The Physical Layer

Physical Layer

- The physical layer deals with **transporting bits between two machines**.
- How do we communicate 0's and 1's across a medium?
  - By varying some sort of physical property such as **voltage** or **current**.
- Our goal is to understand what happens to a signal as it travels across some physical media. That is, will the receiver see the exact same signal generated by the sender? Why or why not?

The basis for Data communication

Information can be transmitted on wires by varying some physical property such as **voltage** or **current**.

By representing the value of this voltage or current as a single-valued function of time, f(t), we can model the behavior of the signal and analyze it mathematically. This analysis is the subject of the following sections.

1. **Fourier Analysis**
2. **Bandwidth-Limited Signals**
3. **The Maximum Data Rate of a Channel**

So what does this have to do with data communication? The following facts are important:

1. Signals attenuate (strength of signal falls with distance) during transmission. The exact amount is dependent on physical properties of the medium.

2. Distortion results because attenuation is non-uniform across the frequency spectrum; some frequencies distort more than others.

3. A transmission medium carries signals lying within in a spectrum or range of frequencies; the absolute width of the spectrum is called the bandwidth of the channel.

❑ **Conclusion**: It's essentially impossible to receive the exact signal that was sent. The key is to receive enough of the signal so that the receiver can figure out what the original signal was.

➢ **Note**: “**bandwidth**" - the term “bandwidth" is often also used to refer to the data rate of the channel, in bps.

Factors determining the rate of data transmission

1. **The baud rate** (also known as the modulation rate) refers to **the maximum rate at which the signal changes value** (e.g., switches voltages).

   - For example, if “0"s and “1"s were represented as +5V, -5V, respectively, the baud rate would refer to the number of times per second the signal switches as its transmitting a string of alternating 0's and 1’s.
   - Note that we can potentially achieve a higher data rate by switching the voltage faster.

2. **The encoding method** determines the amount of information carried in one baud.
   - In our example we encoded only one bit of information (0 or 1).
   - For example, 0, 1, 2, 3 could be represented as -10, -5, +5 and +10 volts respectively.

Note: baud rate is not the same thing as the data rate. For a given baud rate, we can increase the data rate by changing the encoding method.

Guided Transmission Media

- Guided (a physical path) vs. unguided media (waves propagated, but not in a directed manner).

❖Guided Transmission Media
  - Magnetic media
  - Twisted pairs
  - Coaxial cable
  - Power lines
  - Fiber optics

Magnetic media

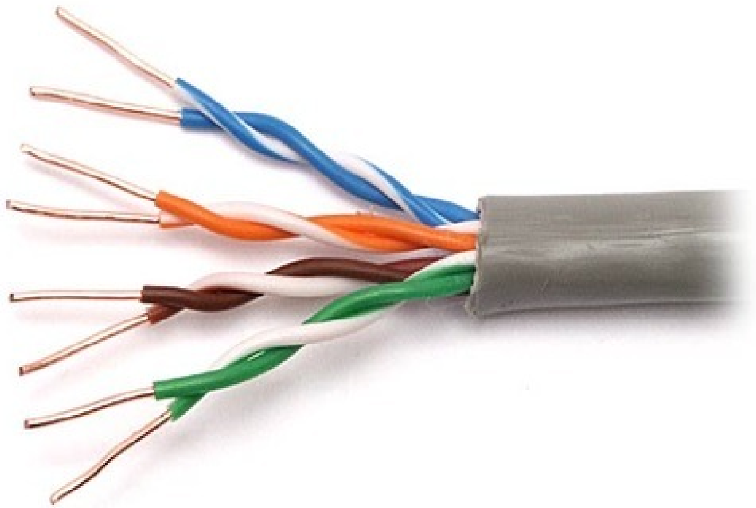
- One of the most common ways to transport data from one computer to another is to write them onto magnetic tape or removable media (e.g., recordable DVDs), physically transport the tape or disks to the destination machine, and read them back in again.

- Magnetic storage uses different patterns of magnetisation in a magnetisable material to store data and is a form of non-volatile memory.
- There are 3 types of magnetic media storage : - 1. **Hard Drive** 2. **Floppy Disk** 3. **Tapes**

Twisted pairs

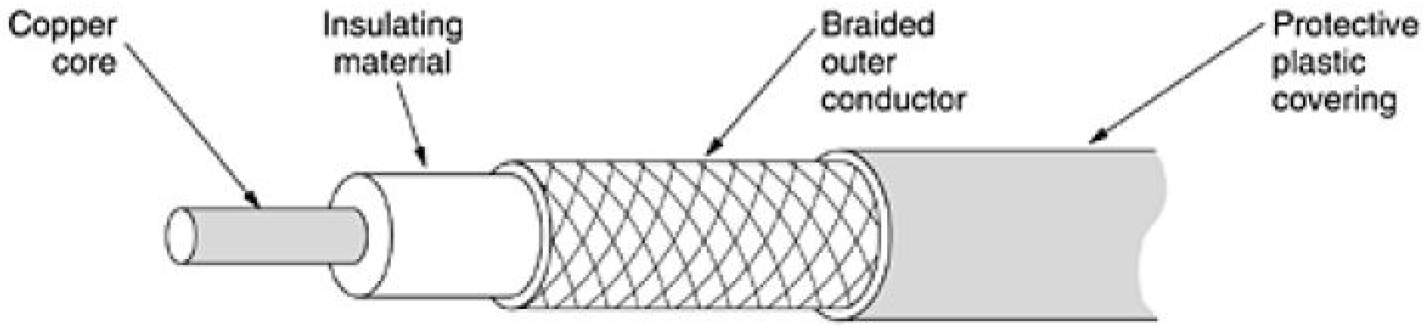
In twisted pair technology, two copper wires are strung between sites:

- The two wires are typically “twisted" together in a helix to reduce interference between the two conductors.
- Can carry analog or digital signals. Actually, they carry only analog signals. However, the “analog" signals can very closely correspond to the square waves representing bits, so we often think of them as carrying digital data.
- Data rates of several Mbps common.
- Spans distances of several kilometers.
- Data rate determined by wire thickness and length. In addition, shielding to eliminate interference from other wires impacts S/N, and ultimately, the data rate.
- Good, low-cost communication. Indeed, many sites already have twisted pair installed in offices -- existing phone lines!



Coaxial cable

- With “coax", the medium consists of a **copper core surrounded by insulating material** and a braided outer conductor.
- Coaxial cable is a type of cable that has an inner conductor surrounded by an insulating layer, surrounded by a conductive shielding.
- Many also have an insulating outer jacket .
- Electrical signal flows through the center conductor.



Fiber optics

- In fiber optic technology, the medium consists of a hair-width strand of silicon or glass, and the signal consists of pulses of light. For instance, a **pulse of light means “1"**, **lack of pulse means “0".**
- Three components are required:
  1. **Fiber medium**: Current technology carries light pulses for tremendous distances (e.g., 100s of kilometers) with virtually no signal loss.
  2. **Light source**: typically a Light Emitting Diode (LED) or laser diode. Running current through the material generates a pulse of light.
  3. **A photo diode light detector**, which converts light pulses into electrical signals.

Advantages:

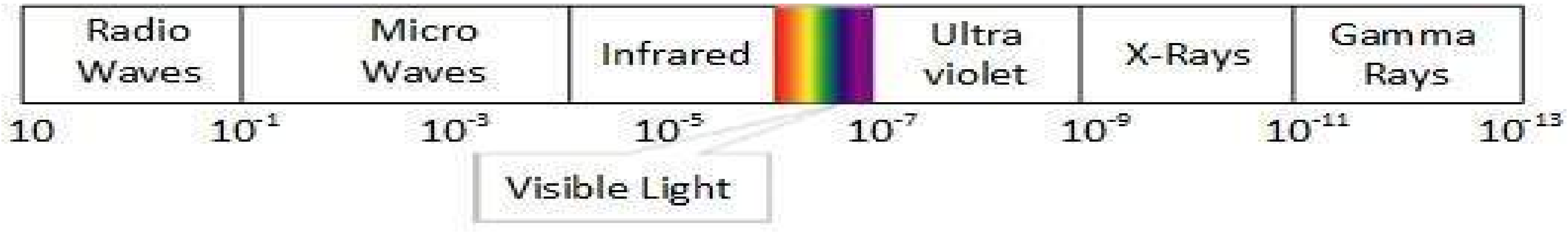
1. Tremendously high data rate, low error rate. 1000 Mbps (1 Gbps) over distances of kilometers common. Error rates are so low they are almost negligible.
2. Difficult to tap, which makes it hard for unauthorized taps as well.
3. Much thinner (per logical phone line) than existing copper circuits. Because of its thinness, phone companies can replace thick copper wiring with fibers having much more capacity for same volume.
4. Not susceptible to electrical interference (lightning) or corrosion (rust).
5. Greater repeater distance than coax.

