Module-2
Basics of Signals and Transmission

Analog vs. Digital signals

- Bandwidth and Frequency Spectrum

- Transmission media: Wired (Copper, Fiber- optic) and Wireless

Analog vs. Digital signals

- **Analog Signal**

  An **analog signal** is a continuous signal that varies smoothly over time. It can take **any value** within a given range.

  Key Points:

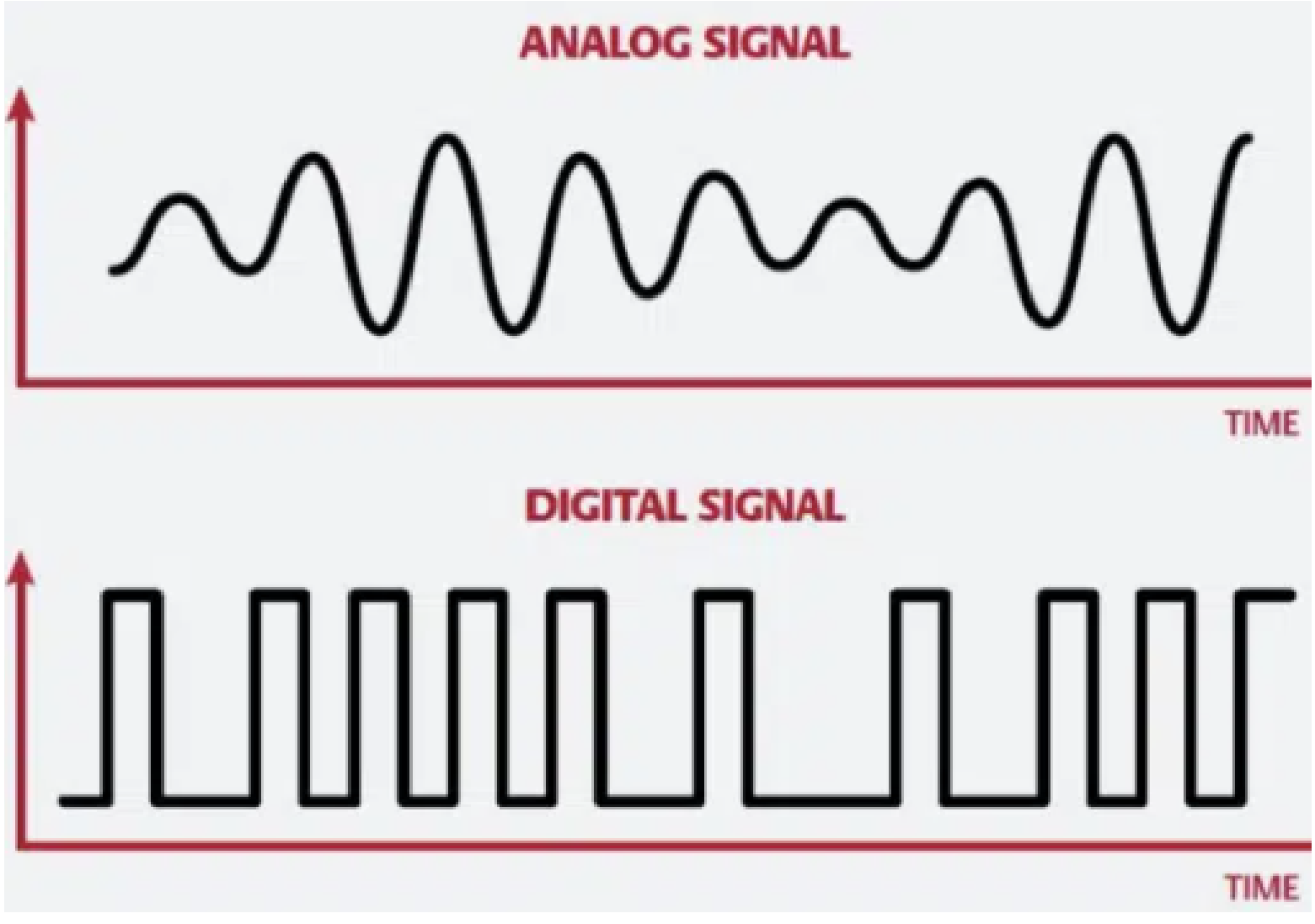
- Continuous and smooth waveform
- Represents natural signals like sound, light, temperature
- More affected by noise and distortion
- Example: Human voice, radio signals
- **Digital Signal**

  A **digital signal** is a discrete signal that uses **binary values (0 and 1)**. It changes in steps rather than continuously.

