Evolution of Mobile Communication Networks: 2G, 3G, and 4G

The evolution of mobile communication networks from 2G to 4G brought significant advancements in terms of speed, capacity, and features. Below is a detailed explanation of the changes introduced by these technologies:

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1. 2G Network (Second Generation)

- **Introduction**: Launched in the 1990s, 2G was the first digital mobile communication system, replacing the analog 1G.
- **Key Features**:
  - **Digital Communication**: Shifted from analog signals to digital signals, improving clarity and reducing noise.
  - **Voice and SMS**: Introduced text messaging (SMS) and basic data services like MMS (Multimedia Messaging Service).
  - **Encryption**: Enhanced security through encryption, preventing eavesdropping.
  - **Data Speed**: Maximum speed of up to **64 kbps**.
- **Impact**:
  - Enabled global roaming due to the adoption of GSM (Global System for Mobile Communications).
  - Paved the way for basic data applications like SMS and picture messaging.

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2. 3G Network (Third Generation)

- **Introduction**: Introduced in the early 2000s, 3G aimed to improve data services and enable internet access.
- **Key Features**:
  - **High-Speed Internet**: Data rates of up to **2 Mbps** for stationary users and **384 kbps** for mobile users.
  - **Video Calling**: Supported real-time video calls for the first time.
  - **Mobile Broadband**: Allowed access to web browsing, email, and online applications.
  - **WCDMA and CDMA2000**: Used Wideband Code Division Multiple Access (WCDMA) and CDMA2000 for better spectrum efficiency.
- **Impact**:
  - Facilitated the rise of smartphones and mobile apps.

- Enhanced multimedia services, such as video streaming and online gaming.

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3. 4G Network (Fourth Generation)

- **Introduction**: Launched in 2010, 4G marked a shift toward all-IP (Internet Protocol) networks, designed for faster and more efficient data communication.
- **Key Features**:
  - **High-Speed Data**: Data rates of up to **100 Mbps** for mobile users and **1 Gbps** for stationary users.
  - **OFDM Technology**: Used Orthogonal Frequency Division Multiplexing (OFDM) for better spectrum utilization and reduced interference.
  - **LTE (Long-Term Evolution)**: Became the standard for 4G networks, offering low latency and improved capacity.
  - **Support for HD Services**: Enabled high-definition video streaming, online gaming, and real-time video conferencing.
- **Impact**:
  - Revolutionized mobile internet by supporting applications like Uber, YouTube, and social media.
  - Led to the proliferation of IoT (Internet of Things) devices, enabling smart homes and connected devices.

Comparison of 2G, 3G, and 4G

Feature	2G	3G	4G
Launch	1990s	Early 2000s	2010s
Technology	GSM, CDMA	WCDMA, CDMA2000	LTE, OFDM
Data Speed	Up to 64 kbps	Up to 2 Mbps	Up to 1 Gbps
Services	SMS, MMS	Video calling,	HD video, IoT
		Mobile internet	Smart apps

What is cell ?

• Each cellular base station is allocated a group of radio channels within a small geographic area called a cell.

General Model of a Wireless Communication Link/Components of WC

The general model of a wireless communication link includes all the key components and parameters that describe how information is transmitted wirelessly from a transmitter to a receiver. Here's a concise overview:

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1. Transmitter (Tx)

The transmitter is responsible for encoding, modulating, and transmitting data.

1. **Data Source**: The original data to be transmitted (e.g., voice, video, text).
2. **Source Encoder**: Compresses and encodes data to reduce redundancy and improve efficiency.
3. **Channel Encoder**: Adds redundancy to make data robust against errors.
4. **Modulator**: Converts digital signals into analog waveforms for transmission (e.g., AM, FM, QPSK).
5. **Power Amplifier**: Boosts the signal's power to ensure it reaches the required range.

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2. Channel

The medium through which the signal travels from the transmitter to the receiver, subject to impairments:

1. **Noise**: Unwanted signals that corrupt data.
2. **Interference**: Overlapping signals from other sources.
3. **Fading**: Variations in signal strength caused by multipath propagation (reflections and scattering).

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3. Receiver (Rx)

The receiver demodulates, decodes, and reconstructs the original data.

1. **Demodulator**: Extracts the transmitted information by reversing modulation.
2. **Channel Decoder**: Corrects errors introduced during transmission.
3. **Source Decoder**: Restores the original data if source encoding was applied.

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4. Channel State Information (CSI)

The receiver may provide feedback about the channel's condition to the transmitter, allowing it to adjust transmission parameters (e.g., power, modulation) for optimal performance.

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5. Propagation Model

Describes how signals propagate through the environment, accounting for factors like path loss, shadowing, and multipath fading. Different models apply to free space, urban, or indoor environments.

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6. Antennas

Antennas at both the transmitter and receiver are essential for signal transmission and reception. Antenna design affects coverage, gain, and directionality.

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7. Signal Quality Metrics

Metrics like Signal-to-Noise Ratio (SNR), Bit Error Rate (BER), and Packet Error Rate (PER) are used to assess the quality and reliability of the wireless communication link.

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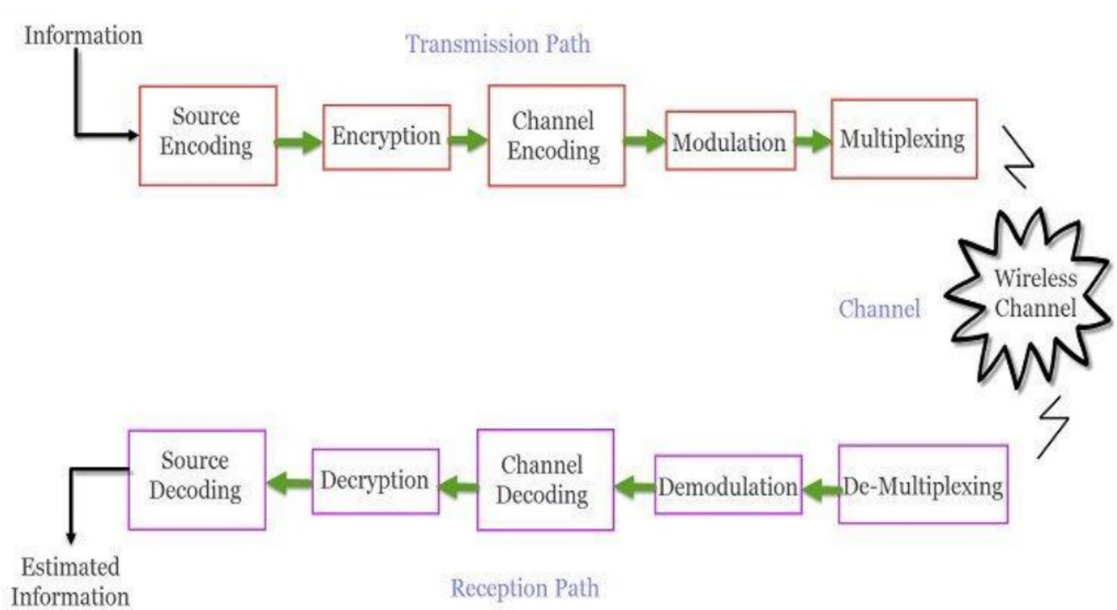
8. Wireless Standards and Protocols

Wireless systems follow specific standards and protocols (e.g., Wi-Fi, Bluetooth, 4G LTE, 5G NR) that define rules for communication, such as modulation schemes, frequency bands, and protocol stacks.