Disadvantages:

1. Difficult to tap. It really is point-to-point technology. In contrast, tapping into coax is trivial. No special training or expensive tools or parts are required.
2. One way channel. Two fibers needed to get full duplex (both ways) communication.

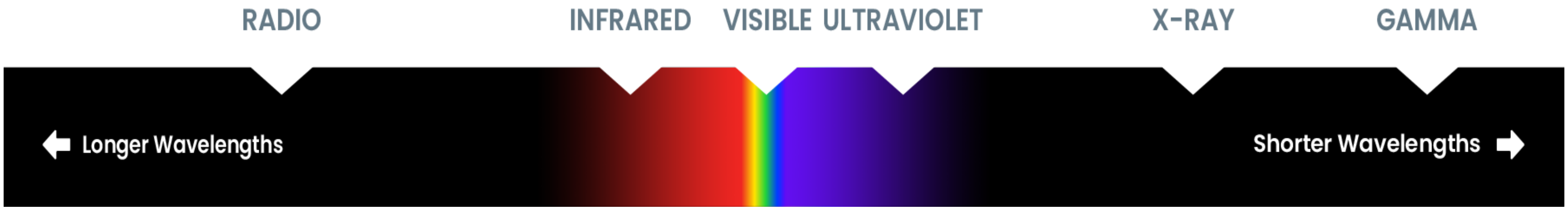
Wireless Transmission

- Wireless transmission is a form of **unguided media**.
- Wireless communication involves **no physical link established between two or more devices,** communicating wirelessly.
- Wireless signals are spread over in the air and are received and interpreted by appropriate antennas.
- When an antenna is attached to electrical circuit of a computer or wireless device, it converts the digital data into wireless signals and spread all over within its frequency range. The receptor on the other end receives these signals and converts them back to digital data.
- A little part of electromagnetic spectrum can be used for wireless transmission.



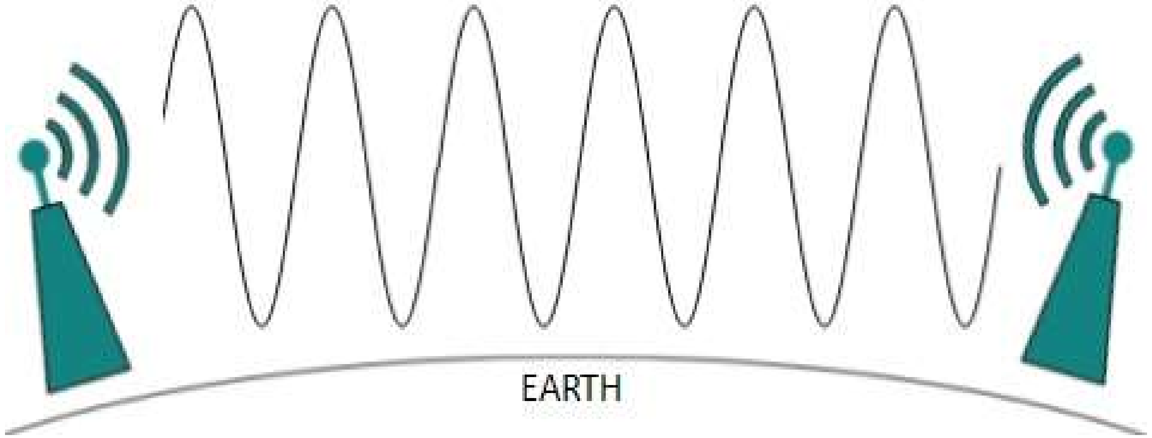
The Electromagnetic Spectrum

- Electromagnetic radiation is one of the many ways that **energy travels through space**.
- The heat from a burning fire, the light from the sun, the X-rays used by your doctor, as well as the energy used to cook food in a microwave are all forms of electromagnetic radiation.
- While these forms of energy might seem quite different from one another, they are related in that they all exhibit **wavelike** properties.
- Electromagnetic waves can be classified and arranged according to their various wavelengths/frequencies; this classification is known as the **electromagnetic spectrum**.

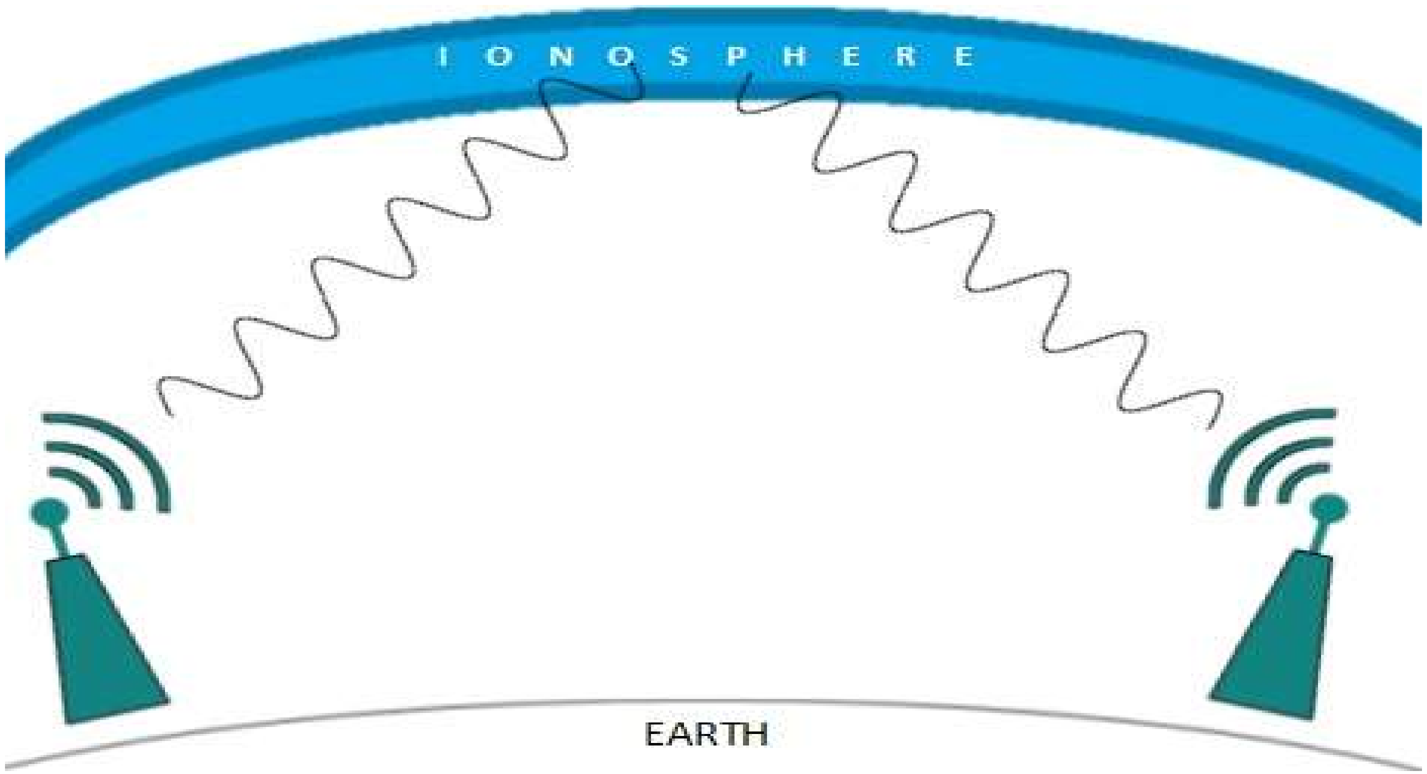


Radio Transmission

- Radio frequency is easier to generate and because of its **large wavelength** it can **penetrate through walls and structures alike.**
- Radio waves can have wavelength from **1 mm – 100,000 km** and have frequency ranging from **3 Hz** (Extremely Low Frequency) to **300 GHz** (Extremely High Frequency).
- Radio waves at ***lower frequencies can travel through walls*** whereas ***higher RF can travel in straight line and bounce back.***
- The power of low frequency waves decreases sharply as they cover long distance. High frequency radio waves have more power.
- Lower frequencies such as VLF, LF, MF bands can travel on the ground up to 1000 kilometers, over the earth's surface.

