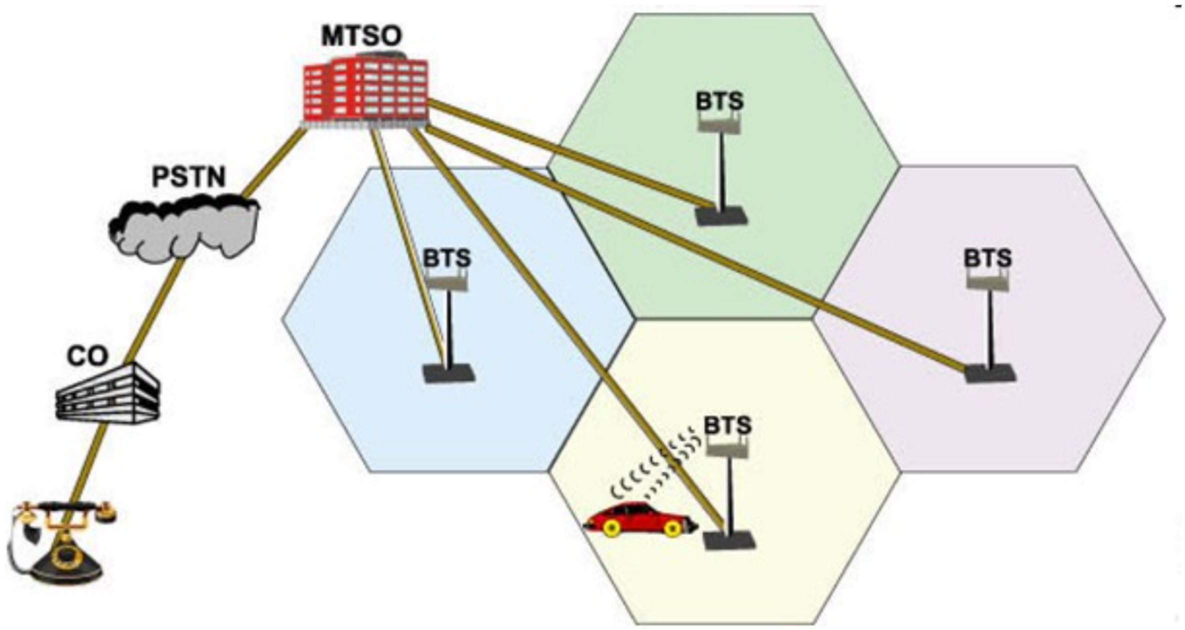
WIRELESS & MOBILE COMMUNICATION

(Unit-2)

Cellular Concept:

The cellular concept is a fundamental principle in mobile communication systems that allows for the efficient use of radio frequencies and the widespread coverage of mobile networks. It was first developed by Bell Labs engineer Martin Cooper in the 1970s and has since become the basis for modern cellular networks, including 2G, 3G, 4G, and 5G.



Here's an overview of the cellular concept in mobile communication:

Cell: In a cellular network, the entire service area is divided into smaller geographic areas called cells. Each cell is typically served by a base station or cell tower equipped with antennas and radio equipment.

Frequency Reuse: To maximize the use of available radio frequencies, the same frequency band can be reused in cells that are sufficiently far apart to avoid interference. This concept is known as frequency reuse. By reusing frequencies, cellular networks can support a large number of simultaneous users without excessive interference.

Handoff: As mobile users move from one cell to another while making a call or using data services, the network seamlessly transfers their connection from one cell to another. This process is called a handoff or handover and ensures continuous connectivity as users move around.

Cell Splitting: In areas with high user density, a cell can become overloaded with too many users, leading to dropped calls and slow data speeds. In such cases, a cell can be split into smaller cells, often referred to as microcells or picocells, to accommodate more users and improve capacity.

Cell Sectorization: Each cell can be divided into sectors by using directional antennas. Sectorization increases the capacity of a cell by allowing it to handle more calls and data traffic in a specific direction, which is particularly useful in areas with high user demand.

Handset Power Control: To minimize interference and conserve battery life, cellular handsets adjust their transmit power based on their proximity to the nearest base station. This ensures that the handset uses the minimum amount of power necessary to maintain a reliable connection.

Cell Planning: Cellular network planning involves optimizing the placement and configuration of cell sites to provide seamless coverage and capacity. Factors like terrain, building structures, and user density are considered during cell planning.

Frequency Bands: Different frequency bands are allocated for cellular communication by regulatory authorities. These bands are divided into uplink (from mobile device to cell tower) and downlink (from cell tower to mobile device) frequencies and are used to provide various cellular services like voice and data.

Cellular Generations: The cellular concept has evolved through different generations, including 2G (GSM), 3G (UMTS), 4G (LTE), and 5G. Each generation brings advancements in technology, data speeds, and network capacity while building upon the basic principles of the cellular concept.

The cellular concept has revolutionized communication by enabling widespread and efficient mobile networks. It has paved the way for the development of modern smartphones and the delivery of various services, from voice calls and text messaging to high-speed internet access and multimedia streaming.

Cell Area:

In mobile communication, the term "cell area" refers to the geographic coverage area served by an individual cell within a cellular network. Cells are the basic building blocks of cellular networks, and each cell is responsible for providing wireless coverage to a specific area. Here are some key points related to cell areas in mobile communication:

Cell Size: Cell areas can vary in size depending on several factors, including the population density of the area, the terrain, and the available frequency spectrum. Cells are designed to provide adequate coverage and capacity for a given area.

Cell Coverage: The primary purpose of a cell is to provide radio coverage to mobile devices within its designated area. This coverage allows mobile phones and other wireless devices to connect to the cellular network and communicate with each other.

Cell Overlap: In practice, cell areas are often designed to overlap with neighbouring cells. This overlap ensures that there are no coverage gaps, and it allows for seamless handoffs as mobile users move from one cell to another. Overlapping cells facilitate continuous connectivity as users travel through the network.

Cell Shape: Cells are typically depicted as hexagons on network diagrams, which is an idealized shape that minimizes overlap and maximizes coverage. However, in real-world scenarios, cell shapes can vary based on factors like terrain and the placement of cell towers.

Cell Capacity: The capacity of a cell, which is the number of users and devices it can support simultaneously, depends on factors like the frequency band used, the technology generation (2G, 3G, 4G, 5G), and the density of users in the area.

Cell Splitting: In areas with high user demand, cells may be split into smaller cells (microcells or picocells) to increase capacity and provide better service quality. Cell splitting is a technique used to alleviate congestion and improve network performance.

Cell Planning: Network operators carefully plan and optimize the placement and configuration of cell sites to ensure efficient coverage, minimize interference, and meet capacity requirements. This process involves determining the location and height of cell towers and selecting appropriate antenna types.

Frequency Reuse: To maximize the use of available radio spectrum, the cellular concept employs frequency reuse. This means that the same frequency band can be reused in cells that are sufficiently far apart to minimize interference.

Sectorization: Each cell can be divided into sectors using directional antennas. Sectorization increases the capacity and efficiency of a cell by focusing coverage and capacity in specific directions, where it is needed most.

Cell Identification: Each cell is assigned a unique identification number or code, such as a Cell ID or CGI (Cell Global Identity), which helps mobile devices and the network identify and distinguish between different cells.

Overall, the concept of cell areas is central to the design and operation of cellular networks, allowing for efficient use of radio spectrum and the provision of mobile communication services to a wide range of users across diverse geographic areas.

Signal Strength:

Signal strength in mobile communication refers to the measurement of the power level of the radio frequency (RF) signal received by a mobile device (e.g., a smartphone) from a cell tower or base station. It is a crucial parameter that directly affects the quality and reliability of mobile communication services. Here are some key points to understand about signal strength in mobile communication:

Units of Measurement: Signal strength is typically measured in decibels relative to milliwatts (dBm) or in dB relative to a reference signal (dB). The higher the positive dBm value, the stronger the signal. For example, -60 dBm is a stronger signal than -80 dBm.

Signal Strength Indicator: Most mobile devices display a signal strength indicator on their screens. This indicator is usually represented by bars or dots, with more bars or dots indicating a stronger signal. However, these visual indicators may not always provide precise measurements.