Wireless Local Loop (WLL): Explanation, Components, and Features

WLL is a wireless communication system that uses wireless signals instead of traditional landline networks, mainly deployed in remote and rural areas. It provides voice, data, and internet services without requiring wired infrastructure.

WLL Components and Their Functions

1. **PSTN (Public Switched Telephone Network)**:
    - **Function**: Provides voice and data communication, routes WLL signals to the central office.
2. **Switch Function**:
    - **Function**: Routes PSTN calls and data between WANUs, handles call setup and traffic management.
3. **WANU (Wireless Access Network Unit)**:
    - **Function**: Located at the local exchange, connects all WASUs, routes voice and data, and handles authentication and maintenance.
    - **Sub-Components**: Transceiver, WLL Controller, Access Manager (AM)- responsible for authentication, Home Location Register (HLR).
4. **WASU (Wireless Access Subscriber Unit)**:
    - **Function**: Installed at the subscriber's location, provides voice and data services, processes wireless signals and sends them to user devices.

Features of WLL

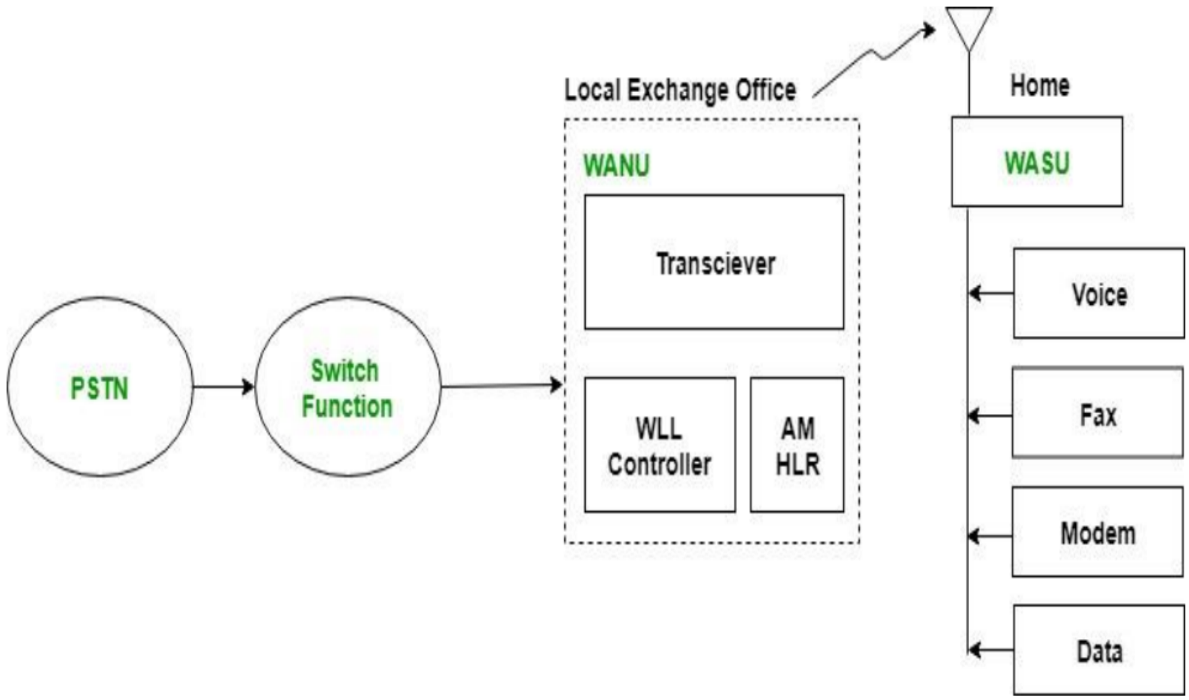
1. **Cost-Effective**:
    - WLL is cheaper than traditional wired systems, especially in remote areas.
2. **Flexibility**:
    - Can be easily deployed and upgraded without requiring extensive wiring.
3. **High-Speed Communication**:
    - Provides reliable and fast communication for voice and data services.
4. **No Need for Extensive Wiring**:
    - Communication is wireless, eliminating the need for traditional wiring.
5. **Supports Multiple Services**:

- Supports voice, data, and internet services.

6. **Scalability**:
    - Can be easily expanded as more users are added.
7. **Easy to Maintain**:
    - Wireless systems are easier to maintain compared to wired infrastructure.

Real-Life Example of WLL

In a rural area, the **WASU** is installed at the subscriber's home and connected to the **WANU**. The **Switch** routes calls, and **PSTN** ensures communication in remote areas without the need for physical wiring.

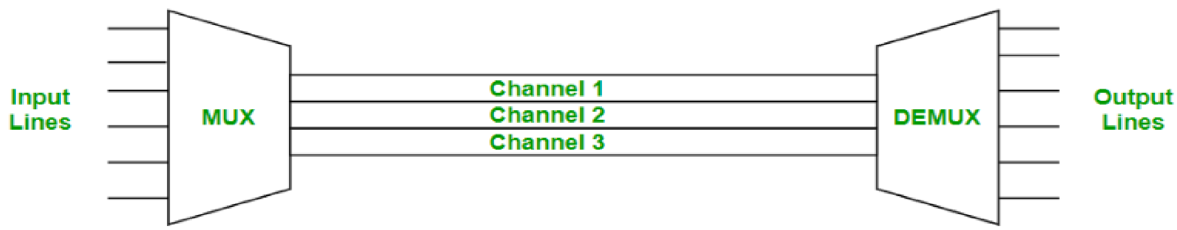


Concept of Multiplexing in Wireless Communication

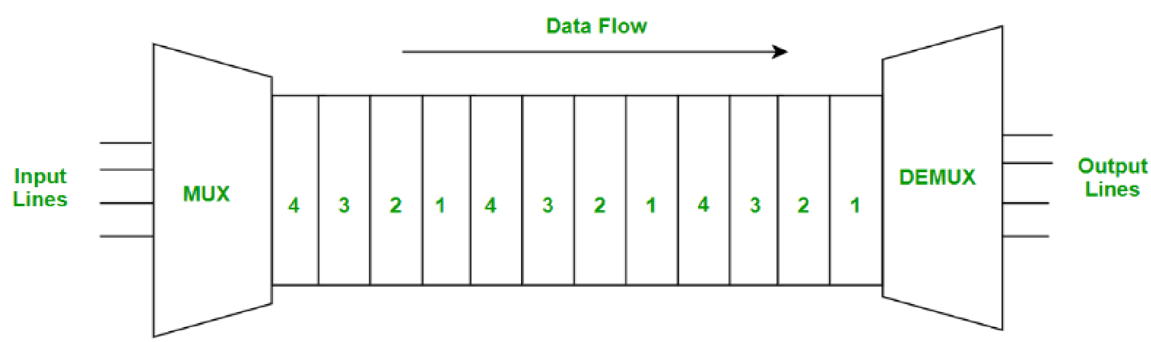
Multiplexing is a technique used in wireless communication to transmit multiple signals over a single communication channel, maximizing the usage of available bandwidth. Instead of having a separate channel for each signal, multiplexing allows different signals to be combined and transmitted simultaneously, enabling efficient spectrum utilization.