  Key Points:

- Non-continuous; represented as bits (0/1)
- More resistant to noise
- Used in computers, mobile communication, digital electronics
- Example: Computer data, digital audio, Internet communication

Analog vs. Digital signals



Analog vs. Digital signals

- **Systems where Analog Signals are used**
- Radio broadcasting (AM/FM radio)
- Television (older analog TV systems)
- Landline telephones (traditional PSTN)
- Audio systems (microphones, speakers)
- Medical instruments (ECG, EEG)
- Temperature and pressure sensors

Analog vs. Digital signals

- **Systems where Digital Signals are used**
- Computers and laptops
- Digital mobile communication (2G/3G/4G/5G)
- Digital TV and DTH systems
- Internet and data communication
- Digital audio systems (CD, MP3)
- IoT devices & smart sensors
- Satellite communication

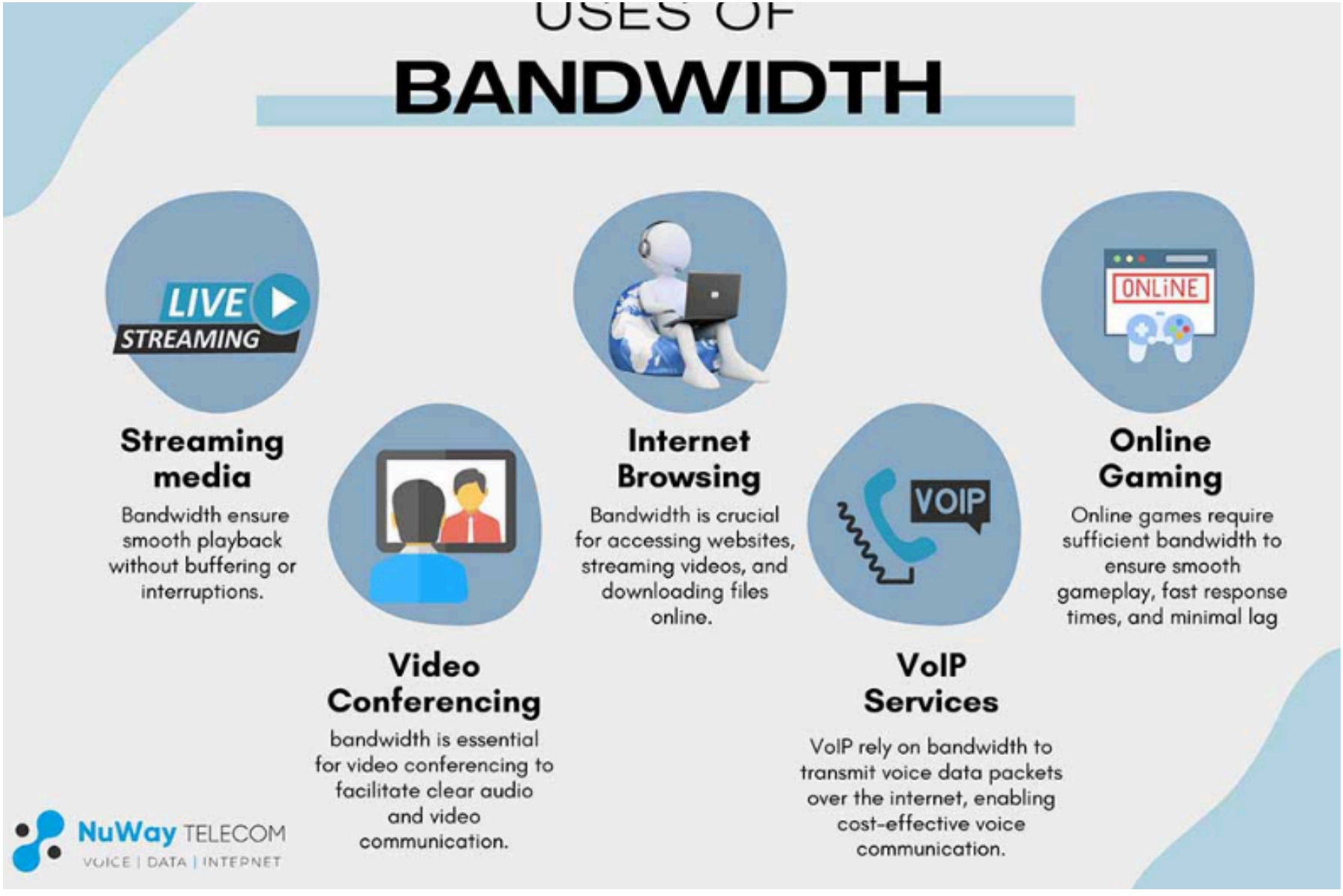
Bandwidth and Frequency Spectrum

- **. Bandwidth**
- **✓ Definition**
- **Bandwidth** is the range of frequencies that a communication channel, signal, or device can transmit.
  It represents **how much data can be sent** over a channel in a given amount of time.
- **✓ Key Points**
- Measured in **Hertz (Hz)** for analog signals.
- Measured in **bits per second (bps)** for digital communication.
- Higher bandwidth → **higher data transfer speed**.
- **✓ Example**
- A 4G network with higher bandwidth can deliver faster internet than 2G.
- An audio signal (20 Hz – 20 kHz) has a bandwidth of **19,980 Hz**.

