Chapter-3: Introduction to Cellular Mobile Systems

Spectrum Allocation

What is Spectrum?

- Spectrum refers to the range of electromagnetic frequencies used for wireless communication.
- Cellular systems primarily operate in 300 MHz to 3 GHz band.
- Wireless communication requires licensed frequency bands to prevent interference.

Frequency Spectrum for Cellular Services

Generation	Frequency Band (Typical)	Notes
1G	800 MHz	Analog
2G	900 MHz / 1800 MHz	GSM, CDMA
3G	2.1 GHz	UMTS, CDMA2000
4G	700 MHz – 2.6 GHz	LTE
5G	600 MHz – 6 GHz (Sub-6), 24–39 GHz (mmWave)	Enhanced throughput

Spectrum Allocation Entities

- ITU (International Telecommunication Union)
  Divides global spectrum into Region 1, 2, 3
- National Authorities (e.g., FCC in US, NTA in Nepal) allocate spectrum locally
- Licensing Models:
  - Auction (highest bidder)
  - Administrative (by policy)
  - Unlicensed (e.g., Wi-Fi, Bluetooth)

Licensed vs Unlicensed Spectrum

Type	Examples	Use Case
Licensed	Cellular (e.g. 900 MHz)	Mobile Operators
Unlicensed	Wi-Fi (2.4 GHz, 5 GHz)	Consumer wireless devices

- Licensed spectrum ensures quality, QoS, and no interference

Numerical Example – Frequency Allocation

- If a cellular operator is allocated 25 MHz, and each channel occupies 200 kHz, how many voice channels can the operator support?

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Solution:

$$25\ \text{MHz}/200\ \text{kHz} = 25\times10^{6}/200\times10^{3}$$
$$= 125\ \text{channels}$$

Challenges in Spectrum Allocation

- Limited spectrum → increasing demand
- Avoiding cross-border interference
- Balancing uplink vs downlink
- Spectrum fragmentation
- Fair allocation in densely populated areas

Basic Cellular Systems

What is a Cellular System?

- A system that divides the coverage area into smaller areas called cells
- Each cell has a base station that communicates with mobile users
- Enables frequency reuse and scalability
- Fundamental goal: increase user capacity and spectral efficiency.

Components of a Cellular System

- Mobile Station (MS) – Handset/Device
- Base Station (BS) – Antenna + Radio Equipment
- Mobile Switching Center (MSC) /(Mobile Telephone Switching Office) MTSO) – Routing, call switching, handoffs
- Public Switched Telephone Network (PSTN) – External phone network

