***UNIT 3 WC***

1. ***Multiple access techniques (SDMA, TDMA, FDMA, and CDMA) :***

Here’s an explanation of the multiple access techniques (SDMA, TDMA, FDMA, and CDMA) based on the document. I’ll keep it simple and detailed:

**1. SDMA (Space Division Multiple Access):**

* **Meaning:** This technique divides users based on their physical location or space. Each user is assigned a unique spatial resource, often managed using smart antennas.
* **Key Idea:** Users operating in different areas can share the same frequency and time resources.
* **Example:** Two mobile phones in different cities can use the same frequency because their locations are far apart.
* **Features** :

Allocates resources based on spatial locations.

Uses smart antennas to direct signals to specific users.

Supports simultaneous use of the same frequency and time in different spatial areas.

Suitable for applications like satellite communication and cellular networks.

Efficient for managing users spread over large areas.

**2. TDMA (Time Division Multiple Access):**

* **Meaning:** Here, users share the same frequency but at different times. The time is divided into slots, and each user gets a dedicated time slot to transmit data.
* **Key Idea:** Only one user can send data in a given time slot, avoiding interference.
* **Example:** In a conference call, each person speaks one after the other, not simultaneously.
* **Featues :**

Divides time into slots; each user gets a unique time slot.

Users share the same frequency but transmit at different times.

Simple to implement but needs precise synchronization.

Reduces interference since only one user transmits in a slot.

Used in 2G technologies like GSM and other time-based systems.

**3. FDMA (Frequency Division Multiple Access):**

* **Meaning:** In this technique, the available bandwidth (frequency) is divided into smaller channels, and each user gets a unique frequency band.
* **Key Idea:** Each user communicates simultaneously using a different frequency band.
* **Example:** Think of radio stations. Each station has a unique frequency to avoid overlapping.
* **Features :**

Divides the available frequency spectrum into multiple channels.

Each user is assigned a unique frequency band.

Users can transmit data simultaneously without interference.

Requires filters to prevent overlapping of frequencies.

Commonly used in analog communication systems like radio broadcasting.

**4. CDMA (Code Division Multiple Access):**

* **Meaning:** CDMA allows all users to transmit data at the same time and frequency but uses unique codes to differentiate between users.
* **Key Idea:** Data is spread over the entire bandwidth, and receivers decode the intended signal using the specific code.
* **Example:** Imagine a party where everyone is speaking different languages. You focus only on the language you understand (the code).
* **Features :**

Allows all users to share the same frequency and time.

Differentiates users using unique codes (spreading codes).

Highly secure and resistant to interference.

Efficient for voice and data communication with multiple users.

Widely used in 3G networks and GPS systems.

**Summary (Point-wise):**

* **SDMA:** Assigns resources based on physical space; uses smart antennas.  
  **Example:** Mobile phones in different cities using the same frequency.
* **TDMA:** Divides time into slots for users.  
  **Example:** One person talks at a time in a call.
* **FDMA:** Divides frequency into separate channels.  
  **Example:** Radio stations with different frequencies.
* **CDMA:** Uses unique codes to differentiate users sharing the same frequency.  
  **Example:** Party conversations in different languages.

1. ***Comparison of SDMA, TDMA, FDMA, and CDMA***

**Comparison Table**

| **Aspect** | **SDMA** | **TDMA** | **FDMA** | **CDMA** |
| --- | --- | --- | --- | --- |
| **Division Basis** | Space (Physical location) | Time (Time slots) | Frequency (Channels) | Code (Unique codes for each user) |
| **Resource Sharing** | Same frequency and time but different areas | Same frequency but at different times | Different frequency bands for each user | Same frequency and time with unique codes |
| **Interference** | Low (users are spatially separated) | Minimal (time slots avoid overlap) | Minimal (frequencies don’t overlap) | Resistant to interference due to coding |
| **Synchronization** | Less critical | Requires strict timing | Requires frequency coordination | Requires complex code synchronization |
| **Efficiency** | High for large, spread-out user bases | Moderate due to time division | Moderate; some bandwidth gets unused | High; accommodates many users effectively |
| **Technology Use** | Satellite systems, smart antennas | GSM, Digital cellular systems | Analog systems, radio broadcasting | 3G networks, GPS, modern communication |
| **Scalability** | Limited by spatial overlap | Limited by the number of time slots | Limited by available frequency spectrum | High scalability with many simultaneous users |
| **Security** | Moderate | Moderate | Low | High due to unique coding |