Types of Multiplexing in Wireless Communication

1. **Frequency Division Multiplexing (FDM)**:
    - **Concept**: FDM divides the available bandwidth into multiple smaller frequency bands, each carrying a separate signal.
    - **Example**: In radio broadcasting, different stations transmit their signals at different frequencies within the same frequency spectrum.
    - **Application**: Used in systems like AM/FM radio, TV broadcasting, and some mobile communication systems.

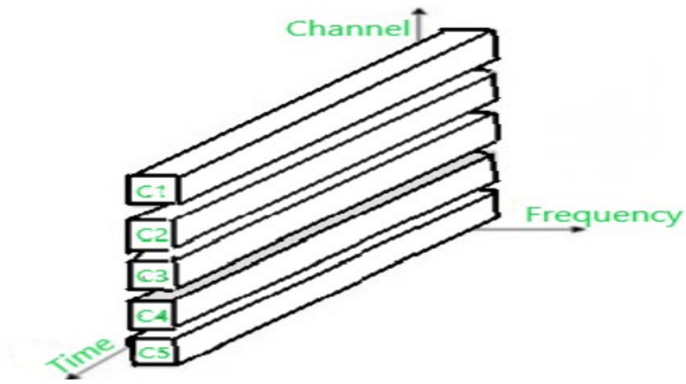


2. **Time Division Multiplexing (TDM)**:
    - **Concept**: TDM allocates specific time slots for each signal on the same frequency channel. Each signal is transmitted in a specific time interval.
    - **Example**: In a telephone system, multiple users can share the same communication channel by taking turns using it.
    - **Application**: Used in digital communication systems like GSM and 4G LTE networks.



3. **Code Division Multiplexing (CDM)**:
    - **Concept**: CDM assigns a unique code to each signal. Multiple signals can occupy the same frequency band and be distinguished by their unique codes.

- **Example**: In CDMA-based mobile networks, multiple users share the same frequency but are differentiated by different spreading codes.
- **Application**: Used in CDMA systems like 3G and some Wi-Fi systems.



Importance of Multiplexing in Wireless Communication

1. **Efficient Spectrum Usage**:
   - Multiplexing allows multiple signals to be transmitted simultaneously over a single channel, maximizing the use of available bandwidth.
2. **Improved Data Transmission**:
   - By using multiplexing techniques, the overall data rate increases without the need for additional channels, improving the communication capacity.
3. **Cost-Effective**:
   - Instead of laying down separate communication channels for each signal, multiplexing reduces the infrastructure cost, as fewer channels are required.
4. **Increased Capacity**:
   - Multiplexing enables multiple users or data streams to share the same frequency band, increasing the overall capacity of the network.

Real-Life Example of Multiplexing

In a cellular network (e.g., 4G LTE), multiple users are connected to the same cell tower. **TDM** is used to allocate different time slots for each user, **FDM** is used to assign different frequency bands, and **CDM** is used to differentiate the users by unique codes. This allows several users to share the same wireless resources without interference.

Paging Technology: How It Works and Its Applications

Paging technology is a one-way communication system used to send short messages or alerts to users, typically in scenarios where immediate attention is required. It is commonly used for notifying people of incoming calls, emergencies, or for general messaging purposes.

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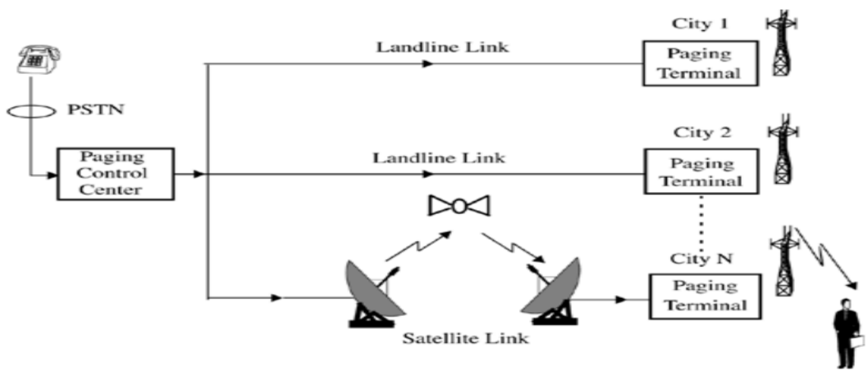

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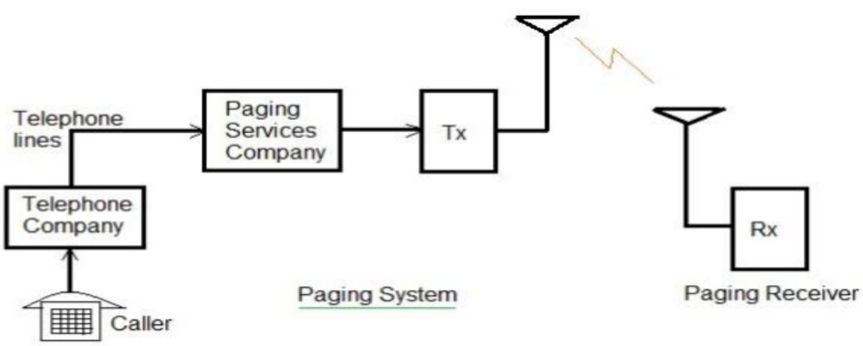

How Paging Technology Works

1. **Transmission**:
    - Paging works by transmitting a message or alert signal from a central paging station (also known as a paging terminal) to a large area using a dedicated paging network.
    - The paging terminal sends a message containing the phone number or an alphanumeric message to a local transmitter (paging base station).
2. **Signal Broadcast**:
    - The signal is broadcasted over a wide area, and the pagers, which are small portable devices, continuously listen for their unique identification code (e.g., a phone number or user ID).

3. **Reception**:
   - When the pager detects its unique code in the broadcasted signal, it displays the message or alert to the user, either as a numeric code (like a phone number to call) or as text (in the case of alphanumeric pagers).
4. **User Action**:
   - The user, after receiving the page, can take the appropriate action, such as making a call, responding to an emergency, or checking the message.

