MODULE 6

CHAPTER 6

Network Design and Management

Syllabus

6.1 Transmission system model, power penalty, transmitter, receiver, optical amplifiers, crosstalk.

6.2 Network management functions, configuration management, performance management, fault management, optical safety, and service interface.

6.3 Introduction to free space optics and its challenges.

6.1 TRANSMISSION SYSTEM MODEL

A typical transmission system model is shown in Fig. 6.1.1.

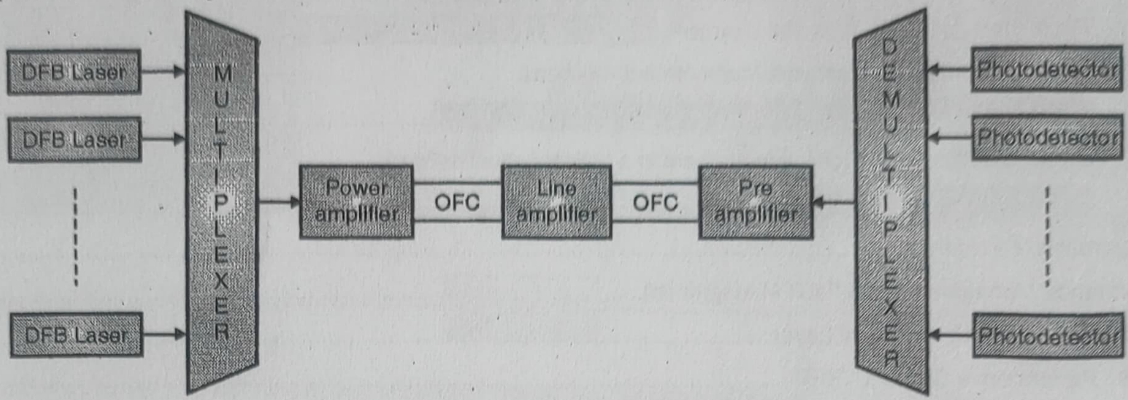

Fig. 6.1.1 Typical Transmission System Model

- Fig. 6.1.1 shows the block diagram of unidirectional wavelength division multiplexing using Optical Fiber Cable (OFC).
- Depending on the applications; there can be 'n' number of optical transmitter. Usually DFB laser is used as a transmitter. Each laser transmits the different wavelength of light.
- Multiplexer is used to combine all these wavelengths and then all these signals are transmitted using single optical fiber cable.
- To, increase the transmission power; power amplifier is used. The power amplifier boosts the power of multiplexed signal.
- When the signals are transmitting through optical cable; attenuation takes place. To compensate it; many time in-line optical amplifiers are used.
- To avoid the dispersion effect; at the output of each amplifier dispersion compensating module may be used. The use of dispersion compensating module depends on various factors like Bit Error Rate (BER), transmission distance and the type of fiber used.
- Usually the requirement of BER is 10^{-12}; it also depends on the amount of noise.

6.2 POWER PENALTY

> **UQ.** Derive the expression of power penalty with impairment and without impairment.
>
> **MU - Q. 3(c), Dec. 16, 7 Marks, Q. 5(b), Dec. 17, 10 Marks**

- In case of optical communication; in between transmitter and receiver; there can be power loss due to nonlinearities in fiber, dispersion etc.
- So each of such impairment causes power penalty to the system.
- Due to the power losses taking place at such impairments; some extra power is required to be transmitted. It is called as a power penalty.
- Power penalty also indicates reduction in signal to noise ratio due to the power loss taking place across such elements placed between transmitter and receiver.
- Consider a digital data transmission through optical cable.

  Let P_1 = Optical power received when bit '1' is transmitted.

  P_0 = Optical power received when bit '0' is transmitted.
- Let us denote the noise standard distributions by σ_1 and σ_0 corresponding to bit '1' and bit '0' respectively.
- If the probability of occurance of '1' and '0' is same then, Bit Error Rate (BER) is given by,

$$\text{BER} = Q\left(\frac{R\,(P_1 - P_0)}{\sigma_1 + \sigma_0}\right) \qquad \ldots(6.2.1)$$

  Here $Q(-)$ is the Q function

  R = Responsivity of photodetector
- In the presence of impairments, let the quantities are denoted by P_1', P_0', σ_1' and σ_0'. Then the Power Penalty (PP) is given by,

$$PP = -10\log\left[\frac{\dfrac{R(P_1'-P_0')}{\sigma_1'+\sigma_0'}}{\dfrac{R(P_1-P_0)}{\sigma_1+\sigma_0}}\right] \quad ...(6.2.2)$$

- Consider the receiver is a PIN photodiode in which the noise is independent of signal power. Then,

$$\sigma_1 = \sigma_0 = \sigma_1' = \sigma_0'$$

- The corresponding power penalty is signal independent (PP_{SI}) and it is given by,

$$PP_{SI} = -10\log\left(\frac{P_1'-P_0'}{P_1-P_0}\right) \quad ...(6.2.3)$$

- If the receiver is APD then the shot noise is dominant noise component. It is amplified by the gain of APD.
- In this case $P_1 >> P_0$ and the power penalty is dependent on noise. It is denoted by PP_{SD} and is given by,

$$PP_{SD} = -5\log\left(\frac{P_1'}{P_1}\right) \quad ...(6.2.4)$$

- The power penalty is also dependent on the polarization. The polarization changes with respect to time; so the power penalty also changes with respect to time.

6.3 TRANSMITTER

- Depending on the type of application; amount of transmitter power is decided.
- If DFB laser source is used as a transmitter then its output is varying from 1 mW to 10 mW; that means from 0 dBm to 10 dBm.
- Many times, it is required to use power amplifier, to amplify the output of transmitter. The transmitted power may be increased upto 17 dBm.
- An important parameter, while selecting a transmitter is an extinction ratio. It is the ratio of power transmitted for bit '1' to the power transmitted for bit '0'.
- These powers are denoted by P_1 and P_0 respectively. The extinction ratio is denoted by γ and $\gamma = \frac{P_1}{P_0}$
- Typical extinction ratios for transmitter are 10 to 20.
- Let us denote the average transmitted power by P; then P_0 and P_1 can be expressed in terms of extinction ratios as,

$$P_0 = \frac{2P}{\gamma+1} \quad ...(6.3.1)$$

and $$P_1 = \frac{2\gamma P}{\gamma+1} \quad ...(6.3.2)$$

- Since, the extinction ratio is the ratio of power transmitted for '1' bit to power transmitted for '0' bit; if we reduce the extinction ratio then the difference between '1' and '0' levels gets reduced. So it produces the penalty.
- The power penalty for signal independent noise is expressed in terms of non-ideal extinction ratio as,

$$PP_{SI} = -10\log\frac{\gamma-1}{\gamma+1} \quad ...(6.3.3)$$

- This power penalty indicates the decrease in value of signal to noise ratio.
- The non-linear effects also produces the limit on peak transmitted power from the laser source.
- When optical system is limited by signal dependent noise then the power penalty is high.
- An example of signal dependent noise is laser relative intensity noise. This type of noise represents the fluctuations in laser beam due to reflections from splices and connected used in optical system.
- When the direct modulation is applied for laser beam then the spectrum will be broad and this will increase the power penalty.
- Wavelength division multiplexing and demultiplexing also increases the power penalty.
- The increase in power penalty, due to all such effects can be reduced by reducing the extinction ratio.

