WIRELESS & MOBILE COMMUNICATION

Diploma in Electronics & Communication Engineering

NAME OF FACULTY : MRS. ANSHU BHALLA **SEMESTER : 5th**

TABLE OF CONTENTS / SYLLABUS MAP

Course outcomes covered	Simple meaning
CO1	Understand basics of mobile and wireless communication.
CO2	Study channel interference and control methods.
CO3	Describe FDMA, TDMA, CDMA, WCDMA and OFDMA.
CO4	Define GSM, GPRS, EDGE, Bluetooth, Wi-Fi, UMTS, LTE and 5G systems.
CO5	Compare 3G, 4G and 5G systems in a simple way.

SYLLABUS COVERAGE CHECKLIST

Unit	Topics covered in these notes
Unit I	Basics, advantages, electromagnetic waves, frequency spectrum, cellular network systems, propagation range and fading.
Unit II	2G, cell area, cell site, capacity, frequency reuse, co-channel/adjacent interference, power control, cell splitting and sectoring.
Unit III	Multiple access, FDMA, TDMA, CDMA, WCDMA and OFDMA.
Unit IV	GSM architecture, GPRS, EDGE, Bluetooth and Wi-Fi.
Unit V	UMTS, LTE, 5G NR and comparison of 4G with 5G.

UNIT I - WIRELESS COMMUNICATION

Topic no.	Syllabus topic
1.1	Basics
1.2	Advantages of wireless communication
1.3	Electromagnetic waves
1.4	Frequency spectrum used
1.5	Cellular network systems
1.6	Propagation considerations - range and fading

1.1 Basics of Wireless Communication

Definition: Wireless communication is the transfer of information from one point to another without using a physical wire. The information is carried by electromagnetic waves through air or free space.

Simple idea: A transmitter changes voice/data into a radio signal, the antenna radiates it, and the receiver converts it back into useful information.

- Message signal: original information such as voice, video, text or sensor data.
- Transmitter: converts the message into a high-frequency radio signal and amplifies it.
- Antenna: converts electrical signal into electromagnetic wave and vice versa.
- Channel: the path through which the radio wave travels. In wireless systems, the channel is usually air.
- Receiver: selects the desired signal, removes unwanted noise, demodulates it and gives output.

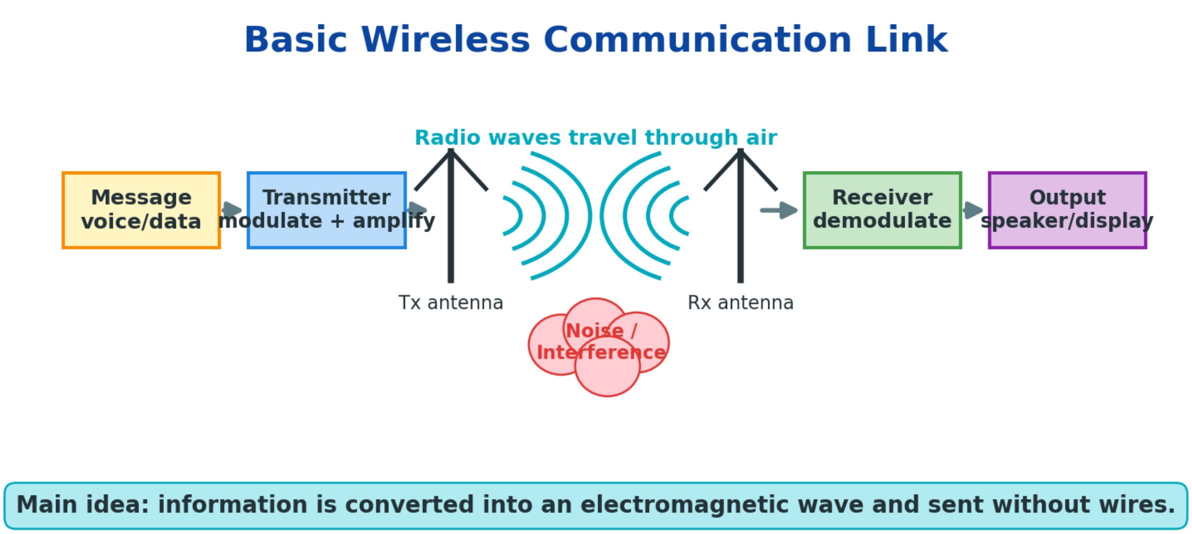

Fig. 1.1 Basic wireless communication link

Example: When you speak on a mobile phone, your voice is converted into digital data, sent as a radio signal to the nearest tower, transferred through the mobile network, and finally received by the other phone.

Exam tip: In exams, write the block diagram first and then explain each block in one or two lines.

Term	Easy meaning
RF	Radio frequency signal used for wireless transmission.
Channel	Medium or path between transmitter and receiver.
Bandwidth	Range of frequencies occupied by a signal.
Antenna	Device that radiates or receives electromagnetic waves.

1.2 Advantages of Wireless Communication

Meaning: Wireless communication became popular because it gives communication without laying cables everywhere. It is useful for mobile users, remote places and temporary networks.

