2.2 Guided Transmission Media

Guided Transmission Media

- Media are roughly grouped into
- **Guided media**, such as copper wire and fiber optics
- **Unguided media**, such as radio and lasers through the air
- Guided Transmission media
  - Magnetic Media
  - Twisted Pair
  - Coaxial Cable
  - **Fiber Optics**

Magnetic Media

- One of the most common ways to transport data from one computer to another is to write them onto magnetic tape or removable media (e.g., recordable DVDs), physically transport the tape or disks to the destination machine, and read them back in again.
- Although this method is not as sophisticated as using a geosynchronous communication satellite, it is often more cost effective, especially for applications in which high bandwidth or cost per bit transported is the key factor.

Twisted Pair

- Although the bandwidth characteristics of magnetic tape are excellent, the delay characteristics are poor. Transmission time is measured in minutes or hours, not milliseconds.
- For many applications an on-line connection is needed.
- One of the oldest and still most common transmission media is twisted pair.
- A twisted pair consists of two insulated copper wires, typically about 1 mm thick. The wires are twisted together in a helical form, just like a DNA molecule.
- Twisting is done because two parallel wires constitute a fine antenna. When the wires are twisted, **the waves from different twists cancel out, so the wire radiates less effectively.**

Figure. (a) Category 3 UTP. (b) Category 5 UTP.

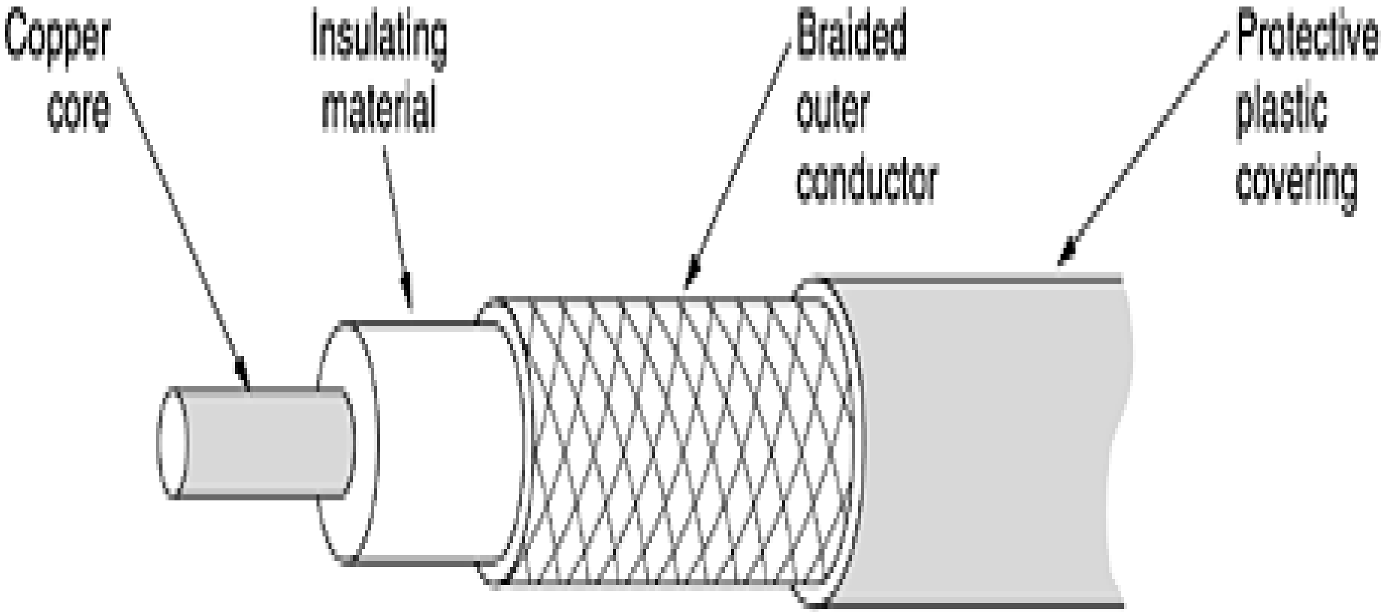
- The most common application of the twisted pair is the **telephone system.** Nearly all telephones are connected to the telephone company (telco) office by a twisted pair.
- Twisted pairs can run several kilometers without amplification, but for longer distances, repeaters are needed.
- When many twisted pairs run in parallel for a substantial distance, such as all the wires coming from an apartment building to the telephone company office, they are bundled together and encased in a protective sheath.
- The pairs in these bundles would interfere with one another if it were not for the twisting.
- **Twisted pairs can be used for transmitting either analog or digital signals.**
- **The bandwidth depends on the thickness of the wire and the distance traveled**, but several megabits/sec can be achieved for a few kilometers in many cases.
- Due to their adequate performance and low cost, twisted pairs are widely used.