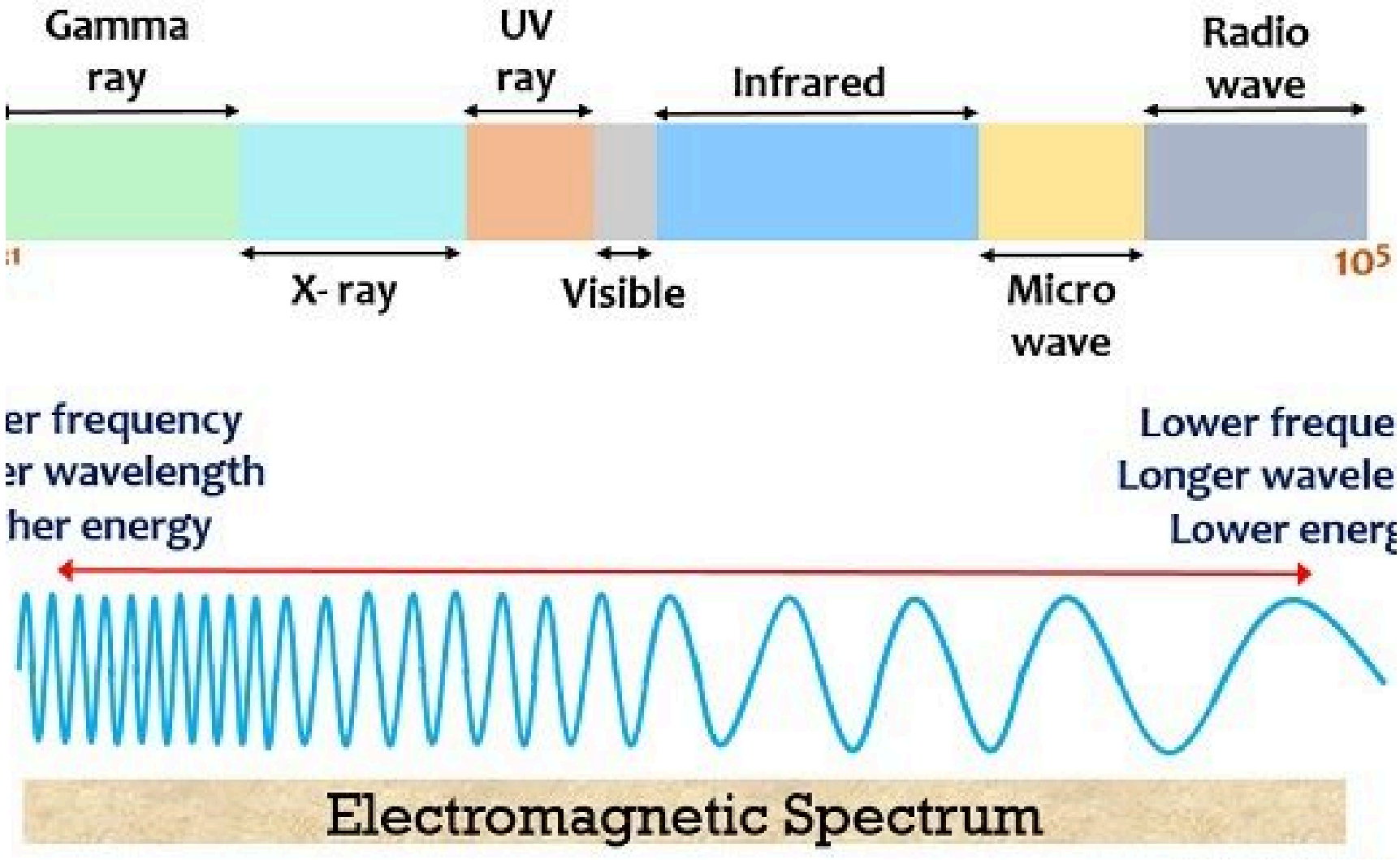
Bandwidth and Frequency Spectrum

- **2. Frequency Spectrum**
- ✓ **Definition**
- The **Frequency Spectrum** is the complete range of electromagnetic frequencies used for communication.
  It includes all possible frequencies from **low-frequency radio waves** to **high-frequency microwaves** and **light waves**.
- ✓ **Key Points**
- Divided into bands: LF, HF, VHF, UHF, microwave, etc.
- Used in radio, TV, mobile communication, satellite, Wi-Fi.
- Managed by government agencies (in India: **TRAI / DoT**).
- ✓ **Example**
- **Mobile networks** use different parts of the frequency spectrum (e.g., 700 MHz, 1800 MHz, 2300 MHz).
- **FM radio** uses the **88–108 MHz** band.

