DATA COMMUNICATION AND NETWORKING

Software Department – Fourth Class

Transmission Media

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Introduction

In a data transmission system, the transmission medium is the physical path between transmitter and receiver. For ***guided media***, electromagnetic waves are guided along a solid medium, such as copper twisted pair, copper coaxial cable, and optical fiber. For ***unguided media***, wireless transmission occurs through the atmosphere, outer space, or water. The characteristics and quality of a data transmission are determined both by the characteristics of the medium and the characteristics of the signal. In the case of guided media, the medium itself is more important in determining the limitations of transmission. For unguided media, the bandwidth of the signal produced by the transmitting antenna is more important than the medium in determining transmission characteristics. One key property of signals transmitted by antenna is directionality. In considering the design of data transmission systems, key concerns are data rate and distance: the greater the data rate and distance the better. A number of design factors relating to the transmission medium and the signal determine the data rate and distance:

- ***Bandwidth***: All other factors remaining constant, the greater the bandwidth of a signal, the higher the data rate that can be achieved.
- ***Transmission impairments***: Impairments, such as attenuation, limit the distance. For guided media, twisted pair generally suffers more impairment than coaxial cable, which in turn suffers more than optical fiber.
- ***Interference***: Interference from competing signals in overlapping frequency bands can distort or wipe out a signal. Interference is of particular concern for unguided media, but is

also a problem with guided media. For guided media, interference can be caused by emanations from nearby cables.

- ***Number of receivers***: A guided medium can be used to construct a point-to-point link or a shared link with multiple attachments. In the latter case, each attachment introduces some attenuation and distortion on the line, limiting distance and/or data rate.

1. Guided Transmission Media

For guided transmission media, the transmission capacity, in terms of either data rate or bandwidth, depends critically on the distance and on whether the medium is point-to-point or multipoint. The three guided media commonly used for data transmission are twisted pair, coaxial cable, and optical fiber.

❖ Twisted Pair

Physical Description A twisted pair (see Figure 1), consists of two insulated copper wires arranged in a regular spiral pattern. A wire pair acts as a single communication link. Typically, a number of these pairs are bundled together into a cable by wrapping them in a tough protective sheath. Over longer distances, cables may contain hundreds of pairs. The twisting tends to decrease the crosstalk interference between adjacent pairs in a cable. Neighboring pairs in a bundle typically have somewhat different twist lengths to reduce the crosstalk interference. On long-distance links, the twist length typically varies from 5 to 15 cm. The wires in a pair have thicknesses of from 0.4 to 0.9 mm.

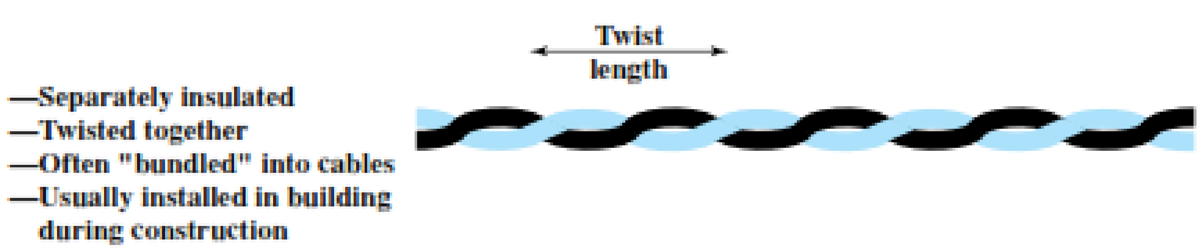

Figure 1. Twisted Pair

Applications By far the most common guided transmission medium for both analog and digital signals is twisted pair.

- It is the most commonly used medium in the telephone network and is the workhorse for communications within buildings.