6.4 RECEIVER

- The selection of receiver, for a particular application depends on sensitivity and overload parameters. The average optical power required to obtain a particular value of bit error rate is called as sensitivity and typical value of BER is 10^{-6}.
- The maximum value of input power, that can be handled by receiver is called as overload.
- If the requirement of bit rate is high then APD receivers are preferred because they have more sensitivity then PIN receivers.
- But if a preamplifier is used along a PINFET receiver then its sensitivity is comparable with APD receivers.
- The overload parameter represents the dynamic range of receiver and it can be as high as 0 dBm.

6.5 OPTICAL AMPLIFIERS

UQ. What is optical amplifier ? Explain in brief its different types. **MU – Q. 3(b), May 19, 10 Marks**

- In between transmitter and receiver; to boost the power of signal, different amplifiers are required as shown in Fig. 6.5.1.

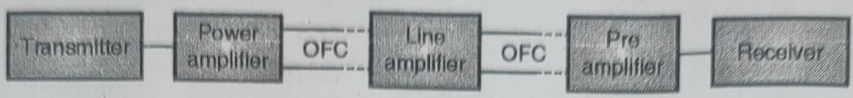

Fig. 6.5.1

- Depending upon the distance between transmitter and receiver, losses takes place in the system etc; it is required to boost the power of transmitter.
- The **power amplifiers** are required to increase the transmitted power. These amplifiers should have maximum output power.
- When the signal is passing through optical cable; different losses are taking place inside the cable. To compensate these losses, **line amplifiers** are used.
- **Line amplifiers** are high gain and it produces the maximum possible output power.
- In order to increase the sensitivity; preamplifiers are used before the optical receiver. It is designed to have maximum gain and it introduces minimum noise in the signal.
- The **Erbium Dopped Fiber Amplifier (EDFA)** is most commonly used optical amplifier in majority application.
- EDFA amplifiers can amplify many WDM channels simultaneously. But for longer distance communication, Raman amplifiers are connected in cascade with EDFA.
- Some of the major limitations of optical amplifiers are as follows

  (i) During amplification process, noise is introduced in the signal.

  (ii) The gain of amplifier is directly proportional to input power. For high input powers, the amplifier tends to saturate and the gain of amplifier is reduced. It produces the transients in optical signals.

  (iii) In case of EDFA; a constant gain is not provided to all channels. Some of the channels get less gain compared to others.

6.6 CROSSTALK

UQ. Define crosstalk. What are the types of crosstalk in optical transmission system? **MU – Q. 1(e), Dec. 16, 5 Marks**

UQ. Write short note on : Crosstalk. **MU – Q. 6(a), May 17, 10 Marks, Q. 5(a), Dec. 17, 5 Marks**

UQ. Write short notes on : Crosstalk in optical system. **MU – Q. 6(c), Dec. 18, 10 Marks, Q. 6(c), May 19, 5 Marks**

- The effect of undesired signals on the desired signal is called as crosstalk.
- The non-linearities inside the fiber produces crosstalk. Similarly the system components like multiplexers, demultiplexers, optical switches, optical amplifiers etc., also produces the cross talk.
- The two major types of crosstalk are as follows :

1. Intrachannel cross talk
2. Interchannel crosstalk

1. Intrachannel crosstalk

- It is also called as coherent crosstalk. In this case the wavelength of crosstalk signal and desired signal are close to each other.
- The difference between wavelength of crosstalk signal and the desired signal lies in the electrical bandwidth of receiver.
- The following two are major sources of intrachannel crosstalk :

(i) Consider the application in which demultiplexer and multiplexer are connected in cascade.

- The function of demux is to separate out different wavelengths $\lambda_1, \lambda_2 \ldots \lambda_n$. During separation, it may happen that the portion of wavelength λ_1 gets mixed with λ_2.

- Now when all such wavelengths are multiplexed; the extra portion of λ_1, which was leaked into λ_2 gets added at the end.
- Original wavelength λ_1 is also existing and the extra portion of λ_1 will also exist. It represents intrachannel crosstalk.

(ii) In case of optical switch; the two ports are not ideally isolated from each other.

- Always there is some leakage of data from one port to other. It represents the crosstalk.
- The intrachannel crosstalk is maximum under the following conditions :
  (a) If the State Of Polarization (SOP) of crosstalk signal is same as the SOP of desired signal.
  (b) If the desired signal and crosstalk signals are out off phase.

2. Interchannel crosstalk

- As the name indicates, it is a crosstalk taking place due to mixing of data between two channels.
- In case of WDM system, a filter is used to receive the data from desired channel and to reject the data from remaining channels.
- Here the data from two adjacent channels gets mixed and it represents interchannel crosstalk.
- Similarly, in case of demultiplexer, one particular channel should be selected at a time.
- But the demultiplexer does not perfectly rejects other channels, so mixing of data between two channel takes place.

6.6.1 Other Sources of Crosstalk

- In case of optical network, there are many nodes, and optical signal propagates through various nodes. The network contains demux and optical switches, which are the major source of crosstalk.
- At each node, accumulation of crosstalk takes place due to all sources; connected to that node.
- Consider the case of bidirectional communication between A and B. It may happen that, there will be back reflection of signal transmitted from A.
- This back reflected signal enters into A and it creates a crosstalk.
- Consider an example of WDM MUX / DEMUX as shown in Fig. 6.6.1.

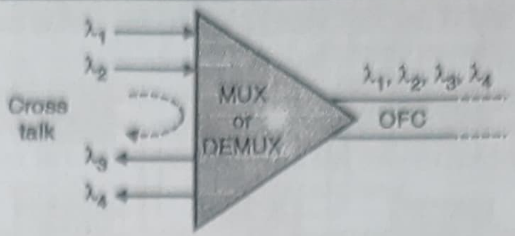

Fig. 6.6.1

- As shown in Fig. 6.6.1, the transmitted wavelength λ_2 enters into the port which is designed to receive the wavelength λ_3. It creates a crosstalk.
- If optical circulator is used in the network then cross talk takes place because of imperfect isolation.