Applications of Paging Technology

1. **Healthcare**:
   - **Example**: Doctors, nurses, and healthcare staff use pagers in hospitals to receive emergency notifications, patient updates, or alerts about critical conditions. This is important in scenarios where cellular phones may be restricted or unreliable.
2. **Emergency Services**:
   - **Example**: Emergency responders (e.g., firefighters, police) often rely on paging systems to receive critical alerts, ensuring they are always available for urgent calls even when other communication systems fail or are overloaded.
3. **Hospitality**:
   - **Example**: In restaurants or hotels, pagers are used to notify customers when their table is ready or when there is an update about their service, allowing staff to manage operations smoothly.
4. **Business**:
   - **Example**: Businesses use paging systems for internal communication. Employees can receive messages about meetings, important updates, or alerts for time-sensitive tasks.
5. **Public Safety**:
   - **Example**: Pagers are commonly used for alerting public safety personnel about natural disasters, civil emergencies, or urgent public warnings, as they operate in areas with poor cellular network coverage.

Advantages of Paging Technology

- **Reliability**: Works even in areas with weak or no cellular network, such as remote locations or underground areas.
- **Battery Efficiency**: Pagers have long battery life since they only receive messages and don't require constant communication.

- **Immediate Notification**: Provides immediate alerts, often faster than mobile phones in certain environments (e.g., hospitals or emergency situations).

Real-Life Example

In a **hospital**, doctors and nurses are given pagers to receive urgent notifications regarding patient conditions, even in areas with poor cellular service. When a patient requires immediate attention, the paging system ensures the healthcare staff are instantly notified.

Advantages of Satellite-Based Mobile Systems

1. **Global Coverage**: Provides communication in remote and hard-to-reach areas where terrestrial networks don't exist.
2. **No Ground Infrastructure Needed**: Reduces the need for extensive terrestrial infrastructure.
3. **Rapid Deployment**: Can be quickly deployed in emergencies or disaster zones.
4. **High Mobility**: Ideal for users in vehicles, ships, or aircraft, providing communication while on the move.
5. **Reliability in Remote Areas**: Unaffected by terrestrial network failures, ensuring reliable communication.

Limitations of Satellite-Based Mobile Systems

1. **High Latency**: Signals take longer to travel, causing delays in communication.
2. **Limited Bandwidth**: Lower data speeds and reduced capacity for simultaneous users.
3. **Weather Dependence**: Susceptible to signal degradation due to weather conditions.
4. **High Cost**: Expensive for users, with higher setup and usage costs compared to terrestrial systems.
5. **Limited Satellite Availability**: Coverage may be restricted if satellite count or positioning is insufficient.
6. **Security Concerns**: Vulnerable to interception or hacking due to space-based transmission.

Classification of Wireless Systems

Wireless systems are classified based on their **coverage area**, **communication medium**, and **technology**. The classification helps in understanding how different systems serve their purpose in communication, from personal networks to large-scale global coverage.

Major Classifications of Wireless Systems

1. **Based on Coverage Area**:
   - **WPAN (Wireless Personal Area Network)**: Provides communication within a very short range (up to 100 meters). Examples include Bluetooth and Zigbee.
   - **WLAN (Wireless Local Area Network)**: Covers a larger area, typically within a building or a campus (up to several kilometers). Examples include Wi-Fi networks.
   - **WWAN (Wireless Wide Area Network)**: Covers a broad area, ranging from a city to global communication. Examples include cellular networks (2G, 3G, 4G, 5G) and satellite communication.
   - **WMAN (Wireless Metropolitan Area Network)**: Covers a city or large metropolitan area (10-50 km). Examples include WiMAX and other broadband wireless access technologies.
2. **Based on Communication Medium**:
   - **Radio Frequency (RF)**: Uses radio waves for communication. This is the most common medium in wireless communication (Wi-Fi, mobile networks).
   - **Microwave**: Uses high-frequency radio waves for point-to-point communication, such as in satellite systems and microwave links.
   - **Optical Wireless Communication (OWC)**: Uses light waves (e.g., infrared, visible light) for communication, such as in Li-Fi.
3. **Based on Technology**:
   - **Analog Wireless Communication**: Involves the transmission of continuous signals, such as AM/FM radio broadcasting.
   - **Digital Wireless Communication**: Involves the transmission of discrete data signals, offering better efficiency and noise immunity, such as 3G, 4G, and 5G networks.

Major Changes in the Classified Wireless System

1. **Introduction of Higher Speed and Bandwidth**:

   - Evolution from **2G to 3G**, **4G**, and **5G** systems brought higher data transfer speeds, low latency, and greater bandwidth, enabling faster internet, better video streaming, and improved mobile services.

2. **Shift from Analog to Digital**:
   - Wireless systems have largely moved from **analog communication** (used in older mobile networks and broadcasting) to **digital communication**, enhancing security, quality, and capacity.

3. **Use of Multiple Access Techniques**:
   - From simple frequency division in early systems, wireless systems now use more advanced methods like **CDMA**, **TDMA**, and **OFDM** to support more users and improve spectral efficiency.

4. **Integration of Satellite Systems**:
   - Satellite-based communication (like **GPS**, **Iridium**, etc.) is now a key component for global connectivity, especially in remote areas, providing a significant change in wireless system classification.

5. **Advanced Wireless Standards**:
   - The advent of **Wi-Fi 6**, **5G**, and **Li-Fi** technologies has pushed the limits of wireless communication, offering ultra-high-speed data transfer and more reliable connectivity for IoT devices.

6. **Convergence of Networks**:
   - Modern systems now offer **multi-mode** operations, where **Wi-Fi**, **cellular networks**, and **satellite systems** can work together to ensure seamless and consistent connectivity across different environments.

Summary

- Wireless systems are classified based on **coverage area** (WPAN, WLAN, WWAN, WMAN), **communication medium** (RF, microwave, optical), and **technology** (analog, digital).
- Major changes include **faster speeds** with 4G/5G, **shift from analog to digital**, **advanced access techniques**, integration of **satellite systems**, and **convergence of networks**.

UNIT – 2

Cellular System and Its Components

A cellular system divides an area into smaller regions called cells, each served by a base station, enabling efficient frequency use and continuous communication over large areas.

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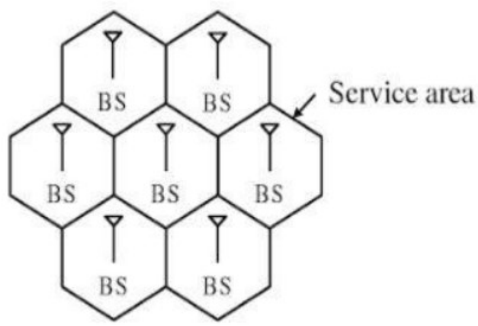
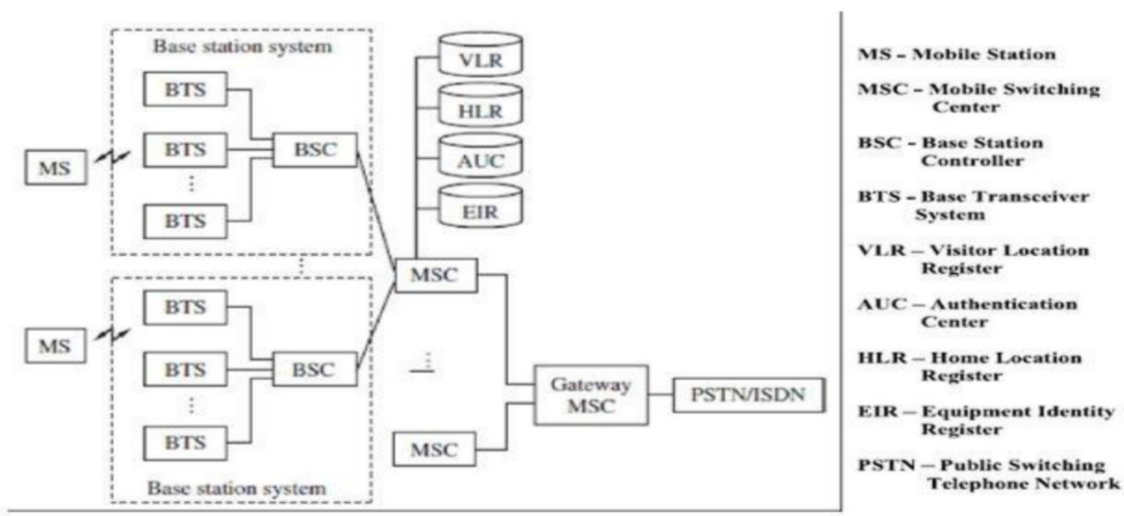