- Twisted pair cabling comes in several varieties, two of which are important for **computer networks**. All of these wiring types are often referred to as UTP **(Unshielded Twisted Pair)**
- **Category 3 UTP - up to 16 MHz bandwidth.**
- **Category 5 UTP - up to 100 MHz bandwidth.**
- Category 3 twisted pairs consist of two insulated wires gently twisted together. Four such pairs are typically grouped in a plastic sheath to protect the wires and keep them together.
- This scheme allowed up to four regular telephones or two multiline telephones in each office to connect to the telephone company equipment in the wiring closet.
- Starting around 1988, the more advanced category 5 twisted pairs were introduced.
- They are similar to category 3 pairs, but with **more twists per centimeter**, which results in **less crosstalk** and a **better-quality signal over longer distances**, making them more suitable for high-speed computer communication.
- Up-and-coming categories are **6** and **7**, which are capable of handling signals with bandwidths of **250 MHz** and **600 MHz**, respectively.

Coaxial Cable

- Another common transmission medium is the coaxial cable (known as just ''coax'' and pronounced ''co-ax'').
- **It has better shielding than twisted pairs, so it can span longer distances at higher speeds.**
- Two kinds of coaxial cable are widely used. One kind, **50-ohm cable**, is commonly used when it is intended for **digital transmission from the start**.
- The other kind, **75-ohm cable**, is commonly used for **analog transmission** and **cable television** but is becoming more important with the **Internet over cable**.
- **A coaxial cable consists of a stiff copper wire as the core, surrounded by an insulating material. The insulator is encased by a cylindrical conductor, often as a closely-woven braided mesh. The outer conductor is covered in a protective plastic sheath.**