- These twisted-pair installations were designed to support voice traffic using analog signaling. However, by means of a modem, these facilities can handle digital data traffic at modest data rates.
- Twisted pair is also the most common medium used for digital signaling. For connections to a digital data switch or digital PBX within a building, a data rate of 64 kbps is common.
- Twisted pair is also commonly used within a building for local area networks supporting personal computers. Data rates for such products are typically in the neighborhood of 100 Mbps.
- For long-distance applications, twisted pair can be used at data rates of 4 Mbps or more.
- Twisted pair is much less expensive than the other commonly used guided transmission media (coaxial cable, optical fiber) and is easier to work with.

Transmission Characteristics Twisted pair may be used to transmit both analog and digital transmission. For analog signals, amplifiers are required about every 5 to 6 km. For digital transmission, repeaters are required every 2 or 3 km. Compared to other commonly used guided transmission media (coaxial cable, optical fiber), twisted pair is limited in distance, bandwidth, and data rate.

The ***attenuation*** for twisted pair is a very strong function of frequency. Other ***impairments*** are also severe for twisted pair. The medium is quite susceptible to interference and noise because of its easy coupling with electromagnetic fields. ***Impulse*** noise also easily intrudes into twisted pair. ***Several measures are taken to reduce impairments.*** Shielding the wire with metallic braid or sheathing reduces interference. The twisting of the wire reduces low-frequency interference, and the use of different twist lengths in adjacent pairs reduces crosstalk.

For point-to-point analog signaling, a bandwidth of up to about 1 MHz is possible. This accommodates a number of voice channels. For long-distance digital point-to-point signaling, data rates of up to a few Mbps are possible; for very short distances, data rates of up to 10 Gbps have been achieved in commercially available products.

❖ Coaxial Cable

Physical Description Coaxial cable, like twisted pair, consists of two conductors, but is constructed differently to permit it to operate over a wider range of frequencies. It consists of a hollow outer cylindrical conductor that surrounds a single inner wire conductor (Figure 2). The inner conductor is held in place by either regularly spaced insulating rings or a solid dielectric material. The outer conductor is covered with a jacket or shield. A single coaxial cable has a diameter of from 1 to 2.5 cm. Coaxial cable can be used over longer distances and support more stations on a shared line than twisted pair.

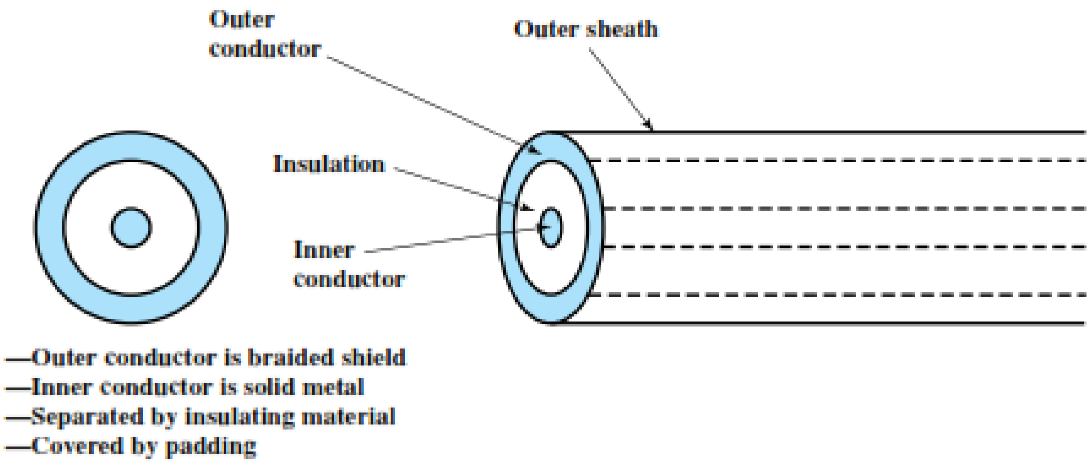

Figure 2. Twisted Pair

Applications Coaxial cable is a versatile transmission medium, used in a wide variety of applications. The most important of these are