**Key Differences**

1. **SDMA:** Focuses on location; best for users in different physical areas.
2. **TDMA:** Divides time; simple but requires precise timing.
3. **FDMA:** Divides frequency; effective but wastes bandwidth.
4. **CDMA:** Uses codes; very secure and efficient for handling multiple users.

**Example to Visualize**

* **SDMA:** Imagine a neighbourhood where each house has its own address; signals only reach a specific house.
* **TDMA:** Think of a classroom where students speak one at a time in fixed turns.
* **FDMA:** Like TV channels, where each show broadcasts on a unique frequency.
* **CDMA:** Like a party where people speak different languages, and you understand only your language.

1. ***IDMA (Interleave Division Multiple Access)***

**Interleave Division Multiple Access (IDMA)**

**Explanation:**

Interleave Division Multiple Access (IDMA) is a multiple access technique used in communication systems. It is an enhancement of Code Division Multiple Access (CDMA) but focuses on user-specific **interleaving** rather than unique codes. Let’s break this down:

1. **Multiple Access Technique**:  
   In a communication system, multiple users share the same transmission channel. IDMA helps multiple users send their data simultaneously without interfering with each other.
2. **Key Concept – Interleaving**:  
   Interleaving is a process of rearranging the order of data bits. In IDMA, each user has a unique interleaver, which makes their data streams appear different, even if they are transmitted simultaneously. This unique arrangement ensures that the receiver can distinguish between the signals from different users.

**Example** :   
If the original data is: ABCDEFGH  
An interleaver might rearrange it as: ACEGBDFH  
At the receiver, it is reordered back to: ABCDEFGH.

1. **Why IDMA Over CDMA?**
   * CDMA uses unique codes for each user, which can be complex to manage.
   * IDMA replaces these codes with simpler, user-specific interleavers. This reduces complexity and improves performance, especially in terms of decoding and handling interference.
2. **Working Process**:
   * **Encoding**: Each user’s data is encoded to protect it from errors.
   * **Interleaving**: The encoded data is interleaved using a unique pattern.
   * **Transmission**: All users' interleaved data is sent over the same channel.
   * **Decoding**: At the receiver, the interleaver patterns help separate and decode each user's data.
3. **Advantages**:
   * **Simpler Design**: No need for complex spreading codes like in CDMA.
   * **Better Performance**: Improved error correction and handling of interference.
   * **Scalability**: Supports more users without significant performance loss.

**Example:**

Imagine three users sending messages:

* User 1 sends: "HELLO"
* User 2 sends: "WORLD"
* User 3 sends: "IDMA"

Using IDMA, each message is encoded and interleaved uniquely:

* User 1 interleaver: H -> L -> E -> L -> O
* User 2 interleaver: W -> R -> O -> L -> D
* User 3 interleaver: I -> M -> D -> A

These interleaved patterns are transmitted together. The receiver knows the interleaving pattern of each user and reorders the bits correctly to recover the original messages.

**Summary:**

1. **What is IDMA?**  
   A communication technique where multiple users share a channel using unique interleaving patterns.
2. **Key Feature**:  
   Interleaving replaces the spreading codes used in CDMA.
3. **Advantages**:  
   Simpler, better error correction, and supports more users.
4. **Example**:  
   Users send interleaved data, which the receiver decodes using the unique interleaving patterns.
5. ***Multi-antenna Technologies :***

**Multi-Antenna Technologies**

**Overview**  
Multi-antenna technologies involve using multiple antennas at the transmitter, receiver, or both to enhance communication system performance. These techniques aim to improve data rates, reduce errors, and increase reliability without increasing the bandwidth.

