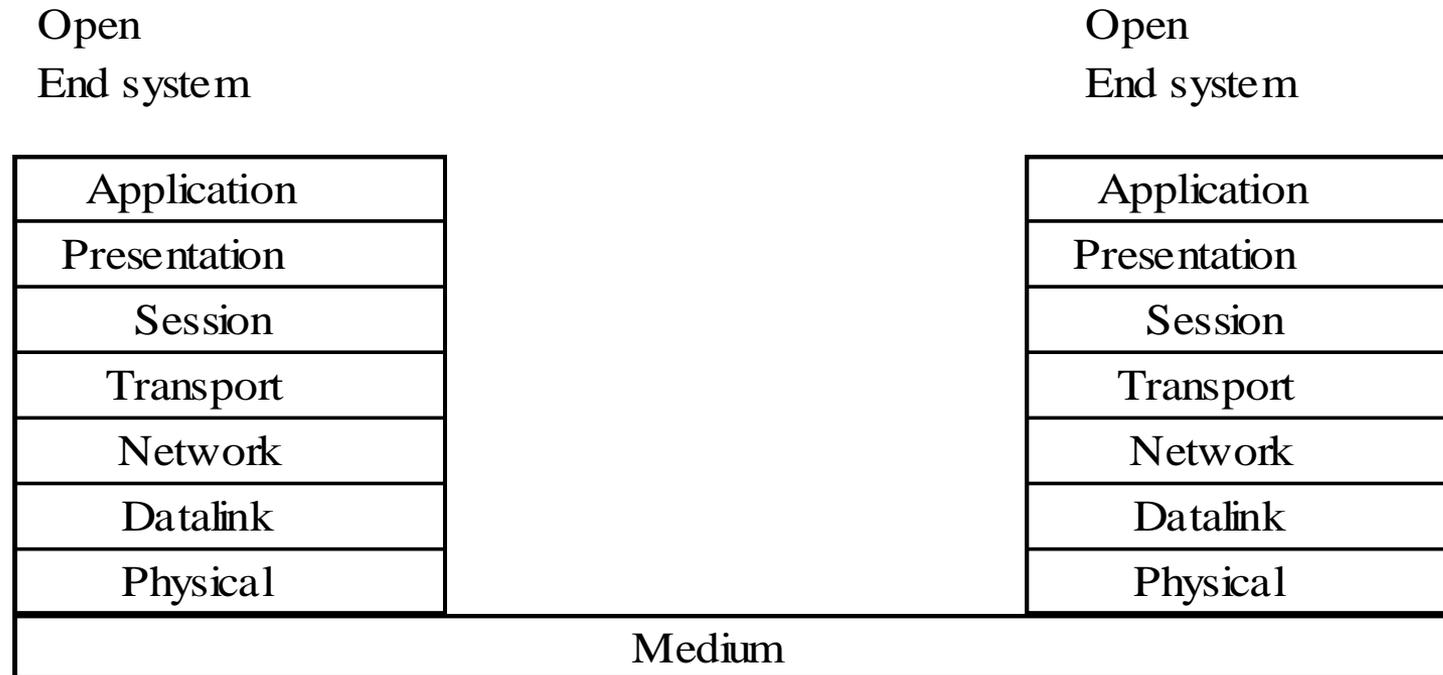


- Today's Lecture – The Physical Layer
 - Transmission Media
 - Guided
 - Unguided
 - Telephone System

- Recall the OSI Reference Model



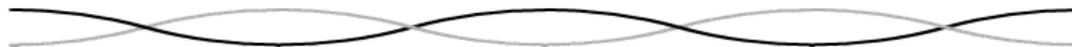
- Physical Layer** is the lowest layer and is concerned with wiring and electrical standards.
 - It provides an unreliable bit transmission/reception service to the layer above it.

- **Transmission basics**
 - **Simplex Communication**
 - Data travels in one direction only e.g. printing
 - **Half Duplex**
 - Also known as two-way alternate
 - Transmission in one direction only
 - This depends on some form of turn around mechanism
 - **Full Duplex / Duplex**
 - Transmission in both directions simultaneously
 - Requires independent forward and backward paths

- **Transmission Media**
 - There are two types of transmission media
 1. Guided – copper wires, fiber optic cable
 2. Unguided – Wireless (Radio Frequency / Microwave)
 - Information is transmitted over:
 - Copper wire by varying the voltage or current time
 - Fiber optic cable by pulsing light on / off in a fiber optic cable over time
 - Radiowaves or Microwaves by varying the frequency or amplitude over time

- **Guided transmission basics**
 - To transmit a single bit down a copper wire, we must send some electrical signal having two discrete states to represent 0 and 1
 - Examples:
 - Voltage $+5\text{v} = 1$ $0\text{V} = 0$
 - Frequency $980\text{ Hz} = 1$ $1180\text{ Hz} = 0$
 - Current one direction = 1 opposite direction = 0
 - If a second bit follows the first
 - There must be some means of indicating the bit boundary or synchronizing the receiver and transmitter so that they agree on where bits start and end.