Cellular Telephone Systems

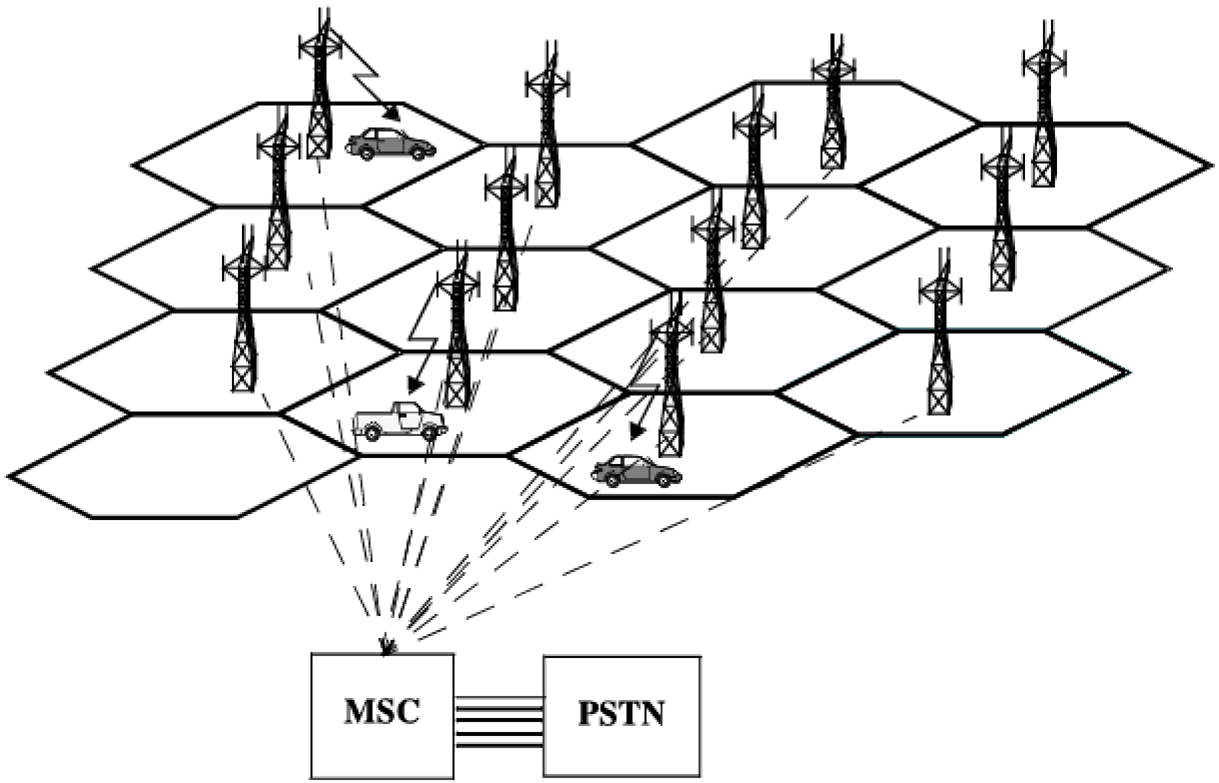


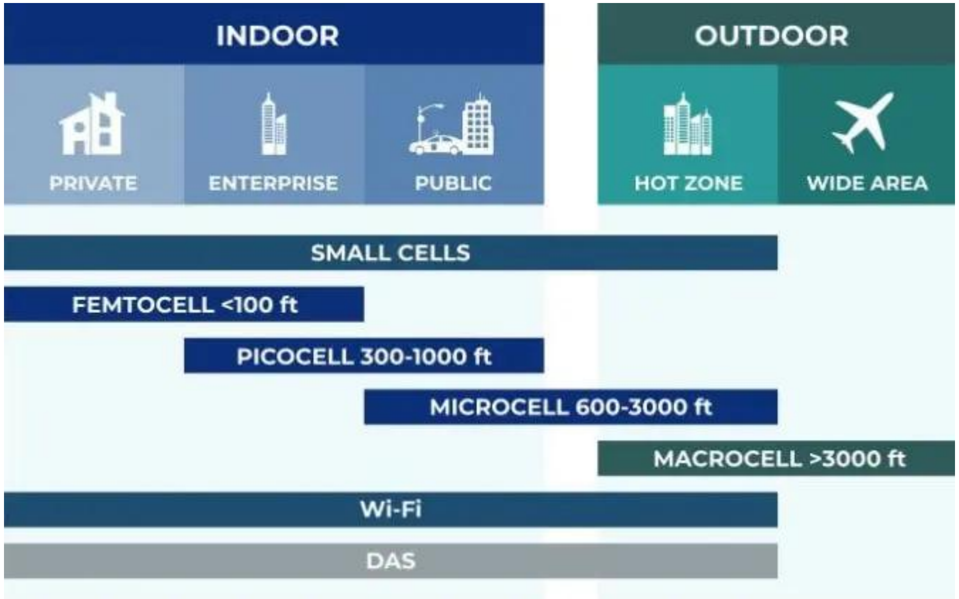
Figure 1.5 A cellular system. The towers represent base stations which provide radio access between mobile users and the mobile switching center (MSC).