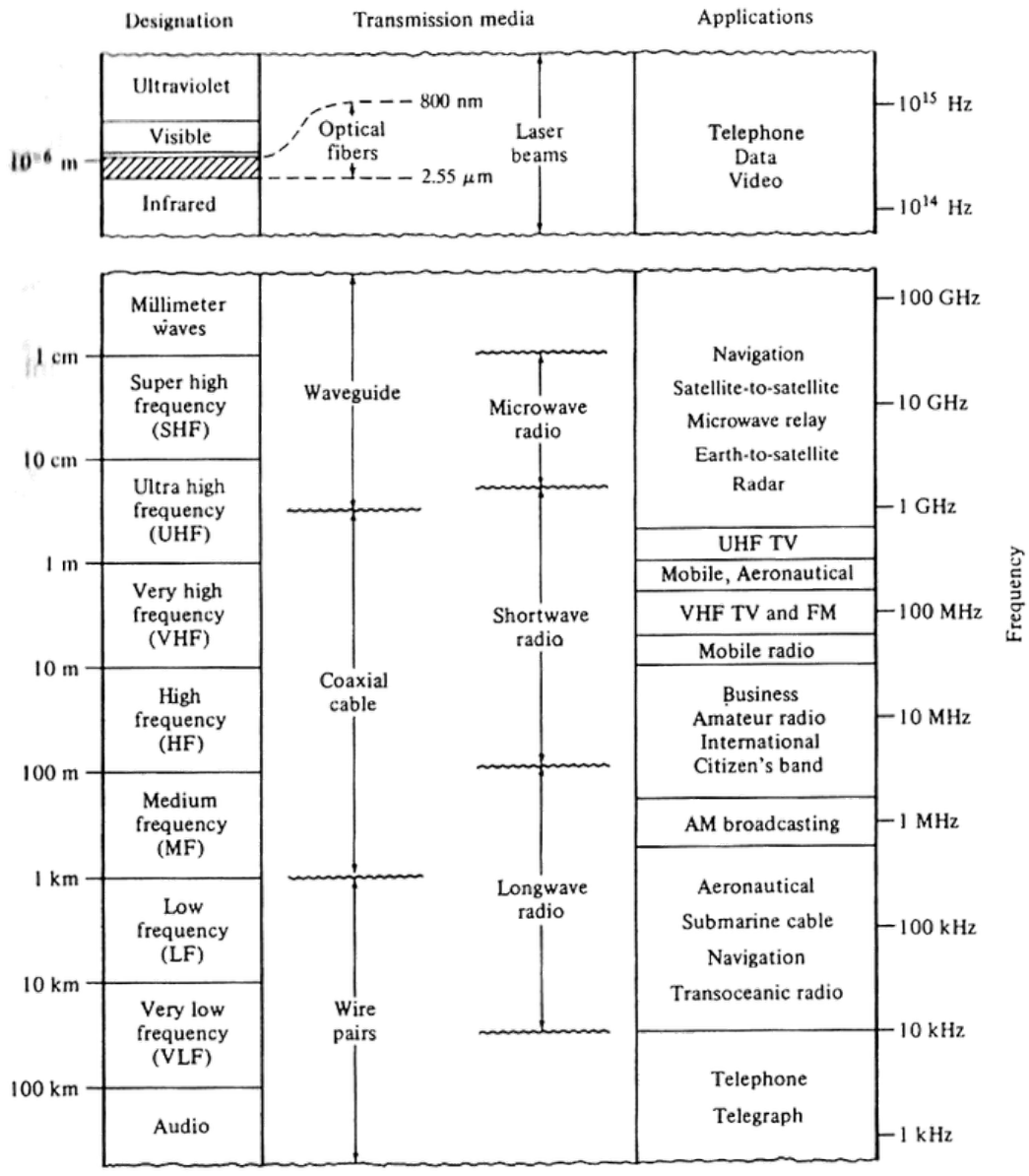
Bandwidth and Frequency Spectrum



Bandwidth and Frequency Spectrum



- Increase of telecommunications capacity and rates requires higher carriers
- Optical systems
  - apply predominantly low-loss silica-fibers
  - started with links, nowadays also in networks
  - very high bandwidths
  - repeater spacing up to thousands of km
- Optical communications is especially applicable in
  - ATM (MPLS)
  - FDDI
  - Gb-Ethernet



Transmission media: Wired (Copper, Fiber- optic) and Wireless

1. Why Copper Is Used in Transmission Media

- Copper is ideal for communication signals because:
- High electrical conductivity → signals travel with less resistance.
- Ductility and flexibility → easy to bend, twist, and install.
- Cost-effective → cheaper compared to optical fiber for short distances.
- Compatibility → widely used in existing LAN infrastructure.

2. Types of Copper Transmission Media

- A. Twisted Pair Cable

1) Unshielded Twisted Pair (UTP)

- Common in Ethernet LANs (Cat5, Cat6, Cat6a, Cat7).
- No shielding → lighter, cheaper, easier to install.

2) Shielded Twisted Pair (STP)

- Metallic foil/braiding reduces noise.
- Used in noisy industrial environments.

Advantages of Twisting-1)Reduces electromagnetic interference (EMI).

2)Minimizes crosstalk between adjacent pairs.