- **Figure. Cutaway view of a coaxial cable**



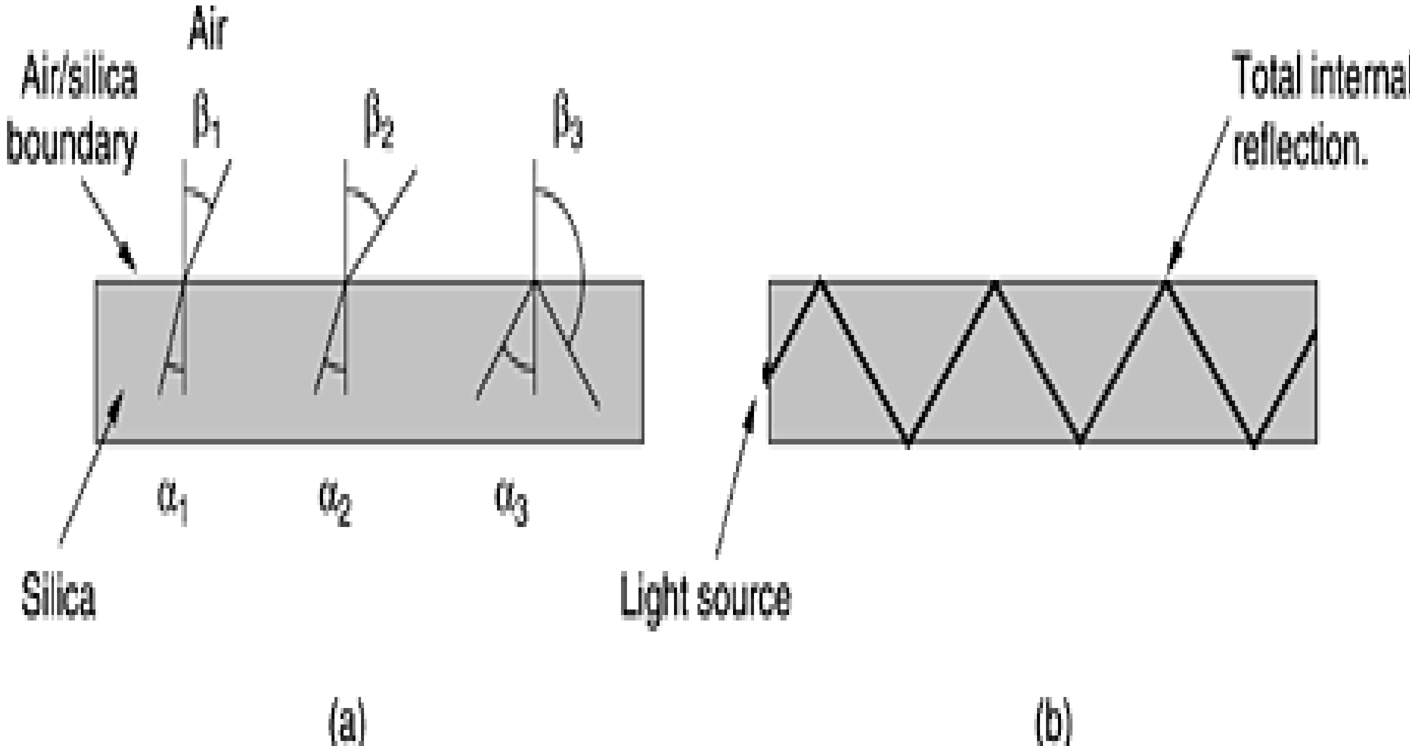
- The construction and shielding of the coaxial cable give it a good combination of **high bandwidth** and **excellent noise immunity**.
- **The bandwidth possible depends on the cable quality, length, and signal-to-noise ratio of the data signal.**
- Modern cables have a bandwidth of close to **1 GHz**.
- Coaxial cables used to be widely used within the **telephone system for long-distance lines** but have now largely been replaced by fiber optics on long-haul routes.
- Coax is still widely used for cable television and metropolitan area networks, however.

Fiber Optics

- In the last 20 years computing speed has increased by a factor of 20 for each decade (IBM PC in 81 ran at 4.77 MHz => 2GHz in 2001).
- In the same period, wide area data communication went from 56 kbps (the ARPANET) to 1 Gbps (modern optical communication), a gain of more than a factor of 125 per decade.
- Moreover the error rate has gone from 10-5 per bit to ~zero in optical networks.
- Semiconductors are close to their physical limit.
- In contrast, **with current fiber technology, the achievable bandwidth is certainly in excess of 50,000 Gbps (50 Tbps) .**
- The current practical signaling limit of about 10 Gbps is due to our inability to convert between electrical and optical signals any faster, although in the laboratory, 100 Gbps has been achieved on a single fiber.

- An optical transmission system has three key components: **the light source, the transmission medium, and the detector.**
- Conventionally, a pulse of light indicates a 1 bit and the absence of light indicates a 0 bit. The transmission medium is an ultra-thin fiber of glass.
- The detector generates an electrical pulse when light falls on it.
- By attaching a light source to one end of an optical fiber and a detector to the other, we have a unidirectional data transmission system that accepts an electrical signal, converts and transmits it by light pulses, and then reconverts the output to an electrical signal at the receiving end.