6.6.2 Crosstalk Reduction

To reduce the crosstalk, usually two methods are used :

1. Spatial dialiation
2. Wavelength dialiation

1. Spatial dialiation

- Consider an example of 2 × 2 optical switch as shown in Fig. 6.6.2(a). Here the crosstalk is $\in$.
- Now, dialiation means addition of extra ports to the switch as shown in Fig. 6.6.2(b). Here some unused extra ports are added and the crosstalk is reduced to $\in 2$. But the drawback of this method is, it is required to increase the number of switches.

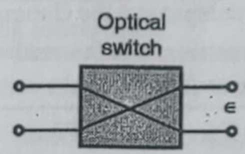

Fig. 6.6.2(a)

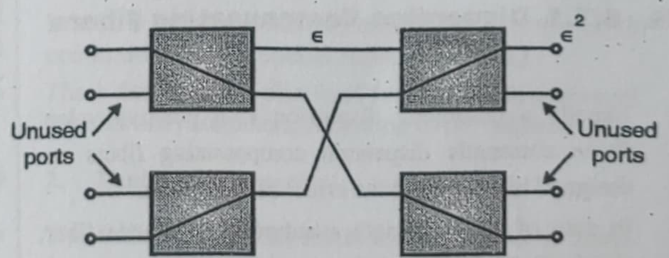

Fig. 6.6.2(b)

2. Wavelength dialiation

- This method is used when single switch is used for multiple wavelengths.

- Instead of one switch; two switches are used to reduce interchannel crosstalk.

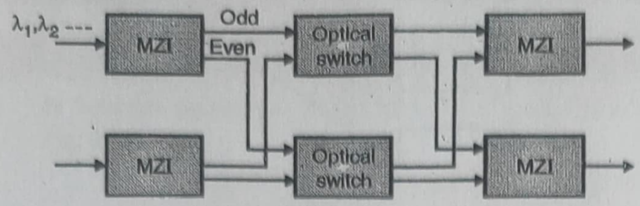

Fig. 6.6.2(c)

- One switch handles odd numbered channels and another handles even numbered channel.
- The Mach-Zehnder Interferrometer (MZI) is used to separate the channels into two groups and again to combine them as shown in Fig. 6.6.2(c).

6.7 DISPERSION

- Inside the optical cable, the different light pulses travel with different velocities. So, all these pulses do not appear at the same time, at the receiver. It causes the stretching of pulse, called as dispersion.
- The dispersion causes intersymbol interference and it leads to the power penalties.
- The major types of dispersion are intramodal, intermodal and polarization mode dispersion.
- We have already studied the dispersion in earlier chapters. The major source of dispersion is a chromatic dispersion. In this section, we will discuss the different methods used to compensate the chromatic dispersion.
- The two common methods used for dispersion compensation are as follows :

(i) Dispersion Compensating Fibers.
(ii) Chirped Fiber Bragg Gratings.

6.7.1 Dispersion Compensating Fibers (DCF)

- Usually a chromatic dispersion is a positive value. Some chromatic dispersion compensating fibers are designed to cancel out the effect of dispersion.
- In case of 80 km length standard single mode fiber, chromatic dispersion, at the rate

  17 ps/nm-km is $17 \times 80 = 1360$ ps/nm.
- DCF are designed in such a way that, it provides a dispersion of – 1360 ps/nm. So, the effect of dispersion is nullified.
- At the location of each amplifier; such Dispersion Compensating Fibers (DCFs) are introduced to provide negative dispersion.
- The major drawback of this method is the loss taking place in DCFs. It is around 9 dB.
- For the evaluation of DCF, the term Figure Of Merit (FOM) is used.
- It is the ratio of absolute amount of chromatic dispersion per unit wavelength to the loss taking place in DCF.
- DCF is basically useful to compensate over a wide range of wavelengths.

6.7.2 Chirped Fiber Bragg Gratings

- The fiber grating is linearly chirped, that means the period of fiber grating changes linearly with the change in position.
- This property of fiber grating causes reflection of different wavelengths at different points along the length of cable.
- That means the fiber grating is used to provide different delay at different frequencies.
- Basically, due to chromatic dispersion, large delay is introduced for lower frequency components of optical pulse and smaller delay for higher frequency components.
- The fiber gratings are designed to introduce the opposite effect, that means to provide small delay for lower frequency components and larger delay for smaller frequency components. Thus, the compensation of chromatic dispersion takes place.
- The chirped fiber bragg grating is suitable for the compensation of individual wavelength instead of a range of wavelengths.

6.8 WAVELENGTH STABILIZATION

UQ. Write a short note on : Wavelength stabilization.
MU – Q. 6(d), Dec. 17, Q. 6(b), Dec. 18, 10 Marks, Q. 6(b), May 19, 5 Marks

UQ. Comment on need of wavelength stabilization.
MU – Q. 4(c), Dec. 16, 4 Marks

- The wavelengths of signal should be kept constant throughout the data transmitting using optical cable. In case of laser source or multiplexer and demultiplexer used in WDM; a change in wavelength takes place if the operating temperature is changed.

- Typical value of temperature coefficient for MUX or DEMUX is 0.01 nm/°C and for DFB laser it is 0.1 nm/°C. To avoid the change in wavelength with respect to temperature; DFB lasers are packed with thermistor and thermoelectric (TE) cooler.
- The measurement of thermistor resistance gives an idea of operating temperature of DFB laser. When it is increased then a drive current of TE cooler is increased and the temperature is maintained.
- But the wavelength of laser also changes due to aging effect. In this case, an external feedback loop is used to stabilize the laser wavelength.
- A small amount of laser output is tapped off and send it to some optical cable. Basically optical cable is wavelength discriminating device. It is called as wavelength locker.
- Output of wavelength locker is monitored and accordingly the laser wavelength can be calculated. Then by adjusting the laser temperature; output wavelength of laser beam can be adjusted.
- Depending on the temperature range needed (typically −10 to 60°C for equipment in telco centraloffices), it may be necessary to temperature-control the multiplexer/demultiplexer as well.
- One problem with temperature control is that it reduces the reliability of the overall component because the TE cooler is often the least reliable component. An additional factor to be considered is the dependence of laser wavelength on its drive current, typically between 100 MHz/mA and 1 GHz/mA.
- In case of multiplexer or demultiplexer also; similar type of TE cooler system is used to stabilize the wavelength. Due to the variation in drive current applied to laser; wavelength of laser source gets changed.
- Basically DFB is operated in two modes, namely constant current mode and constant power mode.
- In **constant current mode**; the laser drive current is kept constant. So there is no change in wavelength. But due to aging output power of laser starts decreasing. So to maintain the same output power, it is required to increase the drive current.
- Similarly in **constant power mode**; the power of laser is maintained constant. But due to aging power is reduced. To maintain it; again the current of laser is increased.
- Thus in both cases, due to change in drive current, there is a small variation in operating wavelength.
- With typical channel spacing's of 100 GHz or thereabouts, this is not a problem, but with tighter channel spacing's, it may be desirable to operate the laser in constant current mode and tolerate the penalty (if any) due to the reduced output power.