- Mobility: user can move while communicating. Example: mobile phone call while travelling.
- Quick installation: no need to lay long cables. Example: setting up Wi-Fi in a classroom.
- Useful in remote areas: wireless links can connect villages, hills, ships and moving vehicles.
- Scalability: new users can be added by adding radio resources or access points.
- Emergency communication: useful during floods, earthquakes and rescue operations when cables are damaged.
- Supports modern applications: mobile internet, GPS tracking, Bluetooth audio, smart meters and IoT sensors.

Advantage	Easy example
Mobility	A student can access the internet while moving inside campus.
Low cabling cost	A Wi-Fi router avoids LAN cables to every room.
Fast deployment	Temporary wireless cameras can be installed for an event.
Communication anywhere	Mobile networks connect a person travelling in a bus or train.

Remember: Wireless is convenient, but it also needs careful control of spectrum, interference, power and security.

1.3 Electromagnetic Waves

Definition: An electromagnetic wave is a wave made of electric field and magnetic field. These fields are perpendicular to each other and travel through free space with the speed of light.

Formula / Key point: $c = f \times \lambda$, where c = speed of light, f = frequency, and λ = wavelength. If frequency increases, wavelength decreases.

- Radio waves, microwaves, infrared, visible light and X-rays are all electromagnetic waves.
- Wireless communication mainly uses radio waves and microwaves.
- Lower frequencies usually travel farther and penetrate obstacles better.
- Higher frequencies can carry more data, but they normally have shorter range and need more cells.

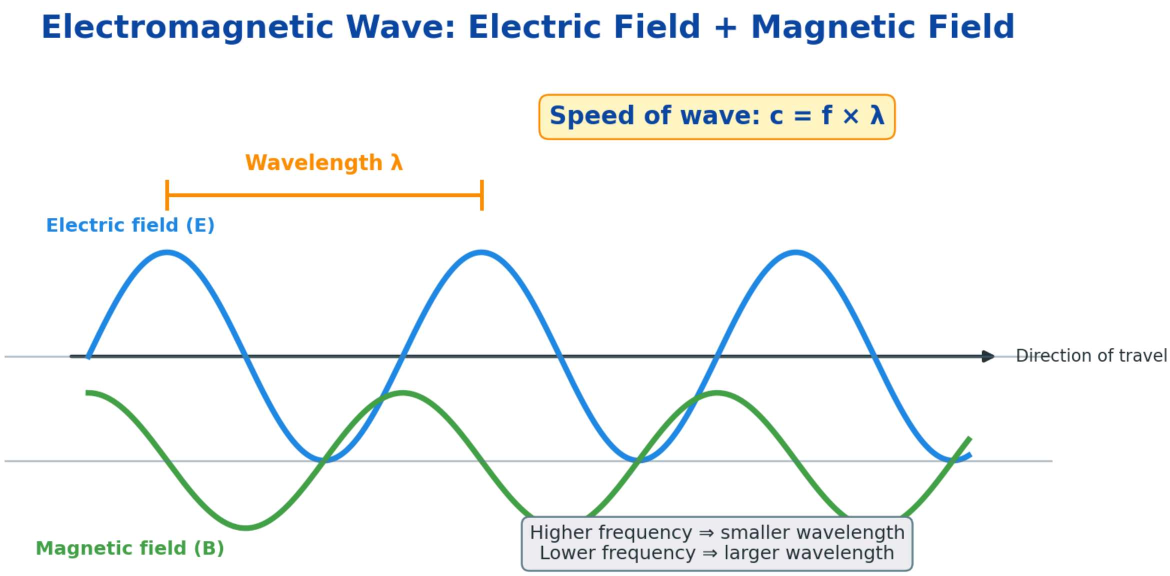

Fig. 1.2 Electromagnetic wave and wavelength λ

Example: A 900 MHz mobile signal has a longer wavelength than a 2.4 GHz Wi-Fi signal. Therefore 900 MHz generally gives better coverage, while 2.4 GHz/5 GHz Wi-Fi provides higher data rate in a shorter range.

1.4 Frequency Spectrum Used

Meaning: Frequency spectrum is the complete range of electromagnetic frequencies. Wireless systems use selected portions of this spectrum according to government rules and technical requirements.

- Licensed spectrum: used by mobile operators. Users cannot transmit freely in these bands.
- Unlicensed spectrum: can be used by devices like Wi-Fi and Bluetooth, but power limits and rules must be followed.
- Channel: a small part of spectrum assigned for communication.
- Guard band: unused frequency space between channels to reduce adjacent channel interference.