- **Figure 2-5. (a) Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles. (b) Light trapped by total internal reflection.**



- This transmission system would leak light and be useless in practice except for an interesting principle of physics.
- When a light ray passes from one medium to another, for example, from fused silica to air, the ray is refracted (bent) at the silica/air boundary, as shown in Fig (a).
- Here we see a light ray incident on the boundary at an angle a_1 emerging at an angle b_1. **The amount of refraction depends on the properties of the two media (in particular, their indices of refraction).**
- **For angles of incidence above a certain critical value, the light is refracted back into the silica; none of it escapes into the air.**
- **Thus, a light ray incident at or above the critical angle is trapped inside the fiber**, as shown in Fig. (b), **and can propagate for many kilometers with virtually no loss.**

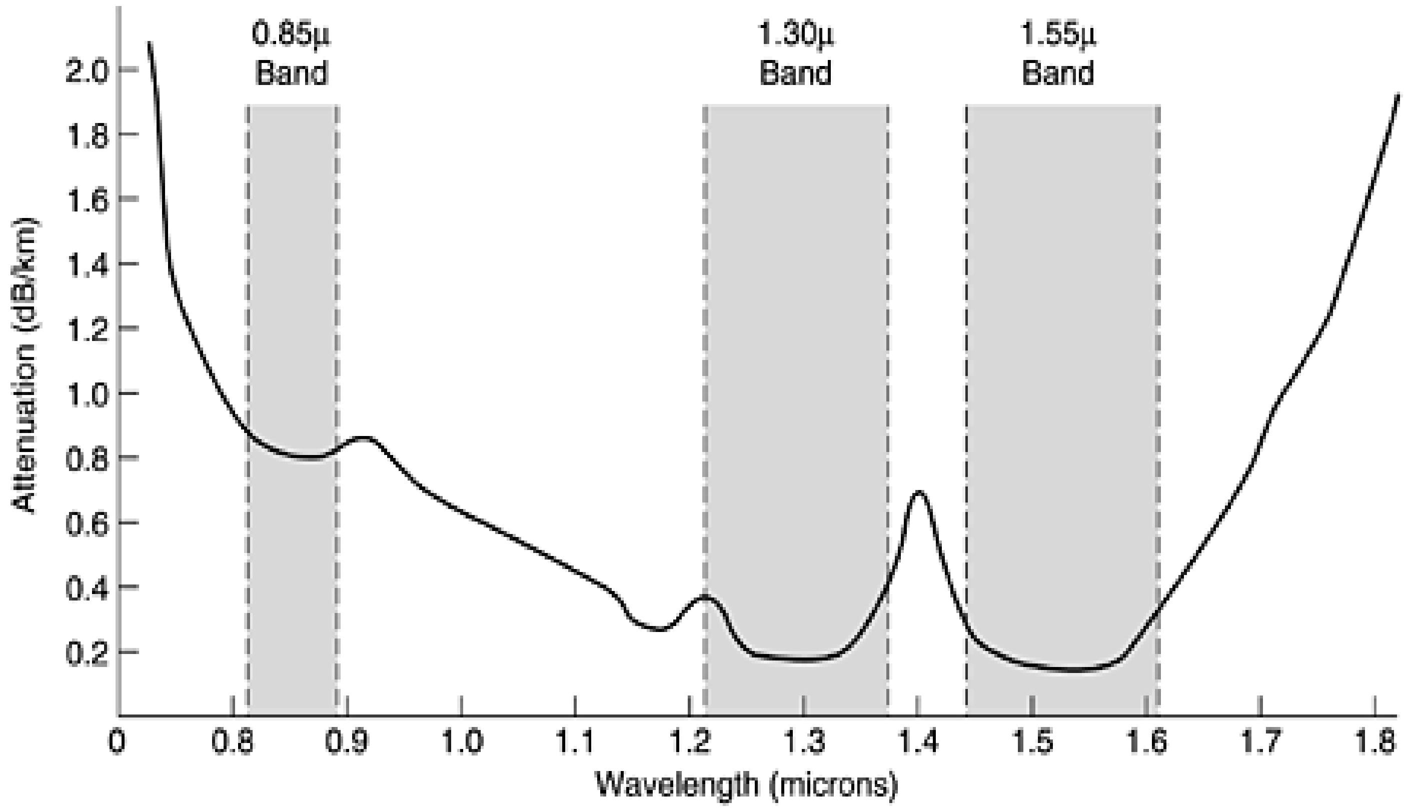
- The sketch of Fig. (b) shows only one trapped ray, but since any light ray incident on the boundary above the critical angle will be reflected internally, many different rays will be bouncing around at different angles.
- Each ray is said to have a different mode, so a fiber having this property is called a **multimode** fiber.
- However, if the fiber's diameter is reduced to a few wavelengths of light, the fiber acts like a wave guide, and the light can propagate only in a straight line, without bouncing, yielding a **single-mode** fiber.
- Single-mode fibers are more expensive but are widely used for longer distances.
- Currently available single-mode fibers can transmit data at **50 Gbps for 100 km without amplification**. Even higher data rates have been achieved in the laboratory for shorter distances.