How a Call is Placed

- MS sends call request to BS
- BS forwards to MSC
- MSC routes to destination via PSTN or another BS
- Call is established and maintained by MSC
- Handover managed if user moves

Cell Structure & Shape

- Ideally hexagonal to simplify frequency reuse
- Real-world cells are irregular due to terrain/buildings
- **Cell Radius:** Typically, 1–30 km depending on power & environment
- **Microcell (Small cell)**, **Macrocell (Cell tower)**, **Pico/Femtocell (Small cell)** used in different settings

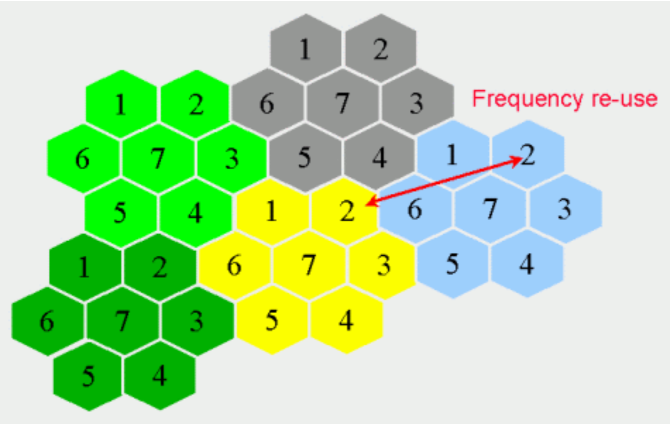


Cell Structure & Shape

Small Cells	Macrocell	Microcell	Picocell	Femtocell
Location	Rural & highways	Outdoors (Dense urban areas)	Indoors (large areas: Malls, airports)	Indoors (small areas: Home, Small Offices)
Range	1-20 km	500m – 2 km	< 200m	< 10m
Users	More than 2,000	100 to 2,000	30 to 100	1 to 32
Power	20-40 W	~ 2 W	< 200 mW	~ 100 mW

Frequency Reuse Concept

- Each cell uses a subset of total frequencies
- Nearby cells use different frequencies to avoid interference
- Reuse improves capacity without needing more spectrum



Numerical Example – Frequency Reuse

Given:

- Total available channels = 280
- Reuse factor N=7

Channels per cell=280/7

=40 channels

Each cell can support **40 simultaneous calls**.

Functions of the Base Station (BS)

The Base Station (BS) plays a crucial role in:

- Transmitting and receiving signals from Mobile Stations
- Power control and channel assignment
- Monitoring signal strength for initiating handoffs
- Communicating with the Mobile Switching Center (MSC)

BS includes antennas, transceivers, and base station controllers (BSCs)

Mobile Switching Center (MSC)

MSC is the central controller of the cellular system. It handles:

- Call setup, routing, and teardown
- Authentication & billing
- Handoff management
- Interfacing with PSTN or other MSCs

Think of the MSC as the "brain" of the cellular network.

What is a Handoff (Handover)?

As a user moves from one cell to another, the ongoing call must be transferred to a new base station — this is called a handoff.

Two Types:

- Hard Handoff: Break-before-make (e.g., GSM)
- Soft Handoff: Make-before-break (e.g., CDMA)

Objective: Ensure call continuity without dropping

Challenges in Cellular System Design

- Interference (co-channel and adjacent channel)
- Power control
- Efficient frequency reuse
- Handoff delays and failures
- High user density in urban areas
- Coverage holes due to terrain or obstacles

Advantages of Cellular Systems

- Supports large number of users
- Efficient spectrum utilization
- Scalable by adding more cells
- Enables mobility and handoffs

Performance Criteria

What are Performance Criteria?

Performance criteria are quantitative measures used to evaluate the effectiveness, quality, and efficiency of a cellular system. They help assess:

- Call quality
- Network reliability
- User satisfaction
- System capacity

Key Performance Criteria Overview

1. Coverage
2. Capacity
3. Quality of Service (QoS)
4. Grade of Service (GoS)
5. Signal-to-Interference Ratio (SIR)
6. Call Blocking & Dropping Probability
7. Handoff Success Rate
8. Spectral Efficiency

Performance Criteria: **Coverage**

Coverage defines the geographical area where service is available. Depends on:

- Transmit power
- Antenna height and gain
- Path loss and shadowing
- Cell radius

Poor coverage leads to call drops and user dissatisfaction.