Frequency Spectrum Used in Wireless Communication

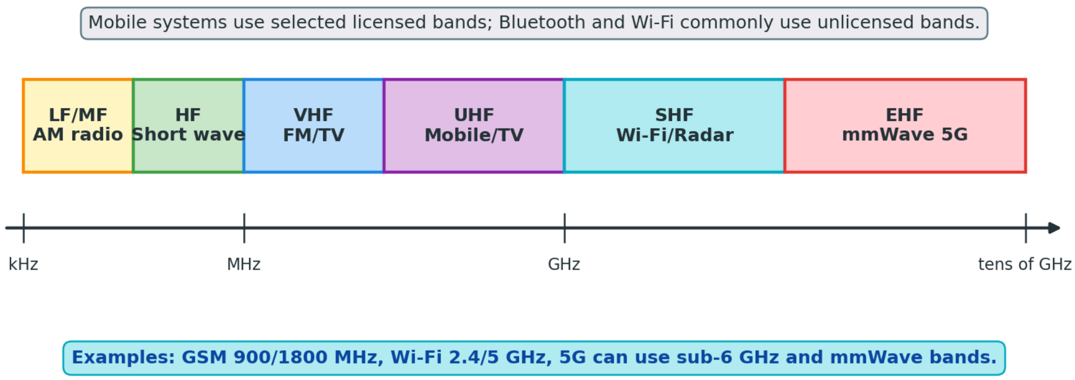

Fig. 1.3 Spectrum examples used in wireless systems

Band / system	Common use	Important point
MF/HF	AM radio, short-wave links	Longer range, lower data rate.
VHF	FM radio, TV, some radio services	Good outdoor coverage.
UHF	Mobile communication, TV, some wireless microphones	Important for cellular networks.
SHF	Wi-Fi, microwave links, radar, satellite	High capacity, shorter range.
EHF / mmWave	Some 5G high-capacity cells	Very high data rate, small coverage area.

Exam tip: For diploma exams, remember: mobile, Wi-Fi and Bluetooth mostly use radio/microwave frequency ranges, not visible light.

1.5 Cellular Network Systems

Definition: A cellular network divides a large service area into many smaller areas called cells. Each cell is served by a base station.

- A mobile phone connects to the nearest or strongest base station.
- When a user moves from one cell to another, the connection is transferred by handover.
- The same frequencies can be reused in far-away cells to increase capacity.
- The core network connects calls/data to other mobile users, landline networks and the internet.

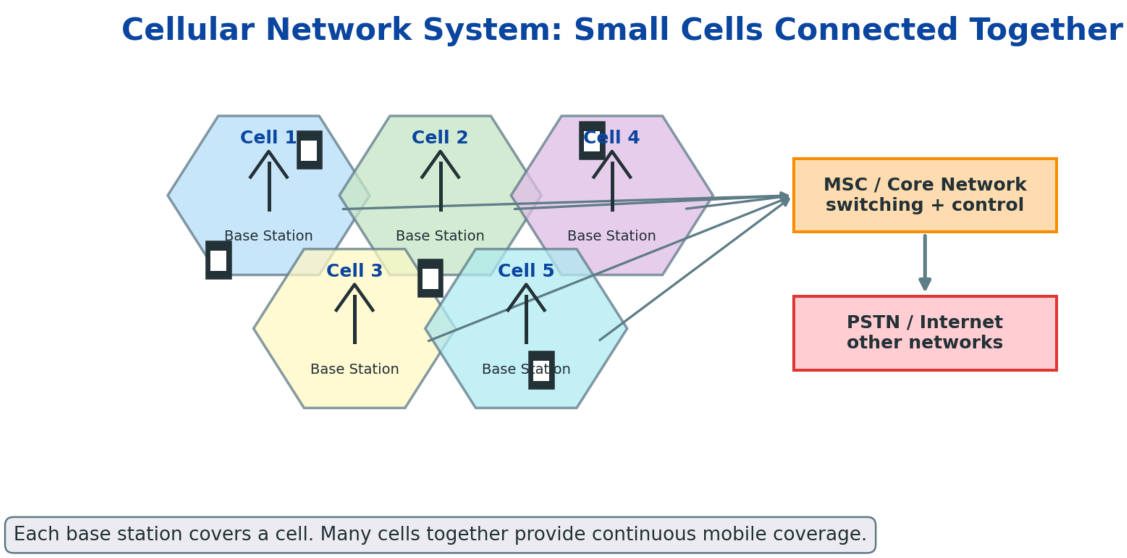

Fig. 1.4 Cellular network with cells, base stations and core network

Example: In a city, hundreds of small cells may be used. Each tower covers nearby users, and all towers are connected to the operator core network.

Key idea: Cellular design solves two big problems: coverage over a large area and capacity for many users.

1.6 Propagation Considerations - Range and Fading

Propagation: Propagation means the way in which a radio signal travels from transmitter to receiver.

Range: Range is the maximum distance up to which communication remains reliable. It depends on transmit power, antenna height, frequency, receiver sensitivity, terrain and obstacles.

Fading: Fading is the variation of received signal strength with time or position. It occurs mainly because signals reach the receiver through many paths.

- Path loss: signal power reduces as distance increases.
- Shadowing: large obstacles such as buildings or hills block the signal.
- Multipath: signal reaches by reflection, diffraction and scattering.
- Fast fading: rapid signal variation due to multipath and movement.
- Slow fading: slower variation due to obstacles or change in terrain.