6.9 NETWORK MANAGEMENT FUNCTIONS

UQ. Explain important network management functions to the operation of the network.
MU – Q. 5(a), Dec. 16, 8 Marks, Q. 5(b), May 18, 10 Marks

UQ. Write short note on : Fault Management.
MU – Q. 6(d), May 17, 10 Marks

UQ. Write short notes on : Network Management functions.
MU – Q. 6(d), Dec. 18, 10 Marks, Q. 6(d), May 19, 5 Marks

UQ. Give the details of network management in a typical optical network.
MU – Q. 3(a), May 16, 10 Marks

The different network management functions are as follows :

1. Performance management
2. Fault management
3. Configuration management
4. Security management
5. Accounting management.

1. Performance management

- As the name indicates, performance management functions are related to improving the performance of network system.
- It is used to monitor the performance parameters of all connections used in optical network.
- These functions are also used to take certain actions of the network parameters, according to the requirements.

2. Fault management

- The fault management functions are related to search for the failure in network and then to generate indication of failure.
- For example, if the incoming light power from source is below the threshold level then these function generates, the corresponding alarm.
- Similarly, if there is failure in any component of optical network then fault management functions give

indication of this failure and then the particular component is isolated.

- During such failures; the optical traffic is routed through another path.

3. Configuration management

- These functions are related to managing of equipments used in optical networks, managing various optical connection in the network and managing adaption of client signals.
- These functions are used to remove or add network equipment in the network.
- For making new connections in the network or removing some connections; again these functions are used.
- When external client enters any signal then to convert it into the signal which is compatible for optical network; adaption configuration management functions are used.

4. Security management

- As the name indicates; security management functions are related to the security of optical network system.
- These functions are related to authentication of user and giving access permission to authenticated users.
- These functions are also related to giving protection to the data, so that any unauthorised user should not attack the data.
- For the data protection, encryption process is used at the transmitter and decryption process is used at the receiver.

5. Accounting management

- These management functions are related to billing information.
- Using these function the history of network components is recorded.

6.10 CONFIGURATION MANAGEMENT

A configuration management function has three parts :

1. Managing the equipment in the network (Equipment Management),
2. Managing the connections in the network (Connection Management), and
3. Managing the adaptation of client signals into the optical layer (Adaptation Mangement).

1. Equipment Management

(i) In general, the principles of managing optical networking equipment are no different from those of managing other high-speed networking equipment.

(ii) It must be able to keep track of the actual equipment in the system (for example, number and location of optical line amplifiers) as well as the equipment in each network element and its capabilities.

(iii) For example, in a terminal of a point-to-point WDM system, we may want to keep track of the maximum number of wavelengths and the number of wavelengths currently equipped, whether or not there are optical pre- and power amplifiers, and so forth.

(iv) Among the considerations in designing network equipment is that it should be able to add to existing equipment in a modular fashion.

(v) For instance, we should be able to add additional wavelengths (up to a designed maximum number) without disrupting the operation of the existing wavelengths.

(vi) Also, ideally the failure of one channel should not affect other channels, and the failed channel should be capable of being serviced without affecting the other channels.

(vii) Using arrayed components can reduce the cost and footprint of the equipment. However, if one element in the array fails, the entire array will have to be replaced.

(viii) But using arrayed components in the system has following disadvantages :

  (i) If a single component in an array is failed then we will have to replace an entire array.

  (ii) If entire array is replaced then the functioning of many channels gets affected.

  (iii) Replacement of array increases the replacement cost of entire module.

(ix) This reduces the system availability, as replacing the array will involve disrupting the operation of multiple channels, and not just a single channel. Using arrays also increases the replacement cost of the module.

(x) Therefore, there is always a trade-off between obtaining reduced cost and footprint on one front against system availability and replacement cost on the other front.

2. Connection Management

(i) In optical networks provides light paths, circuit switched connection to its user.

(ii) Connection management deals with setting up connections, keeping track of them, and taking them down when they are not needed anymore.

(iii) The process usually involves configuring. Equipment from a variety of vendors each with its own management system, and usually one network element at a time.

(iv) Service providers in many cases deploy equipment only when needed.

(v) The net result of this process is that it can take months for a service provider to turn up a new connection in response to a user request.

(vi) Supporting all this requires carriers to predeploy equipment and bandwidth ahead of rime in the network and having methods in place to be able to turn on the service rapidly when needed.

(vii) But in optical networks the dynamic connections are used. All required connections can be made within few seconds.

(viii) Each node in the network contains all the database of network topology. It contains the data of available resources as well as the data of resources used to support the traffic.

(ix) If there are any changes in the network then the database of each node in the network should be updated.

(x) For this purpose the topology management protocol such as OSPF or IS-IS is used.

(xi) Similar to topology management functions; the link management functions are also required.

(xii) In optical network; it is necessary to periodically check the status of optical links.

(xiii) The status of optical links can be checked by measuring the amount of packet losses in the link or by measuring Bit Error Rate (BER).

(xiv) If any link is operating below the threshold level; then also it is considered as link failure.

(xv) **Distributed Control:** Distributed control protocols have been used IP/MPLS and Ethernet networks. Theses protocol can be used to control and manage optical networks.

(xvi) GMPLS protocol support optical connections. The Automatic Switched Transport Network (ASTN) is an architecture for managing connections including optical connections.

Distributed connection control has several components

Topology Management

(i) Each node in the network maintains a database of the network topology and the current set of resources available, as well as the resources used to support traffic.

(ii) In the event of any changes in the network, the updated topology information needs to be propagated to all the network nodes.

(iii) Nodes periodically, or in the event of changes, flood the updated information to all the network nodes. We can use an Internet routing and topology management protocol such as OSPF or IS-IS, with suitable modifications to represent optical layer topology information, and update it automatically.

Link management

(i) The performance of the link can be monitored by keeping statistics on packet losses and bit error rate. If the performance grades below an acceptable threshold, a failure indication signal can be sent to the other end of the link.

(ii) A failure indication signal can also he sent when the performance is degrading to indicate imminent failure. Then an early warning can allow a switch to an alternate link before the link fails.

(iii) Networks may also allow link bundling, where multiple parallel channels between two nodes Operate as a single logical link.

(iv) This will reduce the amount of overhead in the routing protocol and keep track of the network topology.

Route computation

(i) When a connection is requested from the network, the network needs to find a route and obtain resources along the route to support this connection. This can be done by applying a routing algorithm on the topology database of the network.

(ii) The routing algorithm should take into account the various constraints imposed by the network, such as wavelength conversion ability and the available on each link of the network.

Signaling protocol

(i) Once routes are computed, the connection need to be set up.

(ii) This process involves reserving the resources required for the connection and setting the actual switches inside the network to set up the connection.

(iii) The process requires nodes to exchange messages with other nodes.