Fig: Cellular system: small zone



Working of a Cellular System

1. **Cell Structure:** Divides the area into cells, each with a base station to manage communication. Frequency reuse reduces interference.
2. **Handovers:** When a mobile user moves between cells, the system performs a handover to maintain the connection.

Components of a Cellular System

1. **Mobile Station (MS):** The mobile device used by the user for communication.

2. **Base Station (BS):** Central node in a cell, managing communication between mobile stations and the network.
3. **Controller (BSC/MSC):**
   - **BSC:** Manages multiple base stations, handling handovers and power control.
   - **MSC:** Routes calls, handles mobility, and connects to the PSTN.
4. **Core Network (CN):** Connects base stations and handles routing, call control, and data services.
5. **Transmission Links:** Links between base stations, controllers, and the core network (microwave, fiber, satellite).
6. **Subscriber Database (HLR/VLR):**
   - **HLR:** Stores subscriber details and location.
   - **VLR:** Temporary database for roaming subscribers.

Example of a Cellular System

When a person is on a call while driving, the system ensures handover from one cell to another without call interruption by coordinating between base stations and the core network.

Key Features

1. **Frequency Reuse:** Enables efficient use of available bandwidth.
2. **Mobility Management:** Ensures seamless communication as users move.
3. **Scalability:** Allows expansion by adding more cells.
4. **Efficient Spectrum Use:** Maximizes bandwidth by dividing the area into cells.

Summary

The cellular system involves Mobile Stations (MS), Base Stations (BS), Controllers (BSC/MSC), Core Network (CN), and Transmission Links, enabling global coverage, frequency reuse, and mobility management for continuous communication.

<u>Antennas in Cellular Systems</u>

Antennas transmit and receive radio signals between mobile devices and base stations, converting electrical signals to radio waves and vice versa. They are crucial for coverage, signal strength, and data rates.

Types of Antennas for Cellular Systems

1. **Omnidirectional Antennas:**
   - **Function:** Radiates signals uniformly in all directions (360°).
   - **Use:** Base stations for broad area coverage.
2. **Directional Antennas:**
   - **Function:** Focuses signal in a specific direction.
   - **Use:** Point-to-point communication, rural areas.
3. **Sector Antennas:**
   - **Function:** Divides coverage into sectors (60°, 90°, 120°).
   - **Use:** Base stations in urban areas to increase capacity.
4. **MIMO Antennas:**
   - **Function:** Uses multiple antennas for improved data throughput and reliability.
   - **Use:** 4G/5G networks for higher capacity.
5. **Patch Antennas:**
   - **Function:** Compact, flat antennas providing directional coverage.
   - **Use:** Mobile phones, Wi-Fi routers.
6. **Yagi-Uda Antennas:**
   - **Function:** Directional antenna with high gain and narrow beamwidth.
   - **Use:** Long-range communication, backhaul links.
7. **Parabolic Dish Antennas:**
   - **Function:** High gain with narrow beam for long-range communication.
   - **Use:** Satellite communication.

Importance of Antennas

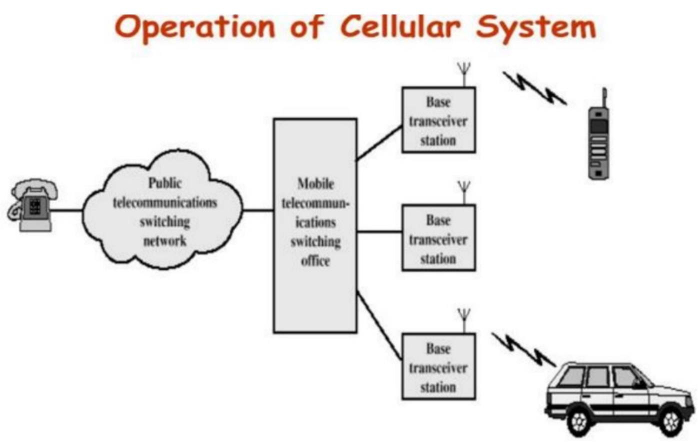
- **Coverage:** Determines the area served.
- **Capacity:** Increases network capacity (MIMO, Sector).
- **Efficiency:** Optimizes signal strength and reduces power consumption.
- **Signal Quality:** Improves call quality and data rates.

Summary

Cellular system antennas include Omnidirectional, Directional, Sector, MIMO, Patch, Yagi-Uda, and Parabolic Dish types. These ensure effective coverage, capacity, and signal quality in mobile communication.

Operation of Cellular Systems

The cellular system operates by dividing a large geographical area into smaller regions called **cells**, enabling efficient frequency reuse and seamless communication for mobile users.



Key Operations of Cellular Systems

1. **Cell Division and Frequency Reuse**:
    - The area is divided into **hexagonal cells**, each served by a base station.
    - **Frequency reuse** allows the same frequency to be used in non-adjacent cells, increasing spectrum efficiency.
2. **Base Station Communication**:
    - Each cell's **base station (BS)** handles communication with mobile users within its coverage area using radio signals.
3. **Handoff (Handover)**:
    - When a mobile user moves from one cell to another, the system transfers the ongoing call or data session to the new cell's base station without interruption.
4. **Call Routing**:
    - Calls are routed through the **Mobile Switching Center (MSC)**, which connects the cellular network to the Public Switched Telephone Network (PSTN).

5. **Power Control**:
    - The system adjusts the mobile device's transmit power to minimize interference and maintain a stable connection.
6. **Mobility Management**:
    - Tracks the location of mobile devices using **Home Location Register (HLR)** and **Visitor Location Register (VLR)** databases for seamless service.
7. **Dynamic Resource Allocation**:
    - Allocates frequencies, time slots, or codes dynamically based on user demand to optimize system performance.