Performance Criteria: **Capacity**

Capacity refers to the maximum number of users or calls the system can handle simultaneously. Influenced by:

- Frequency reuse
- Bandwidth
- Multiple access technique (FDMA/TDMA/CDMA)
- Number of channels per cell

Performance Criteria: **Quality of Service (QoS)**

QoS defines how well a mobile service meets user expectations. Includes:

- Voice clarity
- Low latency
- Minimal call drops
- Fast handoffs

Often measured using Mean Opinion Score (MOS) or delay/jitter metrics in data services.

Performance Criteria: **Grade of Service (GoS)**

GoS is the probability that a call is blocked due to lack of available resources.

- Measured during peak hours.

$$Gos = \frac{Blocked\ Calls}{Total\ Call\ Attempts}$$

- A typical acceptable GoS is 2% (i.e., 2 in 100 calls blocked).

Performance Criteria: **Signal-to-Interference Ratio (SIR)**

SIR is the ratio of desired signal power to interference power from other users.

$$SIR = \frac{S}{I}$$

$$SIR(dB) = 10\, log_{10}\left(\frac{P_{\ signal}}{P_{\ interference}}\right)$$

Where:

- S: Signal from serving base station
- I: Sum of interfering signals

Threshold SIR values:

- Voice (analog): ~18 dB
- Data (digital): ~9–15 dB

Performance Criteria: **Call Blocking and Dropping**

- **Call Blocking**: User tries to initiate a call, but no channel is available
- **Call Dropping**: Ongoing call is terminated abruptly, often during handoff failure or signal loss

Both directly impact user satisfaction and network efficiency

Performance Criteria: **Handoff Success Rate**

A key metric that measures:

- Seamless transition between cells
- Low call-drop probability during user movement

Affected by:

- Network planning
- Signal strength thresholds
- Decision algorithms

Performance Criteria: **Spectral Efficiency**

- Spectral Efficiency measures how efficiently the spectrum is used:

$$\text{Spectral Efficiency} = \frac{bits/sec}{Hz/cell}$$

- Higher spectral efficiency = More data transferred per unit bandwidth
- CDMA and OFDMA-based systems typically offer higher efficiency

Real-World Trade-offs

Goal	Conflict
Higher capacity	May reduce QoS if interference rises
Broad coverage	May increase call blocking due to limited channels
Low GoS	Requires more infrastructure

Operation of Cellular Systems

Call Flow in a Cellular Network

Call Setup Process

- User dials a number
- Mobile Station (MS) sends call request to the Base Station (BS)
- BS forwards the request to the Mobile Switching Center (MSC)
- MSC checks subscriber info via HLR/VLR
- If validated, MSC routes call to:
  - Another mobile (via BS)
  - PSTN (landline)
- BS allocates frequency channel for voice
- Call is connected and monitored

Location Tracking & Updates

The network must always know the approximate location of the mobile user.

- **HLR (Home Location Register)**: Central DB for user data
- **VLR (Visitor Location Register)**: Temporary DB near user's current area

When user moves:

- **Location update** is triggered
- **VLR and MSC** update user’s location in the HLR

Mobility Management

Role of MSC in Mobility

- MSC coordinates:
- Location updates
- Handoff (handover) initiation
- Roaming across networks
- Billing and user authentication

Types of Handoff

When a mobile moves from one cell to another:

- **Hard Handoff**: Old connection is broken before new one is made (used in GSM)
- **Soft Handoff**: New connection established before old one is released (used in CDMA)

Smooth handoff is critical to avoid dropped calls and ensure continuous service

Control vs. Traffic Channels

Types of Channels in Cellular Systems

Channel Type	Description
Control Channels	Used for setup, paging, access (non-voice)
Traffic Channels	Carry actual user data (voice, SMS, data)

