outside the data bandwidth (≈ 2.5 GHz). The subcarrier headers were received by tapping off a small portion of the power (10%) from the incoming signal. Time was divided into slots, with the slot size being equal to 250 ns. Since an ATM packet is only 424/2.488 ≈ 170 ns long, there was a fair amount of guard band in each slot. Slot synchronization between nodes was accomplished by having nodes adjust their clocks based on their propagation delay to the hub.

However, a separate synchronizer node was not used, and one of the nodes itself acted as the synchronizer (called “master” in CORD) node. The data rate on the subcarrier channels was chosen to be 80 Mb/s so that a 20-bit header can be transmitted in the 250 ns slot. In one of the nodes, a feed-forward delay line architecture similar to that shown in was used with aWDMdemux andmux surrounding it, so that signals at the two wavelengths could undergo different delays. Thus this node had greater opportunities to resolve contentions among packets destined to it. This is the origin of the name contention resolution by delay lines for this testbed. The current testbed is built using discrete components, including lithium niobate switches, semiconductor optical amplifiers (for loss compensation), and polarization-maintaining fiber for the delay lines. An integrated version of the contention resolution optics (CRO), which would integrate the three 2 × 2 switches and semiconductor amplifiers on a single InP substrate, is under development

6. Explain in detail about Switch based networks

Switching

In this chapter, we study optical networks that are capable of providing packetswitched service at the optical layer. We call these networks photonic packetswitched (PPS) networks. Packet-switched services are provided today using electronic switches by many networks, such as IP and Ethernet networks. Here, weare interested in networks where the packet-switching functions are performed optically.

The goal of PPS networks is to provide the same services that electronic packet-switched networks provide, but at much higher speeds. The optical networks that we have studied so far provide circuit-switched services. These networks provide lightpaths, which can be established and taken down as needed. In these networks, the optical nodes do not switch signals on a packetby- packet basis, but rather only switch at the time a circuit is established or taken down. Packet switching is done in the electronic domain by other equipment such as IP routers or Ethernet switches. These routers and switches make use of lightpaths provided by the optical layer to establish links between themselves as needed. In addition to switching packets, routers and switches make use of sophisticated software and hardware to perform the control functions needed in a packet-switched network.

In this chapter, we will see that all the building blocks needed for optical packet switching are in a fairly rudimentary state today and exist only in research laboratories. They are either difficult to realize, very bulky, or very expensive, even after a decade of research in this area. Moreover, it is likely that we will need electronics to perform the intelligent control functions for the foreseeable future. Optics can be used to switch the data through, but it does not yet have the computing capabilities to perform many of the control functions required, such as processing the packet header, determining the route for the packet, prioritizing packets based on class of service, maintaining topology information, and so on. However, there are a few motivations for researching optical packet switching. One is that optical packet switches hold the potential for realizing higher capacities than electronic routers (although this potential is yet to be demonstrated!). For instance, the capacity of the best routers today is less than 100 Tb/s, with the highestspeed interfaces being at 40 Gb/s. In contrast, optical switches are, for the most part, bit rate independent, so they can be used to switch tens to hundreds of Tb/s of traffic.

Another motivation for studying optical packet switching is that it can improve the bandwidth utilization within the optical layer. The notion is that high-speed optical links between routers are still underutilized due to the bursty nature of traffic, and using an underlying optical packet layer instead of an optical circuit layer will help improve link utilizations. The question is whether having another high-speed packet-switched layer under an already existing packet-switched layer (say, IP) will provide sufficient improvement in statistical link utilization. The answer depends on the statistical properties of the traffic. The conventional wisdom is that because many lower-speed bursty traffic streams are multiplexed through many layers, the burstiness of the aggregate stream is lower than that of the individual streams. In this case, having an optical packet layer under an electrical packet layer may not help much because the traffic entering the optical layer is already smoothed out. However, it has been shown recently that with some types of bursty traffic, notably the so-called self-similar traffic, the burstiness of a multiplexed stream is not less than that of its constituent individual streams [PF95, ENW96]. For such traffic, using an optical packet layer provides the potential to improve the link Utilization. Figure 12.1 shows a generic example of a store-and-forward packet-switched network. In this network, the nodes A–F are the switching/routing nodes; the end nodes 1–6 are the sources and sinks of packet data.

We will assume that all packets are of fixed length. Packets sent by an end node will, in general, traverse multiple links and hence multiple routing nodes, before they reach their destination end node. For example, if node 1 has to send a packet to node 6, there are several possible routes that it can take, all consisting of multiple links and routing nodes.

If the route chosen for this packet is 1–A–B–D–F–6, this packet traverses the links 1–A, A–B, B–D, D–F, and F–6. The routing nodes traversed are A, B, D, and F. Note that the route chosen may be specified by the packet itself, or the packet may simply specify only the destination node and leave the choice of route to the routing nodes in its path. In the remainder of the discussion, we will assume that the route is chosen by the routing nodes based on the packet destination that is carried in the packet header..