- **Guided transmission media**
 - Guided transmission is where the signal (information or data) is sent through some sort of cable, usually copper or optical fiber.
 - There are many different types of cabling:
 - **Twisted Pair:** This consists of two or more insulated wires twisted together in a shape similar to a helix. The cables are twisted around each other to reduce the amount of external interference
 - This cable can be used at speeds of several Mb/s for a few kilometres.
 - Used today in countries where telephone lines are carried on poles



- Guided transmission media (continued)
 - In computer networks the two types of twisted pair cabling most frequently used is:
 - Category 3
 - Category 5
 - Category 3 twisted pair cables consist of 2 insulated wires gently twisted together.
Four of these pairs are twisted and wrapped in plastic.
Mainly used before 1988. Category 5 now most often used
 - Category 5 cables have more twists per centimetre and teflon insulation to reduce the amount of external interference and improve the signal quality

- Guided transmission media (continued)

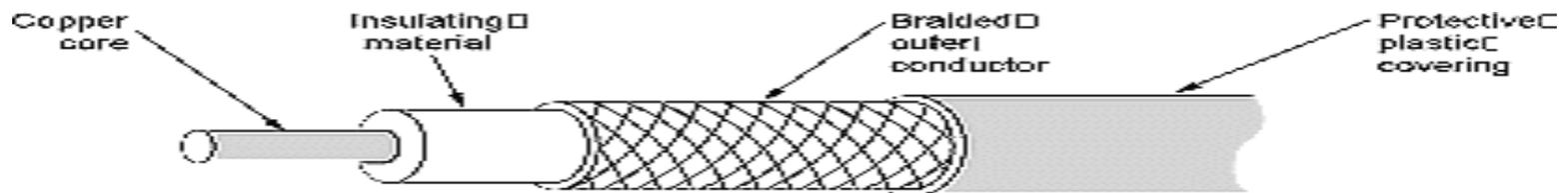
- Coaxial Cable (coax)

- This consists of a copper cable inside a layer of insulating material.

The insulating material is then inside a braided outer conductor.

A layer of plastic is on the outermost layer.

- This type of cable was commonly used in the telephone system but has since been replaced by fiber optics on longer routes
- This cable has also been used for Cable TV and Local Area Networks (LANs)



- Guided transmission media (continued)
 - Fiber Optic Cable
 - This consists of a central glass core, surrounded by a glass cladding of lower refractive index, so that the light stays in the core (using Total Internal Reflection)
 - On the outside is a plastic jacket
 - Many fibers may be bundled together surrounded by another plastic cover

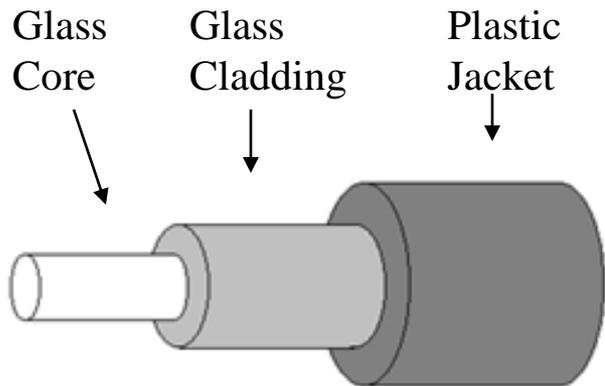


Fig. Single Optical Fiber

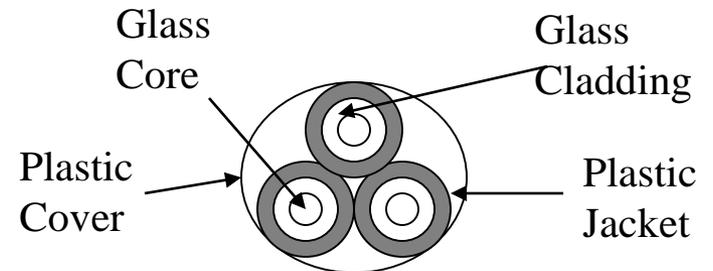


Fig. Bundled Optical Fibers

- **How light travels in a fiber optic cable**
 - The source of light is usually a **Light Emitting Diode (LED)** or a **LASER**. The light source is placed at one end of the optical fiber
 - Light that hits the glass core of the fiber at a certain angle, known as the **critical angle**, is transmitted down through it by **total internal reflection**.
 - The detector, which is placed at the other end of the fiber, is usually a **Photo Diode** and it generates an electrical pulse when light falls on it.