- Television distribution, Coaxial cable is widely used as a means of distributing TV signals to individual homes—cable TV. A cable TV system can carry dozens or even hundreds of TV channels at ranges up to a few tens of kilometers.
- Long-distance telephone transmission, Coaxial cable has traditionally been an important part of the long-distance telephone network. Today, it faces increasing competition from optical fiber, terrestrial microwave, and satellite. A coaxial cable can carry over 10,000 voice channels simultaneously.
- Short-run computer system links, Coaxial cable is also commonly used for short-range connections between devices. Using digital signaling, coaxial cable can be used to provide high-speed I/O channels on computer systems.

Transmission Characteristics Coaxial cable is used to transmit both analog and digital signals. A coaxial cable has frequency characteristics that are superior to those of twisted pair and can hence be used effectively at higher frequencies and data rates. Because of its shielded, concentric construction, coaxial cable is much less susceptible to interference and crosstalk than twisted pair.

The principal constraints on performance are attenuation, thermal noise, and intermodulation noise. The latter is present only when several channels or frequency bands are in use on the cable. For long-distance transmission of analog signals, amplifiers are needed every few kilometers, with closer spacing required if higher frequencies are used. The usable spectrum for analog signaling extends to about 500 MHz. For digital signaling, repeaters are needed every kilometer or so, with closer spacing needed for higher data rates.

❖ Optical Fiber Cable

Optical fiber already enjoys considerable use in long-distance telecommunications, and its use in military applications is growing. The continuing improvements in performance and decline in prices, together with the inherent advantages of optical fiber, have made it increasingly attractive for local area networking.

The following characteristics distinguish optical fiber from twisted pair or coaxial cable:

- ✓ ***Greater capacity:*** data rates of hundreds of Gbps over tens of kilometers have been demonstrated.
- ✓ ***Smaller size and lighter weight:*** The corresponding reduction in weight reduces structural support requirements.
- ✓ ***Lower attenuation:*** Attenuation is significantly lower for optical fiber and is constant over a wide range.
- ✓ ***Electromagnetic isolation:*** Optical fiber systems are not affected by external electromagnetic fields. Thus the system is not vulnerable to interference, impulse noise, or crosstalk. By the same token, fibers do not radiate energy, so there is little interference with other equipment and there is a high degree of security from eavesdropping.
- ✓ ***Greater repeater spacing:*** Fewer repeaters mean lower cost and fewer sources of error. The performance of optical fiber systems from this point of view has been steadily improving.

<u>Physical Description</u> An optical fiber is a thin (2 to 125 μm), flexible medium capable of guiding an optical ray. Various glasses and plastics can be used to make optical fibers. The lowest losses have been obtained using fibers of ultrapure fused silica. Ultrapure fiber is difficult to manufacture; higher-loss multicomponent glass fibers are more economical and still provide good performance. Plastic fiber is even less costly and can be used for short-haul links, for which moderately high losses are acceptable. An optical fiber cable has a cylindrical shape and consists of three concentric sections: the core, the cladding, and the jacket (Figure 3). The ***core*** is the innermost section and consists of one or more very thin strands, or fibers, made of glass or plastic; the core has a diameter in the range of 8 to 50 μm. Each fiber is surrounded by its own ***cladding***, a glass or plastic coating that has optical properties different from those of the core and a diameter of 125 μm. The interface between the core and cladding acts as a reflector to confine light that would otherwise escape the core. The outermost layer, surrounding one or a bundle of cladded fibers, is the ***jacket***. The jacket is composed of plastic and other material layered to protect against moisture, abrasion, crushing, and other environmental dangers.

