***UNIT 6 WC***

1. ***5G New Radio (NR) :***

**5G New Radio (NR):**

**What is 5G New Radio (NR)?** 5G New Radio (NR) is a global standard for wireless communication developed by the **3rd Generation Partnership Project (3GPP)**. It is designed to replace 4G LTE and provides much faster data transfer rates, improved efficiency, and support for a wide range of applications.

Its main goal is to:

1. Use the electromagnetic spectrum efficiently to support faster mobile broadband.
2. Enable ultra-low latency and massive machine-to-machine communication.
3. Provide speeds comparable (**तुलनात्मक)** to fiber-optic connections, making it ideal for high-bandwidth applications like video streaming and connected vehicles.

**Working of 5G NR**

5G NR introduces new technologies to enhance the performance of wireless communication systems.  
Here are some key features of how it works:

1. **Spectrum Diversity**:  
   It uses a wide range of frequencies, This allows:
   * Low bands for long-range coverage , ideal for rural areas.
   * High bands for extremely fast data rates but work over shorter distances suited for urban areas (dense populations and tall buildings).
2. **Advanced Techniques**:
   * **OFDM (Orthogonal Frequency-Division Multiplexing)**: Helps efficiently handle high data rates and reduces interference.
   * **Massive MIMO (Multiple Input Multiple Output)**: Uses multiple antennas for better signal quality and speed.
3. **Frequency Reuse**:  
   Even in crowded areas, it reuses frequencies efficiently, increasing capacity and avoiding congestion.

**Frequency Reuse** refers to the practice of using the same frequency bands in different areas or cells within a network.

1. **Ultra-Low Latency**:  
   Slot-based operations allow 5G NR to process and deliver data with almost no delay, which is essential for:
   * Vehicle-to-vehicle communication.
   * Remote surgeries.

**Primary Requirements of 5G NR**

To be classified as 5G NR, a system must meet these conditions:

1. **Support for mobile connections**: Seamless and fast connectivity for mobile users.
2. **IoT and Sensor Compatibility**: It must support billions of IoT devices efficiently.
3. **Energy Efficiency**: Uses adaptive bandwidth (which adjusts according to the network demand), switching to lower power modes when possible.
4. **Lean Signaling Design**: Activates signals only when needed, reducing device energy consumption.
5. **Strict Data Requirements**: Ensures high-quality and consistent data transfer across the network.

**Benefits of 5G NR**

1. **Larger Capacity**: Can handle more users and devices simultaneously.
2. **Energy Efficiency**: Devices consume less power during communication.
3. **Faster Speeds**: Extremely high data rates improve streaming, gaming, and real-time communication.
4. **Wider Coverage**: Reliable connections over large areas, including urban and rural regions.
5. **Improved Connection Quality**: Ensures consistent performance across different environments.

**Example:**

* Imagine you're in a crowded stadium. With 4G, the network might slow down due to heavy usage. However, with 5G NR’s **massive MIMO** and **frequency reuse**, every user gets fast and reliable connectivity without interruption.

**Summary (Point-to-Point):**

1. 5G NR is a global wireless communication standard developed by **3GPP**.
2. It aims to improve speed, latency, and efficiency over 4G LTE.
3. Features include **spectrum diversity**, **massive MIMO**, and **low latency**.
4. Requirements:
   * Supports IoT, mobile connections, and adaptive bandwidth.
5. Benefits:
   * Faster speeds, energy savings, and better connection quality.
6. Applications: Streaming, IoT, autonomous vehicles, and smart cities.
7. ***Holographic MIMO Surfaces for 6G Wireless Networks :***

**Holographic MIMO Surfaces (HMIMOS) for 6G Wireless Networks**

**What are HMIMOS?**

Holographic MIMO Surfaces (HMIMOS) are an advanced technology concept designed for **6G wireless networks**. They are large, intelligent surfaces made of tiny (लहान), reconfigurable components (metallic or dielectric particles). These surfaces interact with electromagnetic waves to improve communication efficiency and coverage.

**Purpose:**

1. Provide low-power, high-throughput, and low-latency communication.
2. Enable massive connectivity by optimizing how signals travel in the wireless environment.
3. Overcome limitations of current technologies like massive MIMO by being **cost-effective**, **energy-efficient**, and **programmable**.