Factors Affecting Signal Strength:

Distance from the Cell Tower: The farther a mobile device is from the cell tower or base station, the weaker the signal will be. Signal strength decreases with increasing distance from the transmitter.

Obstructions: Buildings, trees, hills, and other physical obstructions can block or weaken the RF signal. Signal strength can be significantly reduced indoors compared to outdoors.

Interference: Electromagnetic interference from other electronic devices or radio sources can disrupt and weaken the signal.

Terrain and Topography: The landscape, such as hills, valleys, and urban canyons, can affect signal strength due to reflection, diffraction, and shadowing of the RF waves.

Weather Conditions: Adverse weather conditions, such as heavy rain, snow, or fog, can attenuate (weaken) the RF signal.

Tower Capacity: Cell towers have a limited capacity for handling simultaneous connections. During times of high demand, the signal strength may decrease as the tower becomes congested.

Signal Strength Measurement Tools: Mobile devices often have hidden menu options or diagnostic modes that allow users to access more detailed signal strength information, including actual dBm values. Apps and third-party tools can also be used to measure and display signal strength.

Impact on Call Quality and Data Speed: Weak signal strength can result in dropped calls, call quality issues (e.g., static or garbled audio), and slow data speeds. A strong signal generally leads to better call quality and faster data transfers.

Signal Boosters: Signal boosters or repeaters can be used to improve signal strength in areas with poor coverage. These devices capture the existing weak signal and amplify it to provide better coverage within a building or a localized area.

Network Handover: In a cellular network, as a mobile device moves, it may need to switch from one cell to another. This process, known as a handover or handoff, is initiated to maintain a consistent and strong signal as the device moves through different cell areas.

Signal strength is a critical aspect of mobile communication quality, and it's essential for users to be aware of their signal strength, especially in areas with poor coverage or where signal boosters may be necessary to ensure reliable communication and data access.

Cell Parameter:

In wireless and mobile communication, cell parameters are specific settings and characteristics that define the behavior and operation of individual cells within a cellular network. These parameters are essential for optimizing network performance, ensuring efficient use of resources, and providing seamless connectivity to mobile users. Here are some key cell parameters in wireless and mobile communication:

Cell ID (Cell Identity):

Definition: A unique identification number or code assigned to each cell within the cellular network.
Purpose: Helps mobile devices and the network identify and distinguish between different cells.

Cell Coverage Area:

Definition: Specifies the geographic area served by a cell, including its boundaries and range.
Purpose: Ensures that the cell provides adequate coverage without overlapping or leaving coverage gaps.

Frequency Band:

Definition: The specific frequency range allocated for communication within the cell.
Purpose: Defines the radio spectrum used by the cell for transmitting and receiving signals.

Frequency Reuse Pattern:

Definition: Describes how the same frequency band is reused across different cells within the network.
Purpose: Maximizes the use of available spectrum and minimizes interference between neighboring cells.

Transmit Power (Tx Power):

Definition: The amount of power used by the cell's transmitter to transmit signals.
Purpose: Determines the cell's coverage area and signal strength, affecting the reach of the cell.

Cell Radius:

Definition: The maximum distance from the cell's antenna at which reliable communication can occur.
Purpose: Helps define the cell's coverage area and influences cell size.

Antenna Type and Gain:

Definition: Specifies the type of antenna used and its gain, which affects signal propagation and coverage.
Purpose: Ensures that the antenna system matches the cell's coverage requirements.

Handoff Thresholds:

Definition: Threshold signal strength levels that trigger the handover (handoff) of a mobile device from one cell to another as the device moves.
Purpose: Controls the timing and conditions for handing off mobile users between cells to maintain connectivity.

Cell Load and Capacity:

Definition: Describes the current number of users and the capacity of the cell.
Purpose: Helps manage and optimize network resources to prevent congestion and maintain quality of service.

Cell Priority:

Definition: Assigns priority levels to cells within the network, which can influence handover decisions.
Purpose: Ensures that certain cells receive preference in handover scenarios, such as emergency cells.

Cell Reselection Parameters:

Definition: Parameters that determine when a mobile device should reselect a different cell with a stronger signal.
Purpose: Allows mobile devices to choose the best available cell for connectivity and performance.

Interference Management Parameters:

Definition: Settings related to mitigating interference from neighboring cells, including power control and interference cancellation techniques.
Purpose: Ensures that signal quality is maintained in the presence of interference.

These cell parameters are part of the cellular network planning and management process. Network operators adjust and optimize these parameters based on factors like user density, traffic patterns, geographic features, and network load to provide reliable and efficient mobile communication services.

Capacity of a Cell:

The capacity of a cell in mobile communication refers to the maximum number of simultaneous users or devices that a cell or base station can support while maintaining acceptable performance levels. It represents the ability of the cell to handle voice calls, data sessions, and other communication services within its coverage area.

The capacity of a cell depends on various factors, including:

Spectrum Availability: The amount of radio frequency spectrum allocated to the cell affects its capacity. More spectrum allows for a higher data throughput and supports a larger number of users.

Channel Bandwidth: The channel bandwidth assigned to the cell determines the data capacity it can provide. Wider bandwidth enables higher data rates and supports more users.

Modulation and Coding Scheme (MCS): The MCS defines how data is encoded and modulated for transmission. Higher MCS values provide higher data rates but require stronger signal conditions. The MCS selection is based on the signal quality of each user.

Signal-to-Noise Ratio (SNR): The SNR represents the quality of the received signal relative to background noise. A higher SNR allows for higher data rates and better capacity.

Interference: Interference from neighboring cells or other sources can degrade the signal quality and reduce the capacity of a cell. Mitigating interference through techniques like frequency planning and interference coordination can help improve capacity.

Traffic Load: The amount of traffic generated by users within the cell affects its capacity. Heavy traffic load can lead to congestion and reduced capacity. Traffic management techniques like scheduling, resource allocation, and admission control help optimize capacity utilization.

Cell Size and Density: The size and density of cells impact their capacity. Smaller cells with a higher density of base stations can support more users and provide better capacity, but at the cost of increased infrastructure deployment.

Service Types: Different services have varying capacity requirements. Voice calls typically require lower capacity compared to data services, which may require higher capacity due to increased data rates and user demands.

Network operators use various techniques to increase cell capacity and optimize network performance, such as:

Sectorization: Dividing a cell into multiple sectors, each served by a separate antenna, to increase capacity and reduce interference.

Carrier Aggregation: Combining multiple frequency bands to increase bandwidth and capacity.

Multiple Input Multiple Output (MIMO): Using multiple antennas for improved spectral efficiency and capacity.