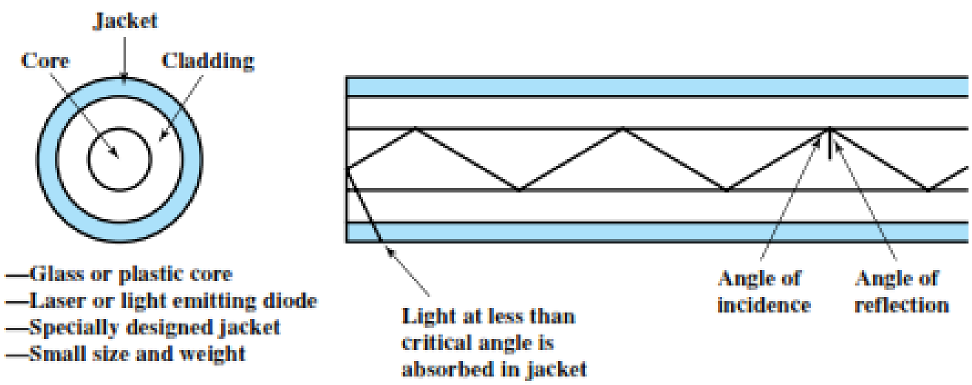

Figure 3. Optical Fiber

Applications

Five basic categories of application have become important for optical fiber:

- ***Long-haul trunks,*** Long-haul fiber transmission is becoming increasingly common in the telephone network. Long-haul routes average about 1500 km in length and offer high capacity (typically 20,000 to 60,000 voice channels).
- ***Metropolitan trunks,*** Metropolitan trunking circuits have an average length of 12 km and may have as many as 100,000 voice channels in a trunk group.
- ***Rural exchange trunks,*** It have circuit lengths ranging from 40 to 160 km and link towns and villages. Most of these systems have fewer than 5000 voice channels.
- ***Subscriber loops,*** It circuits are fibers that run directly from the central exchange to a subscriber as the telephone networks evolve into full-service networks capable of handling not only voice and data, but also image and video.
- ***Local area networks,*** A final important application of optical fiber is for local area networks. Standards have been developed and products introduced for optical fiber

networks that have a total capacity of 100 Mbps to 10 Gbps and can support hundreds or even thousands of stations in a large office building or a complex of buildings.

The advantages of optical fiber over twisted pair and coaxial cable become more compelling as the demand for all types of information (voice, data, image, and video) increases.

Transmission Characteristics Optical fiber transmits a signal-encoded beam of light by means of ***total internal reflection***. Total internal reflection can occur in any transparent medium that has a higher index of refraction than the surrounding medium. Figure 4 shows the principle of optical fiber transmission. Light from a source enters the cylindrical glass or plastic core. Rays at shallow angles are reflected and propagated along the fiber; other rays are absorbed by the surrounding material. This form of propagation is called ***step-index multimode***, referring to the variety of angles that will reflect.