Propagation Considerations: Range, Obstacles and Fading

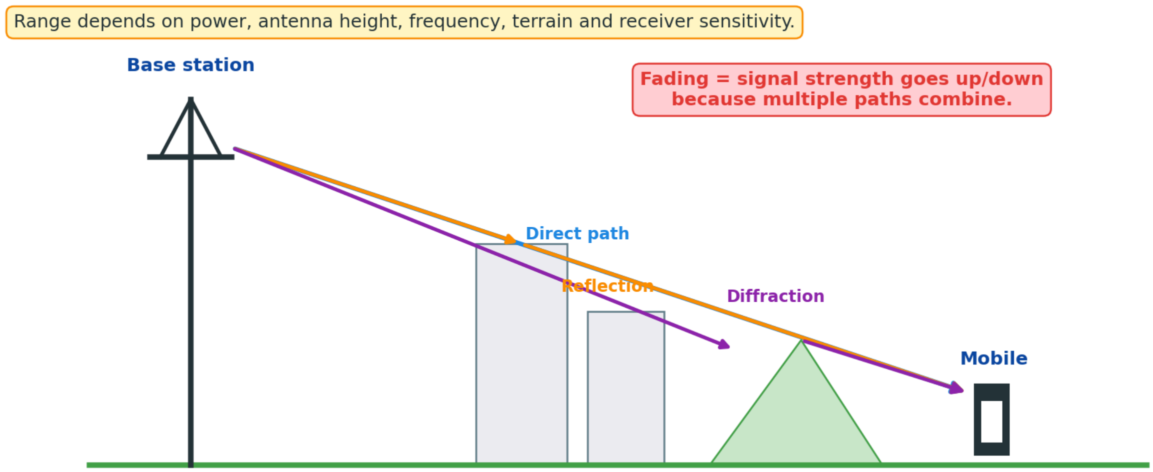

Fig. 1.5 Direct, reflected and diffracted paths causing fading

How engineers reduce fading: Use proper cell planning, antenna diversity, equalization, power control, error correction and handover.

UNIT II - CELLULAR CONCEPT

Topic no.	Syllabus topic
2.1	Introduction to 2G
2.2	Cell area
2.3	Cell site structure
2.4	Capacity of cell
2.5	Concept of frequency reuse
2.6	Co-channel and adjacent channel interference
2.7	Power control for reducing interference
2.8	Fundamentals of cell splitting and sectoring

2.1 Introduction to 2G

Definition: 2G means second generation mobile communication. It replaced 1G analog systems with digital communication.

- 2G made mobile voice communication clearer and more secure than 1G.
- It introduced services such as SMS and basic data services.
- Common 2G technologies include GSM and CDMA-based systems.
- GSM became a very widely used 2G system because it supported SIM cards, roaming and SMS.

Feature	2G simple meaning
Digital voice	Voice is converted into digital bits before transmission.
SMS	Short text message service became widely available.
Better capacity	More users could be served than old analog systems.
Security	Authentication and encryption became possible.

Example: An old GSM phone used for voice calls and SMS is a simple example of a 2G mobile system.

Exam tip: Write that 2G is digital, supports voice + SMS, and uses cellular architecture.

2.2 Cell Area

Definition: Cell area is the geographical area covered by one base station. Inside this area, mobile users can connect to that base station.

- The actual cell shape is irregular because of buildings, hills and signal reflections.
- For study and planning, a hexagon is used because hexagons cover a plane without gaps or overlaps.
- Cell radius R is the distance from the base station to the cell boundary in the planning model.
- Large cells are used in rural areas; small cells are used in busy city areas.