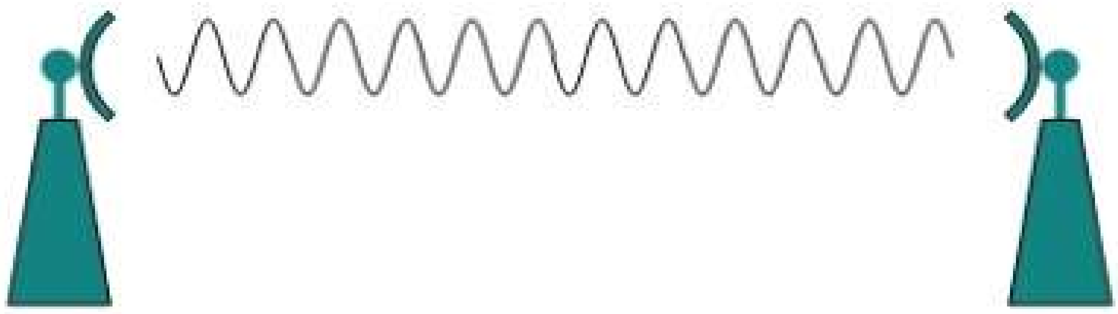


- Radio waves of high frequencies are prone to be absorbed by rain and other obstacles.
- They use **Ionosphere** of earth atmosphere.
- High frequency radio waves such as HF and VHF bands are spread upwards. When they reach Ionosphere, they are refracted back to the earth.



Microwave Transmission

- Electromagnetic waves above **100 MHz** tend to **travel in a straight line** and signals over them can be sent by beaming those waves towards one particular station.
- Because Microwaves travels in straight lines, both sender and receiver must be aligned to be strictly in line-of-sight.
- Microwaves can have wavelength ranging from **1 mm – 1 meter** and frequency ranging from **300 MHz to 300 GHz.**



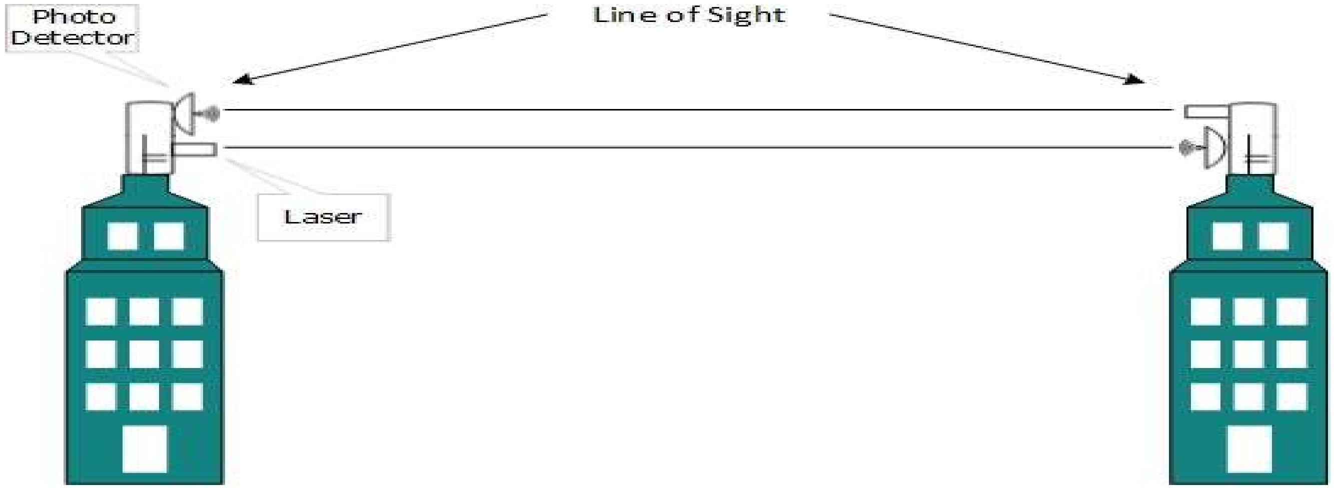
- Microwave antennas concentrate the waves making a beam of it. As shown in picture above, multiple antennas can be aligned to reach farther. Microwaves have higher frequencies and do not penetrate wall like obstacles.
- Microwave transmission depends highly upon the weather conditions and the frequency it is using.

Infrared Transmission

- Infrared wave lies in ***between*** **visible light spectrum** and **microwaves**. It has wavelength of **700-nm** to **1-mm** and frequency ranges from **300-GHz to 430-THz**.
- Infrared wave is used for very **short range communication** purposes such as **television** and it’s **remote**.
- Infrared travels in a straight line hence it is directional by nature.

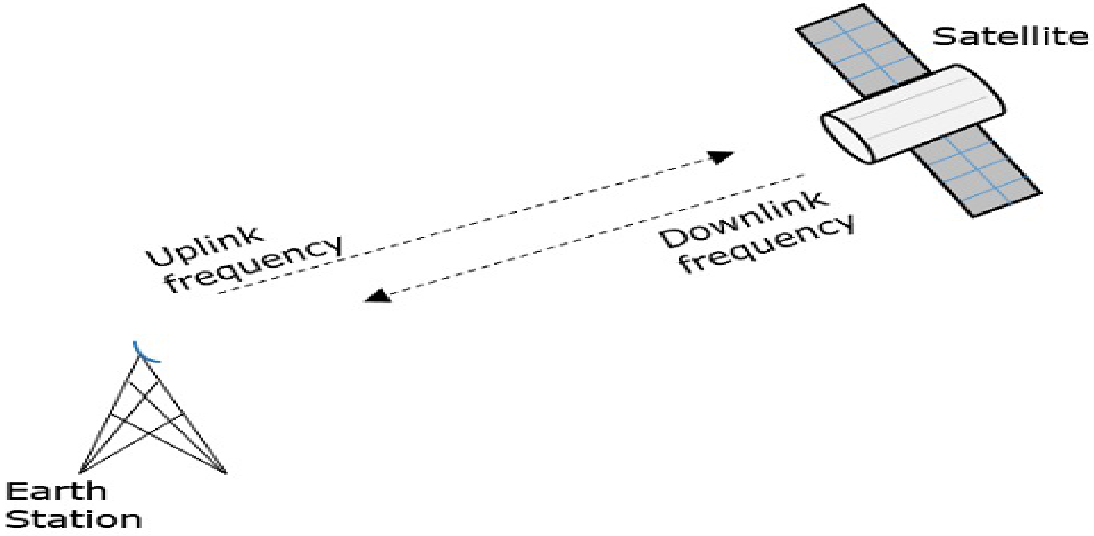
Light Transmission

- Highest most electromagnetic spectrum which can be used for data transmission is **light** or **optical signaling**. This is achieved by means of **LASER**.
- Because of frequency light uses, it tends to travel strictly in straight line.
- Hence the sender and receiver must be in the **line-of-sight**. Because laser transmission is unidirectional, at both ends of communication the laser and the photo-detector needs to be installed.
- **Laser works as Tx (transmitter)** and **photo-detectors works as Rx (receiver).**
- Laser is safe for data transmission as it is very difficult to tap 1mm wide laser without interrupting the communication channel.



Communication Satellites

- A **satellite** is a body that moves around another body in a mathematically predictable path called an **Orbit**. A communication satellite is nothing but a microwave repeater station in space that is helpful in **telecommunications**, **radio**, and **television** along with **internet** applications.
- A **repeater** is a circuit which increases the strength of the signal it receives and retransmits it. But here this repeater works as a **transponder**, which changes the frequency band of the transmitted signal, from the received one.
- The frequency with which the signal is sent into the space is called **Uplink frequency**, while the frequency with which it is sent by the transponder is **Downlink frequency**.



Satellite Communication − Applications

Satellite communication finds its applications in the following areas −

- In Radio broadcasting.
- In TV broadcasting such as DTH.
- In Internet applications such as providing Internet connection for data transfer, GPS applications, Internet surfing, etc.
- For voice communications.
- For research and development sector, in many areas.
- In military applications and navigations.