**Why HMIMOS for 6G?**

Future wireless networks, like 6G, must handle:

* Huge numbers of users and devices.
* High **Spectral Efficiency (SE)** (better usage of frequency spectrum).
* High **Energy Efficiency (EE)** to reduce power consumption.

HMIMOS aim to make wireless environments **intelligent and adaptive** by:

* Sensing, controlling, and optimizing signal propagation.
* Addressing challenges like signal fading, blockage, and noise in dense environments.

**Key Features of HMIMOS**

1. **Programmable Surfaces**:  
   These surfaces can change how they reflect, absorb, or transmit electromagnetic waves, improving communication efficiency.
2. **Low Cost and Power**:  
   Unlike massive MIMO antennas, HMIMOS are lightweight, inexpensive, and consume very little energy.
3. **Enhanced Signal Management**:  
   HMIMOS can reduce interference, focus signals on specific users (beamforming), and improve overall signal quality.
4. **Overcoming Hardware Challenges**:  
   Traditional massive MIMO requires large, costly antenna arrays. HMIMOS minimize this by using advanced software-based techniques.

**HMIMOS Design Models**

HMIMOS can be categorized by their **power consumption** and **hardware structure**:

**1. Based on Power Consumption**

* **Active HMIMOS**:
  + Act as transmitters/receivers.
  + Require **power-intensive** circuits and are more complex.
  + Example: Advanced antennas for signal transmission in smart cities.
* **Passive HMIMOS**:
  + Behave like mirrors, reflecting signals without additional power.
  + Require energy-harvesting modules for operation.
  + Example: Coating building walls to reflect signals into dark corners.

**2. Based on Hardware Structure**

* **Contiguous HMIMOS**:
  + Contains an infinite number of elements forming a smooth, continuous surface.
  + Inspired by optical holography (recording and reconstructing wave patterns).
* **Discrete HMIMOS**:
  + Made up of small, individual units with reconfigurable properties.
  + Example: Surfaces with adjustable components for directing signals efficiently.

**Applications of HMIMOS**

1. **Outdoor Applications**:
   * Enhance coverage in areas like urban environments, airports, and shopping malls.
   * Extend network coverage from outdoor to indoor spaces.
2. **Indoor Applications**:
   * Improve Wi-Fi and cellular network coverage inside buildings.
   * Reduce signal interference caused by walls, furniture, or dense electronic devices.
   * Enable precise indoor positioning systems for navigation.

**Example:**

* In an office building, **passive HMIMOS** installed on walls can reflect signals from a router to areas with weak connectivity. This reduces the need for additional hardware and enhances the network's coverage and speed.

**Summary (Point-to-Point):**

1. **HMIMOS are intelligent surfaces** that optimize wireless communication by interacting with electromagnetic waves.
2. Designed for **6G networks**, they address issues like signal fading, noise, and connectivity challenges.
3. **Key features**: Programmable, low-cost, energy-efficient, and scalable.
4. **Two types**:
   * Active (transmitters/receivers).
   * Passive (signal reflectors).
5. **Applications**: Outdoor (urban areas, airports) and indoor (Wi-Fi coverage, positioning systems).
6. ***HMIMOS Design Models :***

**HMIMOS Design Models: Overview**

Holographic Multiple Input Multiple Output Surfaces (HMIMOS) are an advanced wireless technology aimed at enhancing communication systems by making wireless environments programmable and intelligent. Their design models focus on efficient power use, hardware structure, and operational capabilities.

**1. Categorization Based on Power Consumption**

HMIMOS can be classified into two types depending on power requirements:

* **Active HMIMOS**:
  + Functions as a transmitter, receiver, or reflector.
  + Embeds energy-intensive RF circuits and signal processing units in the surface.
  + Often used in high-performance scenarios with software-controlled antenna elements densely packed into a 2D surface.
  + Implements continuous antenna aperture using numerous tiny antenna elements.
* **Passive HMIMOS**:
  + Also known as Reconfigurable Intelligent Surface (RIS).
  + Acts as a passive reflector without requiring dedicated power sources.
  + Uses energy-harvesting modules to power its circuitry, making it energy-neutral.
  + Can shape and forward radio waves without amplifiers or sophisticated signal processing.