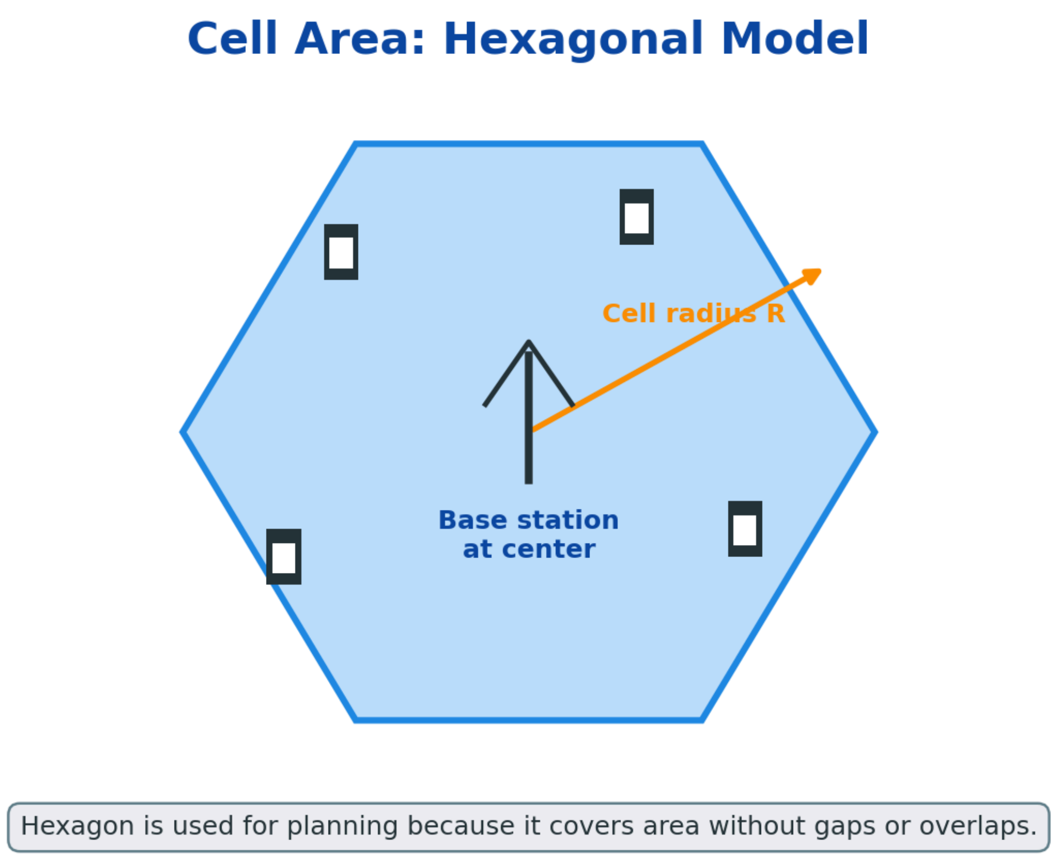

Fig. 2.1 Hexagonal model of cell area

Example: A village may be covered by one large macrocell, while a shopping mall may need several small cells or indoor access points.

2.3 Cell Site Structure

Definition: A cell site is the physical location where the base station equipment is installed. It provides radio coverage to a cell or a sector of a cell.

- Antenna system: radiates and receives RF signals.
- BTS/radio equipment: contains transceivers, filters and signal processing units.
- Power supply and battery backup: keep the site running during power failure.
- Backhaul link: connects the cell site to BSC/MSC/core network using fiber, microwave or other link.
- Tower/mast/building mount: gives antenna height for better coverage.

Cell Site Structure

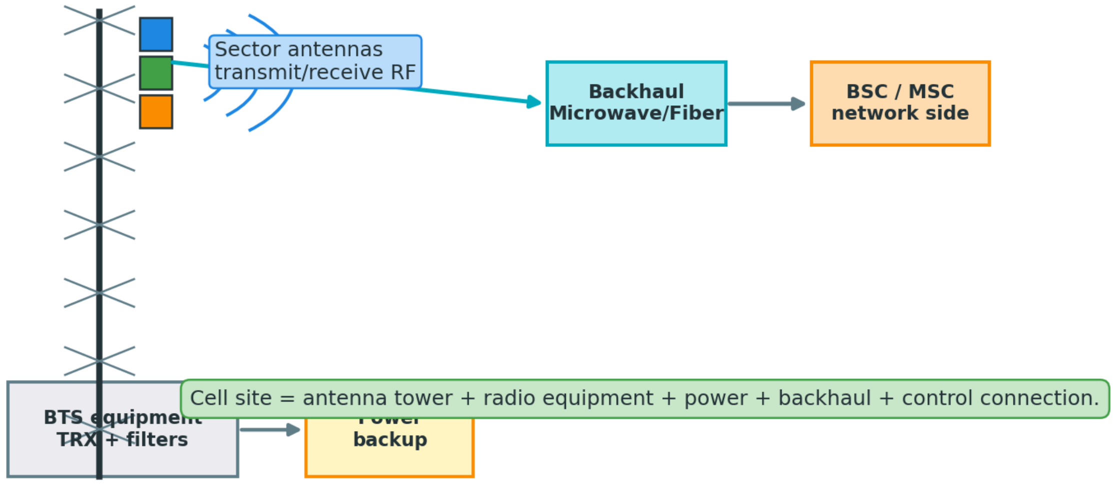

Fig. 2.2 Main parts of a cell site

Simple memory line: Cell site = tower + antennas + BTS equipment + power + backhaul + network control connection.

2.4 Capacity of Cell

Definition: Cell capacity is the number of users or calls that a cell can support with acceptable quality.

- Capacity depends on available bandwidth, number of channels, modulation method, coding, antenna sectors and interference.
- If each call uses one channel, then the number of channels gives an approximate number of simultaneous calls.
- Digital systems improve capacity by using efficient coding, compression and multiple access techniques.
- Smaller cells increase capacity because the same spectrum can be reused more often.

Formula / Key point: If total available channels are S and cluster size is N, then channels per cell = S/N. Smaller N gives more channels per cell but increases interference risk.

