

Computer Networks: The Physical Layer

1. Theoretical Basis for Data Communication

The **Physical Layer (Layer 1)** deals with the actual transmission of **raw bits** over a communication link. The maximum rate at which data can be sent is limited by the channel's characteristics, as described by key theoretical concepts.

Fourier Analysis

The **Fourier theorem** states that any reasonably well-behaved **periodic function**, $g(t)$, can be constructed by summing a series of sine and cosine waves. This means any signal can be broken down into its fundamental frequency and its harmonics.

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$

Here, a_n and b_n are the amplitudes of the sine and cosine components for the n^{th} harmonic (term), and f is the fundamental frequency.

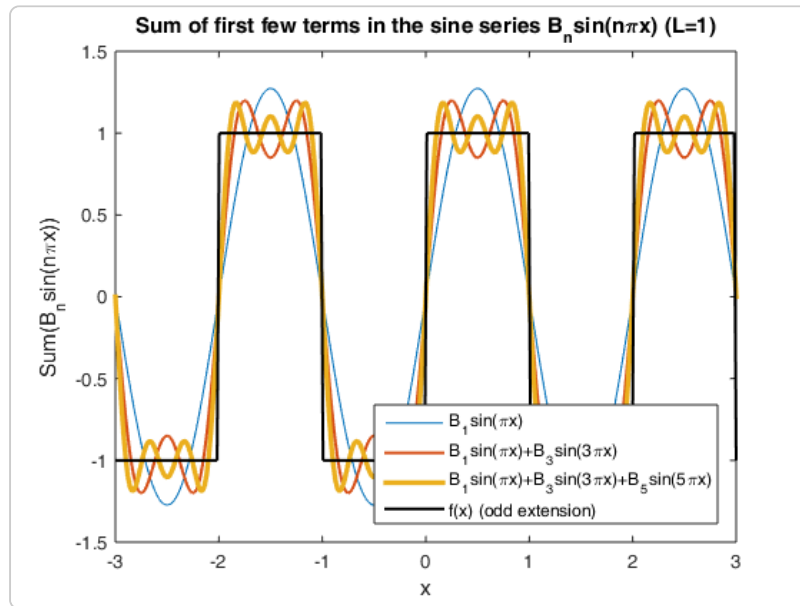


Figure 1: Fourier Series Composition showing square wave construction.

Maximum Data Rate of a Channel

A. Nyquist Theorem (Noiseless Channel)

For a channel with **no noise**, the maximum data rate is determined by the channel's **bandwidth** (H) and the number of **signal levels** (V) used to represent the data.

$$\text{Maximum Data Rate} = 2H \log_2 V \text{ bits per second (bps)}$$

This theorem provides the maximum theoretical rate when noise is ignored. For example, if bandwidth $H=3 \text{ kHz}$ and signal levels $V=2$ (binary), the max data rate is 6000 bps .

B. Shannon Capacity Theorem (Noisy Channel)

When **noise** is present, the channel's maximum capacity (data rate) is limited by the **Signal-to-Noise Ratio (SNR)**, which is the ratio of signal power (S) to noise power (N).

$$\text{Maximum Data Rate} = H \log_2(1+S/N) \text{ bps}$$

The SNR is often measured in decibels (dB). This theorem gives the absolute theoretical upper limit for the data rate, regardless of the number of signal levels used.

2. Transmission Media

The **transmission media** is the physical path that connects the transmitter and receiver. It is the component physically below the Physical Layer.

A. Guided Media (Wired)

Signals are **guided** along a solid, physical path.

i. Twisted Pair Cable (TPC)

Consists of two insulated copper conductors twisted together. **Twisting** is done to **cancel out Electromagnetic Interference (EMI)** from external sources and crosstalk.

- **Unshielded Twisted Pair (UTP):** No metal shielding, cheap, easy to install, but highly susceptible to noise.
- **Shielded Twisted Pair (STP):** Has a metal foil/shield around the conductors to reduce interference, making it better for noise immunity but more costly and bulky.