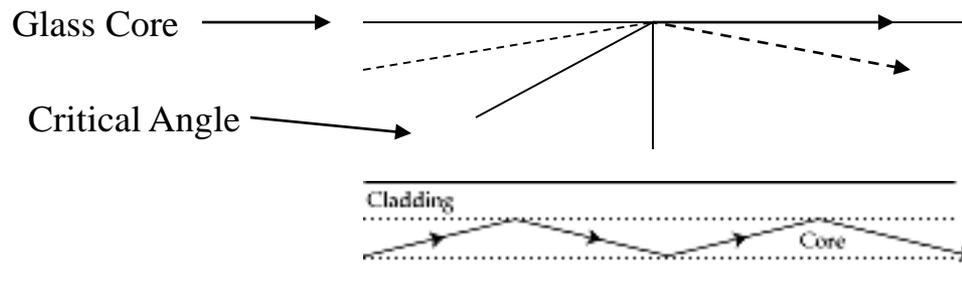


Fig. Diagram of Total Internal Reflection

- **How light travels in a fiber optic cable**
 - Hence by attaching a light source on one end of an optical fiber and a detector at the other end, we have a unidirectional data transmission system (Simplex)
 - The light source would accept an electrical signal, convert and transmit it as light pulses
 - The detector at the far end reconverts the light pulses into an electrical signal to be then interpreted as 1 or a 0.
 - The typical response time of the photodiode when light falls on it is 1 nanosecond. This limits the data rate to 1Gb/sec (1×10^9 bits / sec)

- **Two types of fiber**

- **Stepped Index Fiber:**

- This is where the glass cladding has a lower refractive index than the glass core. The refractive index of the glass core does not change over the length of the optical fiber

- **Graded Index Fiber:**

- This is where the glass cladding has a lower refractive index than the glass core. The refractive index of the glass core changes as you move down the glass core.
- The light rays are redirected towards the central axis of the core as they travel through the fiber.

- **Transmission through a fiber**
 - All rays with an incident angle greater than the critical angle will be trapped in the fiber.
 - Not all of these rays will be guided through the fiber, only some directions are allowed.
 - These allowed directions are called **modes** and their angles satisfy the conditions for **constructive interference** due to the wave nature of light.
 - All the light rays that do not satisfy these conditions will disappear due to destructive interference.

- **Transmission through a fiber**
 - Each light ray is said to have a different mode, so a fiber that allows a lot of rays to travel through it is called a **multimode** fiber.
 - This type of fiber is approximately 50 microns in diameter (width of a human hair) and is used in short distances (up to a few kilometers).
 - A **monomode** (or single mode) fiber is one that allows a small number of wavelengths of light to pass down it.
 - Monomode fibers are typically 8-10 microns in diameter and light rays travel in a straight line (i.e. no bouncing) through them.
 - Monomode fibers are more expensive since they use lasers but they can cover larger distances (approx. 100km).

- Advantages of Fiber Optic over Copper Cable
 - Fiber can handle much higher data rates than copper
 - More information can be sent in one second using fiber
 - Fiber has low loss of signal power (**attenuation**), so repeaters are needed every 100km rather than every 5km for copper
 - Fiber is not affected by power surges, electromagnetic interference or power failure, or corrosive chemicals in the air
 - Photons of light in a fiber do not affect each other as they have no electrical charge and they are not affected by stray photons outside the fiber
 - In the case of copper, electrons move through the cable and these are affected by each other and by electrons outside the cable
 - Fibers are difficult to tap and therefore excellent for security