Transmission media: Wired (Copper, Fiber- optic) and Wireless

- B. Coaxial Cable
- Used in cable TV, broadband Internet, and earlier long-distance telephone networks.
- Structure:
- Central copper conductor/Insulation/Shield (braided copper/aluminum)/Outer jacket
- Types:
- RG-6 → Cable TV & broadband/RG-59 → CCTV/RG-11 → Long-distance runs
- **C. Copper Wire for Power & Signaling**
- Used in telephone subscriber lines (POTS – Plain Old Telephone Service)
- Early telegraph, dial-up Internet, DSL services

Transmission media: Wired (Copper, Fiber- optic) and Wireless

- **3. Electrical Characteristics of Copper Transmission Media**
  A. Bandwidth
- Copper has **lower bandwidth** compared to fiber.
- UTP (Cat6/Cat7) supports up to **10 Gbps**, limited by distance.
  B. Attenuation
- Signal weakens over distance due to resistance.
- Higher frequencies attenuate more.
- Twisted pair effective up to 100–200 meters.
  C. Noise Susceptibility
- Copper is vulnerable to: 1-Electromagnetic interference (from motors, power cables) 2-Crosstalk (between adjacent wires)3-Radio frequency interference (RFI)
  D. Impedance
- For performance:
- UTP → 100 ohms
- Coax → 50 or 75 ohms
  Matching impedance avoids reflections.

Transmission media: Wired (Copper, Fiber- optic) and Wireless

4. How Copper Transmits Signals

- **Analog Transmission**
  Audio signals in telephone lines, AM/FM radio antenna wiring, CCTV analog signals
- **Digital Transmission**
  Binary data in Ethernet cables, DSL broadband technology, Cable Internet via coax, Copper carries both forms depending on modulation and the system.

5. Usage / Applications of Copper as Transmission Media

- **A. Telecommunication Networks**
  Telephone lines (local loop) / DSL broadband (copper pair)/ PBX systems
- **B. Internet & Data Communication**
- LAN Ethernet using UTP/STP, Cable internet via coax, Modem to router connections
- **C. Broadcast & Media**
- Cable TV distribution (coax RG-6), CCTV and security camera feeds
- **D. Industrial & Control Systems**
- Instrumentation control wiring, RS-232, RS-485 communication,Sensor and actuator connections

Transmission media: Wired (Copper, Fiber- optic) and Wireless

- **1. What is Fiber Optic Cable?**
- A **fiber optic cable** is a communication medium that uses **glass or plastic fibers** to transmit information using light signals. The fiber is extremely thin (about the thickness of a human hair).
- Data is transmitted in the form of:
- **Infrared light** (LED or laser sources)
- **Reflected light pulses** inside the fiber core
- This makes communication:
- **Faster**
- **More secure**
- **Long distance**
- **High bandwidth**

Transmission media: Wired (Copper, Fiber- optic) and Wireless

- **2. Construction of a Fiber Optic Cable**
- A typical fiber optic cable has the following layers:
- **Core**
  - Central glass/plastic fiber.
  - Very pure silica.
  - Diameter: 8–62.5 microns.
- **Cladding**
  - Surrounds the core.
  - Has lower refractive index.
  - Helps in total internal reflection.
- **Primary Coating**
  - Protects from moisture and physical damage.
- **Strengthening Members**
  - Kevlar (aramid yarn) for mechanical strength.
- **Outer Jacket**
  - PVC, polyethylene, or fire-resistant material.

Transmission media: Wired (Copper, Fiber- optic) and Wireless

- **3. Principle of Operation**
- Fiber optic communication works mainly on:
- **Total Internal Reflection (TIR)**
- Light is transmitted through the core and reflected internally by the cladding due to the difference in refractive index.
- **Steps:**
- Light pulses (0s and 1s) are generated by **LED or Laser diode**.
- Light enters the core at an angle.
- Light bounces (reflects) inside the core without escaping.
- Light reaches the receiver (photo-detector).
- Photo-detector converts light into electrical signal.
- Because light travels with very low loss, signals can go far without distortion.