**Types of Multi-Antenna Technologies:**

1. **SISO (Single Input Single Output):**
   * **Description:** Uses one antenna for transmission and one for reception.
   * **Application:** Traditional communication systems.
   * **Limitation:** Limited capacity and poor performance in environments with multipath fading.

**Example:** Basic FM radio transmission.

1. **SIMO (Single Input Multiple Output):**
   * **Description:** Single transmission antenna with multiple reception antennas to improve signal quality.
   * **Feature:** Uses *Receive Diversity* to combine signals and improve reliability.
   * **Application:** Increases throughput in areas with high multipath interference.

**Example:** Wireless routers with multiple receiving antennas.

1. **MISO (Multiple Input Single Output):**
   * **Description:** Multiple transmission antennas with a single receiving antenna.
   * **Feature:** Uses *Transmit Diversity* to enhance reliability and reduce fading.
   * **Benefit:** Requires fewer antennas at the user end.
   * **Application:** Mobile communication systems.

**Example:** Base stations in cellular networks.

1. **MIMO (Multiple Input Multiple Output):**
   * **Description:** Both transmitter and receiver have multiple antennas.
   * **Feature:** Combines the benefits of SIMO and MISO.
   * **Advantages:**
     + Higher data rates using *Spatial Multiplexing*.
     + Reduced fading effects.
   * **Application:** Advanced wireless technologies like LTE and Wi-Fi.

**Example:** 4G and 5G communication.

**Advantages of Multi-Antenna Technologies:**

1. Enhanced data rates.
2. Improved reliability and reduced errors.
3. Better performance in multipath fading environments.
4. Increased spatial diversity and spectral efficiency.

**Example for MIMO:**

Imagine two antennas at the transmitter and two at the receiver. The system can send independent data streams on each antenna, doubling the data rate compared to SISO.

**Summary:**

* **SISO:** Basic system with one antenna at each end.
* **SIMO:** Multiple receiving antennas improve reliability.
* **MISO:** Multiple transmitting antennas reduce fading.
* **MIMO:** Combines both for high data rates and robust performance.  
  Multi-antenna technologies are pivotal in modern communication systems for higher capacity and reliability.

1. ***MIMO (Multiple Input Multiple Output) Systems***

**MIMO (Multiple Input Multiple Output) Systems**

**Overview**  
MIMO systems use multiple antennas at both the transmitter and receiver to enhance communication performance. They are a key technology in modern wireless systems, allowing higher data rates, improved reliability, and efficient use of bandwidth.

**Principle**

1. **Multiple Antennas:**
   * MIMO combines the functionalities of SIMO (Single Input Multiple Output) and MISO (Multiple Input Single Output).
   * Multiple antennas transmit and receive signals simultaneously.
2. **Spatial Multiplexing:**
   * Independent data streams are transmitted on different antennas simultaneously.
   * Increases the data rate without requiring additional bandwidth.
3. **Diversity Gain:**
   * Signals take multiple paths to the receiver.
   * Reduces the impact of fading and improves signal quality.
4. **Channel Independence:**
   * Each antenna's data stream uses a separate channel, reducing interference and improving performance.

**Types of MIMO:**

1. **2×2 MIMO:**
   * Two transmit and two receive antennas.
   * Common in 4G systems for improved data rates and reliability.
2. **4×4 MIMO:**
   * Four transmit and four receive antennas.
   * Used in advanced communication systems, though it requires more complex hardware.

**Features of MIMO:**

1. **High Throughput:**
   * Increases data transfer speed by using multiple data streams.
2. **Reduced Fading Effects:**
   * Improves signal reliability in environments with multiple obstacles.
3. **Efficient Spectrum Use:**
   * Allows simultaneous use of the same frequency band without interference.
4. **Scalability:**
   * Easily scalable by increasing the number of antennas.