Signaling Network

(i) Nodes need a signaling channel to exchange control information with other nodes.

3. Adaptation Management

- Adaptation management is the function of taking the client signals and covering them to a form that can be used inside the optical layer. This function includes the following :

(i) Covering the signal to the appropriate wavelength, optical power level, and other optical parameters associated with the optical layer. The WDM is received and converted into standardized signal, such as a short-reach SONET signal.

(ii) Adding and removing appropriate overheads to enable signal to be managed inside the optical layer.

(iii) Policing the client signal to make sure that the client signal stays within boundaries that have been agreed upon as part of the service agreement.

(iv) The WDM network must support different types of interfaces to accommodate a variety of different users requiring different functions.

- **Compliant wavelength interface** : One interface might be to allow the client to send in light at a wavelength that is supported in the network. These wavelengths may be regarded as compliant wavelengths. In this case, the interface might be a purely optical interface, with no optoelectronic conversions required
- **Noncompliant wavelength interface** : This is the most common interface and has variety of different types of attached client equipment that use optical transmitter and/or receiver not compatible with the signals used inside the WDM network.
- **Substrate multiplexing** : Additional adaptation functions include time division multiplexing of lower-speed streams into a higher-speed stream within the WDM equipment prior to transmission.

6.11 PERFORMANCE MANAGEMENT AND FAULT MANAGEMENT

- The performance management functions are used to monitor the performance of entire optical network. These functions are used to check the performance of each connection in the network, periodically.
- If the performance is below the threshold level then some corrective actions are taken. The fault management is closely related to the performance management.
- These functions give indication of the failure of any equipment in the network or failure of any connection.
- In case of such failures; new connections are established.

6.11.1 Transparency of Optical Layer

- The management of light paths in optical network depends on the transparency of optical layer.
- The transparency depends on various factors like Bit Error Rate (BER), signalling rate, different protocols etc.
- The lightpath is optical network can carry analog or digital information. It is difficult to manage the transparency of optical layers because there is no prior idea of BER or type of signal used in optical network.
- For this management, the different protocol formats such as SONET/SDH, OTN etc. are used.

6.11.2 Performance Based on BER

- The performance of optical network can be monitored by measuring Bit Error Rate (BER).
- There are two methods of measuring BER namely **direct method and indirect method**. For direct measurement of BER; the signal must be in electrical domain. The framing protocols used in SONET/SDH and Optical Transport Network (OTN) contains some overhead bytes.
- The part of overhead bytes are parity check bytes, which gives the measurement of BER. By measuring BER we can predict the performance of optical network.
- **Indirect method** of measuring BER contains measurement of signal power or signal to noise ratio.
- But this is not the accurate method. So using this method, only signal quality can be decided but the performance of optical network cannot be predicted precisely.

6.11.3 Optical Path Trace

- Optical path trace is used to locate the fault positions. At each node in the optical network; at the end of light path, optical path trace is provided.
- The optical path trace gives information about identification and verification of light path. So, incorrect connections can be easily identified using optical path trace. Optical path trace information is used in client layer.

6.11.4 Alarm Management

- It may happen that, in case of single failure, multiple alarms are generated.
- Consider that an optical link fails. Then all the light paths of that link fails. So, at the end of each node, an alarm is generated. That means number of alarms are generated for the failure of single link.

- All these unwanted alarm indicates should be suppressed and only alarm indication for the failure of link should be generated.
- For the alarm suppression Forward Defect Indicator (FDI) and Backward Defect Indicator (BDI) signals are used as shown in Fig. 6.11.1.

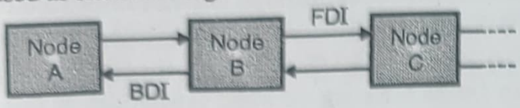

Fig. 6.11.1

- Suppose the failure of link takes place and the node 'B', detects this failure.
- The FDI signal is rapidly transmitted to all the nodes in the network connected after node 'B'. So all these nodes suppress the alarm indication.
- Node 'B' also generates BDI signal to the previous node, that is node A. If node B doesnot receive FDI from node A then it indicates that the link failure takes place at node B.
- A different set of FDI and BDI indicators is required in order to differentiate between failure of link and failure of light path.

6.11.5 Data Communication Network (DCN)

- The different optical elements are communicated with Element Management System (EMS) through Data Communication Network (DCN).
- Even if there is a failure of network; the DCN remains connected through different ways as follows
  - (i) DCN is basically a standard TCP/IP network. So, in case of network failure; carrier makes used of TCP/IP networks to remain connected.
  - (ii) In case of WDM network; DCN remains connected by making use of Optical Supervisory Channel (OSC) and using a separate wavelength.
  - (iii) Through inband optical channel layer at the locations where optical signal is converted into electrical signal.

6.11.6 Monitoring Wavelength and Power

- One of the important functions of network management system, is to monitor wavelength and power level of input signal.
- The power level of incoming signal depends on data rate and type of signal.
- The type of signal and data rate are decided by the user and accordingly the threshold levels are set by the network.
- The power level of incoming signal should be always greater than the threshold value.

6.12 OPTICAL SAFETY

UQ. What is optical safety?
MU – Q. 1(b), Dec. 15, 5 Marks

UQ. Comment on optical safety communication network.
(MU – Q. 5(c), May 16, 5 Marks)

UQ. Write short note on : Optical Safety.
MU – Q. 6(c), May 17, Q. 6(a), Dec. 18, 10 Marks, Q. 5(a), Dec. 17, Q. 6(d), May 19, 5 Marks

- In majority of applications; semiconductor lasers are used as optical source. Even if low power lasers are used; this laser light can damage human eye. This problem is severe if the laser light is in visible range.
- So, whenever lasers are used in optical systems then some safety standards must be maintained. According to the emission levels; lasers are classified as class I and class III ⓐ systems.
- In class I systems; the light from laser source cannot damage human visual system. Even if high power lasers are used; these lasers are well enclosed in suitable enclosure.
- The allowed power level is 10 dBm for the wavelength of 1.55 μm and in case of failure; this power level should not exceed than 10 dBm.
- In case of class III ⓐ systems; the allowed power level is upto 17 dBm of 1.55 μm and it will cause the damage only when the laser beam is directly focused on human eye.
- Usually the optical systems are well enclosed; so that the laser emission cannot be seen from the outside and hence there is no damage. But during installation or in case of fiber cut; the laser light can cause damage.
- To avoid this; the emission of laser light must be always kept below the standard safety level.
- Thus, the safety level considerations provide a limit for the maximum power that can be launched into optical cable.
- In case of single channel system; if optical amplifiers are not used then the launch power is very small. But in multichannel system or the systems in which optical amplifiers are used; the launch power must be limited.
- ***Some common safety mechanisms used in case of fiber cut are as follows :***
  - (i) Some automatic shutdown mechanisms are used. These mechanisms detect the fiber cut and turns off the laser source.