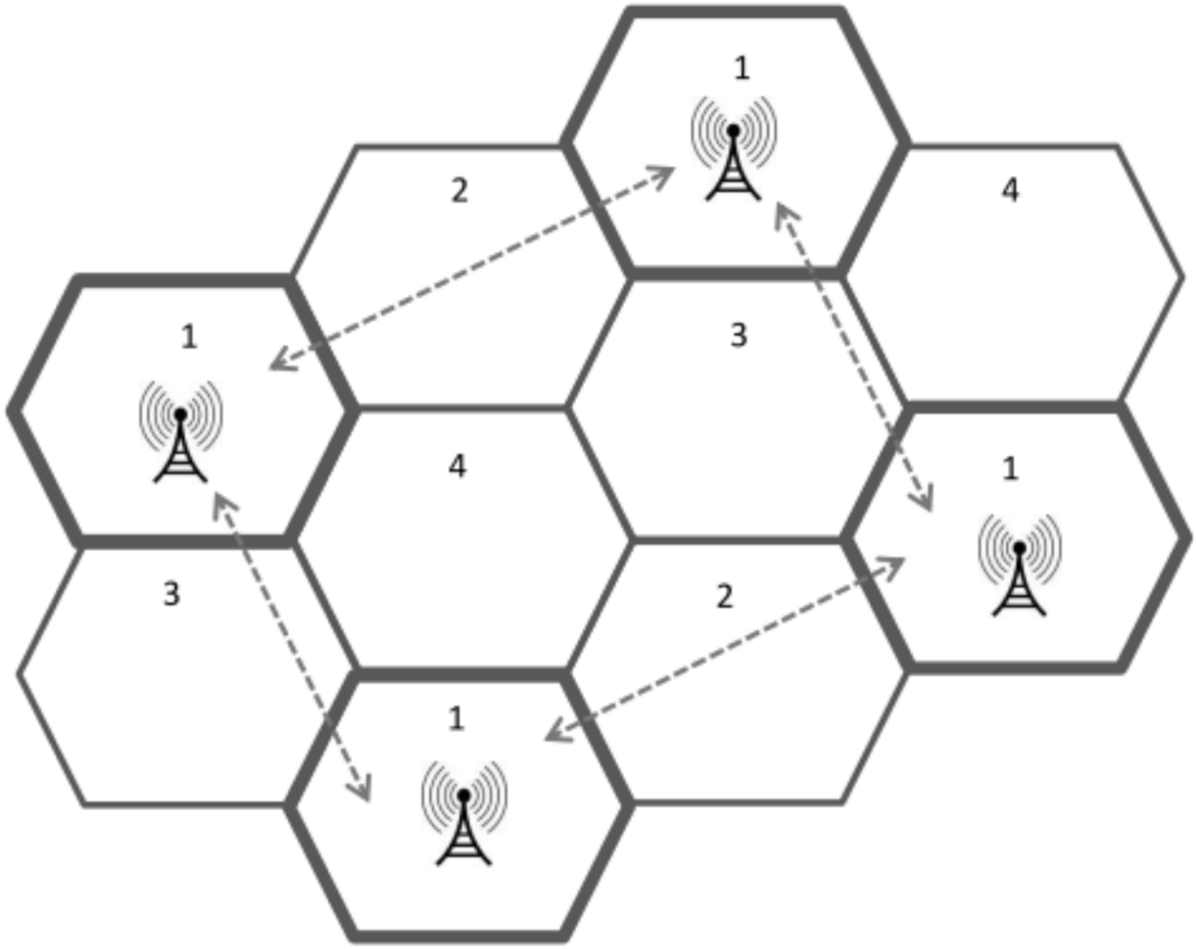
Small Cell Deployment: Installing additional small cells in high-demand areas to offload traffic from macro cells and increase overall capacity.

Traffic Offloading: Directing certain types of traffic, such as data, to Wi-Fi networks or other alternative technologies to reduce the load on cellular networks.

Capacity planning is a critical aspect of network design and optimization to ensure that sufficient resources are allocated to meet the demands of mobile users and provide a satisfactory user experience.

Co-Channel Interference:

Co-channel interference (CCI) in mobile communication refers to the interference that occurs when multiple cells in a cellular network use the same frequency or channel to transmit and receive signals. CCI is a significant challenge in cellular networks, particularly in densely populated areas where multiple cells operate in close proximity.



When cells share the same frequency, CCI can occur due to several reasons:

Frequency Reuse: Cellular networks reuse the same set of frequencies to maximize spectrum efficiency. Cells that are geographically separated but use the same frequency are said to be in the same frequency reuse group. As a result, signals from neighboring cells operating on the same frequency can interfere with each other.

Signal Propagation: Radio signals propagate beyond the intended cell coverage area. Consequently, users located near the cell edge may experience interference from neighboring cells operating on the same frequency.

Insufficient Separation: In cases where cells are not adequately separated, the signal strength from nearby cells can be strong enough to cause interference in a target cell.

Co-channel interference can have several negative effects on mobile communication:

Degraded Signal Quality: Interfering signals can weaken the desired signal, leading to increased bit error rates, dropped calls, and reduced call quality.

Reduced Data Throughput: Interference can lower the achievable data rates, resulting in slower data speeds and decreased network capacity.

Increased Power Consumption: Mobile devices may need to increase their transmit power to maintain a reliable connection in the presence of interference, which can lead to increased power consumption and reduced battery life.

Impaired Network Performance: Co-channel interference can impact the overall network performance by reducing system capacity, increasing congestion, and degrading the user experience.

To mitigate co-channel interference, cellular networks employ various techniques:

Frequency Planning: Careful planning of frequency assignments and allocation helps minimize interference by allocating different frequencies to nearby cells.

Cell Sectorization: Dividing cells into sectors and using directional antennas allows for more precise control of coverage areas and reduces interference between neighboring cells.

Interference Avoidance Techniques: Adaptive interference avoidance techniques dynamically adjust transmission parameters, such as power levels, to minimize interference based on real-time measurements.

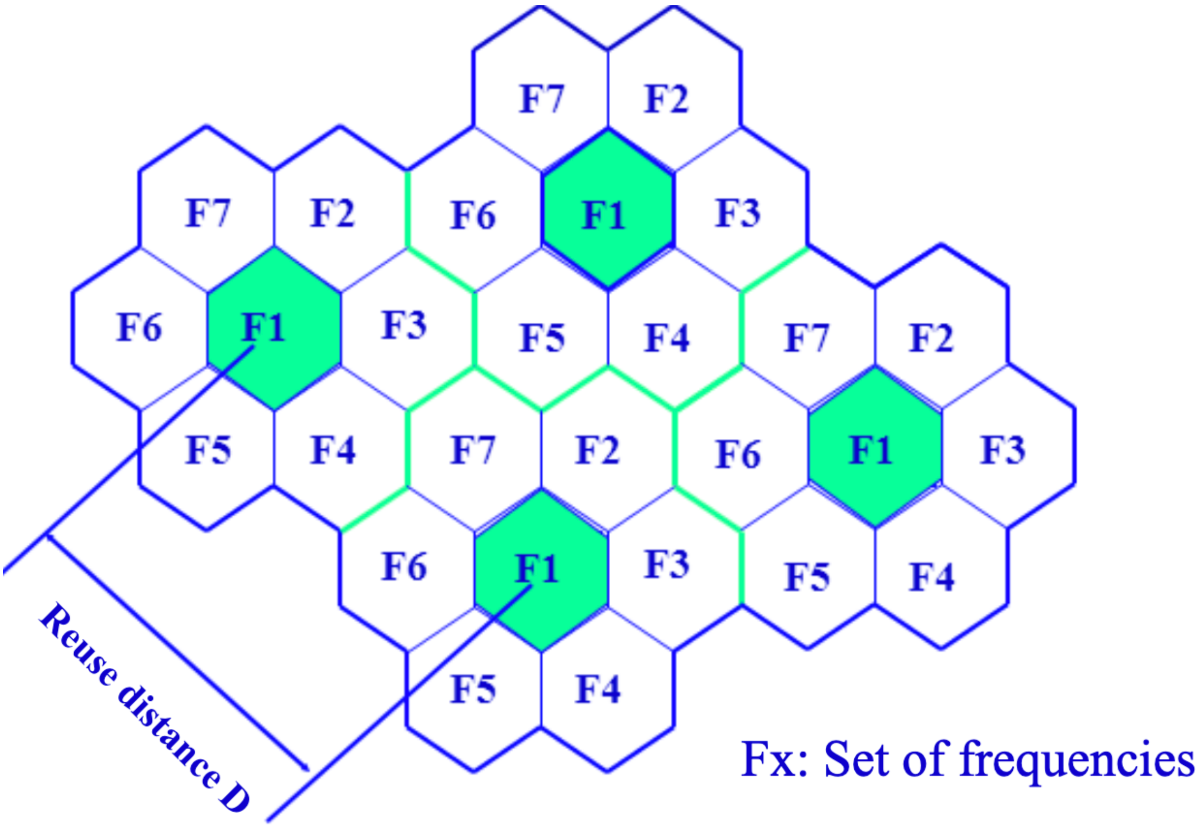
Interference Coordination: Coordinating transmission schedules and power levels between neighbouring cells can help minimize interference and improve overall network performance.

Advanced Antenna Systems: Using advanced antenna technologies like MIMO (Multiple Input Multiple Output) can mitigate interference by exploiting spatial diversity and improving signal quality.

Co-channel interference remains an ongoing challenge in cellular networks, and network operators continually work on optimizing network design, deployment, and interference management techniques to minimize its impact and improve overall network performance.

Frequency Reuse:

Frequency reuse is a fundamental concept in mobile communication that enables efficient utilization of the limited available radio frequency spectrum in cellular networks. It involves the reuse of the same set of frequencies across different cells in a network to increase capacity and coverage. In cellular networks, frequency reuse is implemented through a pattern known as a frequency reuse plan. This plan divides the available spectrum into a set of frequency channels and assigns them to cells in a controlled manner. The goal is to maximize the number of cells that can operate simultaneously while minimizing interference.