**2. Categorization Based on Hardware Structure**

The HMIMOS can be categorized based on their hardware architecture into:

* **Contiguous HMIMOS**:
  + Features an infinite number of elements integrated into a limited surface area, forming a continuous aperture.
  + Inspired by optical holography, enabling precise manipulation of electromagnetic (EM) fields.
  + Benefits include high spatial resolution and minimal undesired side lobes.
* **Discrete HMIMOS**:
  + Built from discrete unit cells made of low-power, software-tunable metamaterials.
  + Features steerable metasurfaces that reflect EM waves based on electronic configurations.
  + Comprises elements like microelectromechanical systems or liquid crystals for customizable EM properties.

**3. Fabrication Methodologies**

The fabrication techniques for HMIMOS vary depending on the desired structure (contiguous or discrete). Key methodologies include:

* **Electron Beam Lithography**: Suitable for high-frequency applications.
* **Nano-Imprint Lithography**: Effective for large-scale production.
* **Direct Laser Writing**: Commonly used for precise structures.
* **Printed Circuit Board Processes**: Applied in microwave-frequency designs.

**4. Operation Modes**

HMIMOS systems operate in four main modes:

1. **Active Transceiver (Continuous)**:
   * Generates RF signals and performs beamforming over a continuous surface using the holographic principle.
2. **Passive Reflector (Discrete)**:
   * Reconfigurable unit cells reflect and redirect signals without energy consumption.
3. **Passive Transceiver (Discrete)**:
   * Combines active control with discrete structural design.
4. **Passive Reflector (Continuous)**:
   * Uses dynamic impedance control to manipulate signal reflection across a continuous surface.

**Example**

Imagine a smart city where HMIMOS panels are embedded into building walls. Passive HMIMOS can reflect Wi-Fi signals to extend coverage in areas with poor connectivity, while active HMIMOS can transmit and receive data for high-density IoT networks.

**Summary (Point-by-Point)**

1. HMIMOS can be **active** (energy-intensive) or **passive** (energy-efficient).
2. Hardware structures are either **contiguous** (continuous surface) or **discrete** (unit cells).
3. Fabrication methods include lithography, laser writing, and PCB processes.
4. Operation modes range from active transceivers to passive reflectors.
5. HMIMOS can enhance wireless communication by reconfiguring EM waves dynamically and intelligently.
6. ***Operation Modes and Communication Applications of HMIMOS***

**Operation Modes and Communication Applications of HMIMOS**

**Operation Modes of HMIMOS**

HMIMOS (Holographic Multiple Input Multiple Output Surfaces) can work in different ways, depending on how they are designed and used. There are four main modes:

1. **Continuous HMIMOS as Active Transceivers**
   * This mode acts like an antenna that actively sends and receives signals.
   * The surface uses countless tiny, programmable elements to create precise beams of radio waves.
   * Example: A smart billboard that transmits advertisements to users’ phones while also receiving user feedback.
2. **Discrete HMIMOS as Passive Reflectors**
   * These act like mirrors. They don’t need power but can reflect signals to specific directions by reconfiguring their small elements.
   * Example: A panel on a building that redirects Wi-Fi signals to improve coverage in nearby areas.
3. **Discrete HMIMOS as Passive Transceivers**
   * This combines active and passive features. It uses less power but can still manipulate signals intelligently.
   * Example: A lightweight system in public transportation that enhances both reception and transmission.
4. **Continuous HMIMOS as Passive Reflectors**
   * These smooth surfaces reflect signals without using much power, relying on dynamic control of their reflective properties.
   * Example: Coating a stadium roof with panels to ensure better signal distribution inside.

