Data Communication
Chapter 5
Transmission Media

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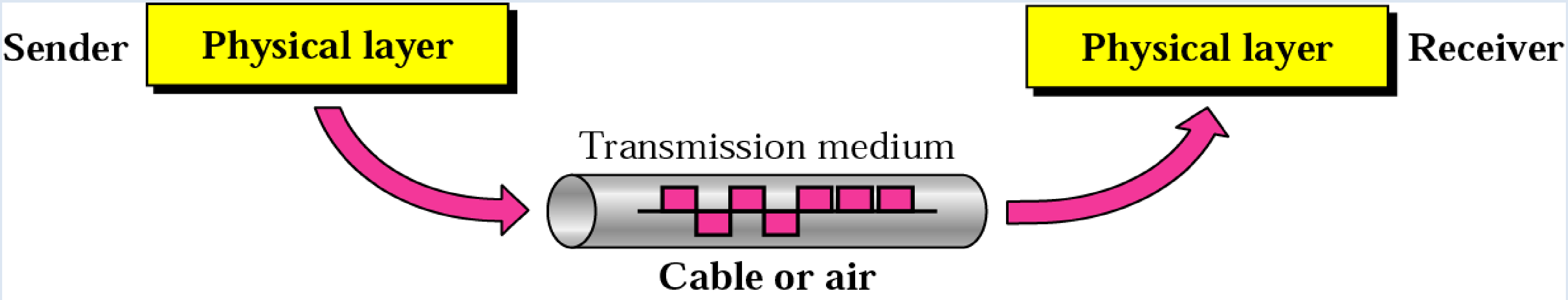
Course Instructor

Relation to Internet Model

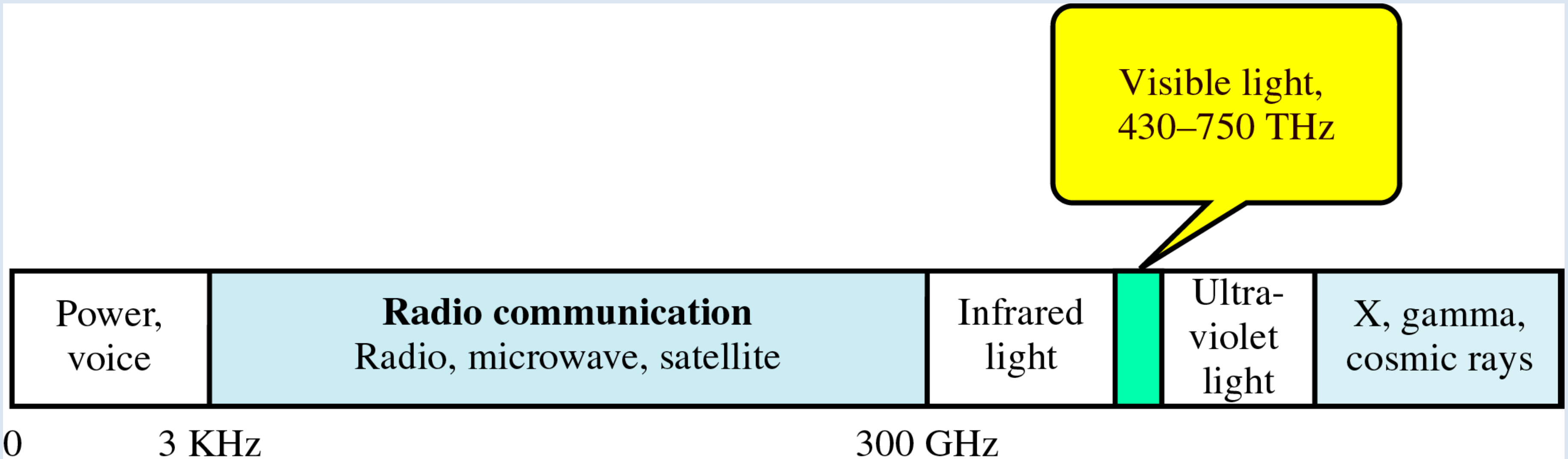
- Actually located below the physical layer
- Directly controlled by the physical layer

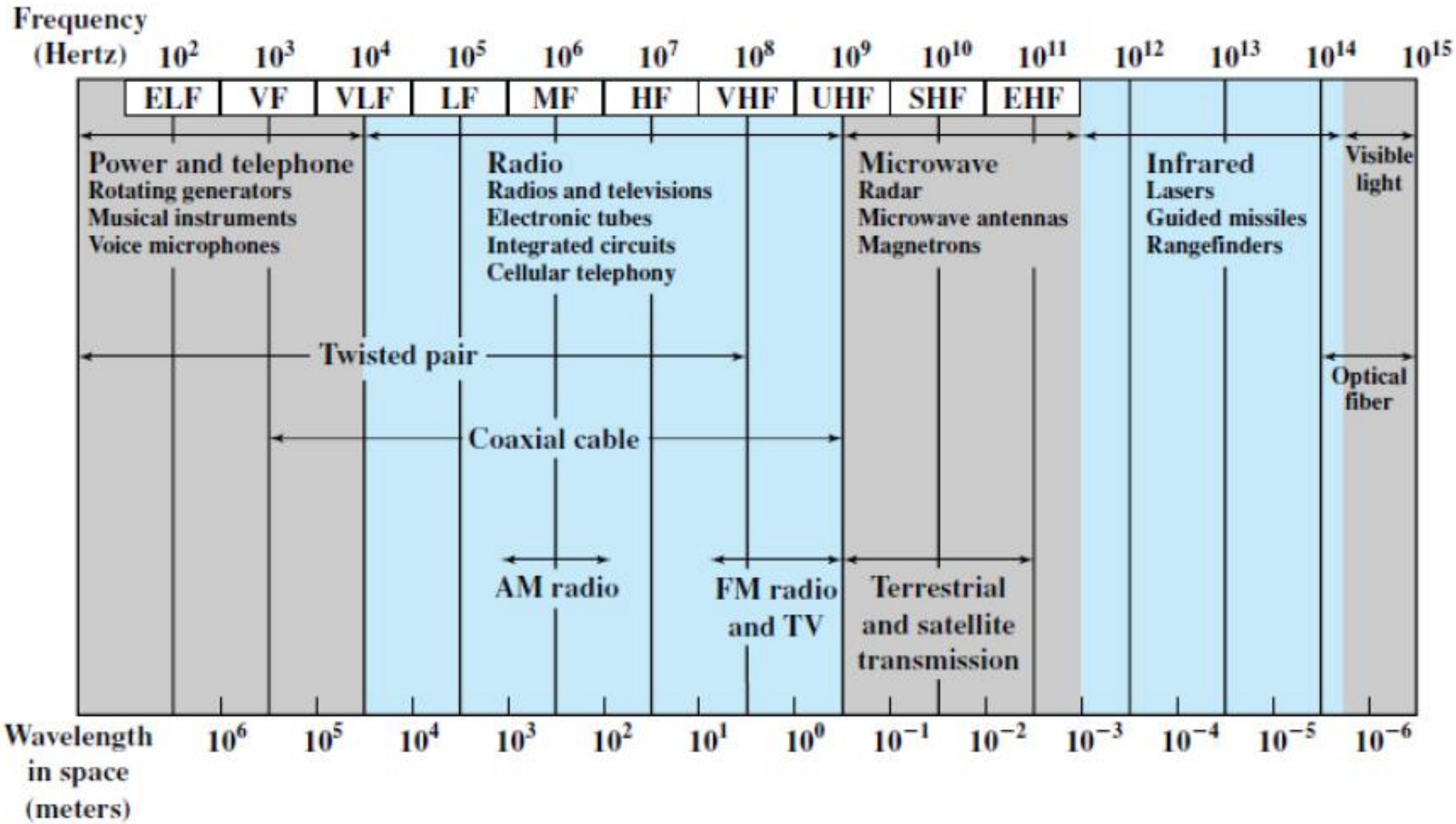


Introduction

- Data must be converted into electromagnetic signals to be transmitted from device to device
- Signals can travel through a vacuum, air, or other media
- May be in the form of power, voice, radio waves, infrared light, and X, gamma, and cosmic rays
- Each of these forms constitutes a portion of the electromagnetic spectrum

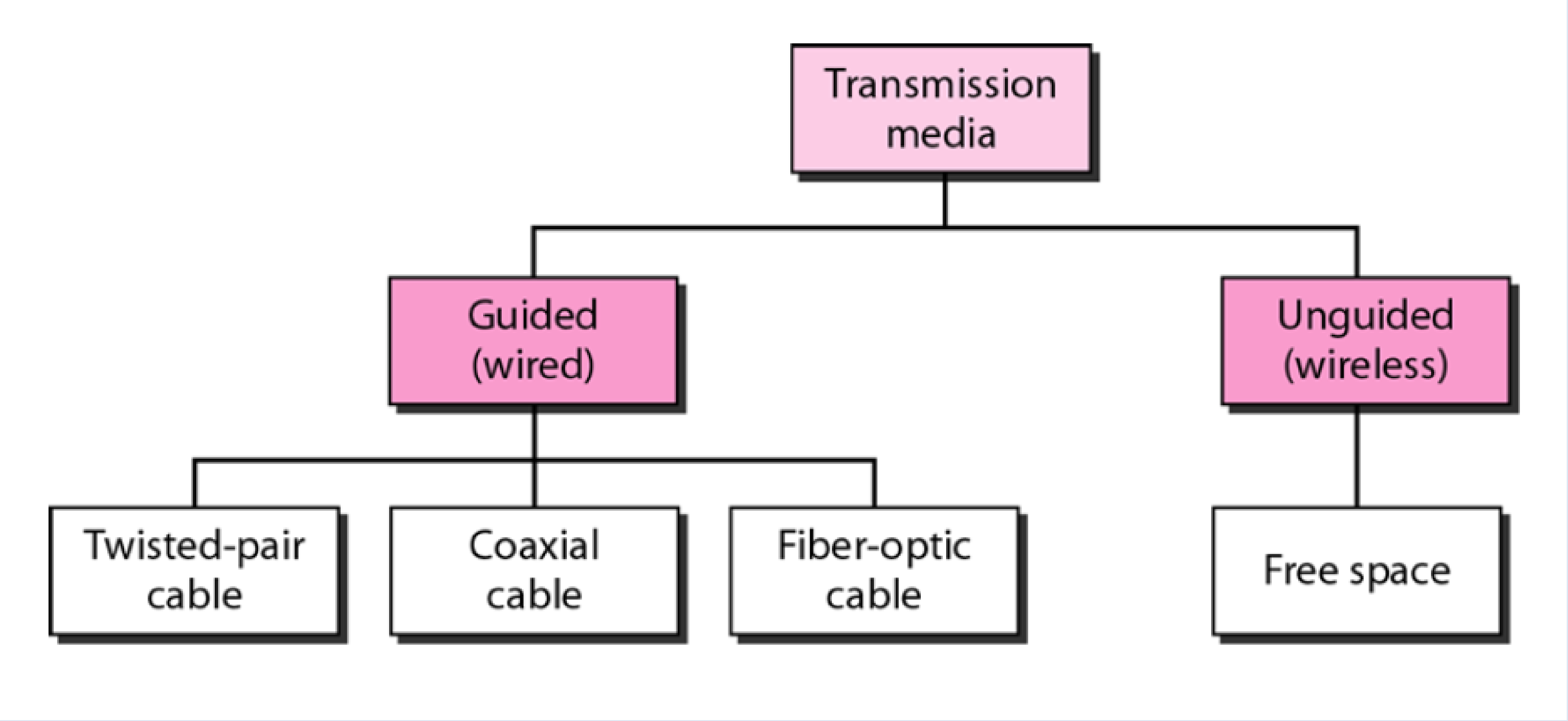
Electromagnetic Spectrum





ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency
MF = Medium frequency
HF = High frequency
VHF = Very high frequency
UHF = Ultra high frequency
SHF = Super high frequency
EHF = Extremely high frequency

Types of Transmission Media



Categories of Media

- Guided Media (Wired)

Waves are guided along a physical path such as Twisted pair, coaxial, and fiber-optic

- Unguided Media (Wireless)

Provide a means for transmitting electromagnetic waves but do not guide them.

