Wireless & Mobile Computing

First Semester 3rd Class

Lecture Ten

2025/2024

Cellular Networks

- The term cellular refers to the fact that the region covered by a cellular network is partitioned into a number of geographic coverage areas, known as cells.
- Each cell contains a base station that transmits signals to, and receives signals from, the mobile devices currently in its cell.
- The coverage area of a cell depends on many factors, including the transmitting power of the base station, the transmitting power of the devices, obstructing buildings in the cell, and the height and type of the base station antennas.

Cellular Networks

- **1G (First Generation)**
- **Timeframe**: Introduced in the 1980s.
- **Technology**: Analog.
- **Key Features**:
  - Based on analog voice communication.
  - Used Frequency Division Multiple Access (FDMA) to separate calls.
  - Offered basic voice services only; no data services.
- **Limitations**:
  - Poor voice quality and security (prone to eavesdropping).
  - Large, bulky devices with limited battery life.
  - No support for text messaging or internet access.
- **Example Standards**: Advanced Mobile Phone System (AMPS)

Cellular Networks

- **2G (Second Generation)**
- **Timeframe**: Introduced in the early 1990s.
- **Technology**: Digital.
- **Key Features**:
  - Enabled digital voice communication.
  - Introduced SMS (Short Message Service) and MMS (Multimedia Messaging Service).
  - Used technologies like Global System for Mobile Communications (GSM), Code Division Multiple Access (CDMA), and IS-95.
  - Supported circuit-switched data at low speeds (9.6–14.4 kbps).
- **Advantages Over 1G**:
  - Better voice quality and security (encryption added).
  - Smaller, more energy-efficient devices.
- **Limitations**:
  - Slow data transfer rates unsuitable for modern internet use.
- **Example Standards**: GSM, CDMA, IS-95.

Cellular Networks

- **Circuit-Switched Data (CSD)**
- It is an older method of data transmission used in telecommunications networks.
- It was primarily employed in 2G and earlier generations and is based on reserving a dedicated communication channel for the entire duration of a connection.

Cellular Networks

- **Key Features of Circuit-Switched Data**

1. Dedicated Channel:
   1. A fixed communication channel (circuit) is established between two endpoints for the entire session.
   2. This channel remains reserved, whether or not data is actively being transmitted.

2. Continuous Connection:
   1. The circuit stays active until the communication session is terminated.
   2. Ensures a stable and predictable connection, which is beneficial for voice calls.

3. Slow Data Speeds:
   1. Data rates are relatively low compared to modern standards.
   2. Typical speed in GSM networks: **9.6 kbps** (up to **14.4 kbps** in some cases).

4. Examples of Use:
   1. Dial-up internet connections on early mobile phones.
   2. Sending basic multimedia (e.g., MMS) over 2G networks.

5. Inefficiency:
   1. The channel is fully reserved even during idle periods, wasting bandwidth.
   2. Not suitable for bursty or intermittent data, like modern web browsing.

Cellular Networks

- **Advantages CSD**
- **Reliable Connection**: Guarantees a stable link for the duration of the session.
- **Predictable Performance**: Because the circuit is reserved, there are no interruptions due to competing traffic.
- **Disadvantages CSD**
- **Low Efficiency**: Bandwidth is wasted during idle periods when no data is being transmitted.
- **Limited Scalability**: As the number of users grows, the fixed allocation of channels can lead to network congestion.
- **Slow Speeds**: Inadequate for modern applications requiring high-speed internet.

Cellular Networks

- **Packet-Switched Data**
- Packet-switched data is a method of transmitting information by dividing it into **packets**, which are routed independently through a shared network.
- This difference with circuit-switched systems, which reserve a dedicated channel for communication.
- Packet-switching is fundamental to modern cellular networks.

Cellular Networks

- **Key Features of Packet-Switched Data**

1.Dynamic Channel Usage:

1. Multiple users share the same network resources, with packets routed based on availability.
2. No need for a dedicated channel for each user.