Cell Capacity and Frequency Reuse

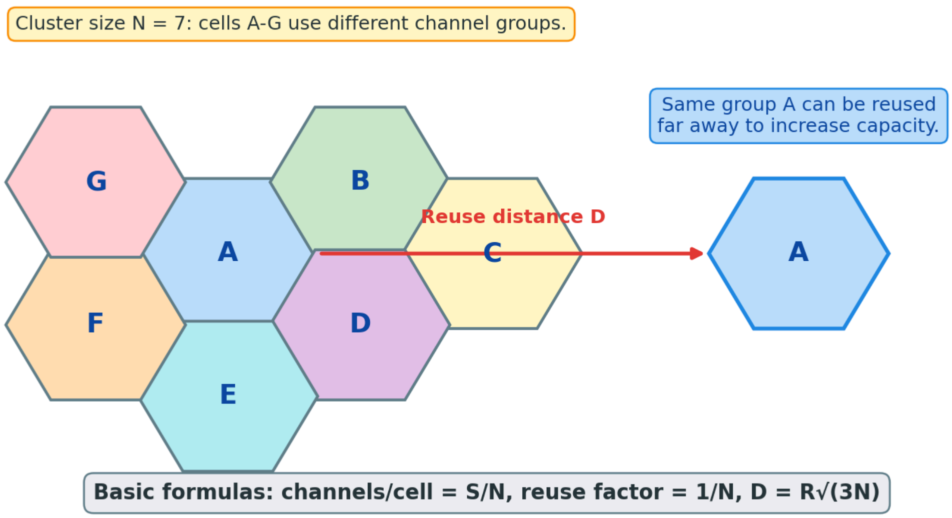

Fig. 2.3 Cell capacity depends strongly on frequency reuse

Example: If S = 140 channels and cluster size N = 7, then channels per cell = 140/7 = 20 channels. If N is reduced to 4, channels per cell = 35, but interference increases.

2.5 Concept of Frequency Reuse

Definition: Frequency reuse means using the same frequency channels again in different cells that are separated by enough distance.

- Frequency reuse is the main reason cellular systems can serve millions of users with limited spectrum.
- A group of cells using all available channel groups is called a cluster.
- Cluster size is represented by N.
- Reuse factor is 1/N.
- If same frequency cells are too close, co-channel interference increases.

Formula / Key point: For hexagonal cells, reuse distance $D = R\sqrt{3N}$, where R is cell radius and N is cluster size.

Cluster size N	Capacity effect	Interference effect
Large N	Lower capacity per cell	Lower co-channel interference
Small N	Higher capacity per cell	Higher co-channel interference

Exam tip: Always connect frequency reuse with capacity and interference. Reuse increases capacity, but poor reuse planning increases co-channel interference.

2.6 Co-channel and Adjacent Channel Interference

Co-channel interference: Interference caused by cells using the same frequency channel. It is mainly controlled by proper reuse distance and antenna sectoring.

Adjacent channel interference: Interference caused by nearby frequency channels leaking into each other due to imperfect filters or insufficient guard band.

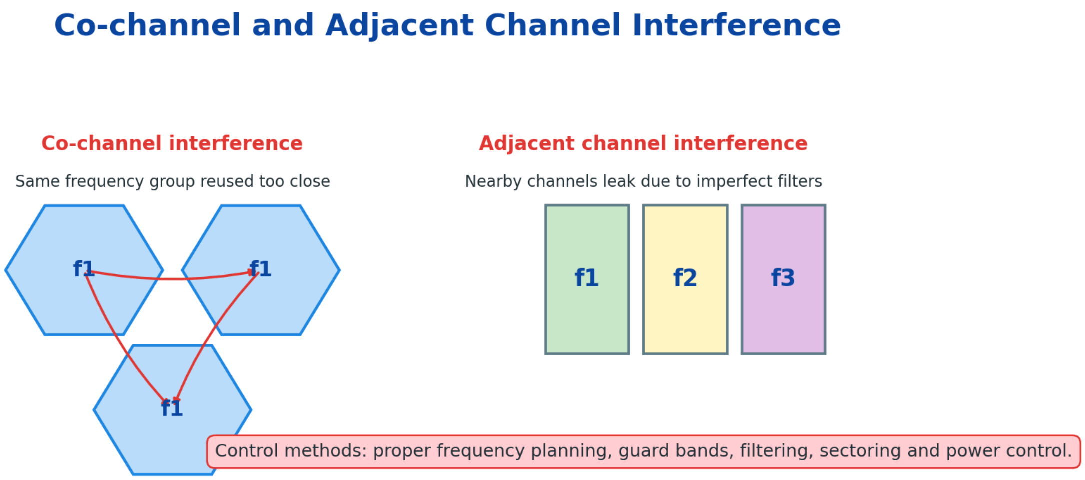

Fig. 2.4 Co-channel and adjacent channel interference

- Effects: call drops, poor voice quality, low data speed and high error rate.
- Control of co-channel interference: increase reuse distance, use sectoring, reduce transmit power and use better planning.
- Control of adjacent channel interference: use filters, guard bands and proper channel assignment.
- In real networks, interference control is continuous because users keep moving.

Type	Cause	Main control method
Co-channel	Same frequency reused too close	Increase reuse distance, sectoring, power control
Adjacent channel	Nearby frequencies overlap/leak	Better filtering and guard bands

2.7 Power Control for Reducing Interference

Definition: Power control means adjusting the transmit power of mobile phones and base stations so that the minimum required power is used.

- It reduces interference to other users and neighbouring cells.
- It saves battery power in mobile devices.
- It helps solve the near-far problem, where a nearby mobile can overpower a far mobile at the base station receiver.
- Closed-loop power control uses feedback from the receiver to increase or decrease power quickly.
- Open-loop power control estimates required power from received signal strength.