  - Radio waves, infrared light, visible light, and X, gamma, and cosmic rays
  - Sent by microwave, satellite, and cellular transmission

Wireless & Wired Media

Wireless Media

- Signal energy propagates in space, limited directionality
- Interference possible, so spectrum regulated
- Limited bandwidth
- Simple infrastructure: antennas & transmitters
- No physical connection between network & user
- Users can move

Wired Media

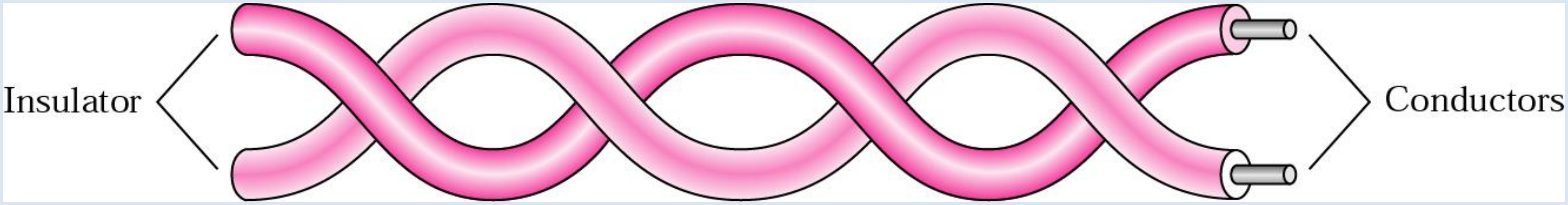
- Signal energy contained & guided within medium
- Spectrum can be re-used in separate media (wires or cables), more scalable
- Extremely high bandwidth
- Complex infrastructure: ducts, conduits, poles, right-of-way

Guided Media

- Guided Transmission media uses a cabling system that guides the data signals along a specific path.
- Twisted-pair and coaxial use copper conductors to accept and transport signals in form of electrical current
- Optical fiber is glass or plastic cable that accepts and transports signals in form of light

Twisted-Pair Cable

- Two conductors surrounded by insulating material
- One wire used to carry signals; other used as a ground reference
- Twisting wires reduces the effect of noise interference or crosstalk since both wires will likely be equally affected
- More twists = better quality



Twisted Pair Bit Rates

Table 3.5 Data rates of 24-gauge twisted pair

Standard	Data Rate	Distance
T-1	1.544 Mbps	18,000 feet, 5.5 km
DS2	6.312 Mbps	12,000 feet, 3.7 km
1/4 STS-1	12.960 Mbps	4500 feet, 1.4 km
1/2 STS-1	25.920 Mbps	3000 feet, 0.9 km
STS-1	51.840 Mbps	1000 feet, 300 m

- Twisted pairs can provide high bit rates at short distances
- Asymmetric Digital Subscriber Loop (ADSL)
  - High-speed Internet Access
  - Lower 3 kHz for voice
  - Different downstream and upstream rates
- Much higher rates possible at shorter distances
  - Strategy for telephone companies is to bring fiber close to home & then twisted pair
  - Higher-speed access + video

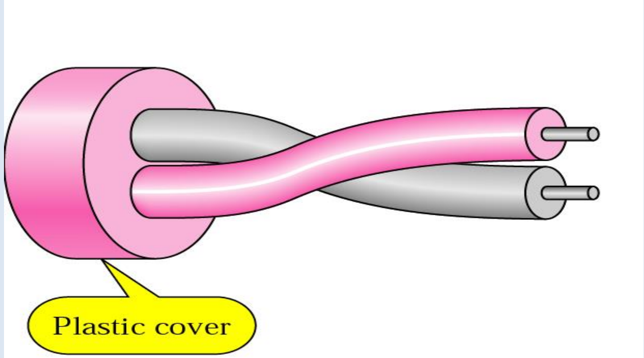
Unshielded Twisted Pair (UTP)

- Cable with wires that are twisted together to reduce noise generated by an external noise
- Most common type; suitable for both voice and data transmission
- Frequency range is from 100 Hz to 5 MHz
- Categories are determined by cable quality
  - Cat 3 commonly used for telephone systems (up to 10 Mbps)
  - Cat 5e usually used for data networks (up to 100 Mbps)
- Performance is measured by attenuation versus frequency and distance
- Advantage: cheaper, flexible, easy to install
- UTP connectors attach to wire;

most commonly used is RJ45,

which have 8 conductors,

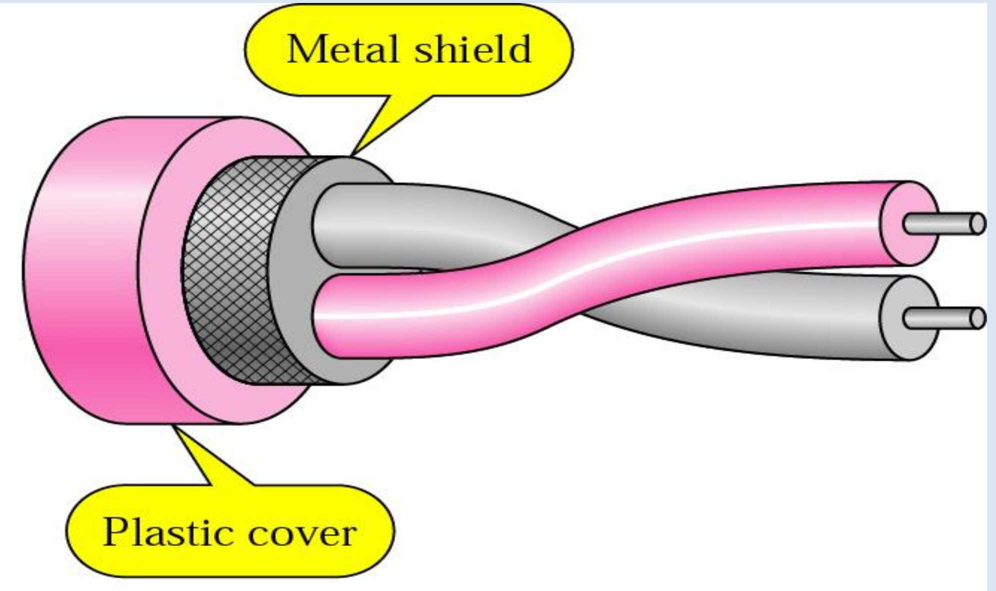
one for each of four twisted pairs



a. UTP

Shielded Twisted Pair (STP)

- A metal foil or braided-mesh covering encases each pair of insulated conductors to prevent electromagnetic noise called crosstalk
- Uses same connectors
- More expensive but less susceptible to noise



b. STP

Coaxial Cable

- Has a central core conductor enclosed in an insulating sheath, encased in an outer conductor of metal foil
- Frequency range is between 100 KHz and 500 MHz
- RG numbers denote physical specs such as
  - wire gauge
  - thickness and type of insulator
  - construction of shield
  - size/type of outer casing

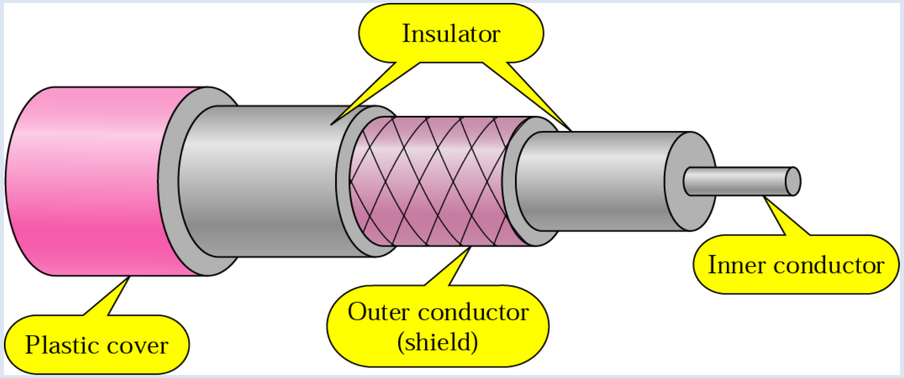
RG numbers

- RG-8, RG-9, and RG-11 used in thick Ethernet (50Ω)
- RG-58 used in thin Ethernet (50Ω)
- RG-59 used for TV (75Ω)

Coaxial Cable

Performance

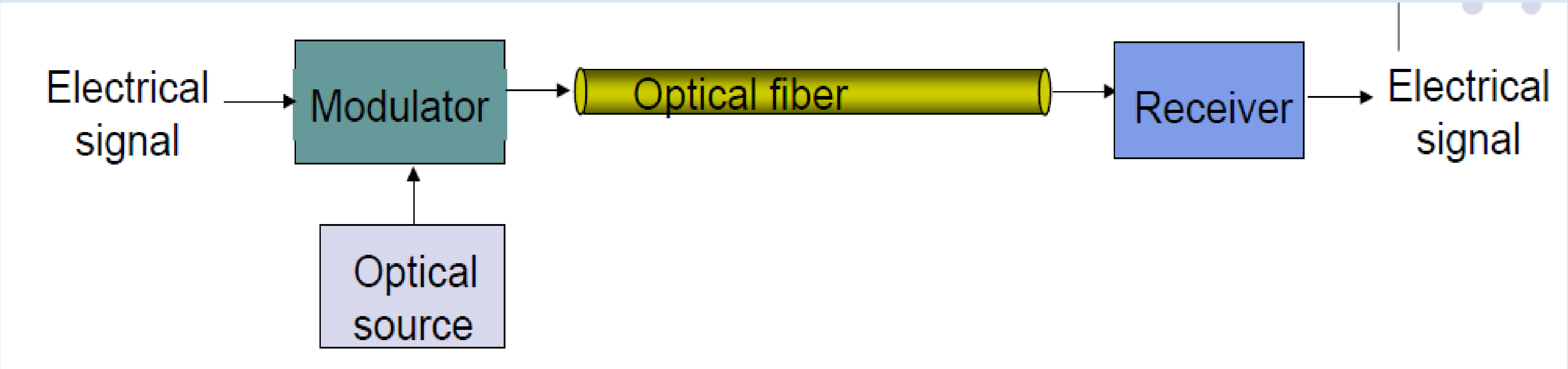
- Higher bandwidth than twisted-pair
- However, attenuation is higher and requires frequent use of repeaters