2.Efficient Bandwidth Usage:

1. Resources are allocated only when data is being sent or received.
2. Idle periods (when no data is transmitted) do not consume bandwidth.

3.Variable Packet Sizes:

1. Data is divided into small packets containing the payload (actual data) and metadata (headers for routing, sequencing, etc.).

4.Applications:

1. Internet browsing, email, multimedia streaming, and real-time communications (VoIP, video calls).

Cellular Networks

- **Advantages of Packet-Switched Data:**
- **Efficiency**: Only uses network resources as needed.
- **Scalability**: Can accommodate more users than circuit-switched systems.
- **Flexibility**: Supports bursty and continuous data streams (e.g., email vs. video streaming).
- **Cost-Effective**: Often billed by the amount of data used rather than connection duration.
- **Disadvantages:**
- **Latency**: Higher latency compared to circuit-switched data due to packet routing and reassembly.
- **Complexity**: Requires more sophisticated protocols for error correction and sequencing (e.g., TCP/IP).

Cellular Networks

- **High-Speed Packet Access (HSPA)**
- HSPA is a family of technologies that enhance 3G networks to deliver faster packet-switched data speeds.
- It includes **HSDPA (High-Speed Downlink Packet Access)** and **HSUPA (High-Speed Uplink Packet Access)**, offering significant improvements in speed and efficiency over earlier 3G systems.

Cellular Networks

- **Key Features of HSPA:**

1. **Enhanced Data Rates**:
    1. **HSDPA** focuses on improving downlink (download) speeds.
    2. **HSUPA** focuses on uplink (upload) speeds.
    3. Combined, they offer speeds of **up to 14.4 Mbps (downlink)** and **5.76 Mbps (uplink)**.
    4. **HSPA+** (Evolved HSPA) extends speeds to **42 Mbps (downlink)** and **11 Mbps (uplink)**.
2. **Improved Spectral Efficiency**:
    1. Utilizes advanced techniques like higher-order modulation (16-QAM, 64-QAM) and fast retransmission mechanisms.
3. **Reduced Latency**:
    1. Delivers lower latency (~50–100 ms) for real-time applications like video calls and gaming.
4. **Backward Compatibility**:
    1. Works seamlessly with earlier 3G systems, allowing gradual network upgrades.
5. **Applications**:
    1. Enables smooth video streaming, large file transfers, cloud-based apps, and richer browsing experiences.

Cellular Networks

- **Advantages of HSPA:**
- **High Speed**: Bridges the gap between 3G and 4G in terms of data rates.
- **Efficiency**: Optimizes resource usage for both high-speed and low-speed data.
- **Scalability**: Supports a growing number of mobile users and their increasing demand for data.
- **Disadvantages:**
- **Infrastructure Cost**: Requires upgrades to base stations and network hardware.
- **Power Consumption**: Devices using HSPA often consume more battery due to high-speed data processing.

Cellular Networks

- Packet-Switched Data: Fundamental to modern mobile networks, supporting efficient data transfer by breaking information into packets.
- HSPA: A major improvement in 3G networks, leveraging packet-switching to deliver high-speed internet and multimedia services, setting the stage for 4G.

Cellular Networks

- **3G (Third Generation)**
- **Timeframe**: Introduced in the early 2000s.
- **Technology**: Digital with improved data services.
- **Key Features**:
  - Designed for both voice and high-speed data services.
  - Supported video calls, mobile internet, and multimedia streaming.
  - Utilized technologies like Wideband Code Division Multiple Access (WCDMA), High-Speed Packet Access (HSPA), and CDMA2000.
  - Data speeds ranged from 144 kbps (mobile scenarios) to several Mbps under ideal conditions.
- **Advantages Over 2G**:
  - Significant improvement in data speeds.
  - Support for always-on internet and advanced services like GPS and mobile apps.
- **Limitations**:
  - Higher battery consumption and cost of deployment.
  - Slower compared to modern 4G and 5G networks.
- **Example Standards**: UMTS (Universal Mobile Telecommunications System), CDMA2000.