Transmission of Light through Fiber

- Optical fibers are made of glass, which, in turn, is made from sand, an inexpensive raw material available in unlimited amounts.
- The attenuation of light through glass depends on the wavelength of the light (as well as on some physical properties of the glass).

$$\text{Attenuation in decibels} = 10 \log_{10} \frac{\text{transmitted power}}{\text{received power}}$$

Attenuation of light through fiber in the infrared region.



- Visible light has slightly shorter wavelengths, from 0.4 to 0.7 microns (1 micron is 10^{-6} meters).
- **Three wavelength bands are used for optical communication. They are centered at 0.85, 1.30, and 1.55 microns, respectively.**
- The last two have good attenuation properties (less than 5 percent loss per kilometer).
- The 0.85 micron band has higher attenuation, but at that wavelength the lasers and electronics can be made from the same material (gallium arsenide).
- All three bands are 25,000 to 30,000 GHz wide.

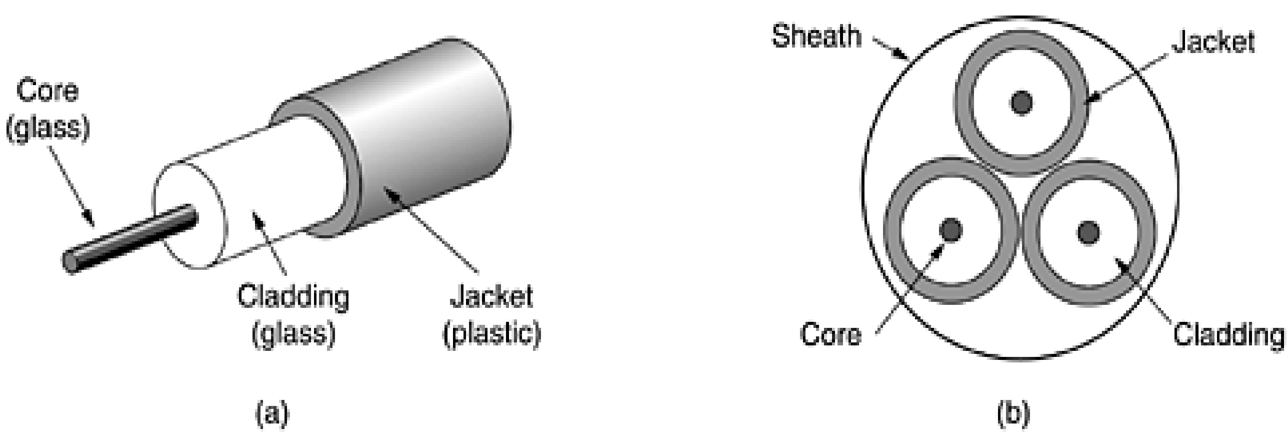
- Light pulses sent down a fiber spread out in length as they propagate. This spreading is called **chromatic dispersion.**
- The amount of it is wavelength dependent. One way to keep these spread-out pulses from overlapping is to increase the distance between them, but this can be done only by reducing the signaling rate.
- Fortunately, it has been discovered that by making the pulses in a special shape related to the **reciprocal of the hyperbolic cosine**, nearly all the dispersion effects cancel out, and it is possible to send pulses for thousands of kilometers without appreciable shape distortion.
- These pulses are called **solitons.**
- A considerable amount of research is going on to take solitons out of the lab and into the field.

Fiber Cables

- Fiber optic cables are similar to coax, except without the braid.
- At the center is the glass core through which the light propagates. In multimode fibers, the core is typically **50 microns in diameter**, about the thickness of a human hair.
- In single-mode fibers, the core is **8 to 10 microns**.