(ii) When optical amplifier detects the loss of signal at its input then it turns off the laser pump.

(iii) Whenever there is a fiber cut then back reflection increases and it can be used to give trigger signal to the automatic shutdown mechanism.

6.13 SERVICE INTERFACE

- Optical layers provide services to other higher layers like SONET/SDH, Ethernet layer, OTN layers etc.
- In this case, optical layer is called as server layer and other higher layers are called as client layers.
- ***The key features of optical service interface are as follows :***

1. According to the requirements of client layers; the light paths must be added or removed.
2. The amount of bandwidth required for data transmission is decided by the client layers.
3. The signals from client layers must be converted into the compatible form required by optical layer. So, adaptation functions are used at input and output of optical layer.
4. The performance management should be adequate to check the typical value of BER which is 10-12.
5. Usually the light paths are bidirectional. But if more bandwidth is required in one direction only then unidirectional light paths are used.
6. In case of connection of multiple rings; the network survivability should be maintained. For this drop and continue function is used. That means a signal is dropped at particular node but the copy of signal is send to the next node.
7. For the distribution of video information; multicasting function must be supported by the network.
8. For SONET/SDH connections; 3R regeneration may be used in the network.
9. While designing the light paths; maximum allowed propagation delay must be considered.
10. The fault management system must be supported by the network.

- In order to implement all these services, there should be control and management interface between optical layer and client layer.
- Using this interface, the performance and fault management information is provided to the client layer.
- In case of large network; whenever new light paths are connected or removed dynamically then it is necessary to specify the signalling interface between optical layer and client layer.
[Written By me]

6.14 INTRODUCTION TO FREE SPACE OPTICS (FSO)

- Free Space Optics (FSO) is a wireless Line Of Sight (LOS) communication technology that uses light for the transmission of information through air or vacuum.
- In FSO, data is transmitted by propagation of light in free space allowing fiber optical connectivity. Free Space Optics is having the same capabilities as that of fiber optics, but at a lower cost and very high speed.
- Free Space Optics works on the principle of laser source driven technology which uses light sources at transmitter end and detector at receiver end to transmit and receive information, through the atmosphere same as Fiber Optics Communication (FOC) link, which also uses light sources and detectors but through optical fiber cable.
- FSO links have some distinct advantages over conventional microwave, radio frequency and optical fiber communication system by virtue of their very high carrier frequencies that permit large capacity, enhanced high security, high data rate and so on respectively.
- FSO systems are being considered for military systems application, because of their inherent benefits as normally most of the systems are rated for greater than one kilometre in three or more lasers operating in sequence parallel to mitigate distance related issues.
- FSO is a LOS (line of sight) technology, where data, voice, and video communication is achieved with maximum 10Gbps of data rate by full duplex (bidirectional) connectivity.

6.14.1 Characteristics of Effective FSO System

An effective FSO system should have the following characteristics :

(a) FSO systems should have the ability to operate at higher power levels for longer distance.

(b) For high speed FSO systems, high speed modulation is important.

(c) An overall system design should have small footprint and low power consumption because of its maintenance.

(d) FSO system should have the ability to operate over wide temperature range and the performance degradation would be less for outdoor systems.

(e) Mean time between failures (MTBF) of system should be more than 10 years.

6.14.2 Architecture of FSO system

- A WOC system consists of three major subsystems :
  - o Transmitter,
  - o Channel, and
  - o Receiver.
- The block diagram of an FSO communication system is shown in Fig. 6.14.1. The role of transmit optics and receive optics are analogous to the antenna used in RF communication.

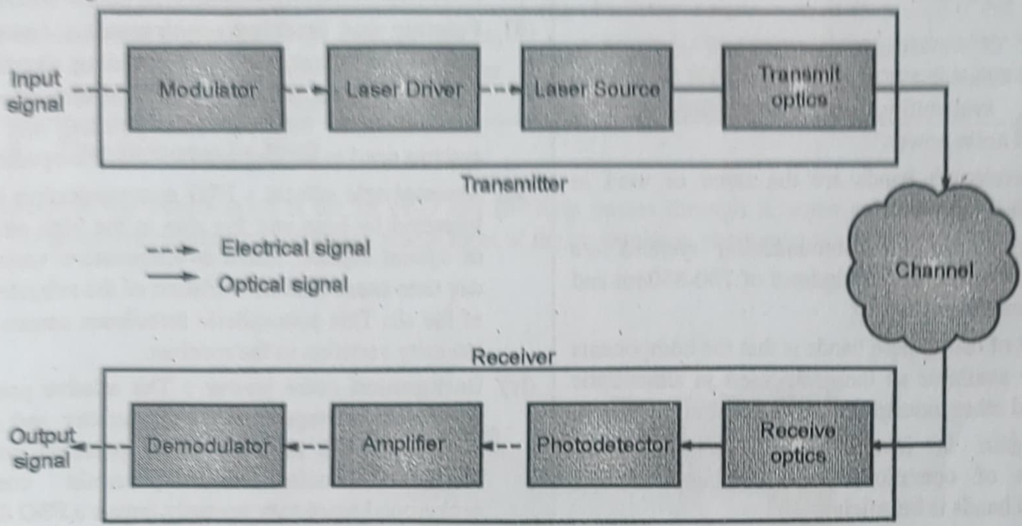

Fig. 6.14.1 : Block diagram of FSO

(a) Transmitter

- Source generates the information that has to be communicated over the optical wireless system. The modulator, using different modulation techniques, modulates the data for transmission.
- The optical light source can be of two types- Light Emitting Diode (LED) or Laser Diode (LD). Laser is preferred because of the high pointedness and coherence that it's beam exhibits
- The role of the transmitter is to convert the information to a signal form suitable for transmission over the channel.
- The modulator modulates the information signal and drives the laser driver. The laser diode acts as the optical source that converts the information in the electrical domain to an optical signal. The transmit optics collects the laser light and directs it towards the receiver.
- The transmitter and receiver are configured to deliver and receive optical signals propagating in free space.
- Transmitter converts incoming electrical signal from driver circuit into optical form to be transmitted over the atmospheric channel.

(b) Channel

- Atmospheric channel through which the optical beam passes throws a lot of challenges for the transmitted signal. Thus the signal has to be properly modulated before transmission.
- For the FSO system, the channel can be vacuum, atmosphere, or water. In case of the atmospheric channel, the signal faces random attenuation due to effects like fog, haze, cloud, and rain.
- Atmospheric turbulence is caused by random fluctuations of the refractive index of the medium due to random temperature fluctuations.
- Atmospheric turbulence is the main limiting factor for the performance of an FSO communication link.

(c) Receiver

- In the receiver, the incident optical signal is captured by the receive optics, and it focuses this signal on the photodetector. The photodetector converts the optical signal to its electrical form.
- Receiver side contains a photo detector which converts the received optical signal to electrical form again which can then be amplified or processed.
- Modulation and demodulation of the signal takes place

in electrical form. Then the amplifier amplifies the signal and also increases the signal-to-noise ratio (SNR).