Components Involved in Operation

1. **Mobile Station (MS)**: User's mobile device for communication.
2. **Base Station (BS)**: Handles radio communication with mobile devices.
3. **Base Station Controller (BSC)**: Manages multiple base stations, handles handovers, and resource allocation.
4. **Mobile Switching Center (MSC)**: Routes calls, connects to PSTN, and manages mobility.
5. **Core Network**: Handles data transfer and routing between base stations and external networks.

Example of Operation

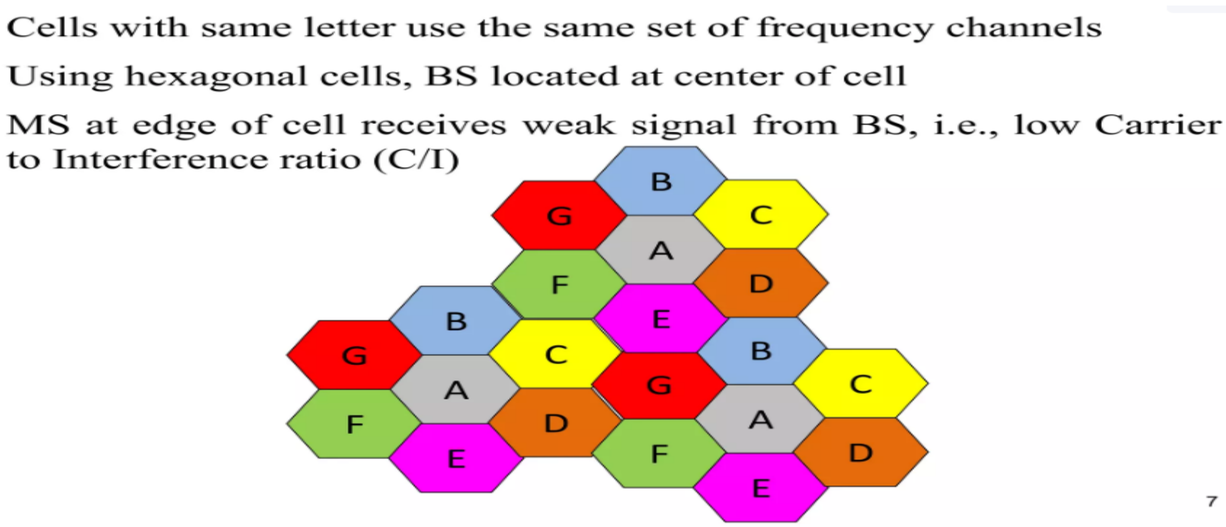
When a user makes a call while traveling, the call is initiated through the base station in their current cell. As they move, **handover** ensures the call continues seamlessly by transferring it to the base station of the next cell.

Summary

The cellular system operates using **cell division**, **frequency reuse**, **handoffs**, and **mobility management**. Components like **Base Stations (BS)**, **MSC**, and **Core Networks** ensure continuous, efficient communication across cells.

Frequency Reuse

Frequency reuse is a key concept in cellular communication that allows the same frequency bands to be used in different geographic areas (cells) to maximize spectrum efficiency while minimizing interference. It enhances system capacity and coverage by dividing the service area into smaller cells.



How Frequency Reuse Works

1. **Cell Division**:
    - The coverage area is divided into hexagonal cells.
    - Each cell is assigned a unique set of frequencies to avoid interference with adjacent cells.
2. **Reuse Pattern**:
    - Cells with sufficient distance between them can reuse the same frequency set without interference.
    - The **reuse factor** (K) represents the number of unique frequency sets, e.g., a reuse factor of 7 means seven unique sets of frequencies are used.
3. **Cluster Formation**:
    - A cluster of cells is formed with no frequency repetition within the cluster.
    - The cluster is repeated across the service area.

Advantages of Frequency Reuse

1. **Increased Capacity**: Enables efficient use of limited spectrum by reusing frequencies.
2. **Cost Efficiency**: Reduces the need for additional spectrum allocation.
3. **Scalability**: Allows network expansion by adding more cells.
4. **Coverage Optimization**: Provides consistent coverage across large areas.

Challenges in Frequency Reuse

1. **Co-channel Interference**: Occurs between cells using the same frequencies.
2. **Cell Planning**: Requires careful design of cell size, frequency allocation, and reuse patterns.

Real-Life Example

In a city, cellular providers use frequency reuse to serve multiple users. For instance, the same frequency set used in one neighborhood (Cell A) can be reused in another neighborhood (Cell B) far enough away to avoid interference.

Channel Assignment Techniques in Cellular Networks

Channel assignment techniques are used to efficiently allocate frequencies, time slots, and bandwidth in cellular networks. Each technique is suited for different traffic conditions.

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1. Fixed Channel Allocation (FCA)

- **Explanation**: Each cell is assigned a fixed set of channels that cannot be changed. If all channels are busy, new calls are blocked.
- **Real-Life Example**: In a small village with consistently low traffic, each tower is given a fixed number of frequencies. If many users make calls simultaneously, additional calls will not connect.

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2. Dynamic Channel Allocation (DCA)

- **Explanation**: Channels are not permanently assigned to any cell. They are allocated dynamically based on real-time traffic demand.
- **Real-Life Example**: In a city like **New York**, where traffic varies throughout the day, more channels are assigned during office hours, and fewer during off-peak times.

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3. Hybrid Channel Allocation (HCA)

- **Explanation**: This is a combination of FCA and DCA. Fixed channels are used first, and when they are full, dynamic channels are allocated.
- **Real-Life Example**: Near a shopping mall, fixed channels suffice on normal days. However, during weekends or festivals, additional dynamic channels handle the increased traffic.

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4. Borrowing Channel Allocation (BCA)

- **Explanation**: If a cell experiences heavy traffic and all its channels are occupied, it borrows unused channels from nearby cells.
- **Real-Life Example**: During a cricket match in a stadium, nearby residential cells lend their unused channels to manage the high demand for calls and data usage in the stadium.

Summary

FCA is suitable for low-traffic areas, DCA handles traffic variations, HCA balances heavy traffic, and BCA ensures flexibility during peak or emergency demands.

Handoff Strategies in Wireless Communication (Summary)

Handoff (or handover) is a critical process in mobile communication that transfers an ongoing call or data session from one cell (base station) to another as the user moves. It ensures seamless communication and maintains call quality.

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1. Hard Handoff (HHO):

In this method, the device disconnects from the current cell before connecting to a new cell. It can cause short interruptions and a higher risk of call drops.

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2. Soft Handoff (SHO):

Used in CDMA systems, the device connects to multiple cells simultaneously during the transition, providing seamless connectivity and better call quality.

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3. Make-Before-Break Handoff:

Common in LTE and 5G, the device establishes a stable connection with the new cell before disconnecting from the old one, minimizing the chances of call drops.

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4. Cell Reselection Handoff:

If the signal from the source cell remains strong, the device switches to a neighboring cell without fully disconnecting from the source, optimizing resource usage.

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5. Network-Controlled Handoff:

The network monitors signal quality, traffic load, and other factors to decide when and where to initiate the handoff, ensuring efficient transitions.

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6. Mobile-Assisted Handoff (MAHO):

The mobile device measures signal strength and quality of neighboring cells, assisting the network in making handoff decisions, reducing congestion, and improving call quality.