- The **core** is surrounded by a glass **cladding** with a lower index of refraction than the core, to keep all the light in the core. Next comes a thin **plastic jacket** to protect the cladding.
- Fibers are typically grouped in bundles, protected by an outer sheath. Figure 2-7(b) shows a sheath with three fibers.

(a) Side view of a single fiber. (b) End view of a sheath with three fibers.



- Fibers can be connected in three different ways.

- First, they can terminate in connectors and be **plugged into fiber sockets**. Connectors lose about **10 to 20** percent of the light, but they make it easy to reconfigure systems.
- Second, they can be **spliced mechanically**. Mechanical splices take trained personnel about 5 minutes and result in a **10 percent light loss**.
- Third, **two pieces of fiber can be fused (melted)** to form a solid connection. A fusion splice is almost as good as a single drawn fiber, but even here, a **small amount of attenuation occurs.**

- For all three kinds of splices, reflections can occur at the point of the splice, and the reflected energy can interfere with the signal.
- Two kinds of light sources are typically used to do the signaling, **LEDs (Light Emitting Diodes) and semiconductor lasers.**
- They can be tuned in wavelength by inserting **Fabry-Perot or Mach-Zehnder interferometers** between the source and the fiber.

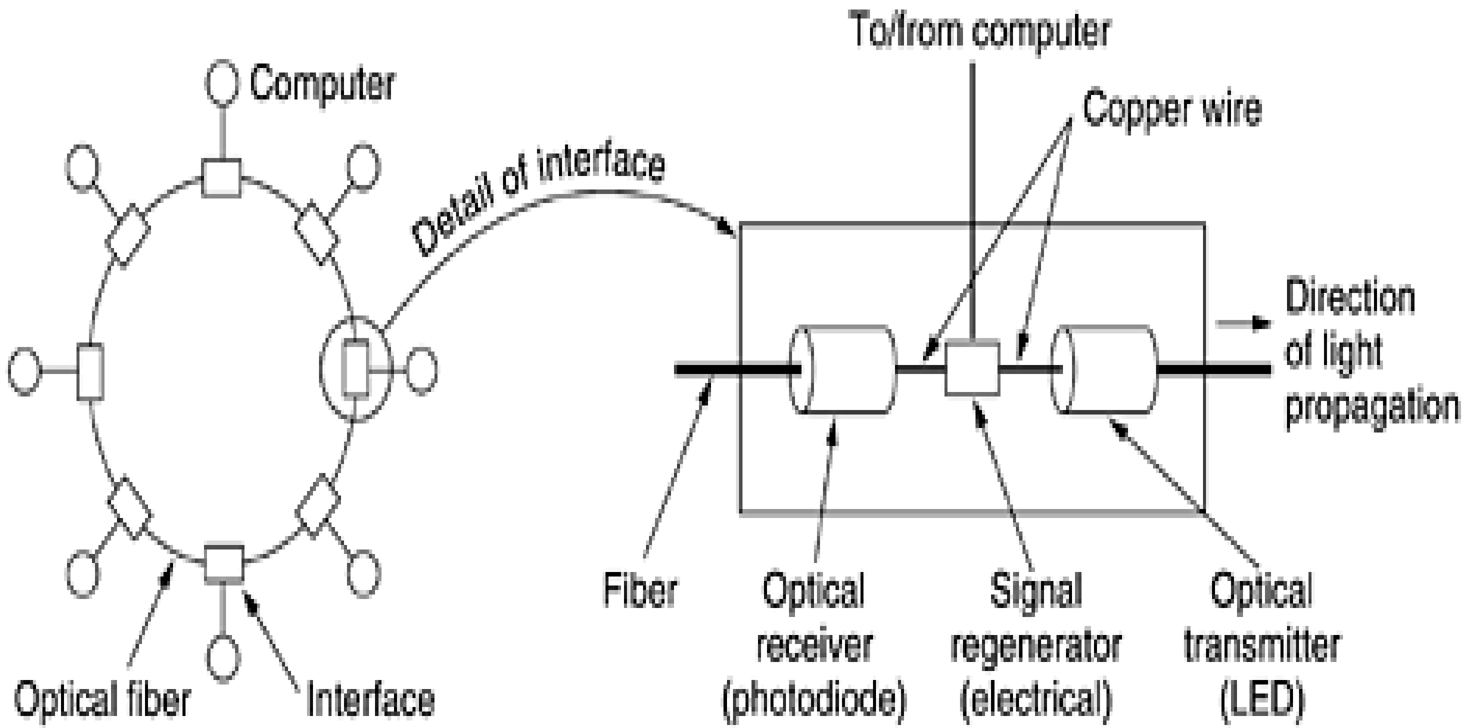
  - **A comparison of semiconductor lasers and LEDs as light sources.**