Key aspects of frequency reuse include:

Frequency Reuse Factor: The frequency reuse factor (N) determines the number of cells that can operate simultaneously using the same set of frequencies. It is defined as the inverse of the reuse distance. For example, if N = 7, it means that cells using the same frequency are separated by at least seven other cells before they are reused.

Reuse Distance: The reuse distance is the minimum distance between cells that use the same frequency. It depends on factors such as the desired signal quality, interference tolerance, and geographical characteristics of the network.

Frequency Reuse Patterns: Frequency reuse patterns define the arrangement of cells and the allocation of frequencies within a network. Common patterns include regular hexagonal grids and sectorized layouts.

The benefits of frequency reuse in mobile communication are:

Increased Capacity: Frequency reuse allows multiple cells to operate simultaneously using the same set of frequencies, thereby increasing the capacity of the network. It enables the support of a larger number of users and accommodates growing demand for voice and data services.

Improved Coverage: By reusing frequencies across different cells, network coverage can be extended, filling coverage gaps and providing service to a larger area.

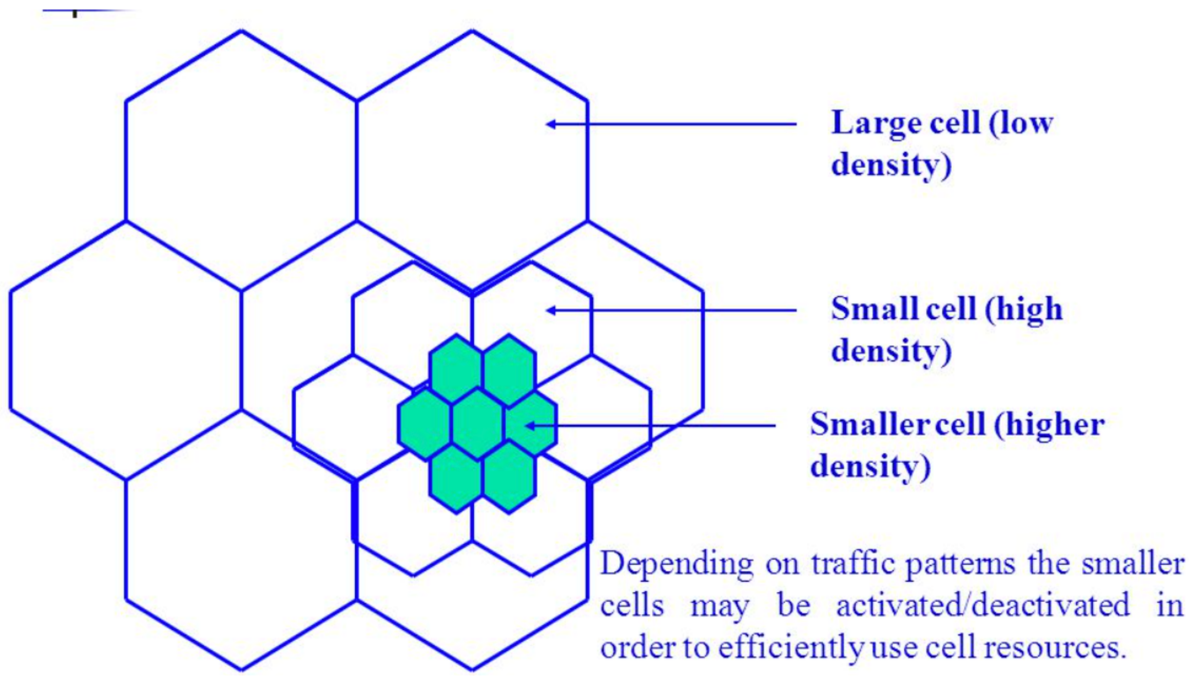
Efficient Spectrum Utilization: The limited radio frequency spectrum is a valuable resource. Frequency reuse optimizes spectrum utilization by allowing multiple cells to share the same frequencies while minimizing interference.

Frequency reuse plans and patterns are carefully designed during network planning and optimization to strike a balance between capacity, coverage, and interference. Network operators consider factors such as user density, traffic demand, propagation characteristics, and interference mitigation techniques to develop an effective frequency reuse strategy.

It's important to note that frequency reuse is not limited to a single technology generation like 2G, 3G, or 4G. It is a concept applied across various generations of cellular networks, including the latest 5G technology, to maximize spectral efficiency and improve network performance.

Cell Splitting:

Cell splitting is a technique used in mobile communication to increase the capacity and coverage of a cellular network by dividing existing cells into smaller cells. It involves reducing the cell size, which results in smaller coverage areas and allows for more efficient use of available resources.



Cell splitting is typically done in areas where the demand for mobile services exceeds the capacity of the existing cells. By splitting cells, network operators can effectively increase the number of cells within a given geographical area, thereby accommodating more users and reducing congestion. The process involves the following steps:

Analysis and Planning: Network operators analyze the traffic patterns, user distribution, and capacity requirements in a particular area to identify cells that are experiencing high demand and congestion. They determine the appropriate cell splitting strategy based on these factors.

Site Selection: New cell sites are identified for the deployment of additional base stations. The selection is based on factors such as geographic location, coverage requirements, available infrastructure, and regulatory considerations.

Installation and Configuration: The new base stations are installed and configured to operate on different frequencies or channels than the existing cells in the area. They are typically connected to the core network infrastructure through backhaul connections.

Cell Parameters Adjustment: Cell parameters such as transmit power, antenna configuration, and handover thresholds are adjusted to ensure smooth handovers between the new smaller cells and neighboring cells. This helps maintain seamless connectivity as users move between cells.

Testing and Optimization: The newly split cells are tested to ensure proper coverage, capacity, and quality of service. Network optimization techniques are applied to fine-tune the performance and mitigate any interference or coverage issues.

The benefits of cell splitting include:

Increased Capacity: By dividing cells into smaller cells, cell splitting increases the capacity of the network in terms of the number of simultaneous users that can be accommodated. Smaller cells allow for more efficient reuse of frequencies and resources.

Improved Coverage and Signal Quality: Smaller cells provide better coverage, especially in areas with high user density or challenging propagation conditions. Users located closer to the smaller cells experience stronger and more reliable signals.

Reduced Interference: Cell splitting helps reduce interference between cells by reducing the distance between base stations. This leads to improved signal quality, higher data rates, and enhanced network performance.

Cell splitting is an effective technique for network expansion and capacity enhancement. It is commonly used in urban areas, stadiums, shopping centers, and other locations with high user concentrations. By improving capacity and coverage, cell splitting enables network operators to meet the increasing demands for mobile services and provide a better user experience.

Cell Sectoring:

Cell sectoring is a technique used in mobile communication to enhance the capacity, coverage, and performance of cellular networks. It involves dividing a cell into multiple sectors, each served by a separate directional antenna. Each sector provides coverage and communication services to a specific portion of the overall cell coverage area.