- Received signal is demodulated and produced in the desired form to the destination.

6.14.3 Wavelengths used in FSO System

- The choice of wavelength is dependent on multiple factors like atmospheric effects, attenuation, eye safety regulations, availability, cost of components, and background noise power.
- Overall wavelength bands are the same as used in optical fibre communication.

  The majority of FSO communication systems are designed to operate in the windows of 780-850nm and 1520-1600nm.
- The benefit of using these bands is that the components are readily available as these are used in fibre optic systems and other industrial and consumer applications.
- Antenna gain is inversely proportional to the wavelength of operation. So, operating in lower wavelength bands is beneficial.
- But eye-safety regulations allow transmitting much more power in higher wavelengths.

6.14.4 Advantages and Disadvantages of FSO system

Advantages of FSO system

The FSO system has several advantages over RF communication system due to the shorter wavelength of operation :

(i) **Higher bandwidth :** An increase in carrier frequency increases the information-carrying capacity of a communication system. In optical communication, the usable bandwidth is almost 105 times of that in the RF communication system.

(ii) **Unlicensed spectrum :** Till now, there is no licensing requirement for the establishment of an FSO communication link. It makes the development and deployment of an FSO communication system easier.

(iii) **Better security :** The beam divergence is proportional to the wavelength. As in the case of FSO communication, the operating wavelength is much less than of RF communication, and the beam divergence is significantly less. As the beam is confined in a narrow region, it provides better security and power efficiency.

(iv) **Less mass and power :** Due to narrow beam divergence, the received power intensity is higher for a given transmitted power. It allows a simpler and lighter transmitter and receiver design. Antenna gain is inversely proportional to the square of the operating wavelength. A small antenna in the FSO system can achieve higher gain.

Disadvantages of FSO system

(i) **LOS requirement :** Due to a very narrow beam divergence, LOS is a critical requirement for successful communication.

(ii) **Pointing and tracking requirement :** Again, due to narrow beam divergence, even building vibrations pose a severe issue to the establishment of a good communication link. Accurate pointing and tracking systems need to be deployed for reliable operation.

(iii) **Atmospheric effects :** FSO communication is highly impacted by haze and fog due to the high attenuation of optical signals. Random temperature variations in day time cause random variation of the refractive index of the air. This atmospheric turbulence causes random intensity variation in the receiver.

(iv) **Background noise power :** The relative position of the sun with respect to the transmitter and receiver plays a crucial role. Sun is a potential source of background noise. Under certain conditions, background noise may severely impair a FSO link.

6.14.5 Application of FSO

FSO communication link is currently in use for many services at many places. These are described below in detail :

(a) **Outdoor wireless access :** it can be used by wireless service providers for communication and it requires no license to use the FSO as it is required in case of microwave bands.

(b) **Storage Area Network (SAN) :** FSO links can be used to form a SAN. It is a network which is known to provide access to consolidated, block level data storage.

(c) **Last-mile access :** to lay cables of users in the last mile is very costly for service providers as the cost of digging to lay fiber is so high and it would make sense to lay as much fiber as possible. FSO can be used to solve such problem by implementing it in the last mile along with other networks. It is a high speed link. It is also used to bypass local-loop systems of other kinds of networks.

(d) **Enterprise connectivity :** FSO systems are easily installable. This feature makes it applicable for interconnecting LAN segments to connect two buildings or other property.

(e) **Fiber backup :** FSO can also be applicable in providing a backup link in case of failure of transmission through fiber link.

(f) **Metro-network extensions :** it can be used in extending the fiber rings of an existing metropolitan area. FSO system can be deployed in lesser time and connection of the new networks and core infrastructure is easily done. It can also be used to complete SONET rings.

(g) **Backhaul :** it can be helpful in carrying the traffic of cellular telephone from antenna towers back to the PSTN with high speed and high data rate. The speed of transmission would increase.

(h) **Service acceleration :** it can also be used to provide instant service to customers when their fiber infrastructure is being deployed in the mean time.

(i) **Bridging WAN Access :** FSO is beneficial in WAN where it supports high speed data services for mobile users and small satellite terminals and acts as a backbone for high speed trunking network.

(j) **Point-to-Point Links :** It can be used to communicate between point-to-point links, for example, two buildings, two ships, and point-to-multipoint links, for example, from aircraft to ground or satellite to ground, for short and long reach communication.

(k) **Military access :** as it is a secure and undetectable system it can connect large areas safely with minimal planning and deployment time and is hence suitable for military applications.

6.14.6 Challenges in FSO

The medium of the transmission is air for FSO and the light passes through it, some environmental challenges are unavoidable. Troposphere regions are the region where most of the atmospheric phenomenon occurred.

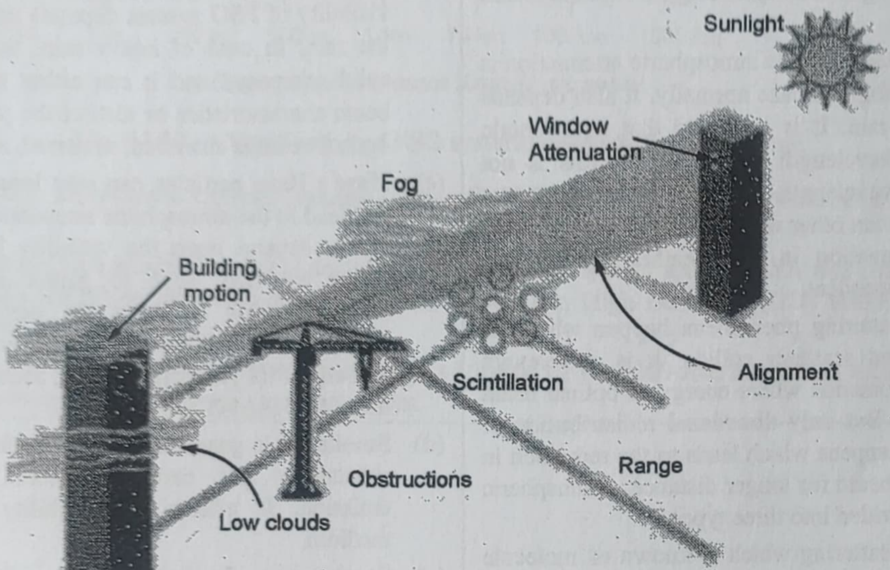

Fig. 6.14.2 : Limitations over the atmosphere

The effect of these limitations over the atmosphere is shown in Fig. 6.14.2. Some of these limitations are briefly described below :

(a) **Physical obstructions :** flying birds, trees, and tall buildings can temporarily block a single beam, when it appears in line of sight (LOS) of transmission of FSO system.