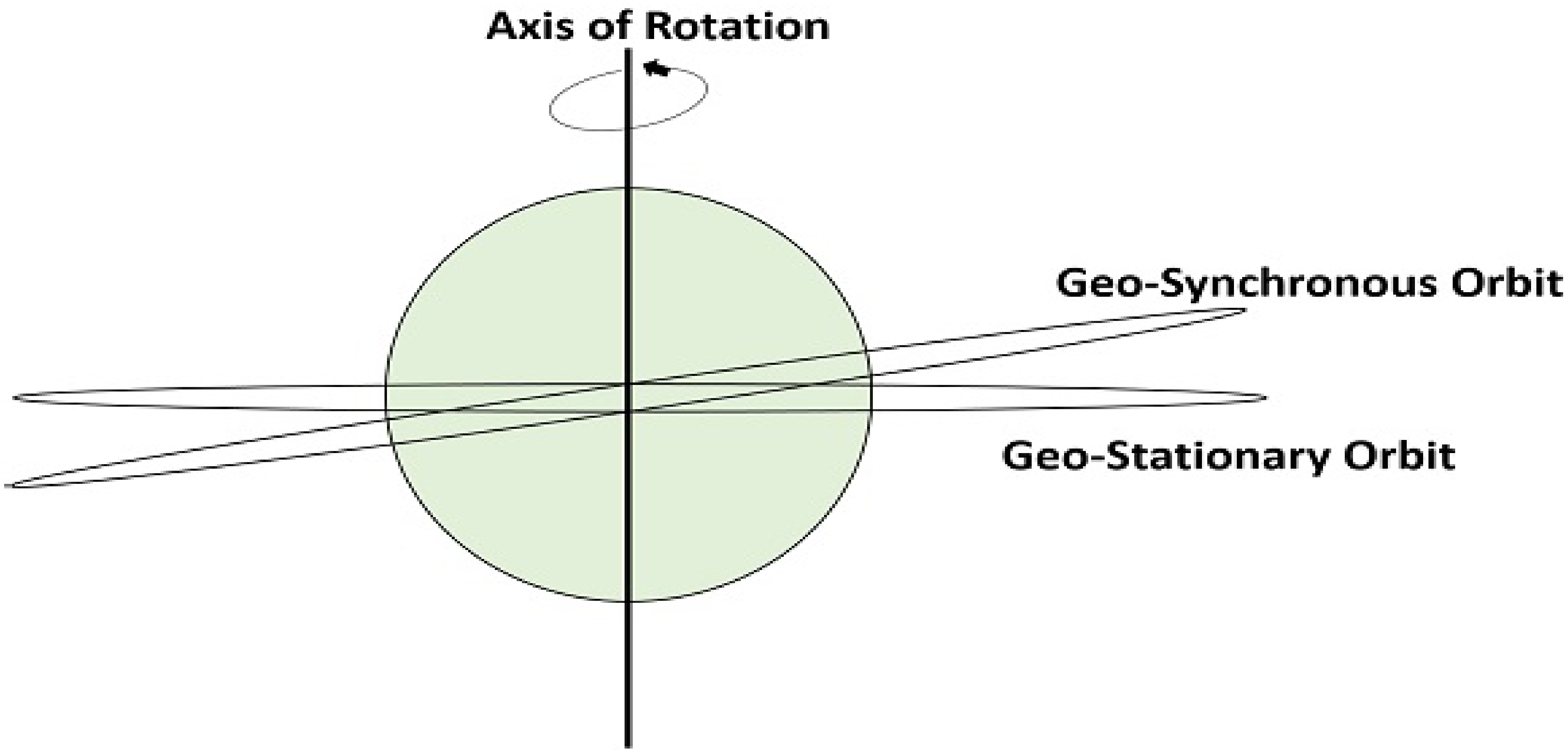
Earth Orbits

- A satellite when launched into space, needs to be placed in a certain orbit to provide a **particular way for its revolution**, so as to **maintain accessibility** and **serve its purpose** whether scientific, military, or commercial.
- Such orbits which are assigned to satellites, with respect to earth are called as **Earth Orbits**. The satellites in these orbits are **Earth Orbit Satellites**.

- The important kinds of Earth Orbits are −
    1. **Geo Synchronous Earth Orbit**
    2. **Medium Earth Orbit**
    3. **Low Earth Orbit**

Geosynchronous Earth Orbit Satellites

- A **Geo-Synchronous Earth Orbit (GEO)** satellite is one which is placed at an altitude of 22,300 miles above the Earth.
- This orbit is synchronized with a **side real day** (i.e., 23hours 56minutes). This orbit can have **inclination and eccentricity**. It may not be circular. This orbit can be tilted at the poles of the earth. But it appears stationary when observed from the Earth.
- The same **geo-synchronous orbit**, if it is circular and in the plane of equator, it is called as **geo-stationary orbit**. These satellites are placed at 35,900kms (same as geosynchronous) above the Earth's Equator and they keep on rotating with respect to earth's direction (west to east). These satellites are considered stationary with respect to earth and hence the name implies.
- ***Geo-Stationary Earth Orbit Satellites*** are used for **weather forecasting**, **satellite TV**, **satellite radio** and other types of **global communications**.
- The following figure shows the difference between Geo-synchronous and Geo-stationary orbits. The axis of rotation indicates the movement of Earth.



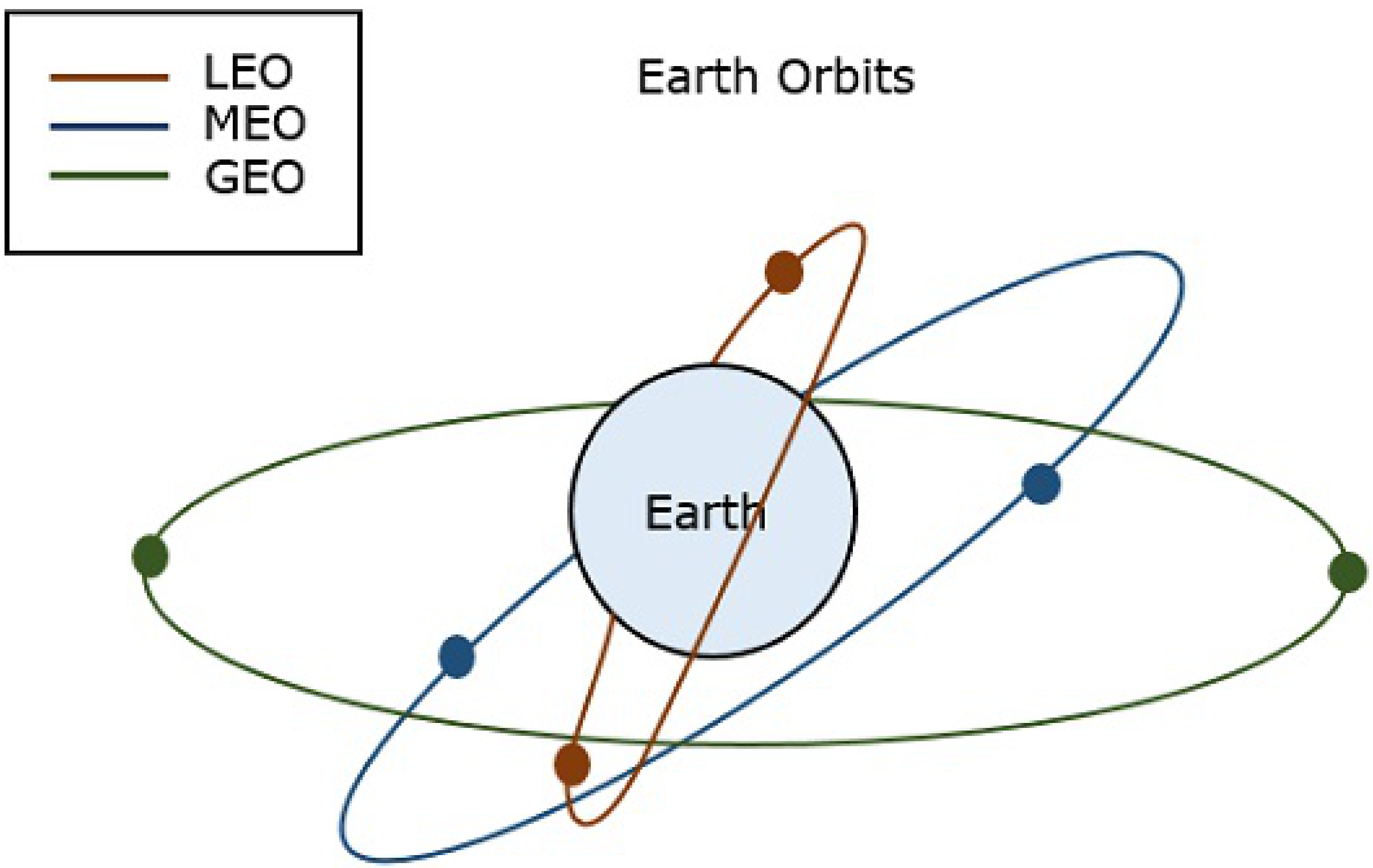
Note − Every geo-stationary orbit is a geo-synchronous orbit. But every geo-synchronous orbit is NOT a Geo-stationary orbit.