**Communication Applications of HMIMOS**

HMIMOS are transforming wireless communication in both outdoor and indoor settings. Here’s how:

1. **Outdoor Applications**
   * **Urban Coverage**: HMIMOS panels can extend network signals in cities, shopping malls, and airports.
   * **Building Connectivity**: They can link buildings to network base stations even when direct signals are blocked.
   * **Energy-Efficient Beamforming**: HMIMOS focus radio waves toward specific users, improving efficiency and saving energy.
   * **Wireless Power Transfer**: Panels can collect ambient energy and transmit it to low-power devices like IoT sensors.
2. **Indoor Applications**
   * **Enhanced In-Building Coverage**: HMIMOS can improve signal strength by redirecting waves to areas with weak connectivity.
   * **High-Accuracy Indoor Positioning**: They enable precise indoor navigation in places where GPS doesn’t work.
   * **RF Pollution Reduction**: By intelligently controlling signals, HMIMOS reduce interference in crowded indoor environments.

**Example**

In a large airport, HMIMOS panels installed on walls and ceilings ensure seamless connectivity. They direct signals to passengers in lounges, optimize signal strength for security systems, and even power small IoT devices used for navigation.

**Summary**

**Operation Modes**:

1. **Active Transceivers**: Actively send and receive signals.
2. **Passive Reflectors**: Redirect signals without power.
3. **Passive Transceivers**: Combine active and passive features.
4. **Passive Reflectors (Continuous)**: Smooth surfaces reflecting signals.

**Applications**:

1. **Outdoor**: Urban coverage, building connections, energy-efficient beamforming, wireless power transfer.
2. **Indoor**: Stronger signal inside buildings, precise indoor navigation, less RF pollution.

Let me know if you want to dive deeper into any part! 😊

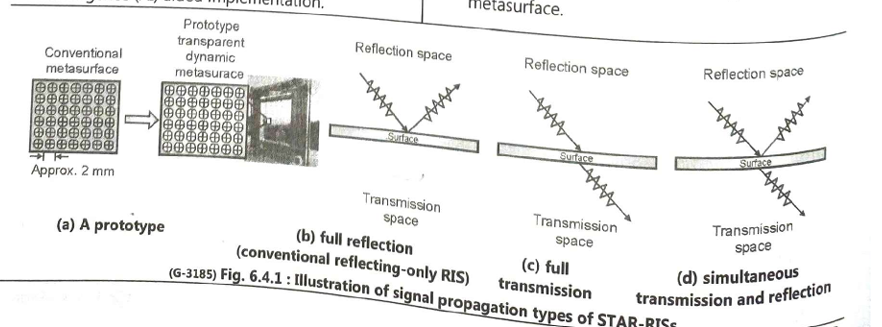
1. ***Simultaneous Transmission and Reflection (STAR) for 360° Coverage :***

**Simultaneous Transmission and Reflection (STAR) for 360° Coverage**

**What is STAR-RIS?**

STAR (Simultaneous Transmission and Reflection) with Reconfigurable Intelligent Surfaces (RIS) is an advanced technology designed to manipulate wireless signals in all directions, enabling **360° coverage**. Unlike traditional RIS, which only reflects signals, STAR-RIS can both **reflect and transmit** signals simultaneously, creating a "full-space" coverage.

**How Does STAR-RIS Work?**

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STAR-RIS uses special reconfigurable elements placed on a transparent substrate. These elements allow incident signals (incoming wireless waves) to:

1. **Reflect** to one side of the surface.
2. **Transmit** to the other side of the surface.

This dual behavior ensures that signals can reach users on both sides of the RIS, providing seamless coverage.

**Advantages of STAR-RIS**

1. **Full-Space Coverage**:
   * Covers both sides of the surface, unlike traditional RIS that only works on one side.
   * Example: A panel installed on a wall can serve users inside and outside a building.
2. **Flexible Signal Control**:
   * STAR-RIS allows independent control of transmitted and reflected signals, making it highly adaptable to different scenarios.
3. **Energy Efficiency**:
   * Signals are intelligently managed without requiring significant additional power, making it eco-friendly.
4. **Compact and Aesthetic Design**:
   * STAR-RIS panels are often transparent, blending easily with environments like windows or walls.