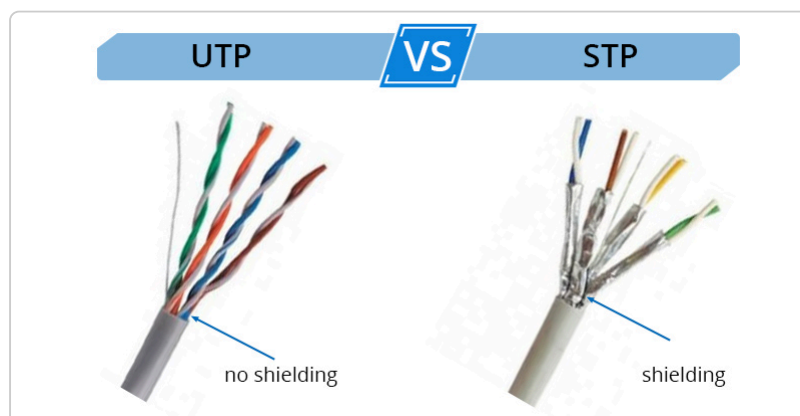


Figure 2: Structure of UTP and STP Cable Construction.

| Feature | UTP (Unshielded) | STP (Shielded) |
|------------|---------------------------------|---------------------------------|
| Noise | Most interference and crosstalk | Less interference and crosstalk |
| Cost | Lowest | Higher |
| Max Length | Typically 100 meters | Can be up to 500 meters |

ii. Coaxial Cable

Features a central copper conductor, plastic foam insulation, a second conductor (braided mesh or foil shield), and an outer jacket. The mesh shield is critical for preventing signal interference/crosstalk.

iii. Fiber Optics

Transmits data using **light waves** through thin glass or plastic threads (fibers).

- **Structure:** **Core** (light travels), **Cladding** (reflects light back into core via total internal reflection), and a **buffer** (protection).
- **Advantages:** **Extremely high bandwidth**, virtually **immune to EMI** (since it uses light), and signals travel long distances.
- **Disadvantages:** Requires two fibers for full duplex (unidirectional light), expensive installation, and complex maintenance.

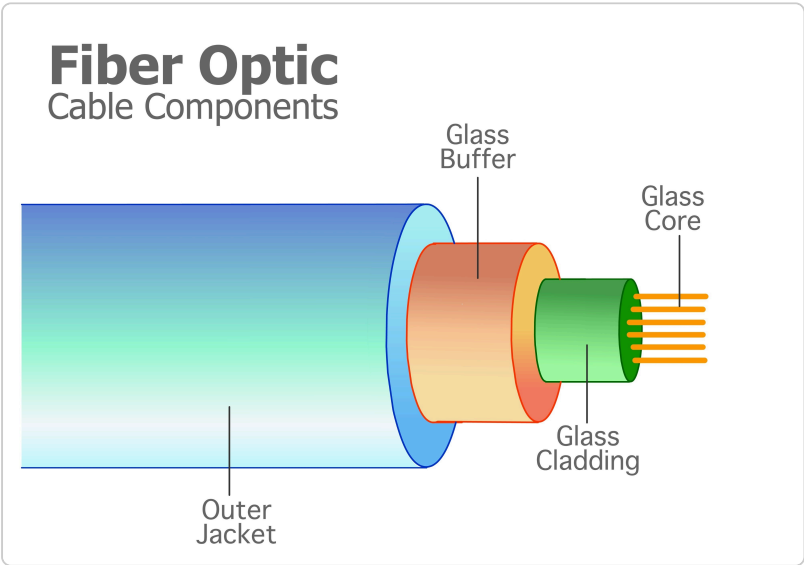


Figure 3: Cross-section of a Fiber Optic Cable.

B. Unguided Media (Wireless)

Transports **electromagnetic waves** through free space without a physical conductor.

- **Radio Waves:** (3 KHz to 1 GHz). Uses **omnidirectional** antennas (signals sent in all directions). Can **penetrate walls**. Used for **multicasting** (e.g., AM/FM radio, TV broadcast).
- **Microwaves:** (1 GHz to 300 GHz). Uses **unidirectional** antennas (narrowly focused). Requires the sending and receiving antennas to be **aligned (Line-of-Sight)**.