Coaxial Applications

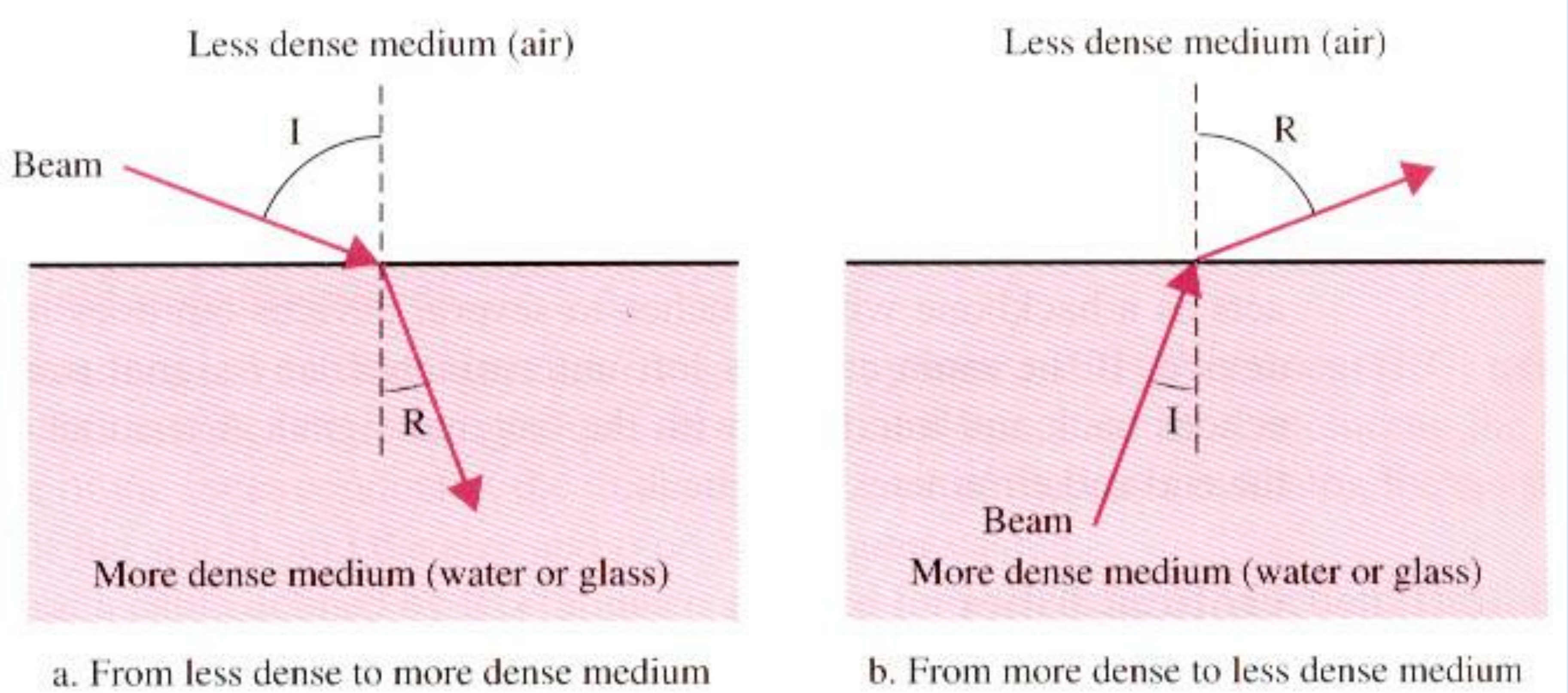
- Analog telephone networks
  - single coaxial network could carry 10,000 voice signals
- Digital telephone networks
  - single coaxial network could carry digital data up to 600 Mbps
- Cable TV networks
- Traditional Ethernet LANs

Fiber-Optic Cable



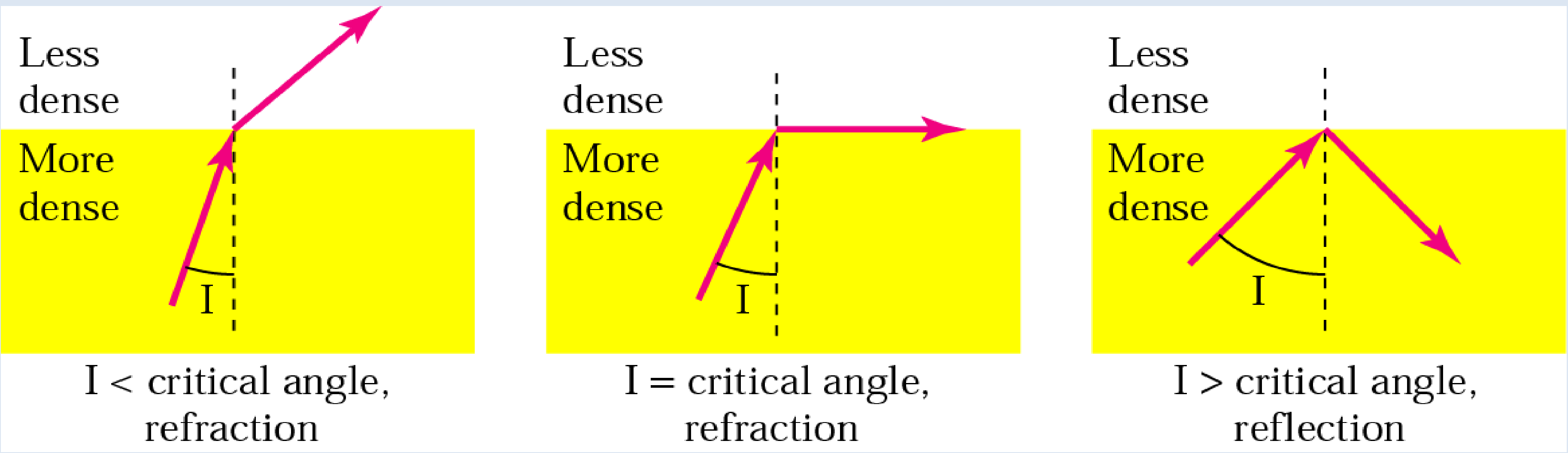
- Made of glass or plastic;
  - signals are transmitted as light pulses from an LED or laser
- Speed depends on density of medium it is traveling through;
  - fastest when in a vacuum, 186,000 miles/second

Refraction

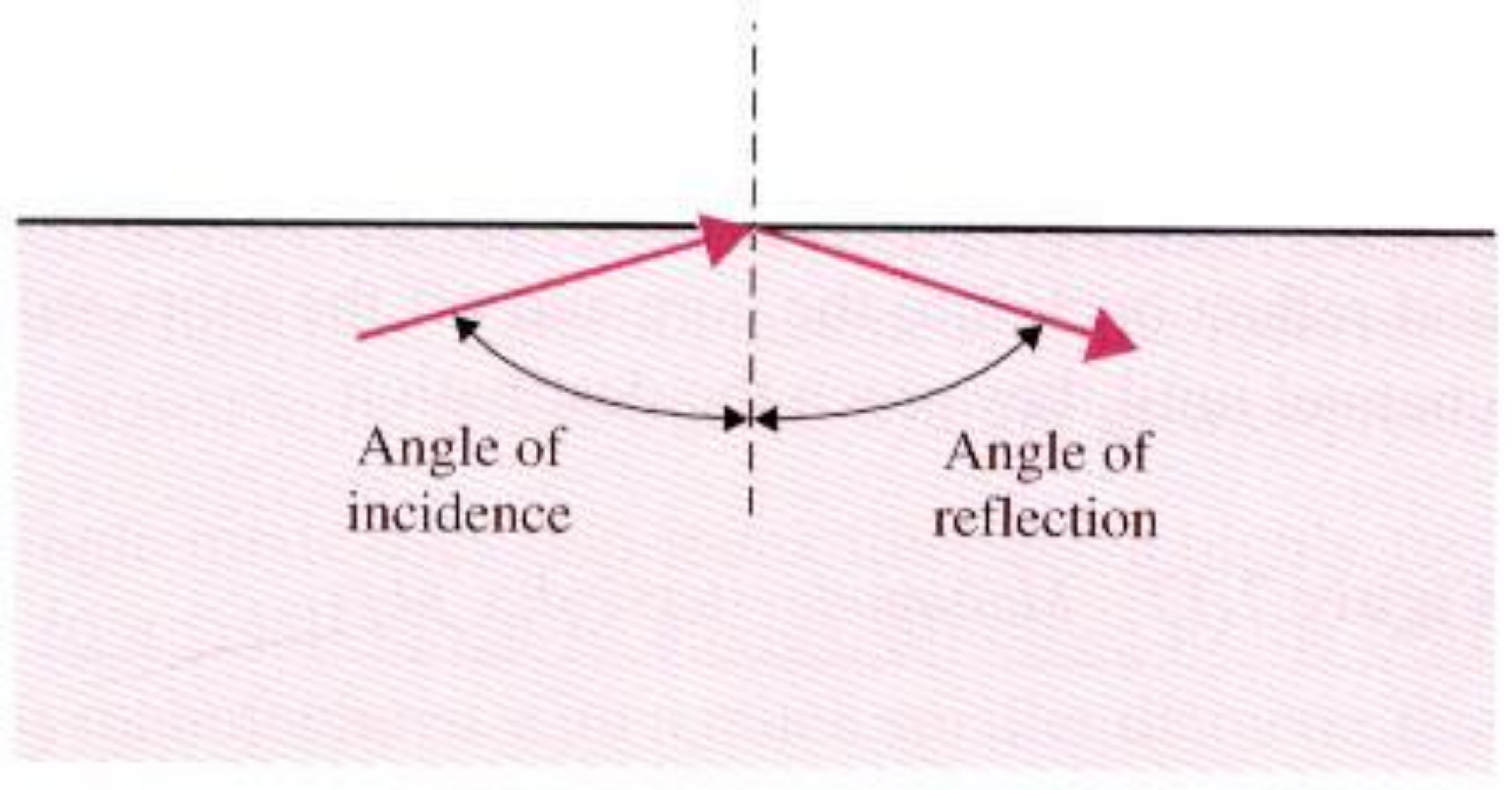


Less dense medium (air)
Beam
I
R
More dense medium (water or glass)
a. From less dense to more dense medium
Less dense medium (air)
R
I
Beam
More dense medium (water or glass)
b. From more dense to less dense medium