Transmission media: Wired (Copper, Fiber- optic) and Wireless

- **4. Types of Fiber Optic Cable**
- **A. Based on Mode of Propagation**
  1) Single-Mode Fiber (SMF)
- Very thin core: **8–10 microns/** Uses **laser light /** Supports **very high bandwidth**
  Suitable for **long-distance communication (up to 40–80 km without repeaters)**
  2) Multimode Fiber (MMF)
- Thicker core: **50–62.5 microns/** Uses **LED light/** Lower cost but shorter distance (2–5 km) / Common in LAN, campus, data centers
- **B. Based on Index Profile**
- **Step Index Fiber**
  - Uniform core refractive index.
  - Simple, low cost.
- **Graded Index Fiber**
  - Gradually changing refractive index.
  - Reduces modal dispersion.
  - Better performance for data networks.

Transmission media: Wired (Copper, Fiber- optic) and Wireless

5. Performance Characteristics

A. Bandwidth

- Extremely high bandwidth (Gbps to Tbps)/ Much higher than copper cables

B. Attenuation

- Very low signal loss (0.2–0.5 dB/km) / Can transmit long distances without repeaters

C. Immunity to Noise

- Not affected by: 1-Electromagnetic interference (EMI) 2-Radio frequency interference (RFI) 3-Lightning or electrical noise

D. Security

- Hard to tap → excellent data security

E. Distance

- SMF: 40–100 km / MMF: 2–5 km
- **F. Data Rate**
- Easily supports: **10 Gbps/ 40 Gbps / 100 Gbps / 400 Gbps / 1 Tbps and beyond**

Transmission media: Wired (Copper, Fiber- optic) and Wireless

6. Usage / Applications of Fiber Optic Cables

A. Telecommunications

- Backbone of telephone networks / International submarine fiber optic cables / DWDM systems / FTTH / FTTP (Fiber to the Home/Premises)

B. Internet Backbone

- High-speed backbone lines / ISP long-distance networks / Metro fiber networks

C. Cable TV & IPTV

- Cable television distribution / High-definition video streaming

D. Computer Networking

- Data centers / Enterprise networks / Campus LAN connections

E. Industrial & Military

- Aircraft communication/ Radar systems /Industrial control systems (noise-free environments)

F. Medical Applications

- Endoscopy equipment/Laser medical devices/

G. Sensors-Fiber sensors measure/Temperature/Pressure/Strain/Vibration

Transmission media: Wired (Copper, Fiber- optic) and Wireless

- 7. Advantages of Fiber Optic Transmission
- Extremely High Bandwidth
- Long Distance Transmission
- Immunity to EMI/RFI
- High Security
- Small Size & Light Weight
- Very Low Signal Loss
- Future-Proof Technology i,e Backbone of 5G, IoT, and cloud

Transmission media: Wired (Copper, Fiber- optic) and Wireless

1. What is Wireless Transmission Media?

- Wireless media refers to communication technologies that transmit information without physical wires, using: Radio waves / Microwave signals /Infrared waves / Light (LASER)

  Data is transmitted by modulating these waves, and the receiver demodulates them into usable information

  2. How Wireless Transmission Works
- Transmitter converts electrical data into electromagnetic waves.
- Waves propagate through air/free space.
- Receiver antenna captures the waves.
- Demodulation converts signals back into data.
- **Very useful where:**
- Cabling is difficult or expensive
- Mobility is required (phones, laptops)
- Long-distance communication is needed

Transmission media: Wired (Copper, Fiber- optic) and Wireless

3. Types of Wireless Transmission Media

- **A. Radio Waves (3 kHz – 1 GHz)-** Used for long-range broadcasting, Can penetrate walls , Omni directional (spread in all directions).
- Uses: FM/AM radio , Television broadcasting, Mobile phones (2G/3G/ …) Wi-Fi (2.4 GHz)
- **B. Microwaves (1 GHz – 300 GHz)**

1) Terrestrial Microwaves

- Point-to-point line-of-sight communication (tower to tower)
- Frequency: 4–6 GHz, 11–18 GHz
- Uses: Telephone backhaul/TV distribution/Long-distance data links

2) Satellite Microwaves

- Geostationary or Low-Earth Orbit satellites
- Frequency: 1–40 GHz (Ku-band, Ka-band)
- Uses: DTH TV/GPS/Global communication/Weather forecasting