Item	LED	Semiconductor laser
Data rate	Low	High
Fiber type	Multimode	Multimode or single mode
Distance	Short	Long
Lifetime	Long life	Short life
Temperature sensitivity	Minor	Substantial
Cost	Low cost	Expensive

- The receiving end of an optical fiber consists of a **photodiode**, which gives off an electrical pulse when struck by light.
- **The typical response time of a photodiode is 1 nsec, which limits data rates to about 1 Gbps.**
- Thermal noise is also an issue, so a pulse of light must carry enough energy to be detected.
- By making the pulses powerful enough, the error rate can be made arbitrarily small.

Fiber Optic Networks

- **A fiber optic ring with active repeaters.**



- Fiber optics can be used for LANs as well as for long-haul transmission.
- One way around the problem is to realize that a ring network is really just a collection of point-to-point links.
- The interface at each computer passes the light pulse stream through to the next link and also serves as a T junction to allow the computer to send and accept messages.
- Two types of interfaces are used.

❑ **A passive interface** consists of two taps fused onto the main fiber. One tap has an LED or laser diode at the end of it (for transmitting), and the other has a photodiode (for receiving).

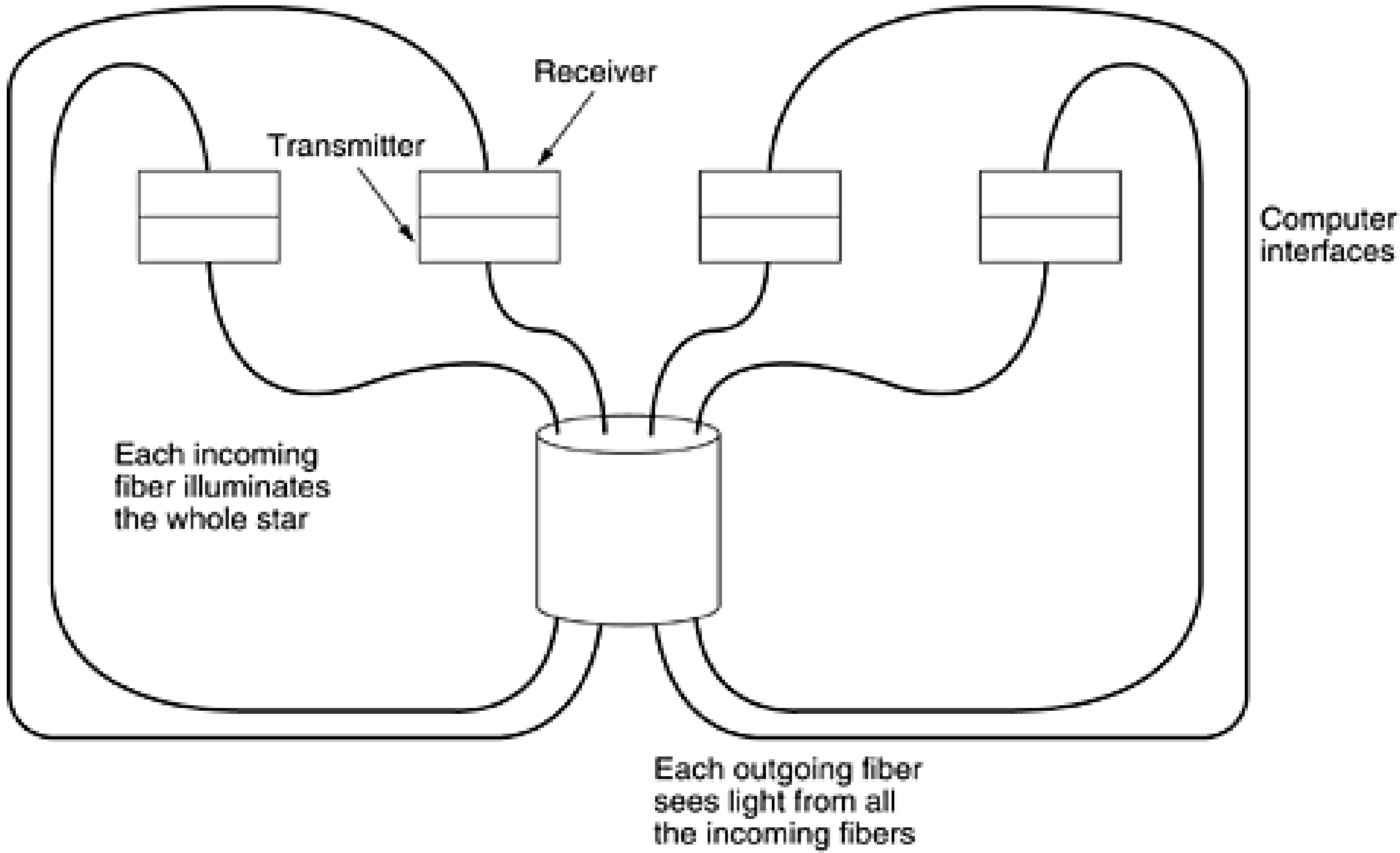
✓ The tap itself is completely passive and is thus **extremely reliable** because a broken LED or photodiode does not break the ring. It just takes one computer off-line.