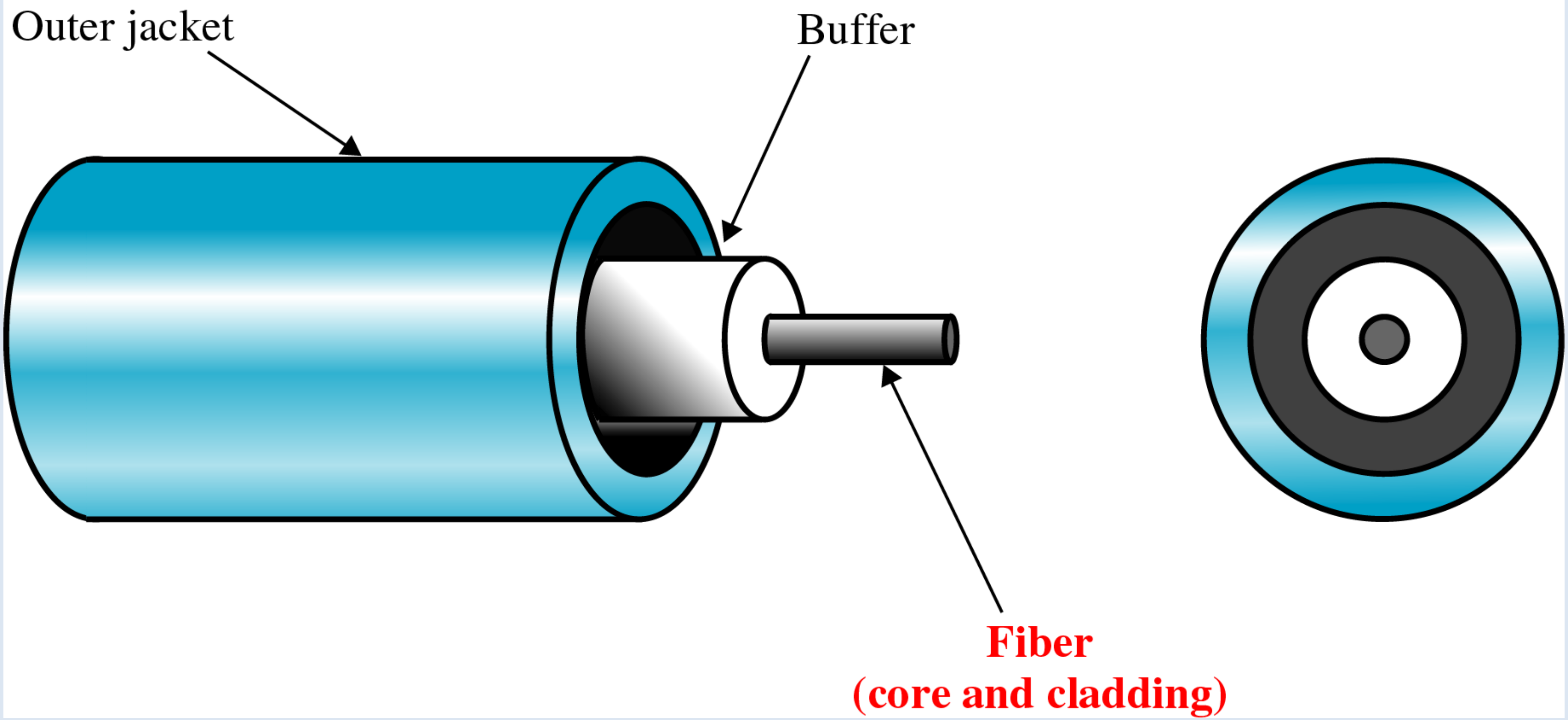
Critical Angle



Reflection

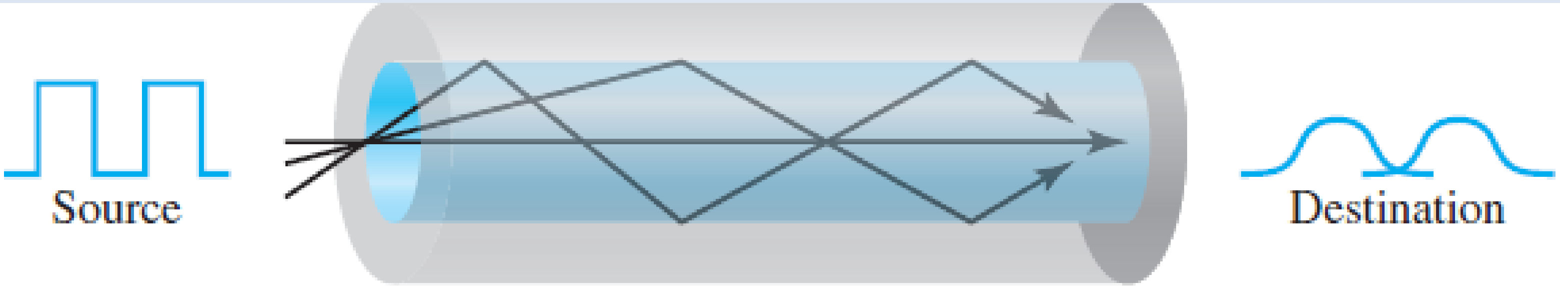


Fiber Construction

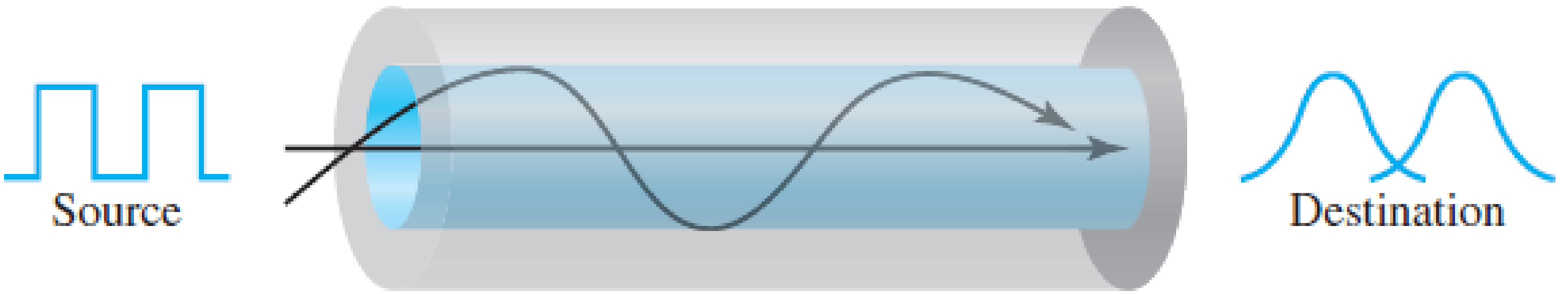


Propagation Modes

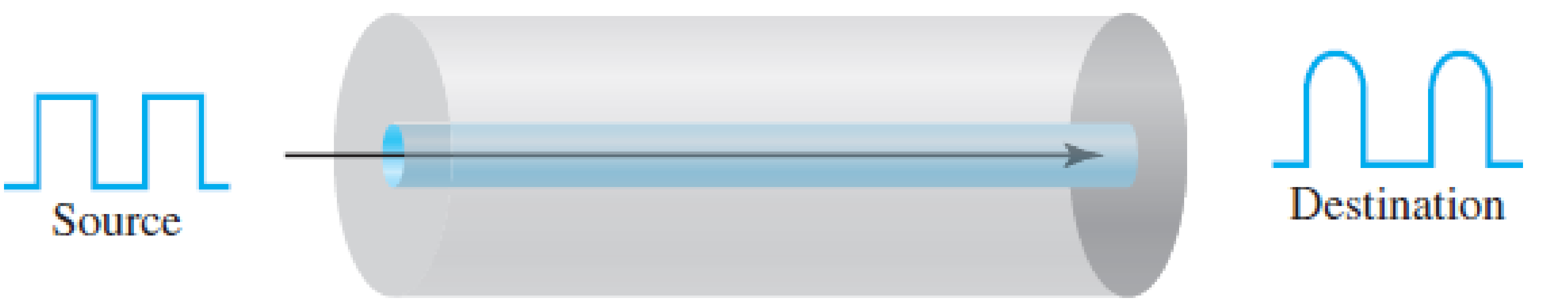
- Method for transmitting optical signals:
  - Multimode
    - Multimode step-index fiber: Core and cladding material has uniform but different index
    - Multimode graded-index fiber: Core material has variable index as a function of the radial distance from the center.
  - Single Mode: The core diameter is almost equal to the wavelength of the emitted light so that it propagates along a single path.



a. Multimode, step index



b. Multimode, graded index



c. Single mode

Multimode

- Multiple beams from light source move through core at different paths
- Multimode step-index fiber
  - *Index* refers to the index of refraction
  - Density remains constant from center to edges
  - Light moves in a straight line until it reaches the cladding
  - Some beams penetrate the cladding and are lost, while others are reflected down the channel to the destination
  - As a result, beams reach the destination at different times and the signal may not be the same as that which was transmitted
- Multimode graded-index fiber
  - May be used to decrease this problem and to allow for more precise transmissions
  - Graded-index refers to varying densities of the fiber; highest at center and decreases at edge
  - Since the core density decreases with distance from the center, the light beams refract into a curve
  - Eliminates problem with some of the signals penetrating the cladding and being lost

Single Mode

- Only one beam from a light source is transmitted using a smaller range of angles
- Smaller diameter
- Makes propagation of beams almost horizontal;
  - delays are negligible
- All beams arrive together and can be recombined without signal distortion

Light Sources

- Light source is light-emitting diode (LED) or a laser
  - LEDs are cheaper but not as precise (unfocused); limited to short-distance use
  - Lasers can have a narrow range, better control over angle
- Receiving device needs a photosensitive cell (photodiode) capable of receiving the signal

Applications of Fiber Optics

- Backbone networks due to wide bandwidth and cost effectiveness
- Up to 1600 Gbps with WDM (Synchronous Optical Network : SONET)
- Cable TV
- LANS
  - 100Base-FX (Fast Ethernet)
  - 1000Base-X

Advantages of Fiber Optics

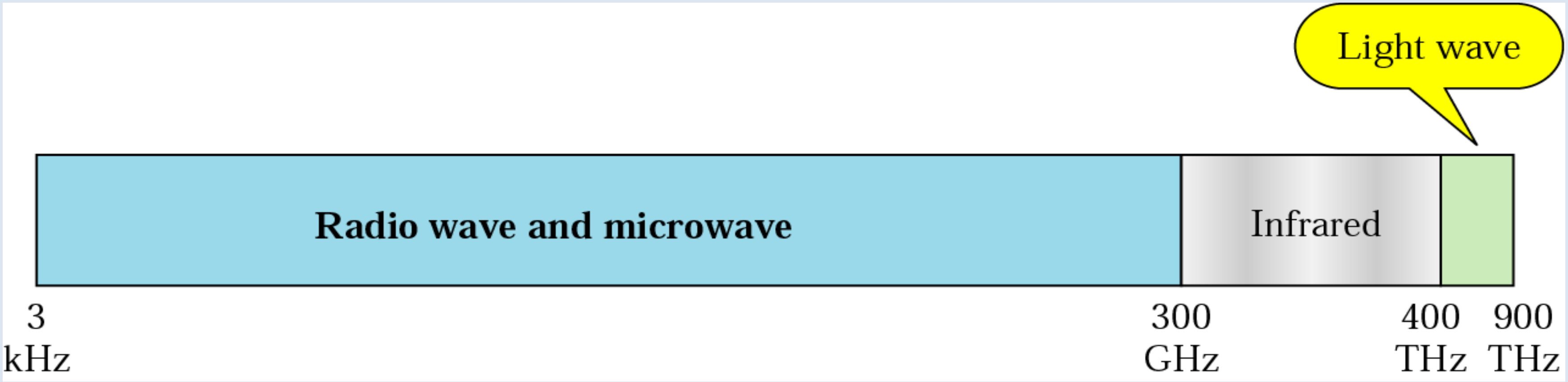
- Higher bandwidth than twisted-pair and coaxial cable; not limited by medium, but by equipment used to generate and receive signals
- Less signal attenuation: Fiber-optic transmission distance is significantly greater than that of other guided media. A signal can run for 50 km without requiring regeneration. We need repeaters every 5 km for coaxial or twisted-pair cable.
- Immunity to Electromagnetic Interference: Electromagnetic noise cannot affect fiber-optic cables.
- More resistant to corrosive materials : Glass is more resistant to corrosive materials than copper.
- Lightweight: Much lighter than copper cables
- Greater security (More immune to tapping than copper cables. Copper cables create antenna effects that can be easily taped.)