- Fibers are thin and lightweight, allowing more cables to fit into a given area
 - 1000 twisted pair cables 1 km long = 800kg
 - 2 optical fiber cables 1km approx = 100kg allows transfer of more data
- **Disadvantages of Fiber Optic over Copper Cable**
 - Fiber technology is relatively new and certain new skills are required in handling it
 - Optical transmission in a fiber is one way only (Simplex)
 - if you want two way communication, then you must use two fibers or else use two frequency bands on the one fiber
 - Fiber optic cables and network interface cards to connect a computer to the fiber are an order of magnitude more expensive than their corresponding copper cable equivalents

- Unguided transmission media
 - Information is usually transmitted by either radio or microwave transmission
- Radio Transmission
 - Radio waves are easy to generate and can travel long distances and penetrate buildings.
 - Radio waves are omni-directional which basically means that they can transmit both ways.
 - The transmitter and receiver do not have to be in direct line of sight

- **Radio Transmission Properties**
 - At low frequencies ($<100\text{MHz}$) radio waves pass through obstacles well but the signal power attenuates (falls off) sharply in air
 - At higher frequencies ($>100\text{MHz}$) radio waves tend to travel in straight lines and bounce off obstacles and can be absorbed by rain (e.g. in the 8GHz range)
 - At all frequencies, radio waves are subject to interference from motors and other electrical equipment
 - In very low frequencies (VLF), low frequencies (LF) and medium frequency bands (MF) ($<1\text{MHz}$) radio waves follow the ground.
 - The maximum possible distance that these waves can travel is approximately 1000km
 - AM radio stations use the MF band as they can penetrate buildings. Their main problem is their relatively low data rates

- **Radio Transmission Properties**
 - In high frequency (HF) and very high frequency (VHF) bands ($> 1\text{MHz}$ and $<100\text{MHz}$) ground waves are absorbed by the earth
 - Waves that reach the outer atmosphere of the earth, the ionosphere, are refracted by it and sent back to earth
 - These frequencies tend to be used by amateur radio operators (ham radio) and the military

- **Microwave Transmission**
 - Above 100MHz, waves travel in straight lines and can be narrowly focused into a small beam using a special parabolic antenna
 - The transmitters and receivers must be aligned correctly
 - Multiple transmitters and receivers can be set up in parallel without interfering with each other
 - Repeaters are needed to retransmit the signals due to the curvature of the earth. Typically, transmitting towers are 100 metres high and repeaters are needed every 80km
 - Unlike radio waves, microwaves typically do not pass through solid objects
 - Some Waves can be refracted due to atmospheric conditions and may take longer to arrive than direct waves. These delayed waves can arrive out of phase with the direct wave, causing **destructive interference** and corrupting the received signal
 - This effect is called **multipath fading**

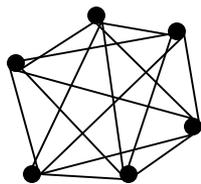
- **Microwave Transmission**
 - Because of increased demand for more spectrum (frequencies used to transmit), transmitters are using higher and higher frequencies
 - However at around 8Ghz, the signal can be absorbed by water. Therefore links have to be shutdown when it rains.
 - Microwave communication is widely used for long distance telephone communication and cell phones
- **Advantages of Microwave over Fiber Optics**
 - No need to lay cables:
 1. This causes less disruption to the areas where the microwave transmitters and receivers are placed
 2. This also means that microwave communication is less expensive than fiber optic cable

- ## Telephone System

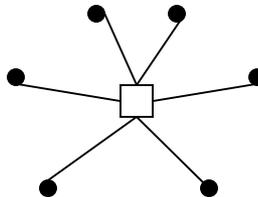
 1. Enabling two computers in the same room to communicate is relatively easy, simply run a cable to connect one to the other
 2. If computers are further apart (e.g. in different cities), network designers need to rely on the existing telecommunications facility
 3. The telephone system was designed and patented in 1876 by Alexander Graham Bell with the aim of transmitting human voice in some form.
 4. Traditionally, telephone lines have been copper resulting in **slow** and **unreliable** transmission of data
 1. Telephone companies have made huge efforts to upgrade their systems to fiber optic cable.
 5. The reason for telephone companies to upgrade is that LANs can transfer data between computers at up to 10^8 bps while a domestic telephone line can transfer data at 10^4 bps

- Telephone System

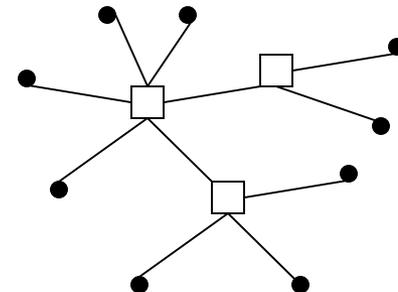
- During the early development of the telephone system, telephones were sold in pairs.
 - Customers bought two phones and connected a line between them
 - This resulted in wires everywhere. To tidy up the lines, a central switching office was set up
 - Customers had a line to the central office and were connected to other customers by human operators
1. Secondary switching offices were needed as demand grew