❑ The other interface type, is the **active repeater**. The incoming light is converted to an electrical signal, regenerated to full strength if it has been weakened, and retransmitted as light.

- The interface with the computer is an ordinary copper wire that comes into the signal regenerator.
- Purely optical repeaters are now being used, too. These devices do not require the optical to electrical to optical conversions.

- If an active repeater fails, the ring is broken and the network goes down.
- The passive interfaces lose light at each junction, so the number of computers and total ring length are greatly restricted.
- A ring topology is not the only way to build a LAN using fiber optics.
- It is also possible to have hardware broadcasting by using the **passive star construction**.
- In this design, each interface has a fiber running from its transmitter to a silica cylinder, with the incoming fibers fused to one end of the cylinder.
- Similarly, fibers fused to the other end of the cylinder are run to each of the receivers.
- Whenever an interface emits a light pulse, it is diffused inside the passive star to illuminate all the receivers, thus achieving broadcast.
- In effect, the passive star combines all the incoming signals and transmits the merged result on all lines.
- Since the incoming energy is divided among all the outgoing lines, the number of nodes in the network is limited by the sensitivity of the photodiodes.

Figure. A passive star connection in a fiber optics network.



Comparison of Fiber Optics and Copper Wire

- Fiber optics can handle much higher bandwidths than copper.
- Due to the low attenuation in fiber optics , repeaters are needed only about every 50 km on long lines, versus about every 5 km for copper, a substantial cost saving.
- Fiber also has the advantage of not being affected by power surges, electromagnetic interference, or power failures. Nor is it affected by corrosive chemicals in the air, making it ideal for harsh factory environments.
- Fiber optic is thin and lightweight.

- Also, fiber is much lighter than copper, which greatly reduces the need for expensive mechanical support systems that must be maintained.
- For new routes, fiber wins hands down due to its much lower installation cost.
- Fibers do not leak light and are quite difficult to tap. These properties gives fiber excellent security.
- **On the downside**, fiber is a less familiar technology requiring skills not all engineers have, and fibers can be damaged easily by being bent too much.
- Since optical transmission is inherently unidirectional, two-way communication requires either two fibers or two frequency bands on one fiber.
- Finally, fiber interfaces cost more than electrical interfaces.