Paging and Access

When someone calls you:

- The system pages your mobile via control channels
- Your device responds on the random access channel (RACH)
- After authentication, a traffic channel is allocated

Frequency Reuse and Interference Handling

Frequency Reuse in Operation

- Cells use reuse patterns (e.g., N = 7)
- Reused frequencies must be sufficiently spaced apart to avoid interference
- Base station power, antenna orientation, and terrain help isolate reused frequencies

Co-Channel and Adjacent Channel Interference

Interference Type	Cause	Solution
Co-channel	Same frequency in different cells	Increase cell separation
Adjacent-channel	Imperfect filtering, overlapping bands	Use guard bands & filters

Analog Cellular System

What is an Analog Cellular System?

- Analog cellular systems were the first generation (1G) mobile systems.
- Based on Frequency Modulation (FM) of voice signals
- Used Frequency Division Multiple Access (FDMA) for channel allocation
- No encryption or digital compression

Characteristics of 1G Analog Systems

Feature	Value
Standard	AMPS (Advanced Mobile Phone System)
Year Introduced	1983 (U.S.)
Frequency Band	800 MHz
Bandwidth per Channel	30 kHz
Access Technique	FDMA
Data Capability	None (Voice only)
Security	Low (easily intercepted)

System Architecture

Components:

- **Mobile Station (MS)** – Analog handset
- **Base Station (BS)** – Handles radio communication
- **Mobile Switching Center (MSC)** – Manages call switching
- **PSTN Interface** – Connects to landlines

Frequency Reuse in AMPS

The 800 MHz band was divided into 416 channels of 30 kHz each.

- Each cellular area was divided into **hexagonal cells**
- Frequencies were **reused** at distant cells using reuse patterns like N = 7

Call Flow in AMPS

- User initiates a call
- Base station allocates a voice channel
- Voice signal is frequency modulated (FM)
- MSC routes the call to PSTN or another BS
- Call continues until terminated or handed over

Advantages of Analog Systems

- Simple hardware design
- Good voice quality in clear signal areas
- Easy deployment and widespread initial adoption
- Enabled mobile freedom for first time

Limitations of Analog Cellular Systems

- No data support
- Susceptible to eavesdropping (no encryption)
- Poor spectral efficiency (FDMA)
- Limited capacity and scalability
- High power consumption

Analog to Digital Transition

Why analog became obsolete:

- Increased user base required better spectral efficiency
- Need for data services and SMS
- Security concerns over analog interception
- Led to 2G systems like GSM (TDMA) and IS-95 (CDMA)

Digital Cellular Systems

What are Digital Cellular Systems?

Digital cellular systems digitize voice and data for transmission.

- Use digital modulation instead of analog FM
- Support both voice and data communication
- Enable encryption, compression, and error correction

Core innovation for 2G, 3G, and beyond

Why Digital?

Limitations of analog systems:

- Poor capacity
- Lack of encryption
- No support for text/data

Digital cellular systems solve these by:

- Efficient spectrum use
- Supporting SMS and internet
- Enhancing voice quality and security