**Differences Between Reflecting-Only RIS and STAR-RIS**

1. **Signal Behavior**:
   * Reflecting-Only RIS: Signals are only reflected.
   * STAR-RIS: Signals are both reflected and transmitted.
2. **Design**:
   * STAR-RIS requires transparent substrates that support both electric and magnetic currents. These are more complex but provide more functionality.
3. **Physics**:
   * Reflecting-Only RIS handles only electric polarization, while STAR-RIS manages both electric and magnetic polarization, offering more degrees of freedom (DoFs) in controlling signals.

**Applications of STAR-RIS in 6G Networks**

1. **Indoor and Outdoor Coverage**:
   * STAR-RIS can extend coverage into areas blocked by walls or obstacles.
   * Example: Ensuring strong signal strength in a building and its surrounding courtyard.
2. **Transmission and Reflection for NOMA (Non-Orthogonal Multiple Access)**:
   * It helps manage signal distribution to multiple users efficiently.
3. **Coordinated Multi-Point Communication**:
   * STAR-RIS can work with multiple base stations, ensuring consistent signal delivery to users across large areas.
4. **Enhanced Physical Layer Security**:
   * STAR-RIS can create secure communication zones by controlling how and where signals propagate.
5. **Indoor Localization and Sensing**:
   * Enables precise indoor positioning and sensing where GPS fails.

**Example**

Imagine a STAR-RIS panel installed in a transparent office window. The panel simultaneously reflects signals to users inside the building and transmits them to users outside. This ensures both indoor employees and people nearby have reliable, strong connectivity.

**Summary**

1. **STAR-RIS** provides full-space (360°) coverage by transmitting and reflecting signals.
2. It enhances signal control flexibility and energy efficiency.
3. Differences from Reflecting-Only RIS include the ability to work on both sides and support for magnetic polarization.
4. **Applications** include indoor-outdoor coverage, secure communication zones, and improved localization.

Let me know if you’d like to explore this further! 😊

1. ***Quantum Technology for 5G / 6G Wireless Networks :***

**Quantum Technology for 5G/6G Wireless Networks**

**What is Quantum Technology?**

Quantum technology is a cutting-edge field that uses the principles of **quantum mechanics** (like superposition and entanglement) to develop advanced communication and computing systems. It is expected to significantly enhance **5G and 6G networks**, enabling smarter, faster, and more secure communication.

**Role of Quantum Technology in 5G and 6G**

1. **Quantum Computing**:
   * Quantum computing uses **qubits** instead of traditional bits. Qubits can represent multiple states simultaneously, allowing for exponentially faster calculations.
   * In 6G, quantum computing can optimize data traffic, improve AI-based decision-making, and secure networks.
   * Example: Google's Sycamore Quantum Computer, which demonstrated processing speeds unattainable by classical systems.
2. **Quantum Communication**:
   * Enables **ultra-secure data transfer** by using quantum encryption techniques like **Quantum Key Distribution (QKD)**.
   * QKD ensures that any attempt to intercept the data would be immediately detected, providing unparalleled security.
   * Example: A 6G-enabled banking system using QKD to secure transactions against hacking.
3. **Quantum Sensing and Metrology**:
   * This aspect focuses on improving the precision of measurements, reducing noise, and enhancing localization accuracy.
   * Example: Quantum sensors in a 6G network can precisely locate devices indoors, where GPS fails.

**Key Principles of Quantum Technology**

1. **Superposition**:
   * A qubit can be in multiple states (e.g., 0 and 1) simultaneously, allowing for faster and more complex calculations.
2. **Entanglement**:
   * Two quantum particles can be linked so that the state of one instantly affects the state of the other, even if they are far apart. This property is vital for secure communication.

**Quantum Computing in 5G/6G Networks**

Quantum computing in 5G/6G networks enhances these aspects:

1. **Data Security and Reliability**:
   * Quantum entanglement provides a tamper-proof communication channel.
   * Example: Military communication networks using quantum encryption for secure data exchange.
2. **Performance Optimization**:
   * Quantum algorithms can optimize signal processing and network routing in real time, even under heavy loads.
3. **Challenges**:
   * Long-distance quantum communication is difficult due to fiber attenuation and operational errors.
   * Quantum repeaters, essential for extending distances, are not yet fully developed.