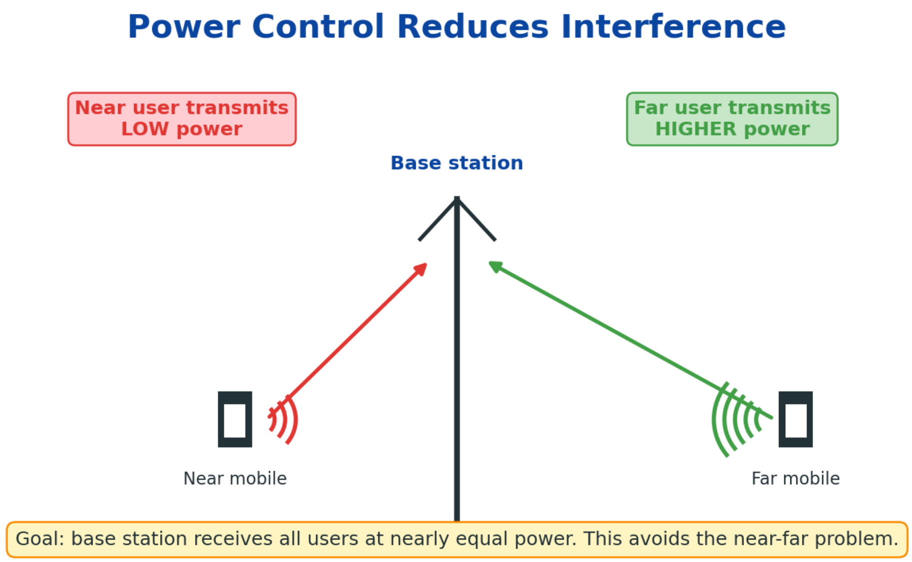

Fig. 2.5 Power control equalizes received power

Example: A phone very near to a tower does not need to transmit at full power. If it does, it will create unnecessary interference. Power control tells it to reduce power.

2.8 Fundamentals of Cell Splitting and Sectoring

Cell splitting: Cell splitting means dividing a large congested cell into smaller cells. It increases capacity because the same frequency groups can be reused more often.

Sectoring: Sectoring means dividing a cell into sectors using directional antennas. Common sectoring is 3 sectors of 120° each or 6 sectors of 60° each.

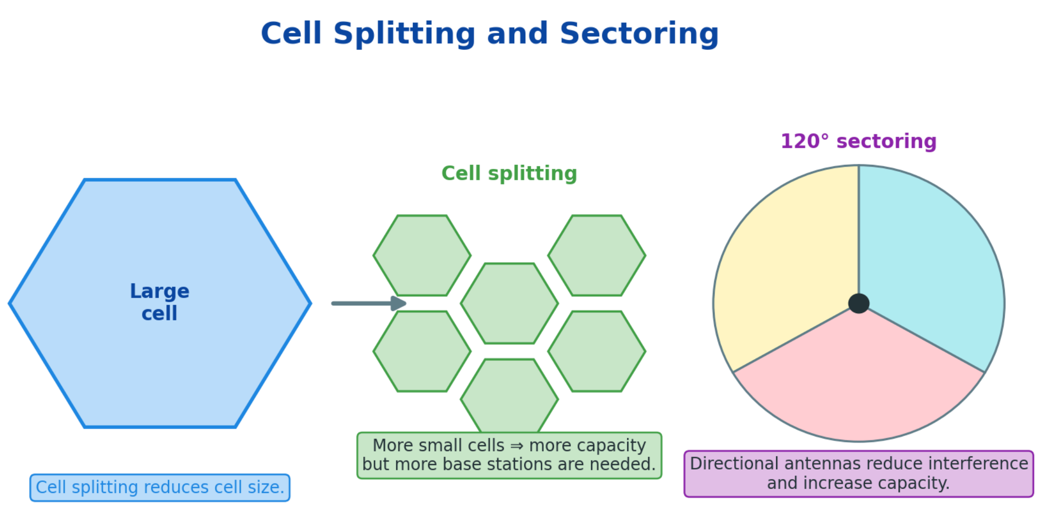

Fig. 2.6 Cell splitting and sectoring

- Cell splitting is useful in high-traffic areas such as markets, railway stations and stadiums.
- Sectoring reduces interference because antennas transmit mainly in one direction.
- Both techniques increase capacity, but they need more equipment, planning and handover control.
- Small cells are common in modern dense mobile networks.

Technique	Main purpose	Limitation
Cell splitting	Increase capacity by using smaller cells	Needs more base stations and handovers
Sectoring	Reduce interference using directional antennas	Needs sector antennas and careful alignment

UNIT III - MULTIPLE ACCESS TECHNIQUES FOR WIRELESS COMMUNICATION

Topic no.	Syllabus topic
3.1	Introduction to multiple access
3.2	FDMA
3.3	TDMA
3.4	CDMA and WCDMA
3.5	Introduction to OFDMA

3.1 Introduction to Multiple Access

Definition: Multiple access is a technique by which many users share the same communication system without interfering with each other.

- The shared resources can be frequency, time, code, power, space or subcarriers.
- The purpose is to use limited spectrum efficiently.
- A good multiple access system provides high capacity, low interference and fair service to users.
- Wireless systems use different methods depending on generation and design.