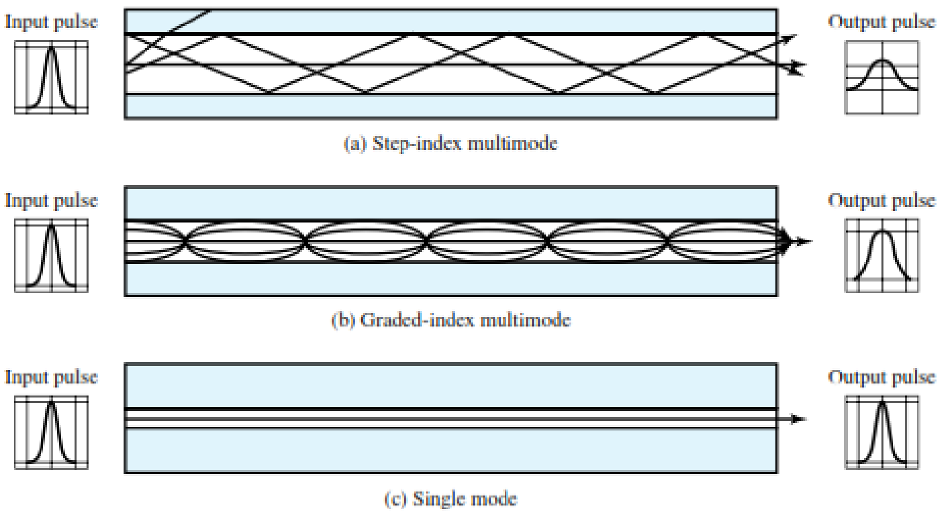

Figure 4. Optical Fiber Transmission Modes

With multimode transmission, multiple propagation paths exist, each with a different path length and hence time to traverse the fiber. This causes signal elements (light pulses) to spread out in time, which limits the rate at which data can be accurately received. This type of fiber is best suited for transmission over very short distances. When the fiber core radius is reduced, fewer angles will reflect. By reducing the radius of the core to the order of a wavelength, only a single angle or mode can pass: the axial ray.

This ***single-mode*** propagation provides superior performance for the following reason. Because there is a single transmission path with single-mode transmission, the distortion found in multimode cannot occur. Single-mode is typically used for long-distance applications, including telephone and cable television. Finally, by varying the index of refraction of the core, a third type of transmission, known as ***graded-index multimode***, is possible. This type is intermediate between the other two in characteristics. Graded-index fibers are often used in local area networks.

Two different types of light source are used in fiber optic systems: the ***Light-Emitting Diode (LED)*** and the ***Injection Laser Diode (ILD)***. Both are semiconductor devices that emit a beam of light when a voltage is applied. The LED is *less costly, operates over a greater temperature range, and has a longer operational life.* The ILD, which operates on the laser principle, is *more efficient and can sustain greater data rates.* There is a relationship among the ***wavelength employed, the type of transmission, and the achievable data rate.*** Both single mode and multimode can support several different wavelengths of light and can employ laser or LED light sources.

2. Wireless Transmission

Since there are many general ranges of frequencies of wireless transmission, only one is of interest in our discussion. Frequencies in the range of about 1 GHz to 40 GHz are referred to as microwave frequencies. At these frequencies, highly directional beams are possible, and microwave is quite suitable for point-to-point transmission. Microwave is also used for satellite communications. Frequencies in the range of 30 MHz to 1 GHz are suitable for omnidirectional applications. We refer to this range as the radio range. Another important frequency range, for local applications, is the infrared portion of the spectrum. This covers, roughly, from to Infrared is useful to local point-to-point and multipoint applications within confined areas, such as a single room.

For unguided media, transmission and reception are achieved by means of an antenna. Before looking at specific categories of wireless transmission, we provide a brief introduction to antennas.

Antennas

An antenna *can be defined as an electrical conductor or system of conductors used either for radiating electromagnetic energy or for collecting electromagnetic energy.*

For transmission of a signal, *radio-frequency electrical energy* from the transmitter is converted into electromagnetic energy by the antenna and radiated into the surrounding environment (atmosphere, space, water). For reception of a signal, *electromagnetic energy impinging* on the antenna is converted into *radio-frequency electrical energy* and fed into the receiver. In two-way communication, the same antenna can be and often is used for both transmission and reception.

An antenna will radiate power in all directions but, typically, does not perform equally well in all directions. A common way to characterize the performance of an antenna is the ***radiation pattern,*** *which is a graphical representation of the radiation properties of an antenna as a function of space coordinates.*

The simplest pattern is produced by an idealized antenna known as the ***isotropic antenna***. An isotropic antenna *is a point in space that radiates power in all directions equally.* *The actual radiation pattern for the isotropic antenna is a sphere with the antenna at the center.*

Parabolic Reflective Antenna

An important type of antenna is the ***parabolic reflective antenna***, which is used in terrestrial ***microwave and satellite applications***. A **parabola** is the locus of all points equidistant from a fixed line and a fixed point not on the line. *The fixed point is called the* ***focus*** *and the fixed line is called the* ***directrix*** (Figure 5). If a parabola is revolved about its axis, the surface generated is called a ***paraboloid***. A cross section through the paraboloid parallel to its axis forms a parabola and a cross section perpendicular to the axis forms a circle. Such surfaces are used in headlights, optical and radio telescopes, and microwave.