- **Infrared Waves:** (300 GHz to 400 THz). Used for **short-range** communication (e.g., remote controls). Cannot penetrate walls, which is a key advantage as it prevents interference between systems in adjacent rooms.

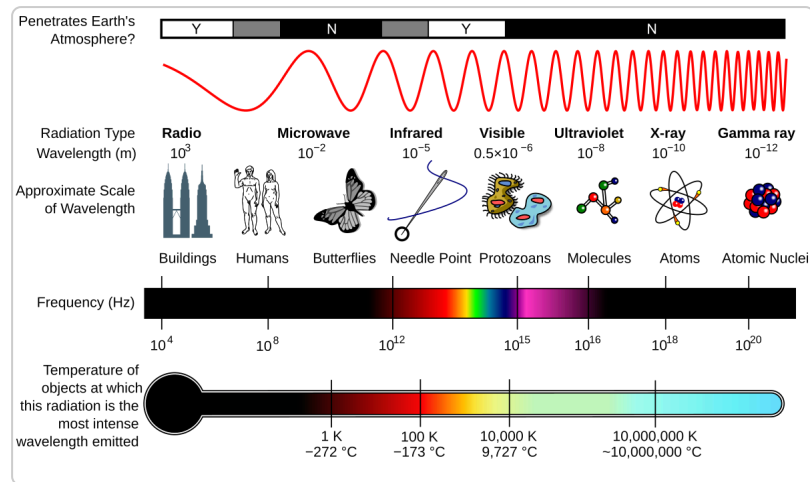


Figure 4: Wireless Frequency Spectrum (Radio, Microwave, Infrared).

3. Satellite Communication

A satellite is essentially a **microwave repeater** in space, used for wide-area coverage. Transmission cost is independent of distance, but the delay is significant (about 0.3 seconds).

How Satellites Work

Earth stations communicate using the satellite as a relay:

- **Uplink:** The signal sent from the Earth Station **to** the satellite.
- **Transponder:** Converts and amplifies the signal on the satellite.
- **Downlink:** The signal sent from the satellite **down** to the receiving Earth Station(s).
- **Footprint:** The area on Earth where the signal can be received with useful strength.

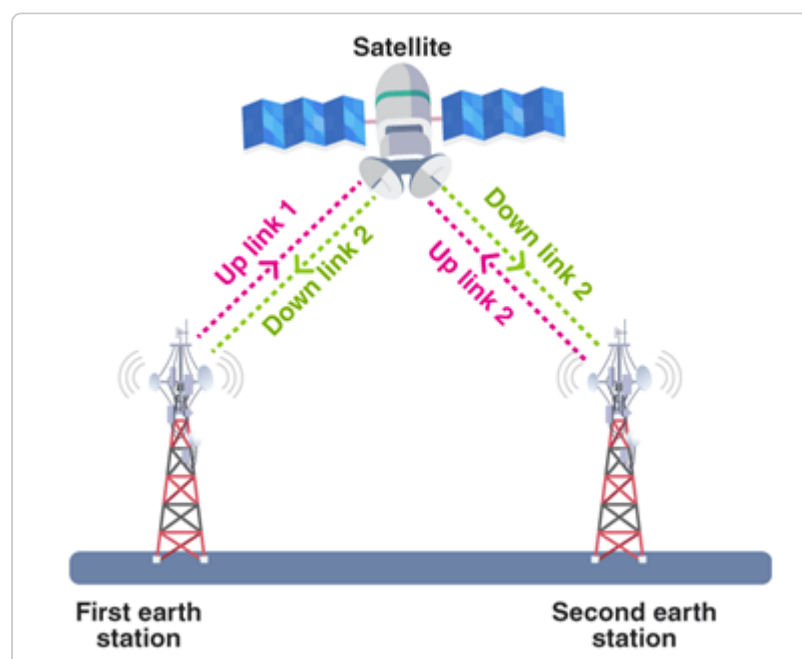


Figure 5: Satellite Communication Uplink, Downlink, and Footprint.