Medium Earth Orbit Satellites

- **Medium Earth Orbit (MEO)** satellite networks will orbit at distances of about **8000 miles** from the earth's surface.
- Signals transmitted from a MEO satellite travel a shorter distance. This translates to improved signal strength at the receiving end. This shows that smaller, more lightweight receiving terminals can be used at the receiving end.
- Since the signal is travelling a shorter distance to and from the satellite, there is less transmission delay. **Transmission delay** can be defined as the time it takes for a signal to travel up to a satellite and back down to a receiving station.
- For real-time communications, the shorter the transmission delay, the better will be the communication system.

Low Earth Orbit Satellites

- The Low Earth Orbit (LEO) satellites are mainly classified into three categories namely, **little LEOs**, **big LEOs**, and **Mega-LEOs**.
- LEOs will orbit at a distance of 500 to 1000 miles above the earth's surface.
- This relatively short distance reduces transmission delay to only 0.05 seconds. This further reduces the need for sensitive and bulky receiving equipment.
  - Little LEOs will operate in the 800 MHz (0.8 GHz) range.
  - Big LEOs will operate in the 2 GHz or above range
  - Mega-LEOs operates in the 20-30 GHz range.
- The higher frequencies associated with **Mega-LEOs** translates into more information carrying capacity and yields to the capability of real-time, low delay video transmission scheme.
- The following figure depicts the paths of LEO, MEO, and GEO.


LEO
MEO
GEO
Earth Orbits
Earth

Digital Modulation and Multiplexing

- **Modulation:-** Modulation is the process of transforming a carrier signal so that it can carry the information of a message signal. It super imposes the contents of the message signal over a high-frequency carrier signal, which is then transmitted over communication channels.
- Modulation can be of two types:
  - **Analog Modulation**
  - **Digital Modulation**

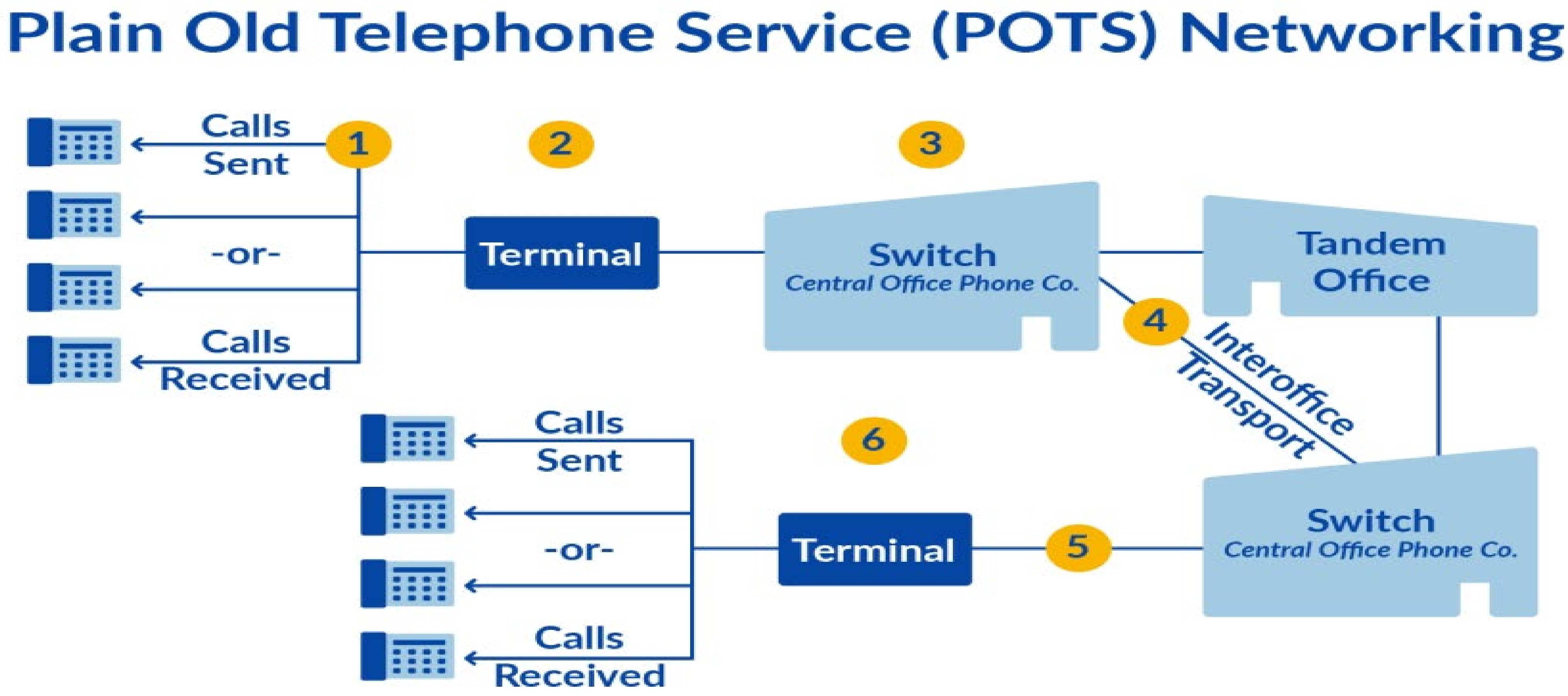
- **Analog Modulation**
  - The analog information signal is transformed to the analog carrier signal so that it can travel large distances without substantial loss.
  - Analog modulation can be of three types:
    - Amplitude Modulation
    - Frequency Modulation
    - Phase Modulation
- **Digital Modulation**
  - Digital modulation is the process of converting a digital bit stream into an analog carrier wave for transmission via a communication channel.
  - Digital modulation is broadly divided into two categories:
    - **Bandpass Modulation as in baseband transmission:** Here, the bits are converted directly into signals.
    - **Passband Modulation as in passband transmission:** Here, the amplitude, phase or frequency of the carrier signal is regulated to transmit the bits.

Multiplexing

- This is a method of **combining more than one signal over a shared medium**.
- Multiplexing divides the capacity of a communication channel into several logical channels, each for a data stream.
- The method of extracting the original data streams from the multiplexed signal is called **demultiplexing**.

The Public Switched Telephone Network,

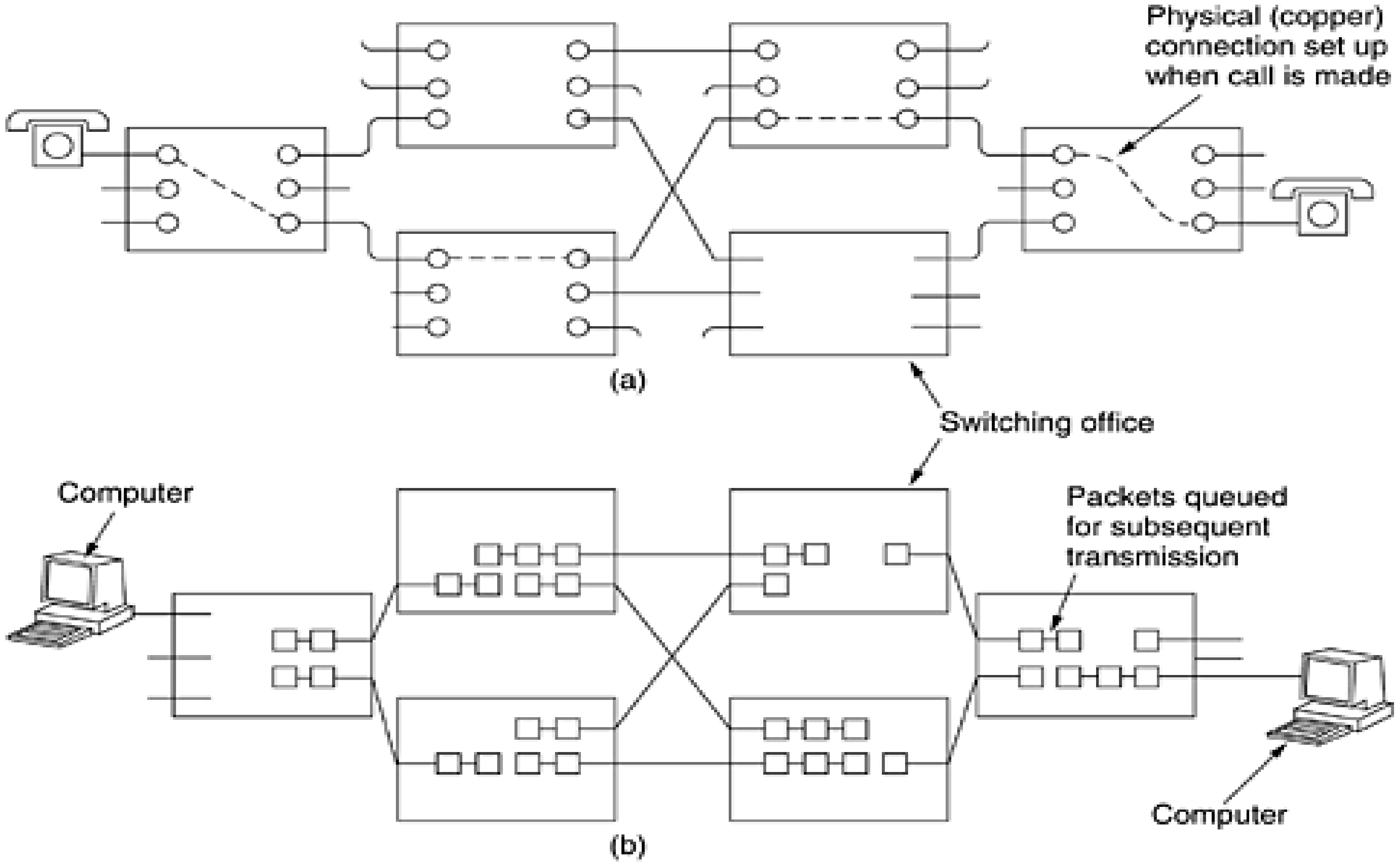
- PSTN stands for **Public Switched Telephone Network**, or the traditional circuit-switched telephone network. This is the system that has been in general use since the late 1800s.