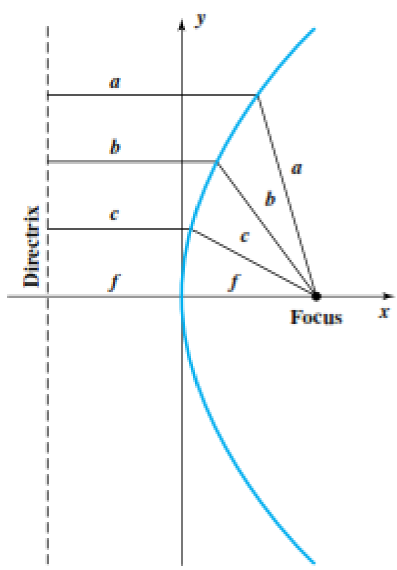

Figure 5. Parabolic Reflective Antenna

Antenna Gain

Antenna gain is a measure of the directionality of an antenna. ***Antenna gain*** is defined ***as the power output, in a particular direction, compared to that produced in any direction by a perfect***

omnidirectional antenna (isotropic antenna). For example, if an antenna has a gain of 3 dB, that antenna improves upon the isotropic antenna in that direction by 3 dB. The increased power radiated in a given direction is at the expense of other directions. In effect, increased power is radiated in one direction by reducing the power radiated in other directions. It is important to note that antenna gain does not refer to obtaining more output power than input power but rather to directionality.

A concept related to that of antenna gain is the effective area of an antenna. The effective area of an antenna is related to the physical size of the antenna and to its shape. The relationship between antenna gain and effective area is

$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi f^2 A_e}{c^2}$$

G = antenna gain
A_e = effective area
f = carrier frequency
c = speed of light ($\approx 3 \times 10^8$ m/s)
λ = carrier wavelength

❖ Terrestrial Microwave

Physical Description The most common type of microwave antenna is the parabolic "dish."A typical size is about 3 m in diameter. The antenna is fixed rigidly and focuses a narrow beam to achieve line-of-sight transmission to the receiving antenna. Microwave antennas are usually located at substantial heights above ground level to extend the range between antennas and to be able to transmit over intervening obstacles.

Applications

- The primary use for terrestrial microwave systems is in long-haul telecommunications service.
- The microwave facility requires far fewer amplifiers or repeaters than coaxial cable over the same distance but requires line-of-sight transmission.
- Microwave is commonly used for both voice and television transmission.

- Another increasingly common use of microwave is for short point-to-point links between buildings. This can be used for closed-circuit TV or as a data link between local area networks.
- Short-haul microwave can also be used for the so-called bypass application.
- A business can establish a microwave link to a long-distance telecommunications facility in the same city, bypassing the local telephone company.
- Another important use of microwave is in cellular systems.

Transmission Characteristics Microwave transmission covers a substantial portion of the electromagnetic spectrum. Common frequencies used for transmission are in the range 1 to 40 GHz. The higher the frequency used, the higher the potential bandwidth and therefore the higher the potential data rate.

As with any transmission system, a main source of loss is attenuation. For microwave (and radio frequencies), the loss can be expressed as:

$$L = 10 \log\left(\frac{4\pi d}{\lambda}\right)^2 \text{dB}$$

Where d is the distance and λ is the wavelength, in the same units. Thus, loss varies as the square of the distance. In contrast, for twisted-pair and coaxial cable, loss varies exponentially with distance (linear in decibels). Thus repeaters or amplifiers may be placed farther apart for microwave systems—10 to 100 km is typical. Attenuation is increased with rainfall. The effects of rainfall become especially noticeable above 10 GHz. Another source of impairment is interference. With the growing popularity of microwave, transmission areas overlap and interference is always a danger shorter distances. In addition, at the higher frequencies, the antennas are smaller and cheaper.

Good Luck