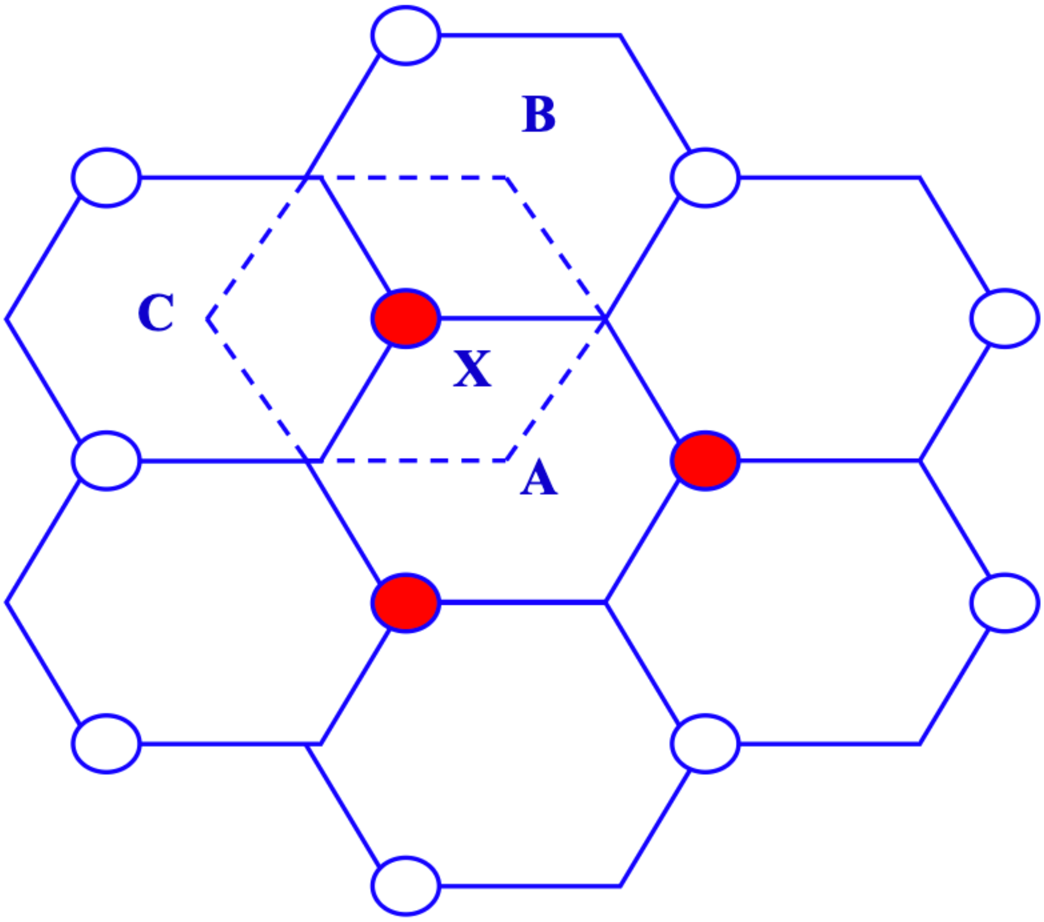
Here are key aspects and benefits of cell sectoring:

Sector Configuration: A cell is divided into sectors using directional antennas, typically with a sector width of 60 degrees, 90 degrees, or 120 degrees. The number of sectors in a cell can vary, with common configurations being three-sector or six-sector cells.

Antenna Beamforming: Sectoring allows for antenna beamforming, where the antenna's radiation pattern is shaped and directed towards the specific sector it serves. Beamforming improves signal strength, quality, and coverage within the sector.

Increased Capacity: Cell sectoring increases the capacity of a cell by enabling the reuse of frequencies within the same cell. By dividing the cell into sectors, each sector can use the same set of frequencies, but with reduced interference due to the directionality of the antennas.

Improved Coverage and Signal Quality: Sectoring enhances coverage and signal quality by concentrating the transmitted power and resources within the specific sector. Users within the sector experience stronger and more reliable signals, resulting in better call quality and higher data rates.



Reduced Interference: By using directional antennas, cell sectoring minimizes interference from neighbouring cells. Signals are focused within the intended sector, reducing the likelihood of interference with adjacent sectors using the same frequencies.

Efficient Resource Allocation: Each sector operates independently, allowing for more efficient allocation of network resources. Traffic, capacity, and quality of service management can be optimized at the sector level based on demand and user distribution.

Enhanced Sector-Specific Optimization: With cell sectoring, network operators can perform sector-specific optimization and fine-tuning to improve network performance. This includes adjusting antenna tilt, power levels, handover parameters, and interference coordination within each sector.

Cell sectoring is commonly used in densely populated areas, urban environments, and areas with high user demand. It is particularly effective in addressing the challenges of interference and capacity limitations in these areas. By dividing a cell into sectors and applying directional antennas, cell sectoring improves coverage, capacity, and overall network performance while minimizing interference and maximizing resource utilization.

Multiple Radio Access Protocols:

Multiple Radio Access Protocols (RANs) in mobile communication refer to the coexistence and support of different wireless technologies or protocols within a single network infrastructure. This allows mobile devices to connect and communicate using various radio access technologies depending on their capabilities and network availability. Some examples of multiple RANs include the coexistence of 2G, 3G, 4G, and 5G technologies within a cellular network.

Here are the key aspects and benefits of multiple RANs:

Technology Evolution and Compatibility: Multiple RANs enable a smooth transition and backward compatibility between different generations of mobile communication technologies. For example, during the deployment of newer technologies like 4G or 5G, existing devices that

Fixed ALOHA and Slotted ALOHA

Fixed ALOHA and Slotted ALOHA are two different variants of the ALOHA protocol, which is a random-access protocol used in early computer networks to coordinate the transmission of data packets. Both Fixed ALOHA and Slotted ALOHA have their own characteristics and advantages.

Fixed ALOHA:

Fixed ALOHA is a simple and straightforward random-access protocol. In Fixed ALOHA, each station or device can transmit data packets at any time, without any synchronization or coordination with other devices. The key features of Fixed ALOHA are:

Random Transmission: Stations transmit their packets randomly, without waiting for any specific time slots.

Collision Detection: If two or more stations transmit at the same time, a collision occurs, and the packets are lost.

Retransmission: In case of a collision, stations retransmit their packets after a random time delay.

Efficiency: The efficiency of Fixed ALOHA is relatively low because collisions can occur frequently, resulting in wasted bandwidth due to retransmissions.

Slotted ALOHA:

Slotted ALOHA introduces a synchronization mechanism by dividing time into discrete slots. Each slot represents a fixed time interval during which a station can transmit a packet. The key features of Slotted ALOHA are:

Time Synchronization: Stations synchronize their transmissions to the start of each time slot.

Collision Detection: If multiple stations transmit in the same slot, a collision occurs, and the packets are lost.

Retransmission: In the case of a collision, stations retransmit their packets in subsequent slots.

Increased Efficiency: Slotted ALOHA has a higher efficiency compared to Fixed ALOHA because collisions are reduced due to the synchronized time slots.

Both Fixed ALOHA and Slotted ALOHA have been used in various network protocols and applications. However, Slotted ALOHA is generally considered more efficient than Fixed ALOHA due to the synchronization mechanism, which reduces the probability of collisions and improves overall network performance.

Multiple Access with Collision Avoidance:

Multiple Access with Collision Avoidance (MACA) is a protocol used in wireless communication to manage access to a shared communication medium, such as a wireless channel, in a way that minimizes collisions between transmitting devices. MACA is designed to overcome the limitations of protocols like ALOHA, where collisions are a common occurrence.

Here are the key characteristics and mechanisms of MACA:

Carrier Sensing: MACA incorporates a carrier sensing mechanism, where devices listen to the wireless channel to detect ongoing transmissions. Before initiating a transmission, a device checks if the channel is idle to avoid collisions.

Request to Send/Clear to Send (RTS/CTS): MACA uses a two-way handshake process to reserve the channel and avoid collisions. The requesting device sends an RTS frame to the intended recipient, indicating its desire to transmit. If the recipient is ready to receive, it responds with a Clear to Send (CTS) frame, granting permission to transmit.

Virtual Channel Reservation: MACA establishes a virtual channel reservation during the RTS/CTS handshake. This reservation prevents other devices from attempting to transmit during the reserved period, avoiding collisions.

Collision Avoidance: With MACA, devices refrain from transmitting if they detect an ongoing transmission or receive a CTS frame from another device. This collision avoidance mechanism ensures that only one device transmits at a time, reducing the likelihood of collisions.

Backoff Mechanism: If a device detects a collision during the RTS/CTS handshake or after starting a transmission, it initiates a random backoff period before attempting another transmission. The backoff period helps prevent repeated collisions between devices.

By incorporating carrier sensing, RTS/CTS handshake, virtual channel reservation, and collision avoidance mechanisms, MACA provides a more efficient and collision-free access to the shared communication medium compared to earlier protocols like ALOHA.

MACA-based protocols, such as IEEE 802.11 (Wi-Fi), use these principles to enable multiple devices to communicate over a wireless channel without causing interference or collisions. MACA is particularly suitable for environments with a high density of devices or networks where multiple devices need to access the wireless medium simultaneously while avoiding collisions and maximizing efficiency.