Two different switching techniques are used nowadays: circuit switching and packet switching

1. Circuit Switching

- When you or your computer places a telephone call, the switching equipment within the telephone system seeks out a physical path all the way from your telephone to the receiver's telephone. This technique is called **circuit switching.**
- An important property of circuit switching is the need to set up an **end-to-end path** before any data can be sent.
- The elapsed time between the end of dialing and the start of ringing can easily be 10 sec, more on long-distance or international calls.

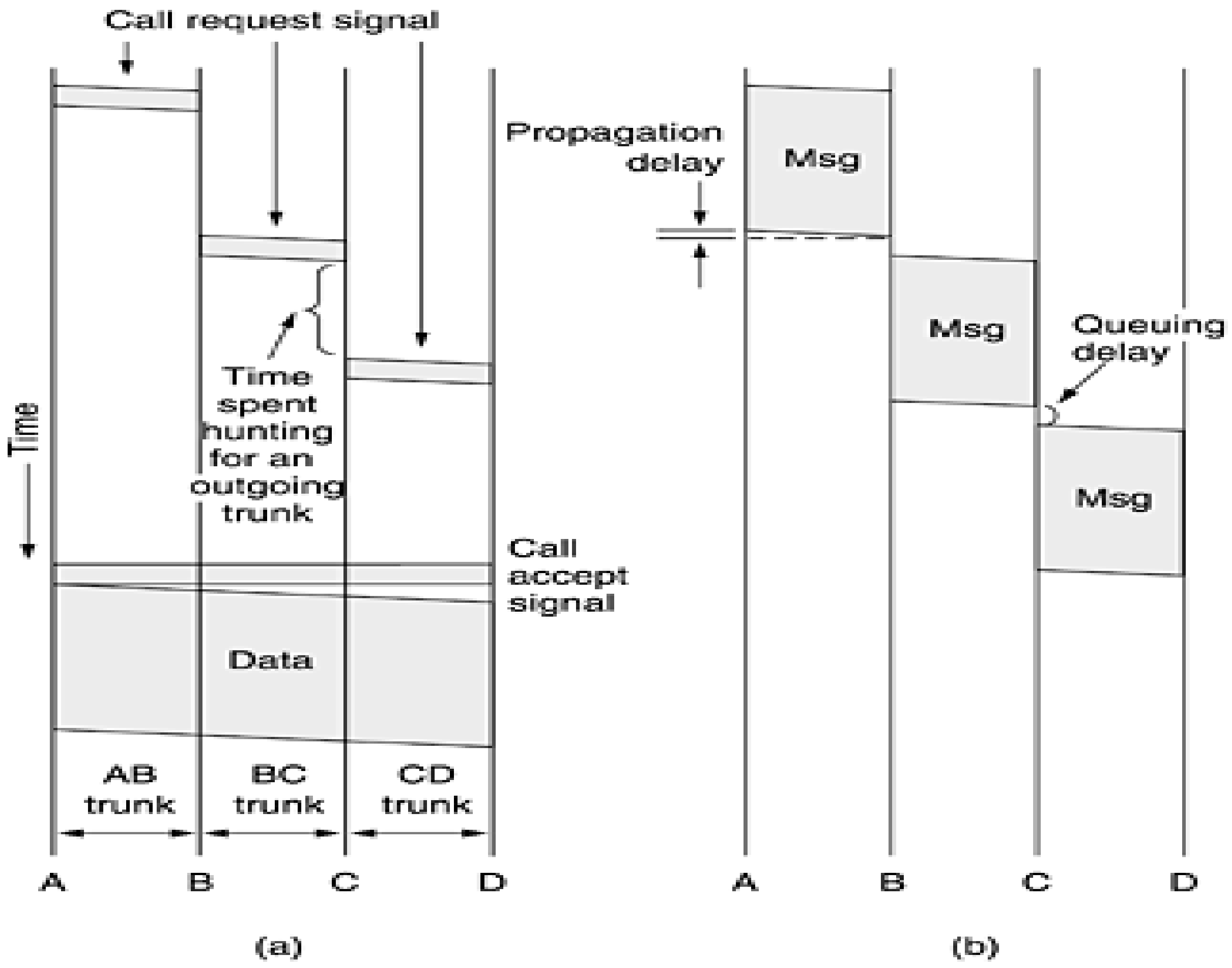


Physical (copper) connection set up when call is made
(a)
Switching office
Computer
Packets queued for subsequent transmission
Computer
(b)

Message Switching

- In message switching **no physical path is established** in advance between sender and receiver.
- Instead, when the sender has a block of data to be sent, it is stored in the first switching office (i.e., router) and then forwarded later, one hop at a time.
- Each block is received in its entirety, inspected for errors, and then retransmitted.
- A network using this technique is called a **store-and-forward network**.
- The first electromechanical telecommunication systems used message switching, namely, for **telegrams**. The message was punched on paper tape (off-line) at the sending office, and then read in and transmitted over a communication line to the next office along the way, where it was punched out on paper tape. An operator there tore the tape off and read it in on one of the many tape readers, one reader per outgoing trunk. Such a switching office was called a **torn tape office**.

Timing of events in (a) circuit switching, (b) message switching, (c) packet switching.



Packet Switching

- With message switching, there is no limit at all on block size, which means that routers must have disks to buffer long blocks.
- To get around these problems, packet switching was invented. Packet-switching networks place a **tight upper limit on block size**, allowing packets to be buffered in router main memory instead of on disk.
- Packet-switching networks are well suited for **handling interactive traffic**.
- A further advantage of packet switching over message switching is shown in Fig. 2-39(b) and (c): ***the first packet of a multipacket message can be forwarded before the second one has fully arrived***, *reducing delay and improving throughput.*
- Packet switching does not require any advance setup. The first packet can just be sent as soon as it is available. With packet switching there is **no path,** so different packets can follow different paths, depending on network conditions at the time they are sent. They may arrive out of order.
- Packet switching is more **fault tolerant** than circuit switching. If a switch goes down, all of the circuits using it are terminated and no more traffic can be sent on any of them. With packet switching, packets can be routed around dead switches.
- With packet switching, **no bandwidth is reserved**, so packets may have to wait their turn to be forwarded.

- ***A comparison of circuit-switched and packet-switched networks.***

Item	Circuit switched	Packet switched
Call setup	Required	Not needed
Dedicated physical path	Yes	No
Each packet follows the same route	Yes	No
Packets arrive in order	Yes	No
Is a switch crash fatal	Yes	No
Bandwidth available	Fixed	Dynamic
Time of possible congestion	At setup time	On every packet
Potentially wasted bandwidth	Yes	No
Store-and-forward transmission	No	Yes
Transparency	Yes	No
Charging	Per minute	Per packet

The Mobile Telephone System

Mobile phones have gone through three distinct generations, with different technologies:

- 1. Analog voice.
- 2. Digital voice.
- 3. Digital voice and data (Internet, e-mail, etc.).