Key Features of Digital Systems

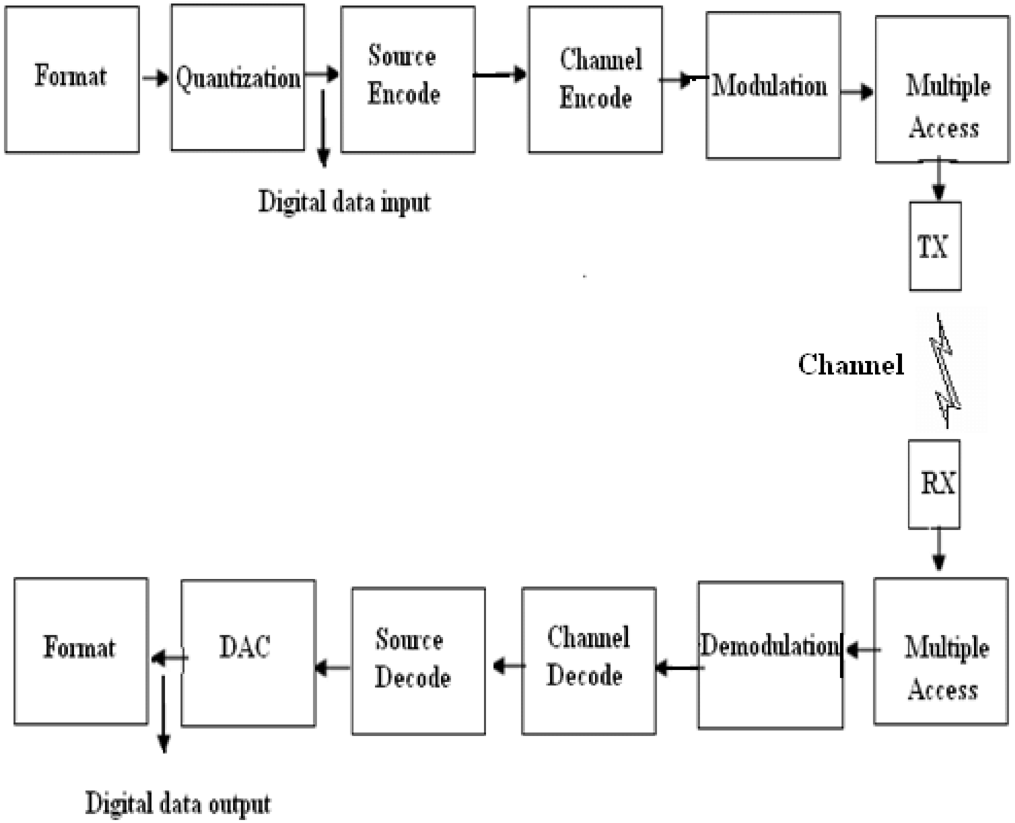
Feature	Benefit
Digital Voice Coding	Efficient compression (e.g., LPC, CELP)
Modulation Techniques	QPSK, GMSK, π/4 DQPSK
Multiple Access	TDMA, CDMA, OFDMA
Channel Coding	Error detection and correction
Encryption	Secure communication
Support for Data	SMS, MMS, Internet, IoT

Major 2G Digital Standards

Standard	Region	Access Method	Carrier
GSM	Europe/World	TDMA	200 kHz
IS-136	USA	TDMA	30 kHz
IS-95	USA/Asia	CDMA	1.25 MHz

Block Diagram of a Digital Cellular System

- Source Encoder (digitizes speech)
- Channel Encoder (adds error correction)
- Modulator (digital modulation like QPSK)
- Transmitter → Air Interface → Receiver
- Demodulation and Decoding at receiver end



Multiple Access in Digital Systems

Technique	Used In	Description
TDMA	GSM	Time slots in a channel
CDMA	IS-95	Code-based separation
OFDMA	LTE	Multiple subcarriers

Capacity Improvement Over Analog

- In digital systems:
- Multiple users per frequency channel (TDMA/CDMA)
- Lower bandwidth per user
- Higher call volume support

Example Calculation (TDMA-GSM):

If GSM uses 200 kHz per carrier, and each carrier supports 8 users:

- In 5 MHz → 5 MHz/200 kHz = 25 carriers
- Total users = 25×8 = 200 simultaneous users

Digital System Advantages

- Improved capacity and spectral efficiency
- Encryption for secure calls
- Support for data (SMS, GPRS, EDGE)
- Lower transmission power → longer battery life
- Error correction improves call clarity

Limitations & Challenges

- Initial rollout was expensive.
- Requires higher synchronization.
- Latency can affect voice in poor signal zones.
- Interference management is complex.

Transition to 2.5G and 3G

Digital systems laid the base for:

- 2.5G: GPRS and EDGE for data packets
- 3G: WCDMA/CDMA2000 with faster internet
- 4G/5G: All-IP digital networks

Chapter 3 Completed