Spread ALOHA Multiple Access:

Spread ALOHA Multiple Access (S-ALOHA) is a multiple access technique used in wireless communication systems to allow multiple users to access a shared communication medium efficiently. It is an enhanced version of the ALOHA protocol that incorporates spreading techniques to increase system capacity and improve overall performance.

Here are the key characteristics and principles of Spread ALOHA Multiple Access:

Spreading Techniques: S-ALOHA utilizes spreading techniques such as frequency spreading or code spreading. These techniques spread the transmitted signal over a wider frequency or code bandwidth, allowing multiple users to share the same frequency resources simultaneously.

Orthogonal Codes: S-ALOHA typically employs orthogonal codes that have desirable properties, such as low cross-correlation between codes. Orthogonal codes enable multiple users to transmit their data simultaneously without causing interference between different users.

Collisions and Recovery: Collisions may still occur in S-ALOHA, but due to the spreading techniques and orthogonal codes, collisions can be detected and resolved efficiently. Users can recover the original data by utilizing error detection and correction mechanisms.

Increased System Capacity: S-ALOHA increases the system capacity compared to traditional ALOHA by allowing multiple users to transmit simultaneously. The spreading techniques and orthogonal codes enable efficient utilization of available frequency or code resources.

Spread Spectrum Technologies: S-ALOHA is closely related to spread spectrum technologies such as Frequency Hopping Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS). These technologies provide the spreading functionality required for S-ALOHA and offer additional benefits such as improved interference resistance and security.

Applications: S-ALOHA is used in various wireless communication systems, including cellular networks, satellite communications, and wireless local area networks (WLANs). It is particularly beneficial in scenarios with a large number of users and a need for efficient utilization of limited frequency resources.

The main advantages of Spread ALOHA Multiple Access include increased system capacity, improved interference resilience, and the ability to support a larger number of simultaneous users. However, S-ALOHA requires synchronization between users to ensure the correct decoding of spread signals and the recovery of transmitted data.

Spread ALOHA Multiple Access has been employed in various communication standards and technologies, including 3G CDMA, 4G LTE, and 5G NR (New Radio), to provide efficient multiple access capabilities and enhance system performance in wireless communication systems.

OFDM & Variants of OFDM

OFDM (Orthogonal Frequency Division Multiplexing) is a modulation and multiple access technique used in wireless communication systems. It divides the available frequency spectrum into multiple orthogonal subcarriers, allowing for efficient data transmission and improved resistance to multipath fading. Variants of OFDM have been developed to address specific requirements and challenges in different applications. Here are some variants of OFDM:

OFDMA (Orthogonal Frequency Division Multiple Access):

OFDMA is a multiple access scheme based on OFDM. It allows multiple users to simultaneously access the available spectrum by assigning different sets of subcarriers to different users. Each user has its own set of subcarriers for data transmission, which can be dynamically allocated based on the users' needs and channel conditions. OFDMA is used in 4G LTE and 5G NR networks for efficient resource allocation and improved system capacity.

SC-FDMA (Single Carrier Frequency Division Multiple Access):

SC-FDMA, also known as DFT-Spread OFDM (Discrete Fourier Transform-Spread OFDM), is a variant of OFDM designed to address the peak-to-average power ratio (PAPR) issue. In traditional OFDM, the high PAPR requires power amplifiers with high linearity, which can be expensive and inefficient. SC-FDMA reduces the PAPR by applying a DFT operation to the input data, spreading the energy across multiple subcarriers. SC-FDMA is used in the uplink transmission of 4G LTE systems.

OFDM-CDMA (Orthogonal Frequency Division Multiplexing-Code Division Multiple Access):

OFDM-CDMA combines the benefits of OFDM and CDMA. It uses spreading codes to separate different users' signals in the frequency domain, allowing multiple users to share the same subcarriers simultaneously. OFDM-CDMA is particularly useful in scenarios where both high data rate and multiple access capabilities are required, such as broadband wireless access systems.

W-OFDM (Wavelet Orthogonal Frequency Division Multiplexing):

W-OFDM is a variant of OFDM that uses wavelet-based subcarrier modulation instead of the traditional discrete Fourier transform. Wavelets provide advantages such as improved spectral localization, robustness against multipath fading, and adaptability to non-stationary channels. W-OFDM is mainly used in wireless multimedia applications, where efficient bandwidth utilization and high-quality transmission are important.

These are some of the variants of OFDM that have been developed to address specific challenges or requirements in different wireless communication systems. Each variant offers unique features and benefits, enabling efficient data transmission, multiple access capabilities, and improved system performance in various applications.

Multiple Access Techniques: Multiple access techniques enable multiple users to share the same frequency resources within a cell. Different generations of cellular networks have employed various multiple access techniques, including Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), and Orthogonal Frequency Division Multiple Access (OFDMA). These techniques allow for efficient allocation of resources and simultaneous communication between multiple users.

Handover: Handover, also known as handoff, is the process of transferring an ongoing call or data session from one cell to another as a mobile device moves from the coverage area of one cell to another. Handover ensures seamless connectivity and uninterrupted service as users move across cells.

Interference Management: Interference is a challenge in cellular networks, particularly in densely populated areas. Interference management techniques, such as power control, adaptive modulation, advanced antenna technologies, and interference cancellation, are employed to mitigate interference and enhance the quality of wireless communication.

Cell Splitting and Sectoring: As the demand for capacity increases in a specific area, cells can be split into smaller cells or divided into sectors to accommodate more users. Cell splitting and sectoring allow for more efficient resource allocation and better coverage in high-density areas.

Roaming and Mobility Management: Roaming enables users to access cellular services outside their home network's coverage area. Mobility management mechanisms, such as location tracking, paging, and authentication procedures, ensure seamless mobility and service continuity as users move between different cells and networks.

Backhaul and Core Network: Cellular networks have a hierarchical structure that includes the access network (radio access) and the core network. The backhaul provides connectivity between the base stations and the core network, enabling data and voice traffic to be transported efficiently.

These cellular concepts collectively form the foundation of mobile communication systems, allowing for efficient and reliable wireless connectivity. They have evolved over time, with advancements in technology and the introduction of new generations of cellular networks, such as 2G, 3G, 4G, and 5G, catering to increasing user demands for higher data rates, improved coverage, and support for a wide range of services and applications.

Introduction to Multiple Access:

Frequency division multiple access (FDMA), time division multiple access (TDMA), and code division multiple access (CDMA) are the three major access techniques used to share the available bandwidth in a wireless communication system. These techniques can be grouped as narrowband and wideband systems, depending upon how the available bandwidth is allocated to the users. The duplexing technique of a multiple access system is usually described along with the particular multiple access scheme, as shown in the examples that follow.

Narrowband Systems — The term narrowband is used to relate the bandwidth of a single channel to the expected coherence bandwidth of the channel. In a narrowband multiple access system, the available radio spectrum is divided into a large number of narrowband channels.