Analog voice : First-Generation Mobile Phones

- This system used a single large transmitter on top of a tall building and had a **single channel**, ***used for both sending and receiving.***
- To talk, the user had to push a button that enabled the transmitter and disabled the receiver. Such systems, known as **push-to-talk systems**.
- CB-radio, taxis, and police cars on television programs often use this technology.
- In all mobile phone systems, a geographic region is divided up into cells, which is why the devices are sometimes called **cell phones**.
- The radio signals used by 1G network are **analog**.

❖ **Drawbacks of 1G mobile communications**

- Analog signals were prone to interferences. So the communication was noisy.
- Analog systems did not support adequate encryption systems. So, security was a vital issue and tapping could not be controlled.

Digital voice : Second-Generation Mobile Phones

- The second generation of mobile phones was digital.
- It was commercially launched in 1991 as GSM standard in Finland.

❖ **Advantages of 2G over 1G**

- It allows voice signals to be digitized and compressed. So, they are more efficient on frequency spectrum than 1G.
- They introduced data services for mobile in form of SMS text messaging.
- Data and voice signals are digitally encrypted.
- Digital signals consume less battery power. And so mobile sets are much more energy efficient than their 1G counterparts.

❖ **Popular 2G Systems**

- **D – AMPS (Digital Advanced Mobile Phone Systems)** : D-AMPS was a digital version of advanced mobile phone systems (AMPS) that coexisted with AMPS. It used time division multiplexing (TDM) for multiple calls.

- **GSM (Global System for Mobile Communications)** : 2G was launched through GSM. It is the most widely globally used technology. It uses frequency division multiplexing (FDM) and time division multiplexing (TDM) for handling multiple calls simultaneously.

- **CDMA (Code Division Multiple Access)** : It uses a different technology from the above and was standardized by International Standards IS-95.

Digital voice and data : Third-Generation Mobile Phones

Third generation mobile phones, or “3G Internet” mobile phones, is a set of standards for wireless mobile communication systems, that promises to deliver **quality multimedia services** along with **high quality voice transmission**.

❖ **Features**

- 3G systems comply with the International Mobile Telecommunications-2000 (IMT-2000) specifications by the International Telecommunication Union (ITU).
- The first 3G services were available in 1998.
- It provides high speed transmission having data transfer rate more than 0.2Mbps.
- Global roaming services are available for both voice and data.
- It offers advanced multimedia access like playing music, viewing videos, television services etc.
- It provides access to all advanced Internet services, for example surfing webpages with audio and video.
- It paved the way for the increased usage of smartphones with wide screens as they provided better viewing of mobile webpages, videos and mobile televisions.

Fourth Generation (4G) Mobile Phones

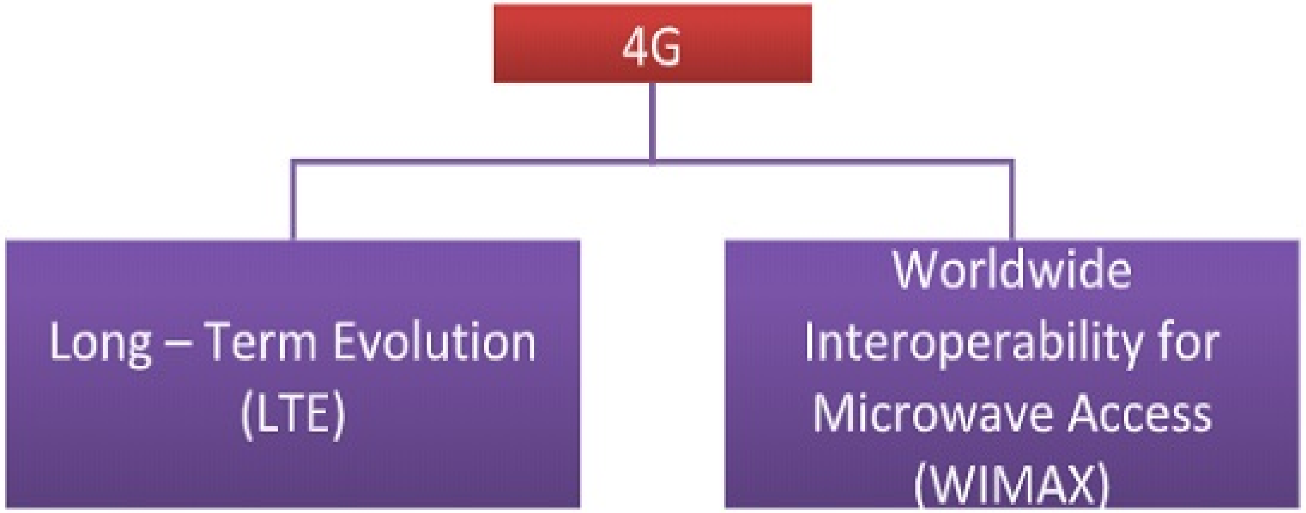
Fourth Generation (4G) mobile phones provides broadband cellular network services and is successor to 3G mobile networks. It provides an all **IP based cellular communications**.

❖ **Features**

- It provides an all IP packet switched network for transmission of voice, data, signals and multimedia.
- It aims to provide high quality uninterrupted services to any location at any time.
- As laid down in IMT-Advanced specifications, 4G networks should have peak data rates of 100Mbps for highly mobile stations like train, car etc., and 1Gbps for low mobility stations like residence etc.
- It also lays down that 4G networks should make it possible for 1 Gbps downlink.

Categories

- 4G comes in two main categories −



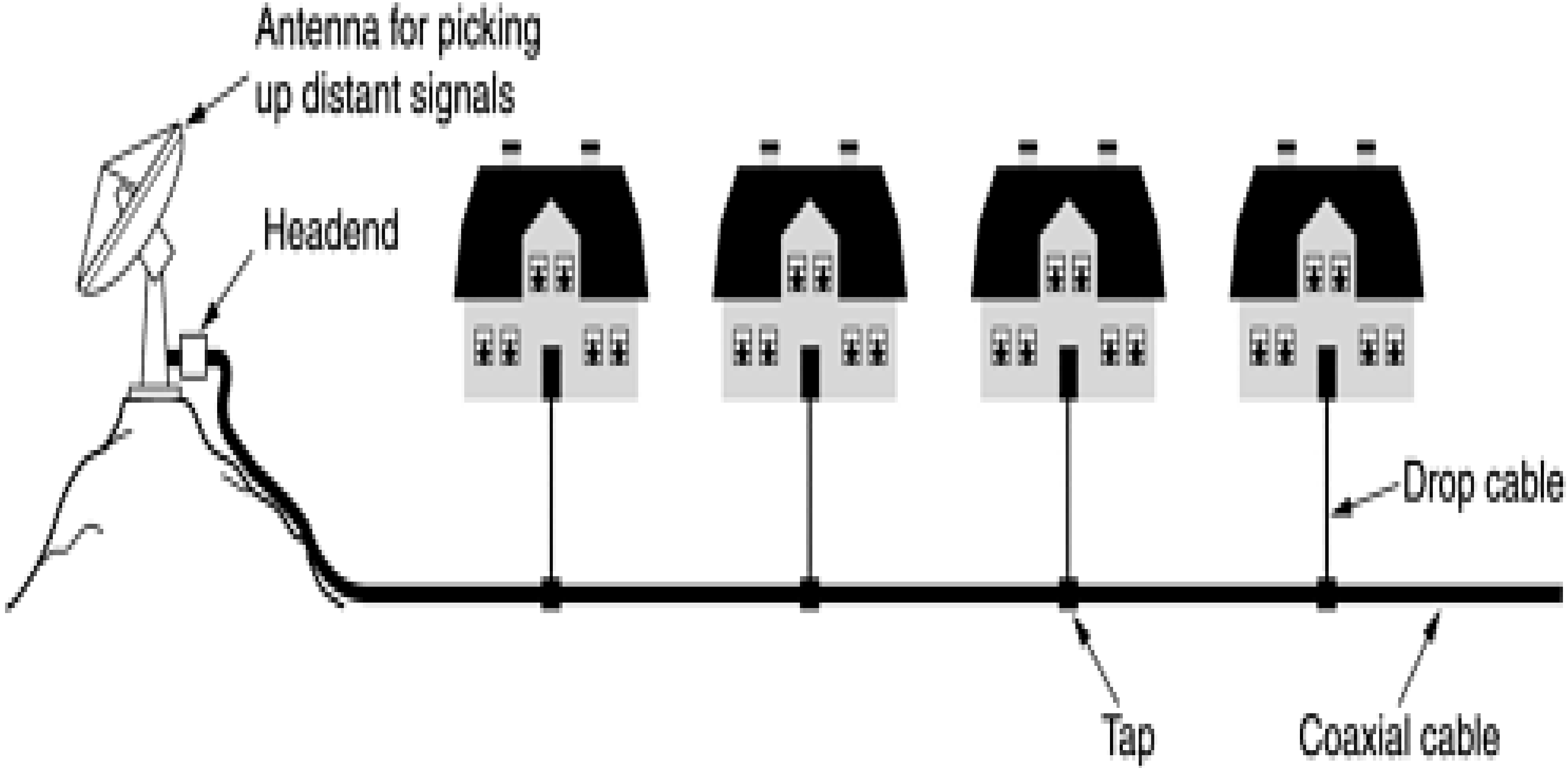
- **Long – Term Evolution (LTE)−** Long – term evolution or LTE is an extension of the 3G technology. It is a standard for high-speed mobile communication, based upon GSM/EDGE and UMTS/HSPA technologies. The peak data rate for download is 100 Mbps and upload is 50 Mbps. Its peak data rates are 1000 Mbps for downlink and 500 Mbps for uplink.