Types of Satellites (Based on Orbit)

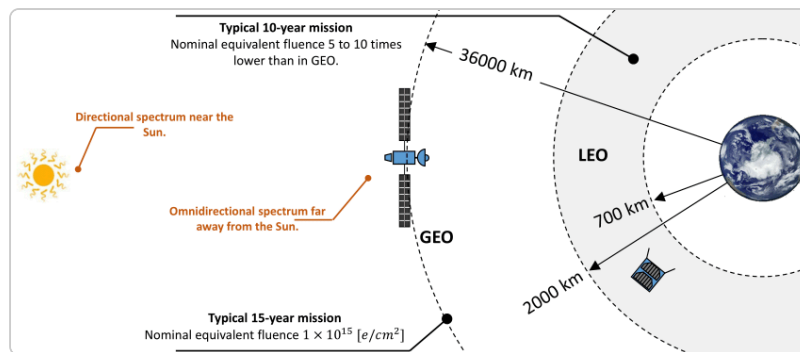


Figure 6: Altitude Comparison of GEO, MEO, and LEO Orbits.

- **GEO (Geostationary Earth Orbit):**
 - **Altitude:** ~36,000 km.
 - **Position:** **Fixed** relative to Earth's surface (revolves at the same speed as Earth).
 - **Coverage:** Requires only three satellites to cover almost the entire Earth. Ideal for **satellite broadcast**.
- **LEO (Low Earth Orbit):**
 - **Altitude:** 500 to 1,500 km.
 - **Position:** Does **not stay fixed**; visible for only a short time per pass.
 - **Use:** Lower time delay (latency) and better signal strength. Good for **point-to-point communication**.
- **MEO (Medium Earth Orbit):**
 - **Altitude:** 8,000 km to 18,000 km.
 - **Position:** Visible for longer than LEO.
 - **Coverage:** Larger coverage area than LEO.

4. Multiplexing

Multiplexing is the technique of allowing the **simultaneous transmission of multiple signals** over a **single data link**.

- **Multiplexer (MUX):** Combines 'n' input lines into one output line.
- **Demultiplexer (DEMUX):** Separates the single combined signal back into its 'n' component signals.

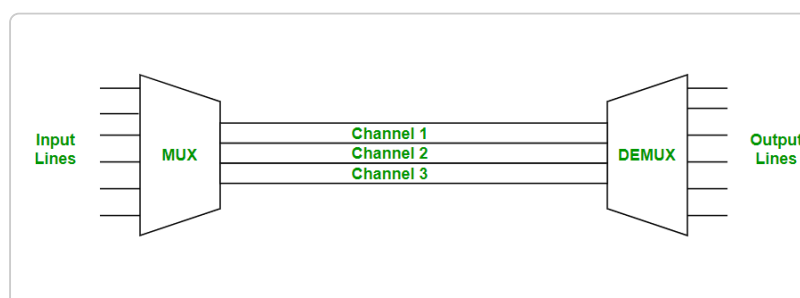


Figure 7: The Multiplexing (MUX/DEMUX) Process.

i. Frequency Division Multiplexing (FDM)

An **analog technique** where signals with **different frequencies** are combined. Each signal is assigned a specific frequency band, separated by **guard bands** to prevent interference. The bandwidth of the link must be greater than the sum of all individual channels' bandwidths.

ii. Wave Division Multiplexing (WDM)

An **analog technique** that works exactly like FDM but is used specifically for **optical or light signals** in fiber optics. Different wavelengths (colors) of light are combined and split using a **PRISM**.

iii. Time Division Multiplexing (TDM)

A **digital technique** where the link's total time is divided into **time slots**. Each user is allocated a specific time slot to transmit their data. This is efficient for digital signals.

| 5. Access Technologies (PSTN, DSL, Cable)

Public Switched Telephone Network (PSTN)

The standard network infrastructure that provides traditional phone services by converting speech into digital data for transmission.

Digital Subscriber Line (DSL)

A general term for services that provide internet connections using a digital modem and existing **copper telephone lines**. Different types exist (SDSL, VDSL, **ADSL**).

- **ADSL (Asymmetric DSL)**: Exploits the **unused analogue bandwidth** in the phone wires to provide faster download speeds than upload speeds.

Cable Modem

A device that allows internet access over a **landline connection** (typically coaxial cable). It converts the received **analog signal** from the cable provider into a **digital signal** for the computer.

Study hard! This note covers all the key concepts.