Disadvantages of Fiber Optics

- Installation/maintenance
  - Relatively new technology
  - need expertise
- Unidirectional, bidirectional communication two fibers are needed
- Cost
  - Cable and interface are relatively more expensive
  - Bandwidth is not high, often the use of fiber cannot be justified

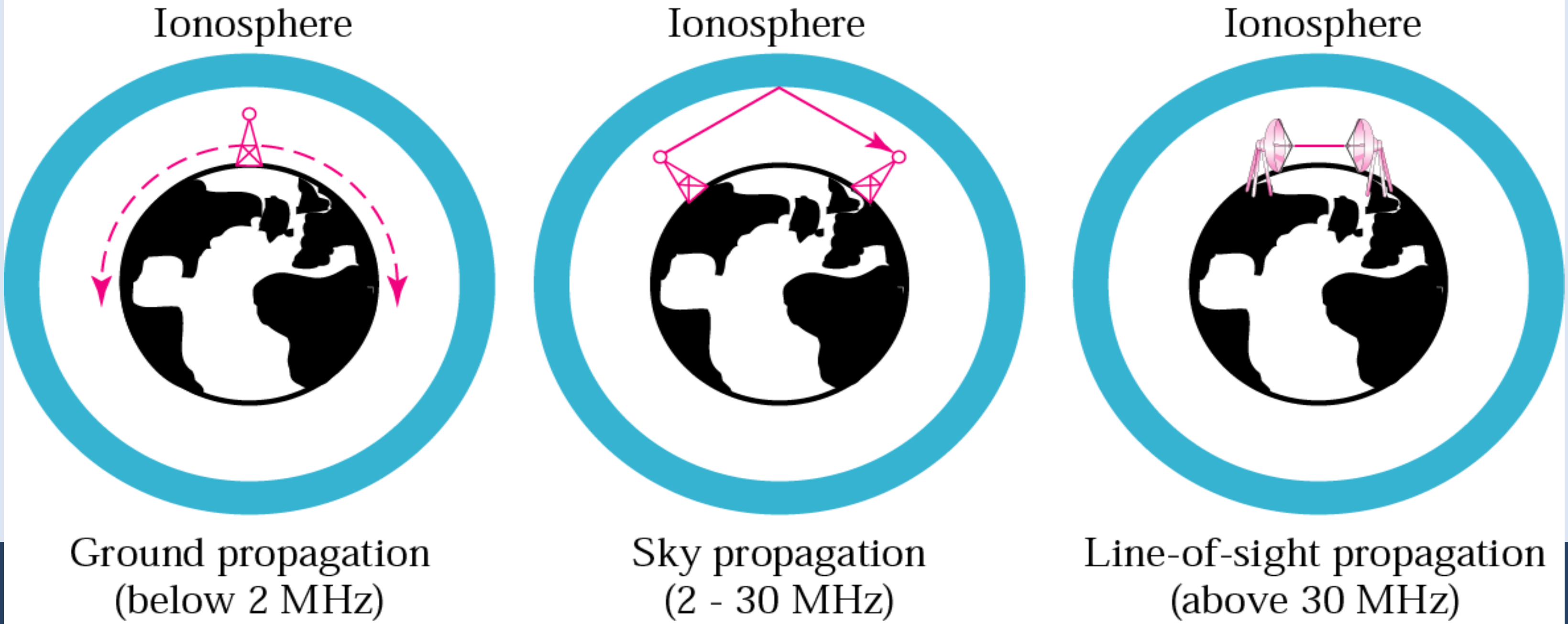
Unguided Media: Wireless

Wireless communication; transporting electromagnetic waves without a physical conductor



Wireless Propagation Methods

- Ground – radio waves travel through lowest portion of atmosphere, hugging the Earth
- Sky – higher-frequency radio waves radiate upward into ionosphere and then reflect back to Earth
- Line-of-sight – high-frequency signals transmitted in straight lines directly from antenna to antenna

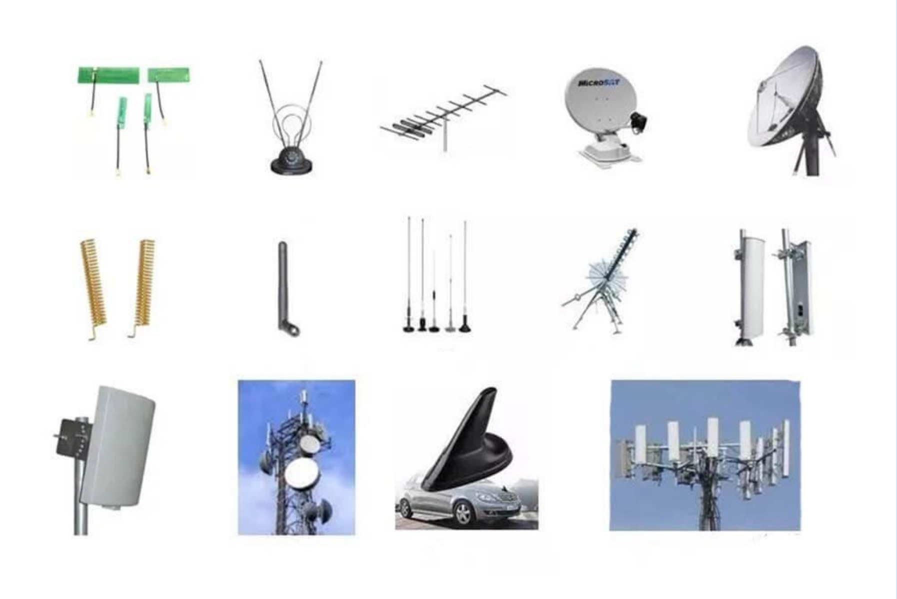


Bands

Band	Range	Propagation	Application
VLF	3–30 KHz	Ground	Long-range radio navigation
LF	30–300 KHz	Ground	Radio beacons and navigational locators
MF	300 KHz–3 MHz	Sky	AM radio
HF	3–30 MHz	Sky	Citizens band (CB), ship/aircraft communication
VHF	30–300 MHz	Sky and line-of-sight	VHF TV, FM radio
UHF	300 MHz–3 GHz	Line-of-sight	UHF TV, cellular phones, paging, satellite
SHF	3–30 GHz	Line-of-sight	Satellite communication
EHF	30–300 GHz	Line-of-sight	Long-range radio navigation

Antenna

- A metallic structure that receives and/or transmits radio electromagnetic waves
- A transmitting antenna is one, which converts electrical signals into electromagnetic waves and radiates them
- A receiving antenna is one, which converts electromagnetic waves from the received beam into electrical signals
- In two-way communication, the same antenna can be used for both transmission and reception



Types of antenna

- Isotropic antenna: a theoretical antenna that radiates equally in all directions - horizontally and vertically with the same intensity
- Omnidirectional antenna: radiates equal radio power in all directions perpendicular to an axis (azimuthal directions), with power varying with angle to the axis (elevation angle), declining to zero on the axis
- Directional antenna: send and receive signals in one direction only, usually in a tightly focused, very narrow beam

Wireless Transmission Waves

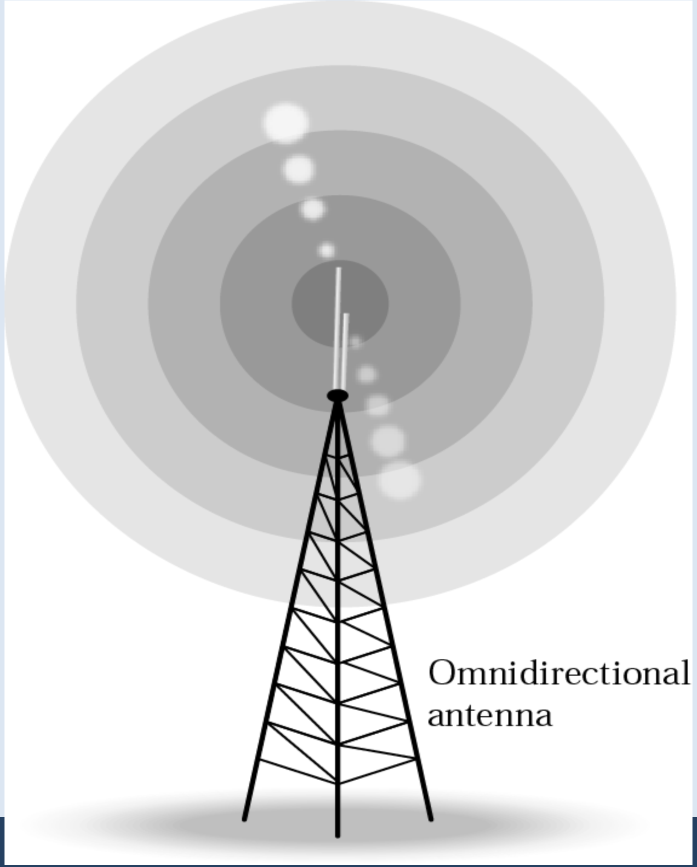
- Radio Waves
- Microwave
- Infrared

Radio Waves

- Frequency ranges: 3 KHz to 1 GHz
- Omnidirectional
- Susceptible to interference by other antennas using same frequency or band
- Ideal for long-distance broadcasting
- May penetrate walls
- Apps: AM and FM radio, TV,

maritime radio, cordless phones,

paging



Terrestrial Microwaves

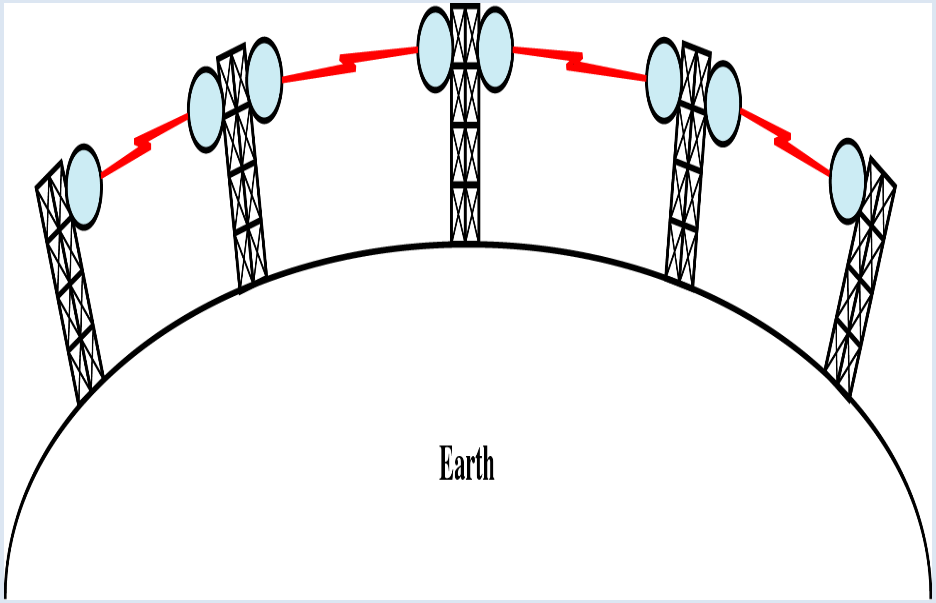
- The directional parabolic antennas are used to transmit and receive signal
    - two frequencies are necessary for two-way communication such as a telephone conversation for transmission and reception of a signal
    - each frequency requires its own transmitter and receiver, i.e., transceiver, which allows a single antenna to serve both transmitting and receiving signals
- The signals are highly focused and the physical path must be a line of sight, i.e., able to look at each other without obstacles between them
- The distance coverable by a line-of-sight signal depends to a large extent on the height of the antenna: the taller the antennas, the longer the sight distance
    - To increase the distance served by terrestrial microwaves, repeaters are installed
- The data rate is 1 Mbps to 10 Gbps

Terrestrial Microwave

- Terrestrial microwave systems operate in the low-gigahertz range, typically at 4-6 GHz and 21-23 GHz, and costs are highly variable depending on requirements
- Long-distance microwave systems can be quite expensive but might be less costly than alternatives