**Advantages:**

1. Higher uplink and downlink data rates.
2. Improved Quality of Service (QoS) and reduced Bit Error Rate (BER).
3. Better Signal-to-Noise Ratio (SNR).
4. Effective in multipath environments (e.g., urban areas).

**Disadvantages:**

1. Complex hardware due to multiple RF chains.
2. High power consumption, leading to faster battery drain.
3. Increased cost due to additional antennas and processing units.

**Example of MIMO in Action:**

A 2×2 MIMO system can send two separate data streams simultaneously using two transmit antennas. At the receiver end, the two antennas decode the signals independently, effectively doubling the data rate compared to a single antenna system.

**Summary:**

* **MIMO uses multiple antennas at both ends for efficient communication.**
* **Key Features:** Spatial multiplexing, diversity gain, and reduced fading.
* **Advantages:** High data rates and reliable signals.
* **Challenges:** Complexity and higher power requirements.  
  MIMO is integral to modern wireless technologies like LTE, Wi-Fi, and 5G.

1. ***Wideband Modulation Technique: OFDM (Orthogonal Frequency Division Multiplexing)***

**Overview**  
Orthogonal Frequency Division Multiplexing (OFDM) is a digital modulation technique widely used in high-speed wireless communication systems. It efficiently transmits data by dividing the bandwidth into multiple orthogonal subcarriers, reducing interference and maximizing data rates.

**Subcarriers** : it is smaller frequency bands into which the entire available spectrum is divided, they do not interfere even though they are closely spaced.

**Key Principles of OFDM:**

1. **Orthogonality:**
   * Subcarriers are orthogonal, meaning they do not interfere with each other.
   * This ensures efficient use of bandwidth without guard bands between subcarriers.
   * Subcarriers are do not interfere even though they are closely spaced.
2. **Frequency Division:**
   * The available spectrum is split into many closely spaced subcarriers.
   * Each subcarrier transmits a portion of the data.
3. **Parallel Transmission:**
   * Data is split into smaller packets, transmitted simultaneously over subcarriers.
   * This reduces transmission delay and increases reliability.

**Features of OFDM:**

1. **Spectral Efficiency:**
   * Closely spaced subcarriers minimize unused bandwidth.
2. **Resistance to Multipath Fading:**
   * Each subcarrier experiences flat fading, which simplifies equalization.
3. **Cyclic Prefix:**
   * A guard interval is added to prevent inter-symbol interference (ISI).
4. **Simple Implementation:**
   * OFDM is implemented using the Fast Fourier Transform (FFT) for modulation and demodulation.

**Advantages of OFDM:**

1. High data rates.
2. Resistance to ISI and frequency-selective fading.
3. Efficient use of bandwidth with overlapping subcarriers.
4. Robust against narrowband interference.
5. Supports single frequency networks (SFN).

**Disadvantages of OFDM:**

1. Sensitive to carrier frequency offsets and phase noise.
2. Requires highly linear amplifiers.
3. High Peak-to-Average Power Ratio (PAPR) can cause inefficiencies.

**Applications of OFDM:**

1. **Wi-Fi (IEEE 802.11 standards)**
2. **4G LTE and 5G**
3. **Digital Video Broadcasting (DVB)**
4. **Power Line Communications**
5. **Li-Fi and other broadband communication systems**

**Example of OFDM:**

In a 4G network, a 20 MHz channel is divided into hundreds of subcarriers. Each subcarrier transmits part of the data, ensuring efficient use of the spectrum and high-speed data delivery to users.

**Summary:**

* **OFDM splits the spectrum into orthogonal subcarriers for efficient and reliable data transmission.**
* **Key Benefits:** High data rates, resistance to fading, and spectral efficiency.
* **Challenges:** Sensitivity to synchronization errors and high PAPR.  
  OFDM is integral to modern wireless communication systems, enabling technologies like LTE, Wi-Fi, and digital broadcasting.