Cellular Networks

- **Wideband Code Division Multiple Access (WCDMA)** is a 3G wireless communication technology designed to provide high-speed data and voice services.
- It is part of the **Universal Mobile Telecommunications System (UMTS)** and was standardized by the **3rd Generation Partnership Project (3GPP)**.

Cellular Networks

- **Key Features of WCDMA**

1. **Wideband Spectrum Usage**:
    1. Operates on a **5 MHz bandwidth**, which is wider than the bandwidth used in previous 2G technologies like GSM.
    2. This wideband operation allows for higher data rates and better spectral efficiency.
2. **Code Division Multiplexing**:
    1. Multiple users share the same frequency spectrum simultaneously, differentiated by unique spreading codes.
    2. Uses **orthogonal spreading codes** to minimize interference among users.
3. **High Data Rates**:
    1. Supports data rates of up to **384 kbps** for mobile scenarios and **2 Mbps** in fixed environments.
    2. Allows for applications like video calling, mobile internet browsing, and multimedia streaming.
4. **Support for Asynchronous Networks**:
    1. Unlike earlier technologies that required strict synchronization, WCDMA allows asynchronous operation, simplifying network deployment.
5. **Variable Data Rates**:
    1. Dynamically allocates bandwidth to users based on demand, improving overall network efficiency.

Cellular Networks

- **Advantages of WCDMA**

1. **High Capacity**: Efficient use of spectrum allows more users to connect simultaneously.
2. **Broadband Data**: Enables high-speed internet and multimedia services.
3. **Global Standardization**: Adopted widely, ensuring interoperability across different regions.
4. **Better Coverage**: Improved signal robustness in urban and rural environments.

Cellular Networks

- **Disadvantages of WCDMA**

1. **Complex Implementation**: Requires advanced infrastructure and more complex hardware compared to older technologies.
2. **Battery Consumption**: High power consumption due to constant communication and power control mechanisms.
3. **Limited to 3G**: As a 3G technology, WCDMA's speeds and capabilities are inferior to newer technologies like LTE and 5G.

Cellular Networks

- **Applications**
- **Mobile Internet**: Browsing, email, and light media consumption.
- **Video Calling**: Facilitated by its support for high data rates.
- **Streaming Services**: Early adoption of mobile video and music streaming.

Cellular Networks

Feature	1G	2G	3G
Technology	Analog	Digital	Digital
Primary Use	Voice calls	Voice, SMS, MMS	Voice, SMS, high-speed data
Data Speeds	None (Voice only)	~9.6–14.4 kbps	144 kbps to several Mbps
Security	Minimal (eavesdropping)	Encrypted, more secure	Highly secure encryption
Applications	Voice calls only	Voice, texting	Internet, video calls, GPS
Standards	AMPS	GSM, CDMA, IS-95	WCDMA, HSPA, CDMA2000
Device Size	Large and bulky	Compact, portable	Smartphones and multimedia devices

Cellular Networks

- **Service**
- This refers to the specific functions or utilities provided by the network to users.
- Services are the outputs of a cellular system that provide communication needs.
- **Examples:**
- **Voice Calls**: Basic telephony in 1G and improved quality in later generations.
- **Text Messaging (SMS)**: Introduced in 2G and continued in all later generations.
- **Internet Access**: Introduced in 3G, greatly improved in 4G, and became ultra-fast in 5G.
- **Multimedia Services**: Support for video calls, streaming, and high-definition media (starting from 3G).
- **IoT Connectivity**: Enhanced in 4G and 5G for machine-to-machine communication.
- **Key Aspect: Services evolve to meet user demands (e.g., faster internet, richer multimedia capabilities).**