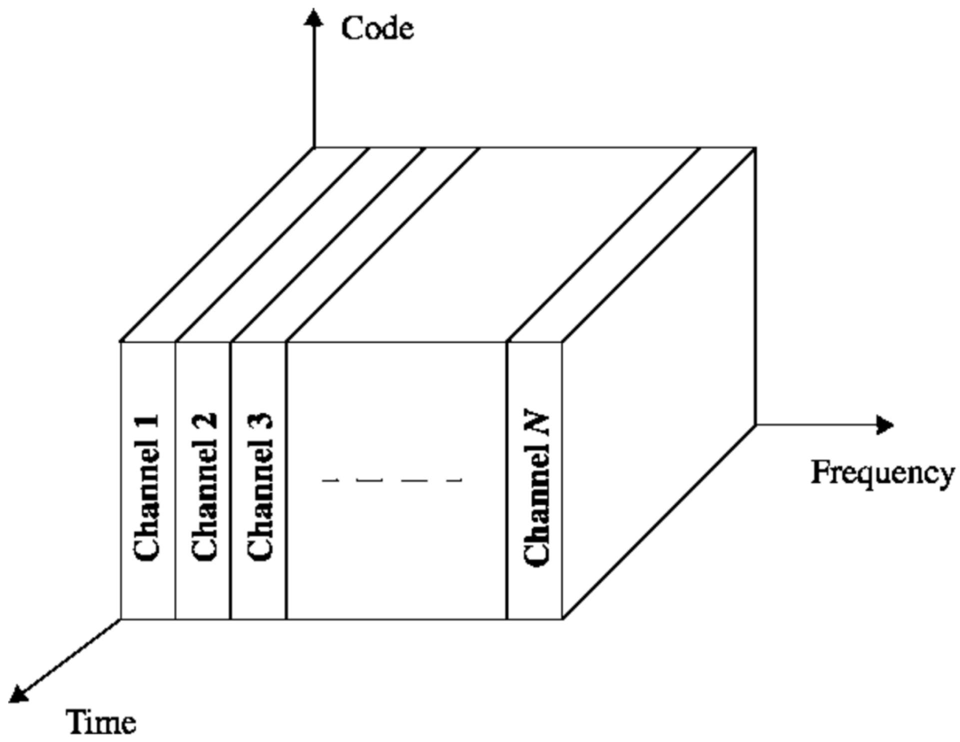
The channels are usually operated using FDD. To minimize interference between forward and reverse links on each channel, the frequency separation is made as great as possible within the frequency spectrum, while still allowing inexpensive duplexers and a common transceiver antenna to be used in each subscriber unit. In narrowband FDMA, a user is assigned a particular channel which is not shared by other users in the vicinity, and if FDD is used (that is, each duplex channel has a forward and reverse simplex channel), then the system is called FDMA/FDD. Narrowband TDMA, on the other hand, allows users to share the same radio channel but allocates a unique time slot to each user in a cyclical fashion on the channel, thus separating a small number of users in time on a single channel. For narrowband TDMA systems, there generally are a large number of radio channels allocated using either FDD or TDD, and each channel is shared using TDMA. Such systems are called TDMA/FDD or TDMA/TDD access systems.

Wideband systems — In wideband systems, the transmission bandwidth of a single channel is much larger than the coherence bandwidth of the channel. Thus, multipath fading does not greatly vary the received signal power within a wideband channel, and frequency selective fades occur in only a small fraction of the signal bandwidth at any instance of time. In wideband multiple access systems, a large number of transmitters are allowed to transmit on the same channel. TDMA allocates time slots to the many transmitters on the same channel and allows only one transmitter to access the channel at any instant of time, whereas spread spectrum CDMA allows all of the transmitters to access the channel at the same time. TDMA and CDMA systems may use either FDD or TDD multiplexing techniques.

In addition to FDMA, TDMA, and CDMA, two other multiple access schemes will be used for wireless communications. These are packet radio (PR) and space division multiple access (SDMA).

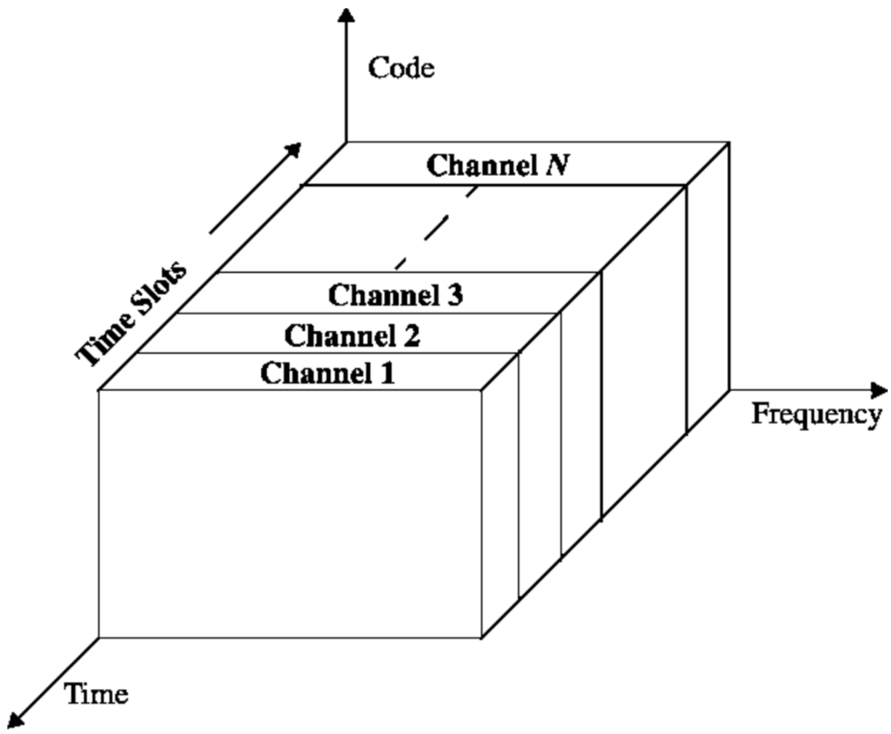
Frequency Division Multiple Access (FDMA):

Frequency division multiple access (FDMA) assigns individual channels to individual users. It can be seen from Figure 2 that each user is allocated a unique frequency band or channel. These channels are assigned on demand to users who request service. During the period of the call, no other user can share the same channel. In FDD systems, the users are assigned a channel as a pair of frequencies; one frequency is used for the forward channel, while the other frequency is used for the reverse channel. Frequency-division multiple access is the oldest of all multiple access schemes, and was used in the first demand assignment system for satellites (i.e., single channel per carrier (SCPC)) and the first-generation of cellular mobile systems (i.e., the advanced mobile phone system (AMPS)). In FDMA, the available channel bandwidth is divided into many nonoverlapping frequency bands, where each band is dynamically assigned to a specific user to transmit data. In an FDMA system, signals, while occupying their assigned frequency bands, can be transmitted simultaneously and continuously without interfering with each other. In FDMA, there is a central controller that allocates the frequency band to users, solely based on their needs. This is usually done during the call set up. Once a band is allocated to a user, it then belongs to the user exclusively for the continuous flow of information during the call. To prevent interference, the allocated bands are separated from one another by small guard bands. In other words, FDMA allows the users to transmit simultaneously, but over disjoint frequency bands, a user exploits a fixed portion of the band all the time, as shown in Figure 11.4a. FDMA is best suited for connection-oriented applications; it is, however, inefficient in terms of utilization of power and bandwidth. If an FDMA channel is not in use by the user, then it sits idle and cannot be used by other users. It has poor spectral efficiency, since guard bands must be employed to avoid overlapping of the adjacent channels, and this in turn reduces the channel capacity.



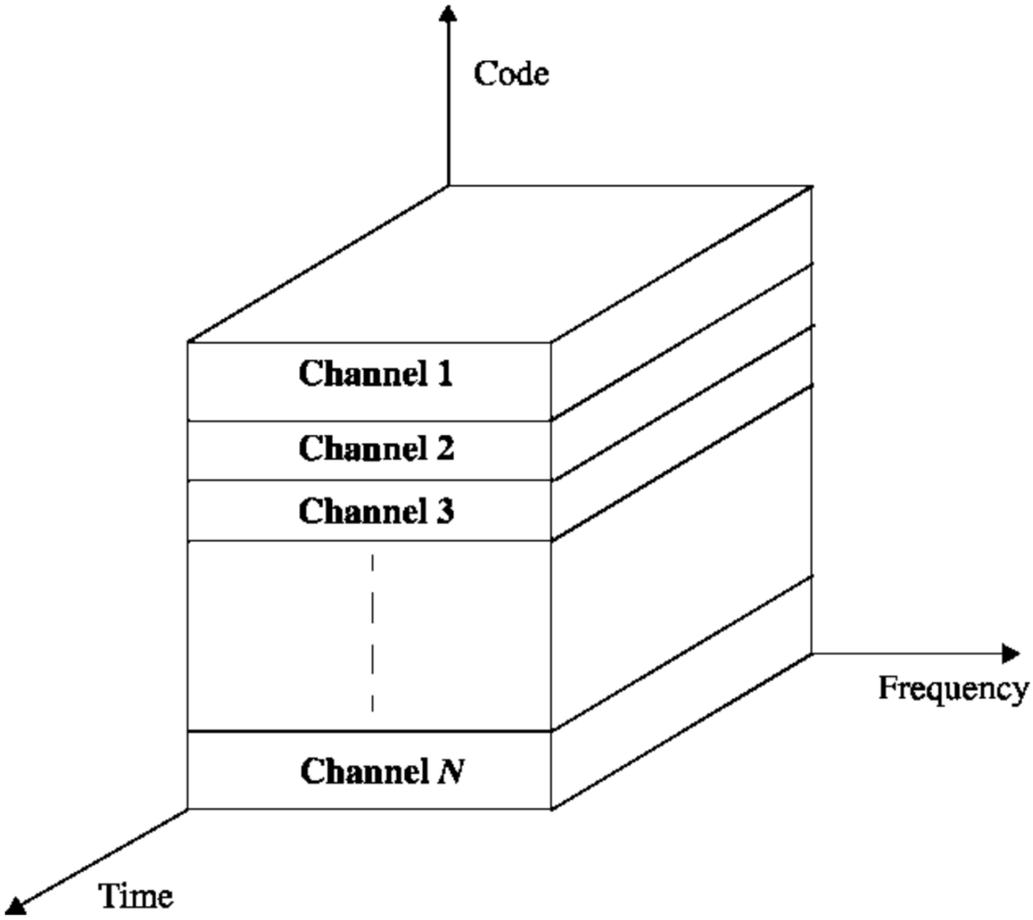
Time Division Multiple Access (TDMA):