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7. Load-Based Handoff:

When a cell is congested, the network transfers the user to a less congested cell to balance the load and maintain service quality.

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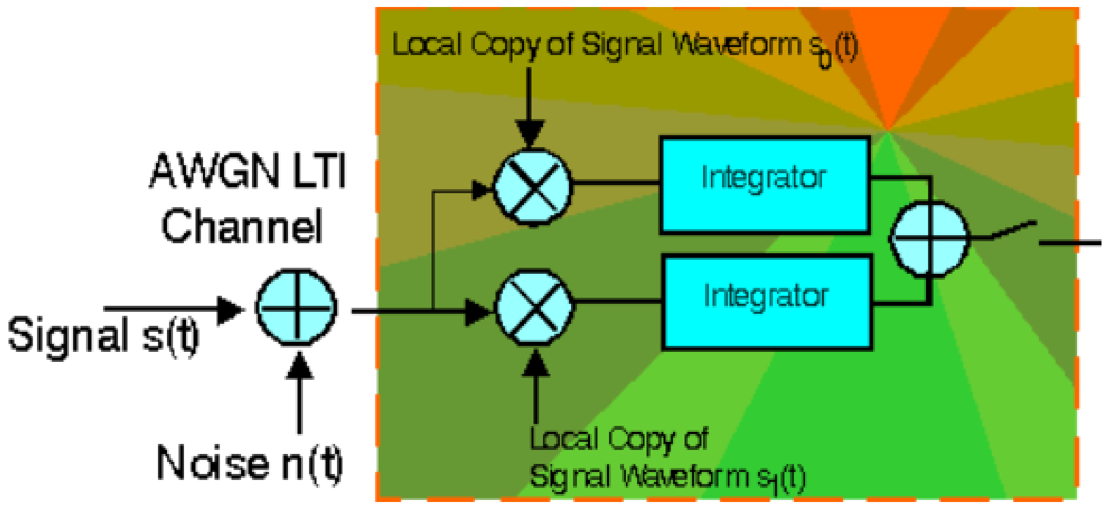
8. Velocity-Based Handoff:

This strategy considers the speed of the user. For fast-moving devices, the network preemptively connects to cells ahead of the user's path for uninterrupted service.

UNIT-3

AWGN Channel (Hinglish Explanation)

AWGN ka matlab hai Additive White Gaussian Noise channel. Yeh ek aisa idealized communication channel hai jo real-world wireless systems ko model karne ke liye use hota hai.



Key Features of AWGN Channel:

1. **Additive Noise:**
   Noise signal transmitted signal ke sath add hoti hai, jo data ko corrupt kar sakti hai.
2. **White Noise:**
   Iska matlab hai ki noise ka power spectral density (PSD) har frequency range me constant hota hai, matlab noise har frequency pe barabar distributed hoti hai.
3. **Gaussian Noise:**
   Noise ka distribution Gaussian hota hai, matlab iska amplitude normal distribution follow karta hai.
4. **No Multipath Effects:**
   AWGN channel me signal ke reflection, fading, ya interference ka effect consider nahi hota, isliye yeh ek simple channel model hota hai.

Why is AWGN Important?

- Yeh communication systems ke performance ko test karne ke liye ek standard model hai.
- Practical systems me AWGN ka use system ke robustness aur error rates evaluate karne ke liye hota hai.

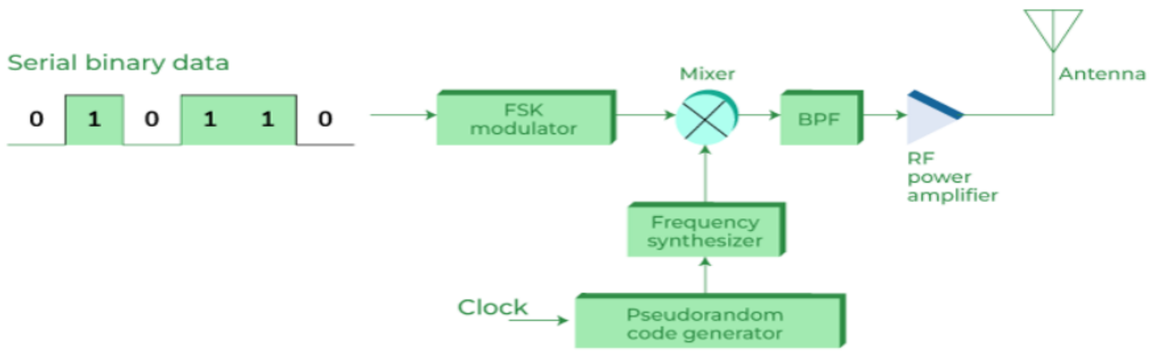
Real-Life Example:

Agar aap ek mobile call karte hain aur line me halki "hissing" ya noise sunte hain, toh yeh noise AWGN ki tarah behave karti hai. Matlab, yeh random aur uniformly distributed hoti hai, jo signal ke sath add hoti hai.

AWGN ek basic aur simplified model hai jo communication systems me noise ke impact ko samajhne aur analyze karne ke liye use hota hai.

Frequency Hopping Spread Spectrum (FHSS)

FHSS एक wireless communication technique है जिसमें signal की carrier frequency को एक predetermined pseudorandom pattern के अनुसार periodically change किया जाता है। यह technique signal की security और interference resistance बढ़ाने के लिए उपयोग की जाती है।



Components of FHSS System

1. Transmitter Side

1. **Data Source**
   - Data या information जो transmit करनी है।
   - Example: Audio, Video, या Text Data.
2. **Modulator**
   - Data को modulate करता है, ताकि इसे wireless frequency पर भेजा जा सके।
   - Common modulation techniques: Frequency Shift Keying (FSK), Phase Shift Keying (PSK).
3. **Pseudorandom Frequency Generator**
   - एक deterministic algorithm के आधार पर random-like frequencies की sequence बनाता है।
   - यह hopping pattern को control करता है।
4. **Frequency Synthesizer**
   - Transmitter के लिए hopping frequencies generate करता है।
   - यह frequencies को pseudorandom generator के output के अनुसार change करता है।
5. **Antenna**
   - Modulated और frequency-hopped signal को broadcast करता है।

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2. Channel

- Wireless medium (air) जो signal को transmitter से receiver तक carry करता है।
- इसमें noise और interference हो सकता है।

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3. Receiver Side

1. **Antenna**
   - Transmitted signal को capture करता है।
2. **Frequency Synthesizer**
   - Receiver में hopping sequence transmitter के साथ perfectly synchronized होना चाहिए।
   - यह pseudorandom generator के अनुसार hopping frequencies को adjust करता है।
3. **Demodulator**
   - Received signal को demodulate करता है ताकि original data recover हो सके।
4. **Data Output**
   - Final decoded data, जो transmitter ने भेजी थी।

Advantages of FHSS

1. **Interference Resistance**: Signal spread करने से narrowband interference से बचाव होता है।
2. **Security**: Unauthorized access या eavesdropping को रोकता है।
3. **Multipath Effects Mitigation**: Different frequencies पर hopping से signal distortion कम होती है।

<u>Small Scale Fading Based on Multipath Time Delay Spread</u>

Small scale fading occurs due to rapid fluctuations of the amplitude, phase, or multipath delays of a received signal over a short period or distance. Based on the multipath time delay spread, fading can be classified into the following types:

Types of Small Scale Fading

1. **Flat Fading**
    - Occurs when the bandwidth of the transmitted signal is smaller than the coherence bandwidth of the channel.
    - All frequency components of the signal experience the same magnitude and phase change.
    - No significant distortion is introduced to the signal.
    - Example: Narrowband signals in urban environments.
2. **Frequency Selective Fading**
    - Occurs when the bandwidth of the transmitted signal is larger than the coherence bandwidth of the channel.
    - Different frequency components of the signal experience different fading (amplitude and phase changes).
    - Causes inter-symbol interference (ISI).
    - Example: Wideband signals or OFDM systems.