Cellular Networks

- **Technology**
- This refers to the underlying technical frameworks and protocols that enable cellular networks to deliver services. It involves the hardware, software, and algorithms that govern communication.
- **Examples:**
- **1G Technology**: Analog signals, FDMA (Frequency Division Multiple Access).
- **2G Technology**: Digital communication, GSM (Global System for Mobile Communications), CDMA (Code Division Multiple Access).
- **3G Technology**: WCDMA (Wideband CDMA), HSPA (High-Speed Packet Access), CDMA2000.
- **4G Technology**: LTE (Long-Term Evolution), OFDMA (Orthogonal Frequency Division Multiple Access).
- **5G Technology**: NR (New Radio), Massive MIMO, mmWave.
- **Key Aspect: Technology focuses on improving spectrum efficiency, speed, and reliability.**

Cellular Networks

- **Generation**
- This refers to the evolutionary phases of cellular networks, each representing a significant leap in both services and technologies.
- **Examples:**
- **1G**: Analog voice-only services (e.g., AMPS).
- **2G**: Digital voice, SMS, and limited data (e.g., GSM, IS-95).
- **3G**: High-speed data, internet browsing, and video calls (e.g., WCDMA, HSPA).
- **4G**: Broadband internet, HD streaming, and low-latency (e.g., LTE).
- **5G**: Ultra-low latency, IoT scalability, and multi-Gbps speeds (e.g., NR).
- **Key Aspect: Generations combine new technologies and services to meet evolving needs and standards.**

Cellular Networks

- **2.5G: The Transition Between 2G and 3G**
- **Timeframe**: Late 1990s to early 2000s.
- **Purpose**: To introduce basic data services and prepare networks for 3G.
- **Technology**:
  - **GPRS (General Packet Radio Service)**:
    - A packet-switched technology layered over existing 2G networks (GSM).
    - Allowed "always-on" data connections without reserving a dedicated channel.
    - Data speeds: **~56–114 kbps** (faster than circuit-switched data in 2G).
  - **EDGE (Enhanced Data rates for GSM Evolution)** (also considered 2.75G in some contexts):
    - Enhanced GPRS with better modulation techniques (8PSK).
    - Data speeds: **up to 384 kbps**.
- **Services**:
  - Email, basic web browsing, and multimedia messaging (MMS).
  - Early mobile apps and lightweight streaming services.

Cellular Networks

- **2.75G: EDGE as an Enhanced Version of 2.5G**
- **Timeframe**: Early to mid-2000s.
- **Purpose**: To push the limits of 2G systems and extend their utility before widespread 3G adoption.
- **Technology**:
  - **EDGE** (often referred to as 2.75G):
    - Upgraded GPRS with **8PSK modulation** to increase data throughput.
    - Offered speeds close to **384 kbps** under ideal conditions, on par with early 3G.
    - Retained backward compatibility with GSM networks.
- **Services**:
  - Improved web browsing, faster email, and basic multimedia downloads.
  - Early support for mobile gaming and video streaming, though limited by speed.

Cellular Networks

- **3.5G: The Leap Before Full 4G**
- **Timeframe**: Mid-2000s to early 2010s.
- **Purpose**: To enhance 3G capabilities and meet increasing demands for mobile broadband.
- **Technology**:
  - **HSPA (High-Speed Packet Access)**:
    - Combined **HSDPA (High-Speed Downlink Packet Access)** and **HSUPA (High-Speed Uplink Packet Access)**.
    - Data speeds:
      - **HSDPA**: Up to **14.4 Mbps**.
      - **HSUPA**: Up to **5.76 Mbps**.
  - **HSPA+** (Evolved HSPA):
    - Advanced version of HSPA using techniques like MIMO and higher-order modulation (64-QAM).
    - Data speeds: Up to **42 Mbps** in the downlink.
- **Services**:
  - Full-featured web browsing, HD video streaming, and real-time gaming.
  - Better support for applications requiring low latency and high-speed data, such as VoIP and video conferencing.