Time division multiple access (TDMA) systems divide the radio spectrum into time slots, and in each slot only one user is allowed to either transmit or receive. It can be seen from Figure that each user occupies a cyclically repeating time slot, so a channel may be thought of as a particular time slot that reoccurs every frame, where N time slots comprise a frame. TDMA systems transmit data in a buffer-and-burst method, thus the transmission for any user is non-continuous. This implies that, unlike in FDMA systems which accommodate analog FM, digital data and digital modulation must be used with TDMA. The transmission from various users is interlaced into a repeating frame structure as shown in Figure 4. It can be seen that a frame consists of a number of slots. Each frame is made up of a preamble, an information message, and tail bits. In TDMA/ TDD, half of the time slots in the frame information message would be used for the forward link channels and half would be used for reverse link channels. In TDMA/FDD systems, an identical or similar frame structure would be used solely for either forward or reverse transmission, but the carrier frequencies would be different for the forward and reverse links. In general, TDMA/FDD systems intentionally induce several time slots of delay between the forward and reverse time slots for a particular user, so that duplexers are not required in the subscriber unit. In a TDMA frame, the preamble contains the address and synchronization information that both the base station and the subscribers use to identify each other. Guard times are utilized to allow synchronization of the receivers between different slots and frames. Different TDMA standards have different TDMA frame structures.



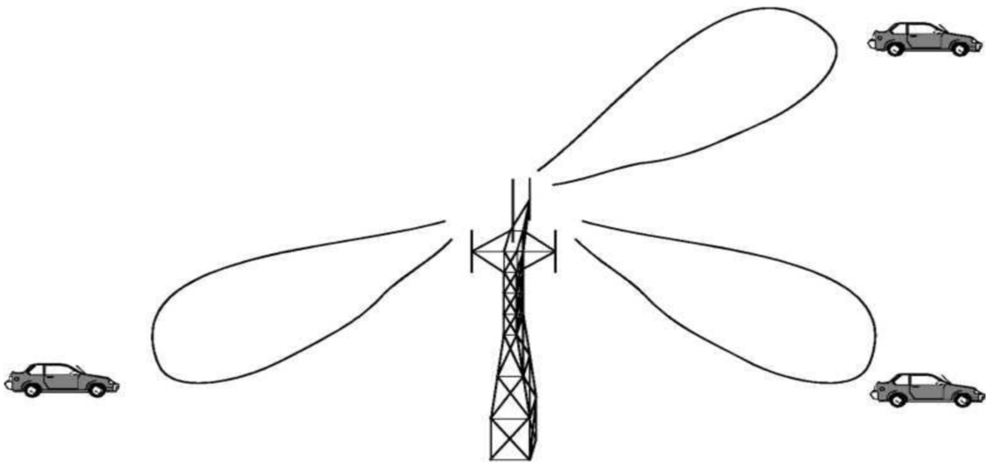
Code Division Multiple Access (CDMA):

In code division multiple access (CDMA) systems, the narrowband message signal is multiplied by a very large bandwidth signal called the spreading signal. The spreading signal is a pseudo-noise code sequence that has a chip rate which is orders of magnitudes greater than the data rate of the message. All users in a CDMA system, as seen from Figure 5, use the same carrier frequency and may transmit simultaneously. Each user has its own pseudorandom codeword which is approximately orthogonal to all other codewords. The receiver performs a time correlation operation to detect only the specific desired codeword. All other code words appear as noise due to de-correlation. For detection of the message signal, the receiver needs to know the codeword used by the transmitter. Each user operates independently with no knowledge of the other users. In CDMA, the power of multiple users at a receiver determines the noise floor after de-correlation. If the power of each user within a cell is not controlled such that they do not appear equal at the base station receiver, then the near-far problem occurs. The near-far problem occurs when many mobile users share the same channel. In general, the strongest received mobile signal will capture the demodulator at a base station. In CDMA, stronger received signal levels raise the noise floor at the base station demodulators for the weaker signals, thereby decreasing the probability that weaker signals will be received. To combat the near-far problem, power control is used in most CDMA implementations. Power control is provided by each base station in a cellular system and assures that each mobile within the base station coverage area provides the same signal level to the base station receiver. This solves the problem of a nearby subscriber overpowering the base station receiver and drowning out the signals of far-away subscribers. Power control is implemented at the base station by rapidly sampling the radio signal strength indicator (RSSI) levels of each mobile and then sending a power change command over the forward radio link. Despite the use of power control within each cell, out-of-cell mobiles provide interference which is not under the control of the receiving base station.



Space Division Multiple Access (SDMA):

Space division multiple access (SDMA) controls the radiated energy for each user in space. It can be seen from Figure 8 that SDMA serves different users by using spot beam antennas. These different areas covered by the antenna beam may be served by the same frequency (in a TDMA or CDMA system) or different frequencies (in an FDMA system). Sectorized antennas may be thought of as a primitive application of SDMA. In the future, adaptive antennas will likely be used to simultaneously steer energy in the direction of many users at once and appear to be best suited for TDMA and CDMA base station architectures. The reverse link presents the most difficulty in cellular systems for several reasons. First, the base station has complete control over the power of all the transmitted signals on the forward link. However, because of different radio propagation paths between each user and the base station, the transmitted power from each subscriber unit must be dynamically controlled to prevent any single user from driving up the interference level for all other users. Second, transmit power is limited by battery consumption at the subscriber unit, therefore there are limits on the degree to which power may be controlled on the reverse link. If the base station antenna is made to spatially filter each desired user so that more energy is detected from each subscriber, then the reverse link for each user is improved and less power is required. Adaptive antennas used at the base station (and eventually at the subscriber units) promise to mitigate some of the problems on the reverse link. In the limiting case of infinitesimal beam-width and infinitely fast-tracking ability, adaptive antennas implement optimal SDMA, thereby providing a unique channel that is free from the interference of all other users in the cell. With SDMA, all users within the system would be able to communicate at the same time using the same channel. In addition, a perfect adaptive antenna system would be able to track individual multipath components for each user and combine them in an optimal manner to collect all of the available signal energy from each user. The perfect adaptive antenna system is not feasible since it requires infinitely large antennas.



Comparison of Multiple Access Techniques:

FDMA	TDMA	CDMA
FDMA stands for Frequency Division Multiple Access.	TDMA stands for Time Division Multiple Access.	CDMA stands for Code Division Multiple Access.
In this, sharing of bandwidth among different stations takes place.	In this, only the sharing of time of satellite transponder takes place.	In this, there is sharing of both i.e. bandwidth and time among different stations takes place.
There is no need of any codeword.	There is no need of any codeword.	Codeword is necessary.
In this, there is only need of guard bands between the adjacent channels are necessary.	In this, guard time of the adjacent slots are necessary.	In this, both guard bands and guard time are necessary.
Synchronization is not required.	Synchronization is required.	Synchronization is not required.
The rate of data is low.	The rate of data is medium.	The rate of data is high.

FDMA	TDMA	CDMA
Mode of data transfer is continuous signal.	Mode of data transfer is signal in bursts.	Mode of data transfer is digital signal.
It is little flexible.	It is moderate flexible.	It is highly flexible.

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