**Applications of Quantum Technology in Wireless Networks**

1. **Secure Communication**:
   * QKD ensures data is transmitted securely, even in highly sensitive industries like banking or defense.
   * Example: Protecting confidential data during a high-level government conference.
2. **Enhanced AI for Network Management**:
   * Quantum computing can accelerate AI tasks like analyzing massive amounts of network data and predicting traffic patterns.
3. **Improved Localization and Sensing**:
   * Quantum sensors can provide high-precision indoor and outdoor location tracking.
   * Example: Navigating a self-driving car in a complex city environment.
4. **Energy Efficiency**:
   * Quantum algorithms help manage power more efficiently across networks.

**Example**

Imagine a 6G-enabled hospital using quantum communication to transmit sensitive patient data between devices securely. Quantum sensors help locate medical equipment with precision, while quantum computing optimizes data handling during emergencies.

**Summary**

1. **Quantum technology** uses principles like superposition and entanglement to revolutionize communication.
2. It improves **data security**, **network optimization**, and **localization accuracy**.
3. Applications include **quantum encryption**, **high-precision sensing**, and **enhanced AI-driven management**.
4. Challenges include developing reliable quantum repeaters for long-distance communication.

Let me know if you'd like more details! 😊

1. ***Applications of Wireless Technology :***

**Applications of Wireless Technology**

Wireless technology has become an integral part of modern life, enabling seamless communication and connectivity. Its applications span various fields, including transportation, business, emergencies, and entertainment. Here's an easy-to-understand breakdown:

**1. Vehicles**

* **Present Use**: Vehicles today are equipped with mobility-aware communication systems, such as navigation and infotainment systems.
* **Future Potential**: Future cars will have more advanced communication systems for autonomous driving and connectivity.
* **Examples**:
  + Digital Audio Broadcasting (DAB) for real-time traffic updates and weather information.
  + Satellite-based **GPS** for navigation.
  + Vehicle-to-Vehicle (V2V) communication for sharing road condition data.

**2. Emergencies**

* Wireless networks are critical during emergencies like natural disasters, where traditional communication systems may fail.
* **Examples**:
  + Ambulances with wireless connections transmit patient data to hospitals in real time.
  + Wireless communication allows rescue teams to coordinate during floods or earthquakes.

**3. Business**

* Wireless technology allows professionals to stay connected while traveling.
* **Examples**:
  + Sales representatives use laptops or tablets with wireless connectivity to access company databases and files on the go.
  + Video conferencing and mobile offices are powered by wireless networks.

**4. Replacement of Wired Networks**

* In many cases, wireless networks are more economical and convenient than traditional wired systems.
* **Examples**:
  + Historic buildings use wireless networks to avoid damaging walls with cabling.
  + Tradeshows and exhibitions rely on wireless LANs for temporary setups.

**5. Infotainment**

* Wireless networks provide both **information** (e.g., news) and **entertainment** (e.g., music, streaming).
* **Examples**:
  + Internet-connected smart TVs and mobile devices.
  + Streaming platforms like Netflix and Spotify rely on wireless internet for seamless service.

**6. Location-Dependent Services**

* Wireless networks enable services tailored to the user's location.
* **Examples**:
  + Navigation apps provide nearby restaurant suggestions.
  + Smart services forward emails or allow video conferencing from the user’s current location.

**7. Mobile and Wireless Devices**

Wireless technology supports various devices that improve productivity and communication, such as:

* **Examples**:
  + Smartphones, laptops, personal digital assistants (PDAs), and IoT devices.

**Example**

Consider a smart city where wireless networks connect cars, ambulances, businesses, and entertainment platforms. Autonomous vehicles use GPS for navigation, businesses conduct meetings on mobile devices, and residents stream their favorite shows seamlessly.

**Summary**

1. **Vehicles**: GPS, V2V communication, and real-time updates.
2. **Emergencies**: Reliable communication for rescue and healthcare.
3. **Business**: Mobile offices and wireless data access.
4. **Wired Replacement**: Wireless networks in historical or temporary setups.
5. **Infotainment**: Streaming and internet-based services.
6. **Location Services**: Customized recommendations based on location.
7. **Devices**: Smartphones, laptops, and IoT integration.