Cellular Networks

- 2.5G: Introduced packet-switched data to GSM, allowing basic internet and MMS.
- 2.75G: Further optimized GSM networks with EDGE, bringing near-3G speeds.

- 3.5G: Enhanced 3G with HSPA technologies, paving the way for mobile broadband and rich media applications.

Cellular Networks

Feature	2.5G (GPRS)	2.75G (EDGE)	3.5G (HSPA/HSPA+)
Data Speed	~56–114 kbps	Up to 384 kbps	14.4 Mbps (HSDPA), up to 42 Mbps (HSPA+)
Technology	GPRS (packet-switched)	EDGE (8PSK modulation)	HSPA, HSPA+ (MIMO, QAM)
Services	Email, MMS, light web	Faster web, multimedia	HD streaming, VoIP, gaming
Efficiency	Moderate	High	Very High
Latency	~500 ms	~250 ms	~100 ms or lower
Application	Text and low data	Early apps, basic media	Real-time apps, rich media

Cellular Networks

- 4G represents a major forward in mobile communication technology, offering **high-speed broadband internet**, low latency, and improved spectral efficiency.
- It was designed to support a wide range of modern applications, from high-definition video streaming to IoT devices, while meeting the demand for faster and more reliable mobile internet.

Cellular Networks

- **Key Features of 4G**

1. **High Data Rates**:
    1. **Peak Speeds**: Up to **1 Gbps** for stationary users and **100 Mbps** for mobile users.
    2. **Average Speeds**: Real-world implementations offer **~10–50 Mbps** for most users.
2. **All-IP Network**:
    1. Based entirely on **Internet Protocol (IP)**, replacing circuit-switched systems.
    2. Supports both data and voice through technologies like **Voice over LTE (VoLTE)**.
3. **Low Latency**:
    1. Typically under **50 ms**, enabling real-time applications like online gaming, video conferencing, and IoT communication.
4. **OFDM and MIMO Technology**:
    1. **Orthogonal Frequency Division Multiplexing (OFDM)** improves spectral efficiency by splitting the signal into multiple subcarriers.
    2. **Multiple Input Multiple Output (MIMO)** uses multiple antennas to boost speed and reliability.
5. **Global Standardization**:
    1. Based on **LTE (Long-Term Evolution)** and **WiMAX** technologies.

Cellular Networks

- **Core Technologies in 4G**

1.LTE (Long-Term Evolution):

1. The most widely deployed 4G standard.
2. Offers high-speed data transmission, low latency, and high spectral efficiency.

2.LTE-Advanced:

1. An enhancement of LTE, supporting speeds up to **3 Gbps**.
2. Introduces carrier aggregation, allowing multiple frequency bands to be used simultaneously.

3.IPv6 Support:

1. Ensures scalability for billions of connected devices in IoT networks.

Cellular Networks

- **Services Enabled by 4G**

1.High-Definition Video Streaming:

1. Supports platforms like YouTube, Netflix, and video-on-demand services.

2.Online Gaming:

1. Low latency ensures a smooth gaming experience.

3.VoLTE (Voice over LTE):

1. High-quality voice calls over IP, with faster call setup times and simultaneous voice/data transmission.

4.IoT Applications:

1. Enables smart home devices, industrial IoT, and connected vehicles.

5.Mobile Broadband:

1. Provides a broadband experience for mobile users, replacing traditional fixed-line broadband in many cases.

Cellular Networks

- **Advantages of 4G**

1.Faster Data Speeds:

1. Seamless streaming, faster downloads/uploads, and enhanced user experience.

2.Lower Latency:

1. Essential for real-time applications like gaming and video calls.

3.Improved Capacity:

1. Handles more simultaneous users, reducing congestion.

4.Global Compatibility:

1. A single, standardized system adopted worldwide.

Cellular Networks

- **Challenges and Limitations of 4G**

1.Infrastructure Costs:

1. Requires extensive upgrades to network infrastructure.

2.Device Compatibility:

1. Older devices are incompatible with 4G, necessitating new hardware.

3.Battery Drain:

1. High-speed data usage can lead to increased power consumption in devices.

4.Coverage Gaps:

1. Limited reach in rural and remote areas compared to 3G networks.

Cellular Networks

- **5G** is the latest generation of mobile networks, offering unparalleled speed, ultra-low latency, and massive connectivity.
- It builds on the foundation of 4G while introducing new technologies to meet the demands of modern digital ecosystems, such as IoT, smart cities, and real-time communications.