Distinction Between Flat Fading and Frequency Selective Fading

Aspect	Flat Fading	Frequency Selective Fading
Signal Bandwidth	Smaller than channel coherence bandwidth.	Larger than channel coherence bandwidth.
Effect on Signal	Entire signal fades uniformly.	Different frequency components fade differently.
ISI	No inter-symbol interference.	Significant inter-symbol interference.
Channel Response	Single-tap response (constant gain and phase).	Multi-tap response (multipath components).
Frequency Domain	Channel appears flat.	Channel exhibits frequency-selective behavior.
Example	Narrowband communication systems.	Wideband systems like CDMA, OFDM.

Rayleigh, Rician, और Nakagami Fading Channels

Wireless communication में fading models signal strength को समझने के लिए इस्तेमाल किए जाते हैं, जो environment और signal propagation पर निर्भर करते हैं। चलिए इन्हें सरल भाषा और real-world examples के साथ समझते हैं।

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1. Rayleigh Fading Channel

Rayleigh fading तब होता है जब signal का कोई dominant **line-of-sight (LOS)** component नहीं होता। Signal multiple paths (reflections, diffractions) से travel करता है, और ये paths random interference create करते हैं।

Key Points:

- LOS path नहीं है, सिर्फ scattered signals हैं।
- Signal amplitude का distribution **Rayleigh distribution** follow करता है।
- Signal strength में तेज़ी से fluctuations होती हैं।

Real-World Example:

- **Urban Areas में Mobile Communication**:
  जब mobile towers से signal buildings, trees, और vehicles से reflect होकर receiver (mobile) तक पहुंचता है।
  Example: Dense city areas जैसे दिल्ली या मुंबई में mobile networks।

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2. Rician Fading Channel

Rician fading तब होता है जब **dominant line-of-sight (LOS)** component मौजूद होता है और साथ में scattered multipath signals भी होते हैं। Signal ज्यादा stable होता है, क्योंकि एक सीधा रास्ता (LOS) है।

Key Points:

- LOS component dominant है।
- Signal amplitude का distribution **Rician distribution** follow करता है।
- Stability ज्यादा है Rayleigh fading की तुलना में।
- **Rician KK-factor**: LOS और scattered components की power ratio।

Real-World Example:

- **Satellite और Microwave Communication**:
  जब satellite से signal किसी remote area में transmit होता है। यहां LOS component ज़्यादा dominant

रहता है।
Example: Direct-To-Home (DTH) TV signals या microwave towers।

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3. Nakagami Fading Channel

Nakagami fading एक generalized model है, जो Rayleigh और Rician fading दोनों को represent कर सकता है। यह fading की severity को control करने के लिए flexibility देता है।

Key Points:

- Parameter mm fading severity को control करता है।
  - m=1m = 1: Rayleigh fading जैसा।
  - m>1m > 1: Rician fading जैसा।
- Signal amplitude का distribution **Nakagami-mm distribution** follow करता है।
- Wireless environments को model करने में flexible है।

Real-World Example:

- **Wireless Sensor Networks**:
  जब sensors अलग-अलग locations पर data transmit करते हैं और environment unpredictable होता है।
  Example: Smart Agriculture systems में sensors।

Comparison with Examples

Aspect	Rayleigh Fading	Rician Fading	Nakagami Fading
LOS Component	Absent	Present	May or may not be present (flexible).
Environment Example	Dense urban areas	Open areas with clear LOS (e.g., satellite links).	Mixed environments (e.g., sensor networks).
Severity of Fading	Severe fluctuations	Less severe (depends on LOS strength).	Adjustable based on parameter mm.
Real-World Example	Mobile networks in cities.	Satellite TV or GPS signals.	Smart IoT applications like farming.

Summary

- **Rayleigh**: जब कोई सीधा रास्ता (LOS) नहीं है। Example: City में mobile networks।
- **Rician**: जब एक direct path (LOS) और scattered signals दोनों हैं। Example: Satellite से TV signals।
- **Nakagami**: Flexible model जो दोनों situations handle करता है। Example: Sensor networks।

Summary of Fading in Wireless Communication

Fading refers to the variation in the strength of a wireless signal as it propagates through the communication channel. It occurs due to factors like multipath propagation, obstacles, or movement of objects. Fading impacts the performance of wireless systems, and it is classified into two main types:

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1. Small-Scale Fading

Occurs over short distances and affects individual symbols or bits due to **multipath propagation**.

Types:

- **Multipath Delay Spread:** Signal takes multiple paths, causing inter-symbol interference (ISI).
    - Mitigation: Equalization, diversity, adaptive modulation.
- **Doppler Spread:** Signal frequency changes due to relative motion between transmitter and receiver.
    - Mitigation: Adaptive techniques like equalization and diversity.

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2. Large-Scale Fading

Occurs over long distances and reduces the overall signal power due to **obstacles like buildings or terrain**.

Types:

- **Path Loss:** Signal weakens with distance.
    - Mitigation: Power control, directional antennas.
- **Shadowing:** Obstructions cause signal strength to vary.
    - Mitigation: Diversity techniques, signal processing.

Fading Models:

1. **Rayleigh Fading:** For non-line-of-sight (NLOS) scenarios.
2. **Rician Fading:** Includes both line-of-sight (LOS) and multipath components.

3. **Nakagami Fading:** Models moderate to severe multipath environments.
4. **Weibull Fading:** Used for changing fading conditions.

Comparison: Small-Scale vs. Large-Scale Fading

Parameter	Small-Scale Fading	Large-Scale Fading
Time Variation	Rapid	Slow
Cause	Multipath	Obstacles
Distance	Few centimeters to meters	Kilometers
Effect	Interference, deep fades	Overall signal reduction
Mitigation Techniques	Equalization, adaptive modulation	Power control, antenna placement

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Conclusion

Fading is a significant challenge in wireless communication, affecting signal quality and reliability. Small-scale fading causes rapid fluctuations due to multipath effects, while large-scale fading results in gradual signal loss due to obstacles. Effective strategies like equalization, diversity, power control, and antenna placement are essential for overcoming fading and ensuring robust communication.