Applications of Microwave

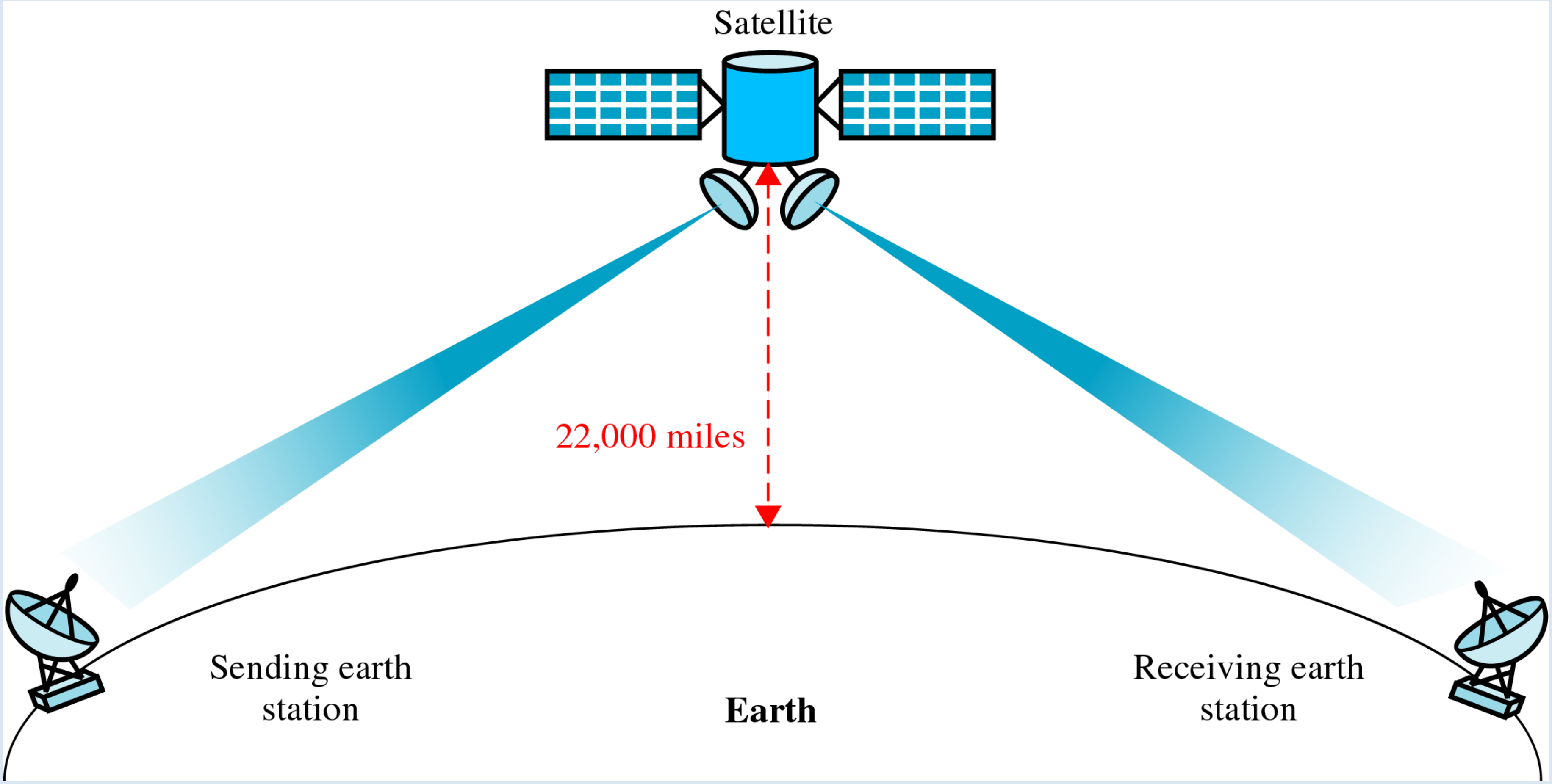
- Cellular phones
- Satellite networks
- Wireless LANs



Satellite Communication

- Similar to terrestrial microwave except the signal travels from a ground station on earth to a satellite and back to another ground station.
- Satellite receives on one frequency, amplifies or repeats signal and transmits on another frequency
- Satellite is relay station
- Television
- Long distance telephone
- Private business networks

Satellite as a repeater



Satellite Communication

- Satellite communications use a combination of orbiting satellites above the Earth and ground stations to transmit and relay information using microwaves from one point to another.
- There are three stages in the process –Uplink, Transponder and Downlink

❑ Take Live Television for example. A broadcaster will send out (or transmit) a signal to a designated satellite via it's user terminal. This is referred to as an "**uplink**."

❑ Once received by the orbiting satellite, onboard amplifiers boost the signal strength and change the frequency of the signal before it is relayed back to a designated Earth station(s) on the ground. This is also referred as the "**transponder**" stage.

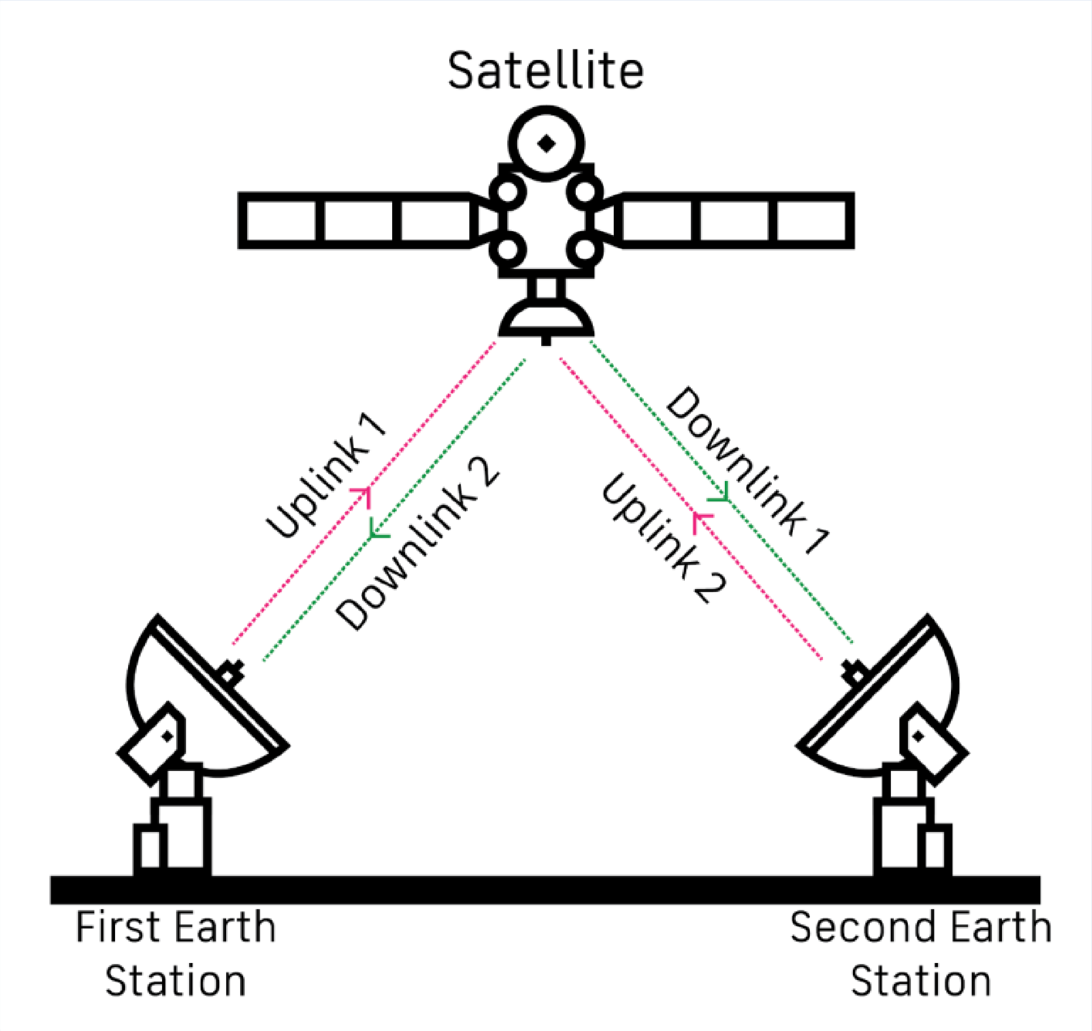
❑ Finally, these transmitters send out one or multiple signals to ground station(s) across the globe back on Earth. This is referred as the "**downlink**."

Frequency Bands

- Communication satellites use multiple frequencies bands, just like a radio, to transmit information. Although there are multiple frequency bands, the most common frequencies in satellite communications are L-band, C-band, S-band, and Ka-band.

Band	Downlink (GHz)	Uplink (GHz)	Bandwidth, (MHz)
C	3.7 to 4.2 GHz	5.925 to 6.425 GHz	500
Ku	11.7 to 12.2 GHz	14 to 14.5 GHz	500
Ka	17.7 to 21 GHz	27.5 to 31 GHz	3500

Two-way satellite communications



Advantages & Disadvantages of Satellite Communication

Advantages

- Area of coverage is more than that of terrestrial systems
- Transmission cost is independent of the coverage area
- More bandwidth and broadcasting possibilities
- Connection can be established in areas where fibre cables cannot reach such as inflight Wi-Fi, offshore platforms, and remote areas on the planet.

Disadvantages

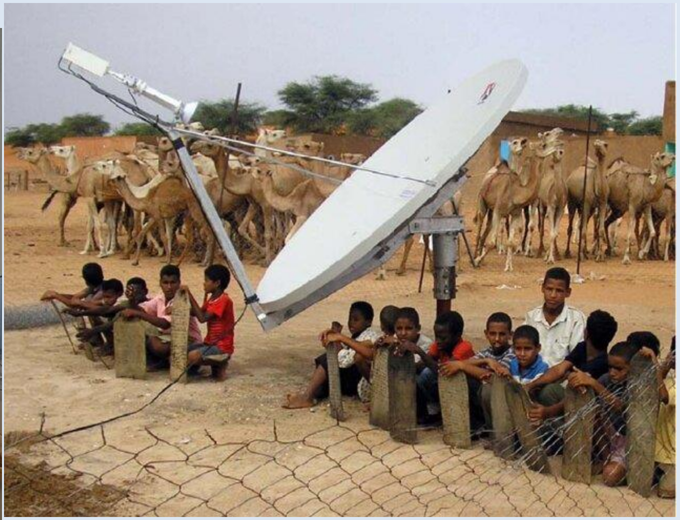
- Launching of satellites into orbits is a costly process.
- Signal latency is rare but can occur where a signal may take a few milliseconds longer to be received.
- Difficult to provide repairing activities if any problem occurs in a satellite system
- Based on reliability and speed, satellite internet is slower with average downloads speed of 15-30 Mbps compared to fibre connections with 50 Mbps-1 Gbps

Applications of satellite communications

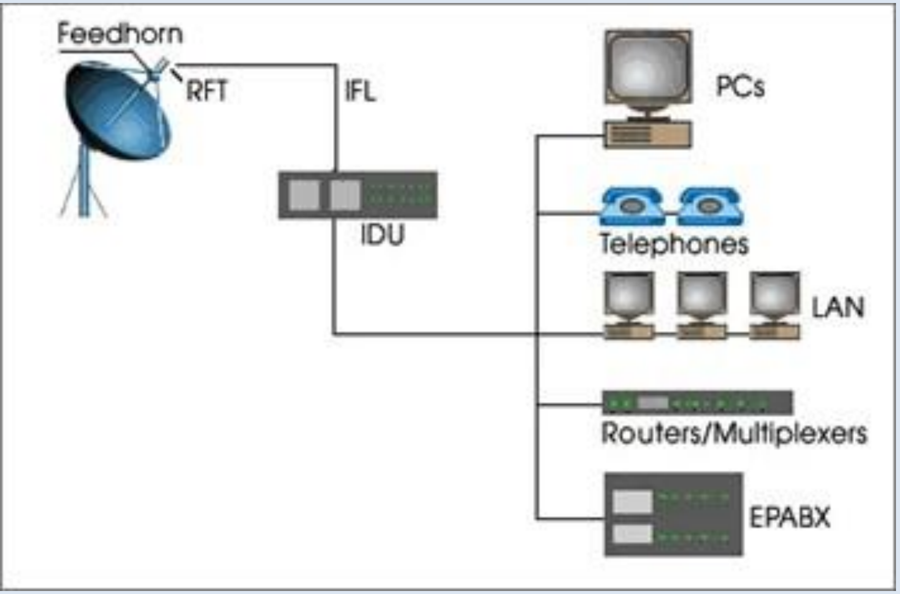
- Weather forecasting
- Radio and TV broadcast
- Military satellites
- Navigation satellites
- Global Telephone
- Weather condition monitoring and forecasting

Very Small Aperture Terminal (VSAT)

- VSAT is a small telecommunication earth station that receives and transmits data, video or voice via satellite
- It is a satellite-based Wide Area Network, with centrally managed hub.
- The “Very Small” component of the VSAT acronym refers to the size of the VSAT dish antenna-typically about 60 cm to 3.8m.