Cellular Networks

- **Key Features of 5G**

1. **Extreme Data Speeds**:
    1. **Peak Speeds**: Up to **10 Gbps**, enabling lightning-fast downloads/uploads.
    2. **Average Speeds**: Typically **100 Mbps–1 Gbps** in real-world scenarios.
2. **Ultra-Low Latency**:
    1. Latency as low as **1 ms**, essential for real-time applications like autonomous vehicles, remote surgery, and online gaming.
3. **Massive Connectivity**:
    1. Supports up to **1 million devices per square kilometer**, crucial for IoT and smart cities.
4. **Improved Energy Efficiency**:
    1. Designed to consume less energy per transmitted bit, extending battery life for IoT devices and smartphones.
5. **Flexible Spectrum Usage**:
    1. Operates across three key frequency bands:
        1. **Low-band (<1 GHz)**: Long-range coverage, ideal for rural areas.
        2. **Mid-band (1–6 GHz)**: Balanced speed and coverage, widely used in urban areas.
        3. **High-band (>24 GHz, mmWave)**: Ultra-fast speeds for dense urban environments, but with limited range.
6. **Network Slicing**:
    1. Allows the creation of virtual networks optimized for specific applications, such as gaming, healthcare, or industrial automation.
7. **Edge Computing**:
    1. Reduces latency by processing data closer to the user rather than relying on distant data centers.

Cellular Networks

- **Core Technologies in 5G**

1.Massive MIMO (Multiple Input Multiple Output):

1. Uses arrays of antennas to enhance network capacity and coverage.

2.Beamforming:

1. Directs signals towards specific users, improving efficiency and reducing interference.

3.Orthogonal Frequency Division Multiplexing (OFDM):

1. Builds on 4G's OFDM but optimized for higher frequencies and better spectral efficiency.

4.New Radio (NR):

1. The standardized air interface for 5G, offering enhanced modulation and coding schemes.

5.Millimeter Waves (mmWave):

1. Utilizes high-frequency bands (>24 GHz) for ultra-fast data transmission over short distances.

Cellular Networks

- **Services and Applications Enabled by 5G**

1.Enhanced Mobile Broadband (eMBB):

1. Supports HD streaming, AR/VR, and cloud-based gaming with ultra-fast speeds.

2.Massive Machine-Type Communications (mMTC):

1. Connects billions of IoT devices, from smart appliances to industrial sensors.

3.Ultra-Reliable Low-Latency Communications (URLLC):

1. Enables critical applications like autonomous vehicles, remote surgery, and smart grid management.

4.Fixed Wireless Access (FWA):

1. Provides high-speed internet in areas lacking traditional broadband infrastructure.

Cellular Networks

- **Advantages of 5G**

1. **Speed**: Up to 100 times faster than 4G.
2. **Capacity**: Can handle exponentially more devices and data traffic.
3. **Latency**: Virtually eliminates delays, enabling real-time applications.
4. **Efficiency**: Supports sustainable network growth with reduced energy consumption.
5. **Flexibility**: Network slicing and edge computing make 5G adaptable to diverse industries.

Cellular Networks

- 6G is the next evolution in wireless communication, currently under development, with expectations for deployment around **2030**.
- It aims to go beyond 5G by delivering **terahertz-level frequencies**, unprecedented speeds, and advanced AI integration, revolutionizing industries and enabling futuristic technologies.

Cellular Networks