Fully Connected

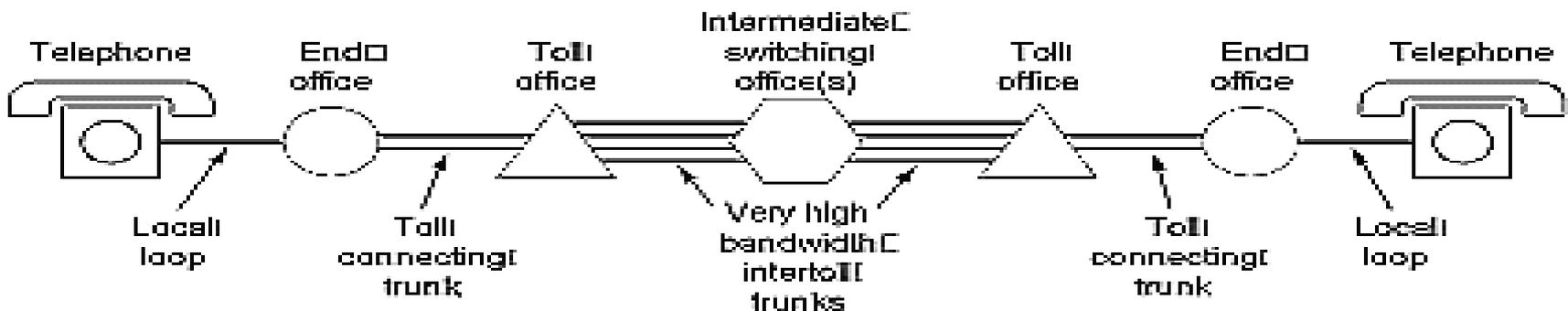


Centralised Switch



Two level hierarchy

- Making a medium distance call
 1. Today, telephones are connected to a local switching office (also called an end office)
 2. A number of End offices are connected to a Toll office which are in turn connected to Intermediate switching offices
 3. Toll offices are connected to Intermediate switching offices using fiber optical cable
 4. Many calls at a toll office are **multiplexed** onto the high speed links to the Intermediate switching office and **de-multiplexed** at the remote toll office



- **Multiplexing Schemes**
 - There are two basic categories of Multiplexing schemes :
 - FDM - Frequency Division Multiplexing**
 - TDM - Time Division Multiplexing**
 - AM radio broadcasting provides illustrations of both kinds of multiplexing
 - The allocated frequency spectrum is about 1MHz, roughly 500 to 1500kHz. Different frequencies are allocated to different logical channels (stations), each operating in a portion of the spectrum with the interchannel separation sufficient to ensure no interference. (**FDM**)
 - In addition it is possible to have two alternate subchannels operating on the same frequency. E.g. music then advertising, then music ... (**TDM**)

- Frequency Division Multiplexing
 - Filters limit the usable bandwidth to about 3000Hz per voice-grade channel
 - Each voice channel is then raised in frequency, each by a different amount.
 - No channels now occupy the same portion of the frequency spectrum, so they can now be combined.
 - The FDM schemes used around the world are to some degree standardized.
 - A variation of FDM for Fiber optic channels Wavelength Division Multiplexing (WDM) is used.
 - Here two fibers come together at their diffraction grating, each with its energy in a different band, and combined onto a single shared fiber, where transmission takes place.
 - Popular as fiber optics are reliable and very fast.

- Time Division Multiplexing
 - FDM requires analog circuitry and is not amenable to being done by a computer, unlike TDM which can be handled completely by digital electronics.
 - Unfortunately TDM can only be used for digital data, therefore multiple analog signals must be digitized and combined onto a single outgoing channel.
 - The analog signals are digitized by a device called a coder-decoder, producing a 8-bit number. Samples are taken /second, sucha that at a lower sampling rate information would be lost, at a higher one, nothing would be gained, called Pulse Code Modulation (PCM)
 - There is no agreed international standard for PCM, for example T1 in US, Japan.
 - TDM allows multiple different T1 carriers to be multiplexed into higher-order carriers, with all given a certain amount of time to use the channel in a round-robin fashion.