Components of VSAT – VSAT Earth Station



- Outdoor unit ODU
- Inter-facility IFL
- Indoor unit IDU

VSAT Earth Station

Outdoor Unit ODU

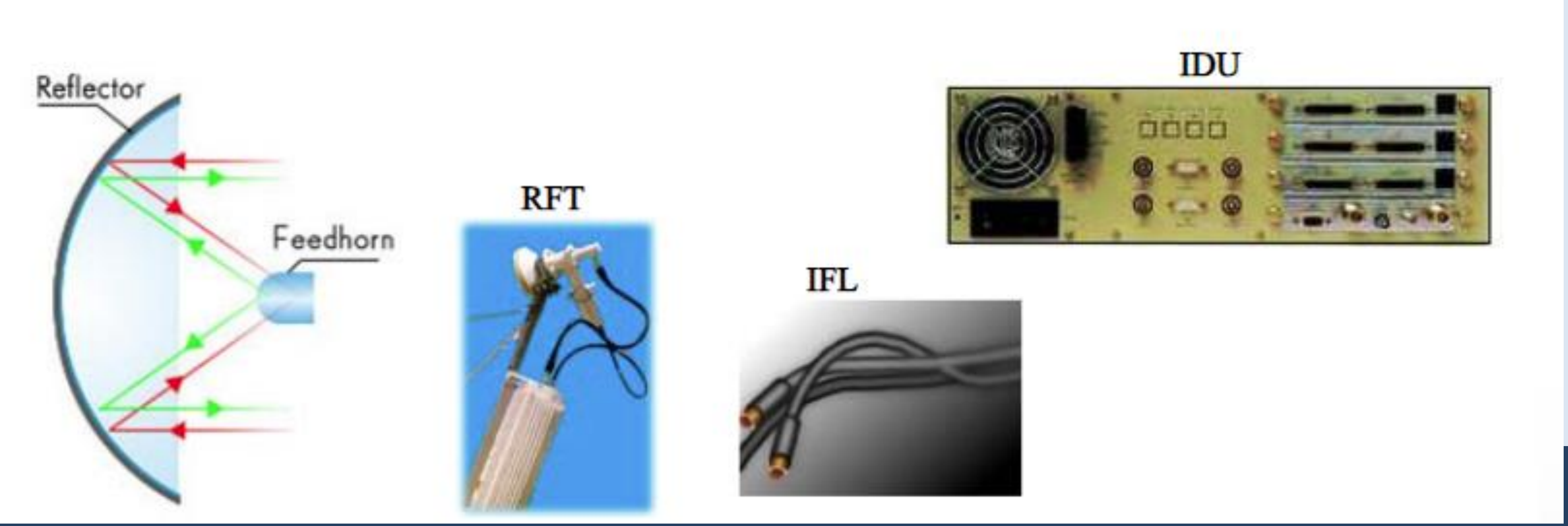
- Located where it will have clear line of sight to the satellite and is free from casual blockage by people and/or equipment moving in front of it. It includes the Radio frequency Transceiver RFT

Inter Facility Link IFL

- It carries the signal between the ODU and Indoor unit IDU as well as power cables for the ODU and control signals from the IDU.

Indoor Unit IDU

- Contains the interface between the VSAT and the user's equipment (PC,TV, Telephones)



Example –Mobile service launched in Gosaikunda with Nepal Telecom's VSAT Technology

https://www.nepalitelecom.com/2023/08/nepal-telecom-launches-mobile-service-in-gosaikunda-via-vsat.html

Mobile service has been launched in Gosaikunda (also spelled Gosainkunda), a popular religious site in the Rasuwa district. Nepal Telecom inaugurated the long-awaited mobile communication service via VSAT (Very Small Aperture Terminal) technology in the remote area from Bhadra 10 to help pilgrims and tourists with connectivity needs.

Abin Khatri, acting Chief of Ntc's Rasuwa branch, said that the company installed 2G equipment by establishing a satellite link to the remote tower. This will now provide users with GSM voice and data services on their mobile devices. The company could also use the same infrastructure to upgrade to 4G later.

VSAT technology uses a small terminal to make connectivity from one place to another over a satellite. Ntc has been using this satellite technology sporadically in remote areas where terrestrial link is difficult to establish. Depending on the feasibility, the company is providing 2G, 3G, and 4G mobile services across the country.

To bring communication to the area, the telecom equipment had to be installed at an elevation of 4,380 meters which was proving difficult. But with the help of the House of Representatives (HoR) member and engineer Mohan Acharya, the telco gears were transported which weighed over a ton.

Characteristics of VSAT

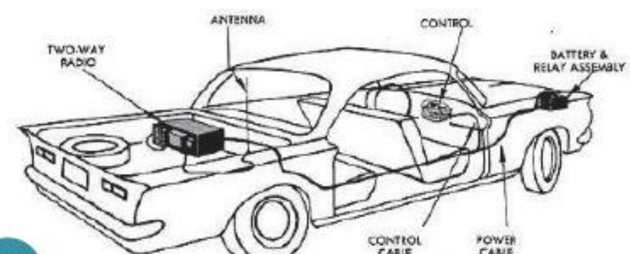
- Compact and Portable
- Cost-effective – Less expensive than satellite counterparts
- Reliable connection in remote , disaster-prone areas
- Global reach
- Lower Bandwidth – Lower bandwidth compared to traditional satellite communication
- Latency – VSAT experiences higher latency compared to terrestrial connections due to the long-distance signals travel to reach the satellite and back.

History: Pre-Cellular (1)

- The **most successful** application of wireless networking has been the **cellular telephone system**.
- 1915: Wireless voice transmission (wireless telephony) between New York and San Francisco was first established by AT&T.
- 1946: First public **mobile telephone** service was introduced in 25 cities across the US. The equipment was expensive at $2,000.
  - More than the price of a typical new car (at that time).

History: Pre-Cellular (2) Car Phone

Now—from your car—you can placé or receive calls from any place in the world with General Electric's Simultaneous Duplex Mobile Telephone.



Typical GE DTO. Series Installation, Circa 1963

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History: Pre-Cellular (3)

- These initial systems used a single **central transmitter** to cover an **entire** metropolitan **area**.
  - High-powered transmitter & Large tower
  - Inefficient!
  - FM push-to-talk
- 1976: (30 yrs after the introduction of the service in 1946),
  - the New York system (10M people) could only support 543 paying customers.
  - 3,700 on the waiting list
- The mobile units weighed about 10 kilograms and put out a steady 20-25 watts.
- The central transmitters that communicate with the mobile units broadcast 200 to 250 watts.

[Klemens, 2010, Chapter 3]

History: Pre-Cellular System (3.1)

- The central station could reliably communicate with the mobile units up to a radius of approximately 25 miles (50 km).

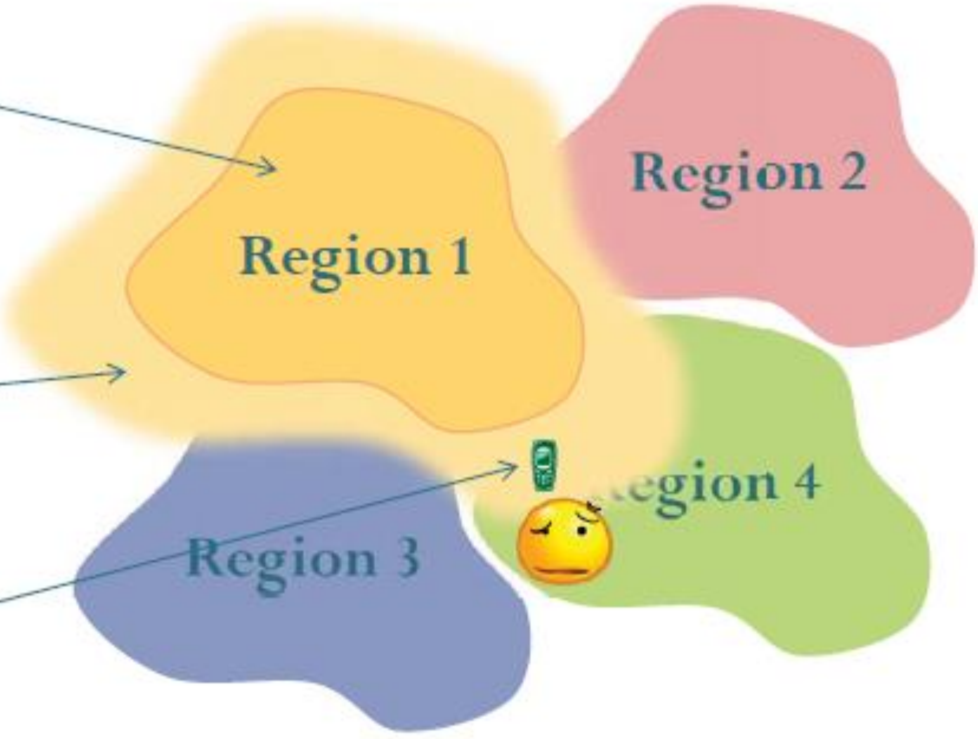
Colored area indicates the coverage area of the central transmitter in the corresponding region

[Klemens, 2010, p 46]

History: Pre-Cellular System (3.2)

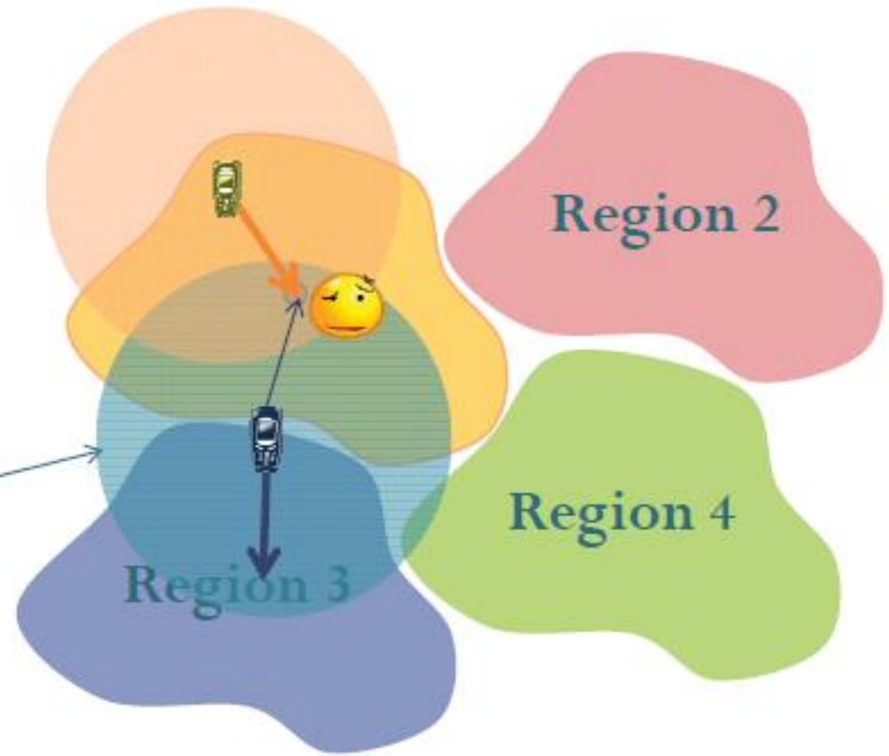
- Beyond that, up to a radius of 60 to 100 miles, the signal was too weak for consistent service, but strong enough to interfere with any other mobile radio system.