(b) **Scintillation :** there would be temperature variations among different air packets due to the heat rising from the earth and the man-made drives like heating ducts. These temperature variations can cause fluctuations in amplitude of the signal which causes "image dancing" at the FSO receiving end. The effect of scintillation is addressed by Light Pointe's unique multibeam system.

(c) **Geometric losses :** geometric losses which can be called optical beam attenuation are induced due to the spreading of beam and reduced the power level of signal as it travelled from transmitted end to receiver end.

(d) **Absorption :** absorption is caused by the water molecules which are suspended in the terrestrial atmosphere. The photons power would be absorbed by these particles. The power density of the optical beam is decreased and the availability of the transmission in a FSO system is directly affected by absorption. Carbon dioxide can also cause the absorption of signal.

(e) **Atmospheric turbulence :** the atmospheric disturbance happens due to weather and environment structure. It is caused by wind and convection which mixed the air parcels at different temperatures. This causes fluctuations in the density of air and it leads to the change in the air refractive index. The scale size of turbulence cell can create different type of effects given below and which would be dominant:

(i) If size of turbulence cell is of larger diameter than optical beam then beam wander would be the dominant effect. Beam wander is explained as the displacement of the optical beam spot rapidly.

(ii) If size of turbulence cell is of smaller diameter than optical beam then the intensity fluctuation or scintillation of the optical beam is a dominant one. Turbulence can lead to degradation of the optical beam of transmission. Change in the refractive index causes refraction of beam at different angle and spreading of optical beam takes place.

(f) **Atmospheric attenuation :** atmospheric attenuation is the resultant of fog and haze normally. It also depends upon dust and rain. It is supposed that atmospheric attenuation is wavelength dependent but this is not true. Haze is wavelength dependent. Attenuation at 1550nm is less than other wavelengths in haze weather condition. Attenuation in fog weather condition is wavelength independent.

(g) **Scattering :** scattering phenomena happen when the optical beam and scatterer collide. It is wavelength dependent phenomenon where energy of optical beam is not changed. But only directional redistribution of optical energy happens which leads to the reduction in the intensity of beam for longer distance. Atmospheric attenuation is divided into three types :

(1) Rayleigh scattering which is known as molecule scattering.

(2) Mie scattering which is known as aerosol scattering.

(3) Nonselective scattering which is known as geometric scattering.

The type of scattering depends upon the physical size of the scatterer :

(i) When it is smaller than the size of wavelength, Rayleigh scattering.

(ii) When the size of the scatterer is comparable to the wavelength, Mie scattering.

(iii) When it is much larger than the size of wavelength, nonselective scattering.

Atmospheric Weather Conditions. Atmosphere is the medium of transmission for a FSO link. Attenuation caused by it depends upon several conditions. Weather conditions are the main cause of attenuation. The region in which a link is being established has some specific weather conditions so that the preceding knowledge of attenuation can be gained; for example, fog and heavy snow are the two primary weather conditions in temperate regions. In tropical regions, heavy rain and haze are two main weather conditions and have major effect on the availability of FSO link in that region. Some of the weather conditions are described below.

(a) **Fog :** Fog substantially attenuates visible radiation. Optical beam of light is absorbed, scattered, and reflected by the hindrance caused by fog. Scattering caused by fog, also known as Mie scattering, is largely a matter of boosting the transmitted power.

(b) **Rain :** Rain attenuation exists due to rain fall and is a nonselective scattering. This type of attenuation is wavelength independent. Rain has the ability to produce the fluctuation effects in laser delivery. The visibility of FSO system depends upon the quantity of the rain. In case of heavy rain, water droplets have solid composed and it can either modify the optical beam characteristics or restrict the passage of beam as optical beam is absorbed, scattered, and reflected.

(c) **Haze :** Haze particles can stay longer time in the air and lead to the atmospheric attenuation. So, attenuation values depend upon the visibility level at that time. There are two ways to gather information about attenuation for checking the performance of FSO system: first, by installing system temporary at the site and check its performance and, second, by using Kim and Kruse model.

(d) **Smoke :** It is generated by the combustion of different substances like carbon, glycerol, and household emission. It affects the visibility of transmission medium.

(e) **Sandstorms :** Sandstorms are the well-known problem in outdoor link communication. These can be characterized by two ways: first, the size of the wind particles which depends on the soil texture and, second, necessary wind speed in order to blow the particles up during a minimum period of time.

(f) **Clouds :** Cloud layers are main part of earth atmosphere. The formation of clouds is done by the condensation or deposition of water above earth's surface. It can completely block the fractions of optical beam transmitted from earth to the space. The attenuation caused by clouds is difficult to calculate because of the diversity and in homogeneity of the cloud particles.

(g) **Snow :** Snow has larger particles which causes the geometric scattering. The snow particles have impact similar to *Rayleigh scattering*.

6.14.7 Communication Networks in the Future

- The crucial issue in Free-Space Communication is to expand the maximum usable distance between transceivers. In Fig. 6.14.3.
- FSO types are presented according to their maximum operational range. In the nearest future, the communication network infrastructure must adjust to the fifth-generation (5G) and the sixth-generation (6G) standards.
- This is connected with the designing and implementation of high-speed detectors. The main difficulty is the effective collection of the data-carrying optical beam.
- Some advances were made by the Facebook Team, including the use of fluorescent materials to collect and focus the light into a tiny optical detector.

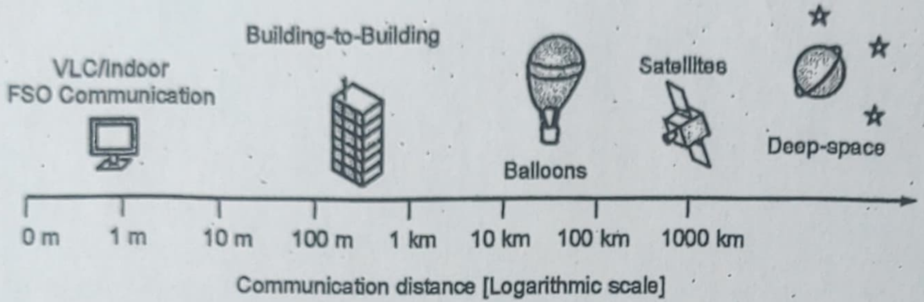

Fig. 6.14.3 : Classification of FSO systems based on their coverage

- In long-range FSO, Deep-Space Optical Communications (DSOC) will take high bandwidth communications to the next level.
- They aim to provide high bandwidth optical downlinks from outside cis-lunar space. NASA also funded a Deep-Space Optical Terminals (DOT) project to develop a tool that allows live High Definition (HD) video, telepresence, and human exploration beyond cis-lunar space.
- The implementation of this system is expected to enable a ten-fold or even 100-fold increase in data returns compared to present Radio Frequency (RF) space communications.

Chapter Ends...

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