Module 1.2

Multiplexing

Multiplexing is a key concept in **Data Communication and Computer Networks** that allows efficient use of resources, especially bandwidth. Here's a detailed explanation:

What is Multiplexing?

Multiplexing is a technique that combines multiple signals (data streams) into one signal over a shared medium or channel. This process allows multiple communication sessions to occur over a single physical communication link, thereby optimizing the use of available bandwidth.

- **Multiplexer (MUX):** The device that performs multiplexing.
- **Demultiplexer (DEMUX):** The device that separates the combined signals back into their original forms at the receiver's end.

Why Use Multiplexing?

1. **Efficient bandwidth utilization**
2. **Cost reduction** (fewer transmission media)
3. **Scalability** (adding more users is easier)
4. **Simplifies infrastructure** (fewer cables or wireless frequencies)

Categories of Multiplexing

Multiplexing is broadly categorized into:

1. Frequency Division Multiplexing (FDM)

➤ Definition:

FDM divides the available bandwidth into multiple frequency bands, each carrying a separate signal simultaneously.

➤ Example:

- Traditional radio and TV broadcasting
- Cable TV

➤ Features:

- Analog technique
- Each signal has its own frequency band
- Requires **bandpass filters**

- Guard bands are used to prevent overlap/interference

➤ **Advantages:**

- Simple
- Simultaneous transmission
- Widely used in analog systems

➤ **Disadvantages:**

- Limited bandwidth
- Crosstalk may occur
- Not suitable for bursty or variable data

2. Time Division Multiplexing (TDM)

➤ **Definition:**

TDM divides the time into equal time slots and assigns each signal a specific time slot.

➤ **Types of TDM:**

a) Synchronous TDM

- Time slots are pre-assigned, whether the sender has data or not.
- Fixed slot structure.

b) Asynchronous TDM (Statistical TDM)

- Slots are assigned dynamically based on demand.
- More efficient use of bandwidth.

➤ **Example:**

- Digital telephony
- ISDN systems

➤ **Features:**

- Digital technique
- Less bandwidth wastage in asynchronous TDM
- Requires synchronization

➤ **Advantages:**

- Efficient in digital communication

- More users in asynchronous mode

➤ **Disadvantages:**

- Synchronous TDM wastes slots if a user has no data
- Complex synchronization required

3. Wavelength Division Multiplexing (WDM)

➤ **Definition:**

WDM is like FDM, but it is used in **optical fiber communication**. It combines multiple light signals (of different wavelengths) into a single optical fiber.

➤ **Types:**

- **Coarse WDM (CWDM)**: Fewer channels, larger wavelength spacing
- **Dense WDM (DWDM)**: More channels, tightly packed wavelengths

➤ **Example:**

- Long-distance fiber optic networks
- Submarine cables

➤ **Features:**

- Optical signal based
- Uses prisms or diffraction gratings

➤ **Advantages:**

- Very high data rates
- Efficient use of fiber
- Easily upgradable by adding more wavelengths

➤ **Disadvantages:**

- Expensive
- Complex equipment needed

Comparison Table

Technique	Type	Used In	Multiplexing Basis	Key Device
FDM	Analog	Radio/TV	Frequency	Bandpass Filters
TDM	Digital	Telephony	Time	Synchronizers
WDM	Optical	Fiber Optics	Wavelength (Color)	Multiplexer (Optical)

Spread Spectrum:

What is Spread Spectrum?

Spread Spectrum (SS) is a technique used in wireless communication where a signal is transmitted over a frequency band much wider than the minimum bandwidth required. The main idea is to spread the transmitted data signal over a wide frequency range, making it more resistant to interference, jamming, and eavesdropping.

Why Spread Spectrum?

- **Resistance to Interference and Jamming:** Since the signal is spread over a large bandwidth, narrowband interference affects only a small part of the signal.
- **Security:** Spread spectrum makes signals harder to intercept or decode without knowing the spreading code.
- **Multipath Resistance:** Helps in mitigating multipath fading effects.
- **Multiple Access:** Allows multiple users to share the same bandwidth simultaneously (e.g., CDMA).

How Does Spread Spectrum Work?

- The original data signal is **multiplied** by a pseudo-random spreading code (called a spreading sequence) that has a much higher bit rate.
- This spreading process increases the bandwidth of the transmitted signal.
- At the receiver, the same spreading code is used to **de-spread** the signal and recover the original data.
- If an unauthorized receiver doesn't know the spreading code, the signal appears as noise.

Categories of Spread Spectrum

Spread Spectrum techniques are mainly classified into two categories:

1. Frequency Hopping Spread Spectrum (FHSS)

➤ How It Works:

- The carrier frequency hops between different frequency channels in a pseudo-random sequence known to both the transmitter and receiver.
- The transmitter rapidly switches (or "hops") frequencies during transmission.
- The receiver follows the same hopping pattern to retrieve the signal.

➤ Features:

- Narrowband signal rapidly changes frequency.
- Uses a predefined hopping sequence.
- Hopping rate can be **slow** (several bits per hop) or **fast** (many hops per bit).

➤ Advantages:

- Robust against narrowband interference.
- Good security due to frequency hopping.
- Resistant to multipath fading.

➤ Disadvantages:

- Requires synchronization between transmitter and receiver.
- Complexity increases with hopping speed.

➤ Applications:

- Bluetooth
- Military communication
- Cordless phones

2. Direct Sequence Spread Spectrum (DSSS)

➤ How It Works:

- The data signal is multiplied by a high-rate pseudo-random bit sequence called a **chip sequence** or **spreading code**.
- This spreading code runs at a much higher frequency than the original data.
- The spreading process increases bandwidth by spreading energy over a wide spectrum.

- The receiver uses the same spreading code to de-spread and recover the original signal.

➤ **Features:**

- Wideband signal with low power spectral density.
- Uses **chips** (smaller bits) instead of data bits to spread the signal.
- More resistant to interference and jamming.

➤ **Advantages:**

- High resistance to noise and interference.
- Better privacy and security.
- Easy to synchronize in some systems.

➤ **Disadvantages:**

- Requires precise timing and synchronization.
- More complex receiver design.

➤ **Applications:**

- GPS (Global Positioning System)
- IEEE 802.11b Wi-Fi (early versions)
- CDMA cellular networks

Other Spread Spectrum Variants

- **Time Hopping Spread Spectrum (THSS):** Spreads the signal by transmitting pulses at pseudo-random time intervals.
- **Hybrid Systems:** Combine FHSS and DSSS for enhanced performance.

Comparison Table

Parameter	FHSS	DSSS
Spreading Mechanism	Hopping carrier frequency	Multiplying data by spreading code
Bandwidth Expansion	Medium	Large
Synchronization	Required to follow hopping pattern	Required for de-spreading
Resistance to Interference	Good	Excellent
Complexity	Moderate	Higher
Security	Good	Very good
Applications	Bluetooth, military comms	GPS, CDMA, Wi-Fi

Key Terms:

- **Spreading Code:** A pseudo-random sequence used to spread the signal.
- **Chips:** The bits of the spreading code in DSSS.
- **Processing Gain:** Ratio of spread bandwidth to original bandwidth, indicating how much the signal is spread.

Summary

- Spread Spectrum increases signal bandwidth to improve **security**, **robustness**, and **interference resistance**.
- Two main types:
  - **Frequency Hopping Spread Spectrum (FHSS):** Hops carrier frequency pseudo-randomly.
  - **Direct Sequence Spread Spectrum (DSSS):** Multiplies data with a high-rate spreading code.
- Used widely in **wireless communication systems** and **military applications** for reliable and secure transmission.