Transmission media: Wired (Copper, Fiber- optic) and Wireless

C. Infrared Waves (IR)

- Short-range, line-of-sight , Cannot penetrate walls
- **Uses:** Remote controls (TV, AC) /IrDA ports (legacy laptops)/short-range sensors

D. Bluetooth and ZigBee

- Short-range personal communication/Low power consumption
- **Uses:** Wireless headphones/Smart home IoT systems/Wearables

E. Wi-Fi (2.4 GHz / 5 GHz / 6 GHz)

- Wireless LAN for high-speed internet/Range: 20–100 meters
- **Uses:** Home and office internet/Public hotspots/Smart devices

F. Cellular Networks (Mobile Communication)

- Uses licensed spectrum for large-scale mobile communication.
- **Generations: 2G** – GSM, basic voice/text/**3G** – Video call, mobile internet
  4G LTE – High-speed internet/**5G** – Ultra-fast, IoT, low latency
- **Uses:** Smartphones/IoT devices/vehicular communication

Transmission media: Wired (Copper, Fiber- optic) and Wireless

G. LASER (Light Amplification by Stimulated Emission of Radiation)

- Optical wireless communication/High-speed, line-of-sight
- **Uses:** Building-to-building links / Free space optical communication (FSO)

4. Characteristics of Wireless Transmission Media

A. Bandwidth- Varies widely based on the frequency band/Wi-Fi 6 → up to 9.6 Gbps

5G → 1–20 Gbps/Satellite → 10–100 Mbps

B. Attenuation

- Signal weakens due to: Distance/Atmospheric conditions (rain, fog)

C. Interference- Wireless signals may be affected by:

- Other wireless devices/Microwave ovens/Physical obstacles/Weather

D. Mobility

- **Major advantage** → Allows communication on the move.
- **E. Coverage**
- Can be local (Wi-Fi) or global (satellite, cellular).

Transmission media: Wired (Copper, Fiber- optic) and Wireless

5. Usage / Applications of Wireless Transmission Media

A. Mobile Communication-Smart phones, tablets/Voice, SMS, data services/4G/5G networks

B. Wi-Fi Networks-Home broadband/Campus networking/Enterprise WLANs

C. Satellite Communication

- TV broadcasting (DTH)/GPS navigation/Remote area connectivity/Military comm.

D. Broadcasting-AM/FM radio/Digital TV/News and entertainment channels

E. IoT (Internet of Things)-Smart home devices (Alexa, smart bulbs)/Smart agriculture/Industrial automation/ Smart healthcare

F. Short-Range Communication-Bluetooth audio/Smartwatches/Wireless keyboards/mouse

G. Emergency & Defense Communication-Radar systems/Drone communication Disaster management networks

H. Transportation-Vehicle-to-vehicle (V2V) communication/Intelligent traffic systems/Aviation (air traffic control)

Transmission media: Wired (Copper, Fiber- optic) and Wireless

- 6. Advantages of Wireless Transmission Media
  Mobility/ Easy Installation / Cost Saving / Scalability / Wide Coverage / Flexibility
- 7. Limitations of Wireless Transmission Media
  Interference / Security Risks / Limited Bandwidth / Environmental Impact / Lower Reliability / Latency Issues.

Wireless vs. Wired Media – Comparison Table

Feature	Wireless Media	Wired Media (Copper/Fiber)
Transmission Medium	Air / Free Space	Physical cables (Copper, Coaxial, Fiber Optic)
Mobility	Very high – users can move freely	Low – user/device must stay connected by cable
Installation	Easy, quick, low physical work	More complex – requires cabling and infrastructure
Cost	Lower initial cost	Higher installation and material cost
Bandwidth	Moderate to high (depends on technology like Wi-Fi, 4G/5G)	Very high (especially fiber optics)
Interference	High (EMI, obstacles, other wireless devices)	Very low (almost none in fiber; some in copper)
Use Cases	Mobile devices, IoT, Wi-Fi networks, satellite, sensor networks	High-speed internet backbone, LAN, data centers, enterprise networks