Downlink signal in this region is strong enough for communication



The signal in this region is *not* strong enough for communication but still impose significant *interference* on users in other regions

History: Pre-Cellular System (3.3)



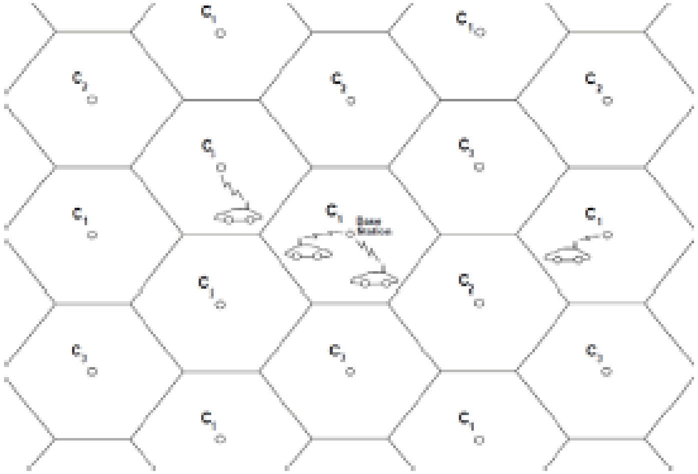
Uplink signals from user of a cell can reach the BS of a different region.

History: Pre-Cellular System (3.4)

- Regions need to be well-separated!
- As a result, the central transmitters had to be at least 100 miles apart, leaving a 50 mile **blank space** between them.
- So a customer could use the sporadic and unreliable service only within the confines of one area.

History: 1G Cellular (1)

- A solution to this capacity problem emerged during the 50's and 60's when researchers at AT&T **Bell Lab**oratories developed the **cellular concept**.
- 1968: AT&T proposed the concept to the FCC
- Cellular systems exploit the fact that the power of a transmitted signal falls off with distance.
- Thus, two users can operate on the same frequency at spatially-separate locations with minimal interference between them.
  - Frequency reuse



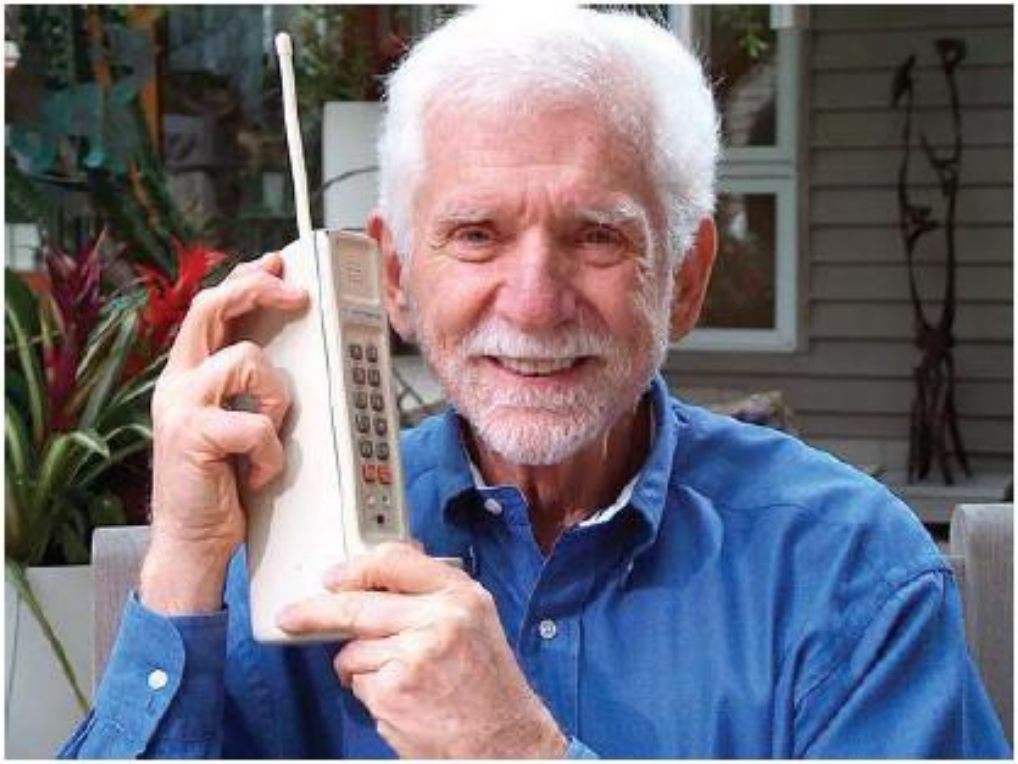
Marty Cooper: Cellphone Inventor

- **1973**
- Motorola DynaTAC prototype

- Weighed nearly **two kilos**
- Cost approximately **$1 million** for Motorola to produce.

- **20 minutes** battery life

Not a problem because you could not hold it up for twenty minutes; it was so heavy.



[http://gizmodo.com]

First Cell Phone Call in 1973

First commercially available cell phone

(Dynamic Adaptive Total Area Coverage)

Motorola's DynaTAC

First **commercially available** cell phone in 1983

- Weighed about 2 lbs (1 Kg)
- 10 inches high, making it larger than some Chihuahuas
- Battery life: 30 minutes of talk time
- $4,000

Demo of 1 G phone

- https://www.youtube.com/watch?v=GH_t2ZIX794

A Tektronix CMD 80 cellular service monitor is used to simulate a cell tower.

1G

2 G , 2.5 G GPRS, 2.75 G EDGE

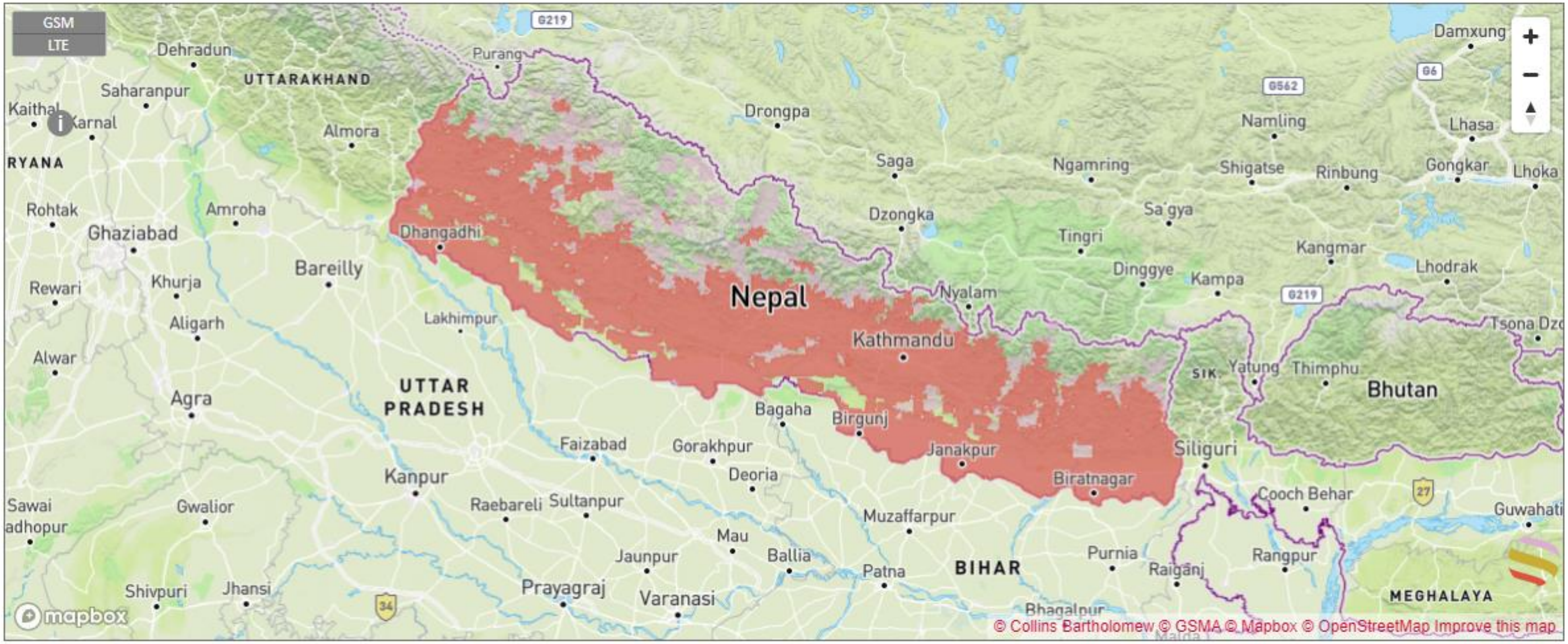
3G

4G

5G

Nepal

Operator: Nepal Telecom



Nepal

Operator: Ncell Axiata

Cellular Telephony

- In the early years of mobile radio systems: a single high-powered transmitter with the antenna mounted on tall tower is used for a large coverage . But this approach does not allow the reuse of the same radio frequencies due to interference.
- The cellular concept was invented in solving the spectral congestion and user capacity.
- Cellular Telephony is a system-level concept, which replaces a single high power transmitter with a large number of low-power transmitters for communication between any two devices over a large geographical area.

Why Cellular Telephony?

- Primary goal of the cellular telephone network is to provide wireless communication between two moving devices called mobile stations or between one mobile unit and a secondary unit, commonly referred to as land-line unit

Cellular Telephone system

- A service provider must be able to
  - Locate and track a caller
  - Assign a channel to the call
  - Handoff

Components

- Mobile station MS: Mobile handsets
- Cell: Small regions that divide cellular service area
- Base station BS: Each cell contains an antenna, which is controlled by small office
- Mobile Switching Center MSC: a switching office that control each base station

Cell

- To accommodate a large number of users over a large geographical area, the cellular telephone system uses a large number of low-power wireless transmitters to create cells
- Cell size not fixed –depends on the population of that area and demand
- Hexagonal shape

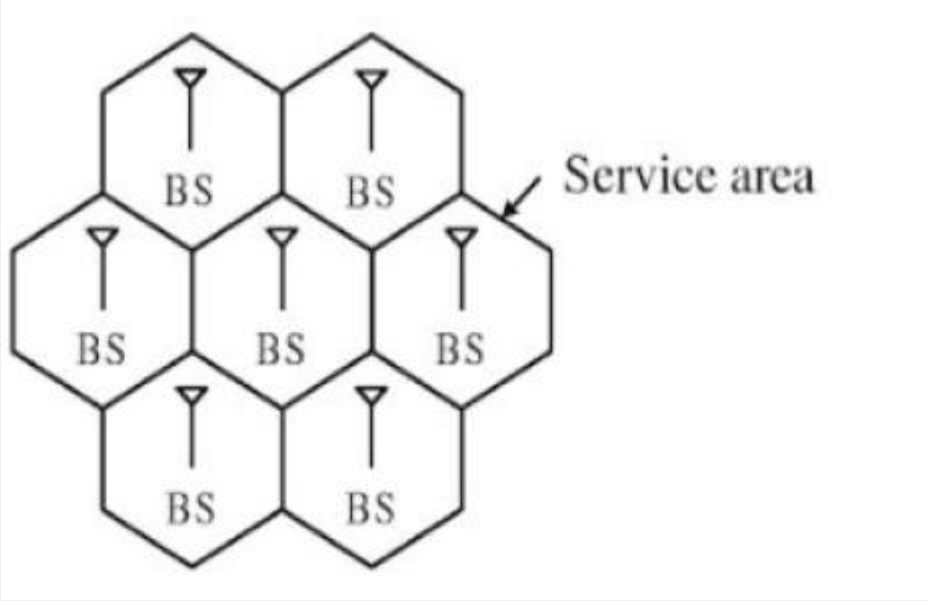


Figure: Cellular system: small zone