- **Worldwide Interoperability for Microwave Access (WIMAX)−** WiMAX is a mobile wireless broadband access (MWBA) standard is sometimes branded 4G. It offers peak data rates of 128 Mbps for downlink and 56 Mbps for uplink over 20 MHz wide channels.

Cable Television.

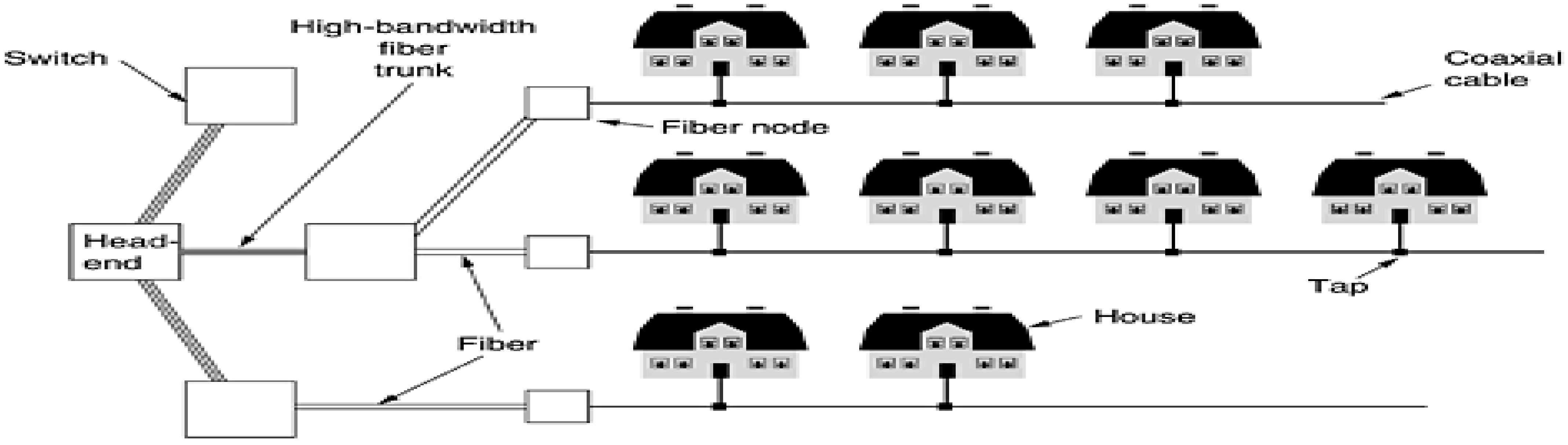
- Many people already get their telephone and Internet service over the cable, and the cable operators are actively working to increase their market share.
- In the following sections we will look at cable television as a networking system in more detail and contrast it with the telephone systems we have just studied.

1. **Community Antenna Television**
    - Cable television was conceived in the late 1940s as a way to provide better reception to people living in rural or mountainous areas.
    - The system initially consisted of a big antenna on top of a hill to pluck the television signal out of the air, an amplifier, called the head end, to strengthen it, and a coaxial cable to deliver it to people's houses


Antenna for picking
up distant signals
Headend
Drop cable
Tap
Coaxial cable

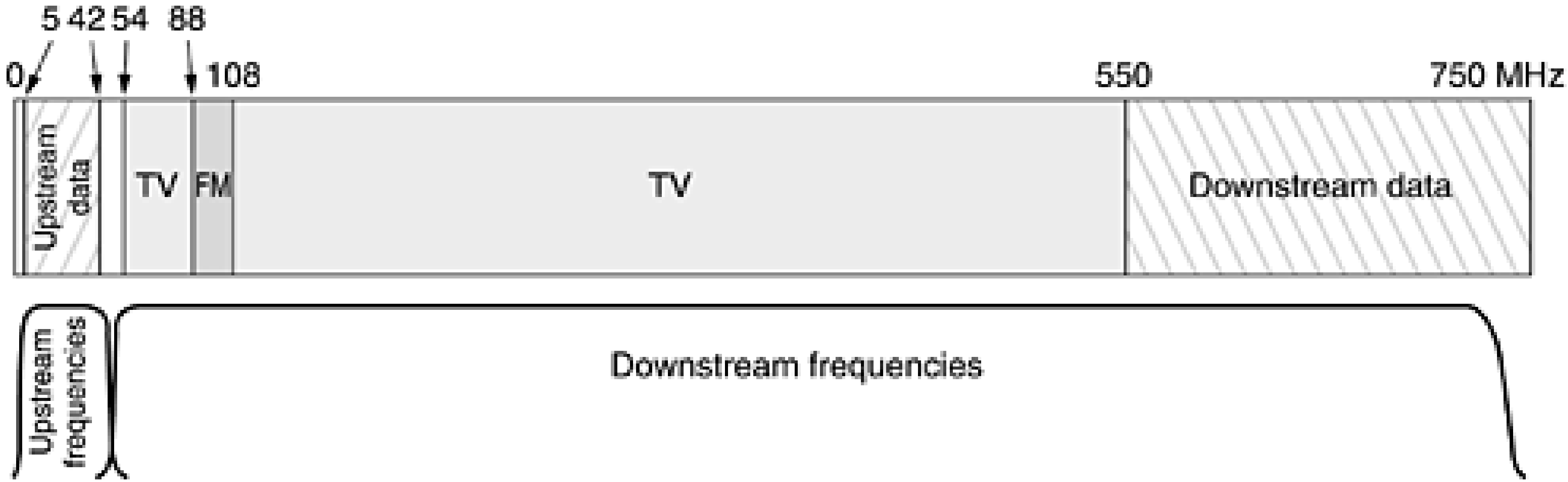
2. Internet over Cable

- Over the course of the years the cable system grew and the cables between the various cities were replaced by high-bandwidth fiber, similar to what was happening in the telephone system.
- A system with fiber for the long haul runs and coaxial cable to the houses is called an **HFC** (Hybrid Fiber Coax) system. The electro-optical converters that interface between the optical and electrical parts of the system are called **fiber nodes**.
- Because the bandwidth of fiber is so much more than that of coax, a fiber node can feed multiple coaxial cables.



3. Spectrum Allocation

- Throwing off all the TV channels and using the cable infrastructure strictly for Internet access would probably generate a fair number of irate customers, so cable companies are hesitant to do this.
- Furthermore, most cities heavily regulate what is on the cable, so the cable operators would not be allowed to do this even if they really wanted to.
- As a consequence, they needed to find a way to have television and Internet coexist on the same cable.
- Cable television channels in North America normally occupy the 54–550 MHz region (except for FM radio from 88 to 108 MHz).



4. Cable Modems

- Internet access requires a cable modem, a device that has two interfaces on it:
  - one to the computer and
  - one to the cable network.

- In the early years of cable Internet, each operator had a proprietary cable modem, which was installed by a cable company technician. However, it soon became apparent that an open standard would create a competitive cable modem market and drive down prices, thus encouraging use of the service. Furthermore, having the customers buy cable modems in stores and install them themselves (as they do with V.9x telephone modems) would eliminate the dreaded truck rolls.