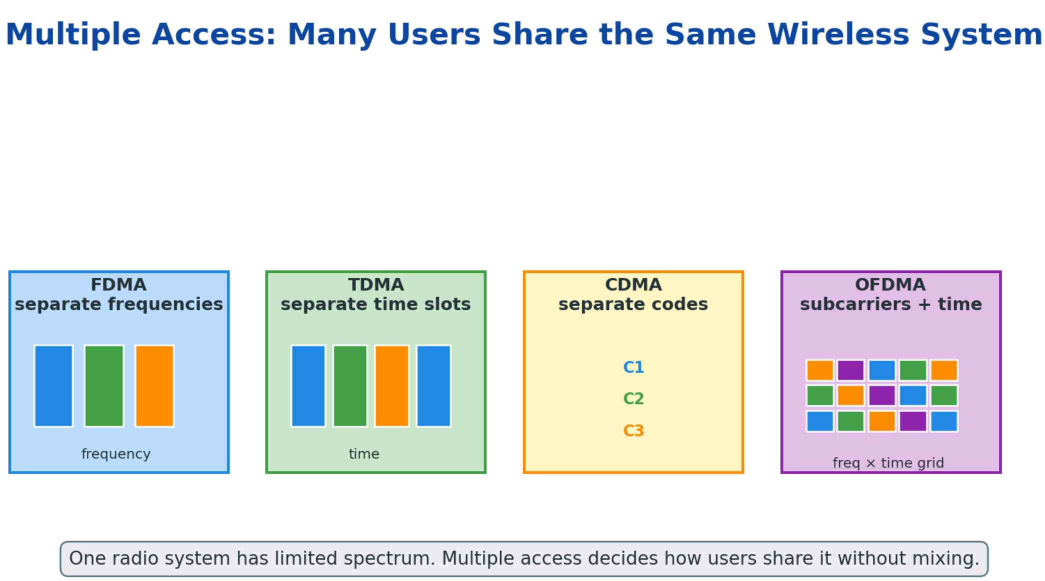

Fig. 3.1 Simple comparison of FDMA, TDMA, CDMA and OFDMA

Term	Easy meaning
FDMA	Users get separate frequency channels.

TDMA	Users get separate time slots.
CDMA	Users use different codes on same frequency and time.
OFDMA	Users get groups of orthogonal subcarriers in time-frequency grid.

3.2 Frequency Division Multiple Access - FDMA

Definition: FDMA divides the available spectrum into different frequency channels. Each user is assigned a separate frequency channel.

- Users transmit at the same time but on different frequencies.
- Guard bands are kept between adjacent channels to reduce interference.
- It is simple to understand and implement.
- Capacity is wasted if an assigned channel is idle.
- FDMA was used in early analog cellular systems and is also combined with other methods.

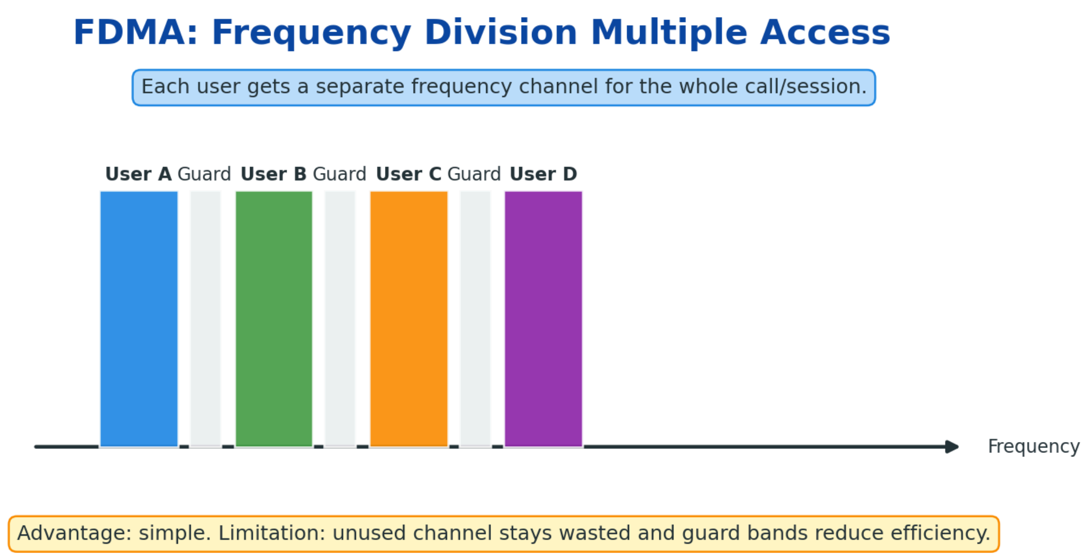

Fig. 3.2 FDMA channel allocation

FDMA advantage	FDMA disadvantage
Simple allocation and continuous communication for each user.	Needs guard bands and is not very flexible for bursty data.
No strict time synchronization between users.	If a user is silent, the assigned frequency may remain unused.

Example: Think of FDMA like different radio stations: each station transmits at a different frequency, so a receiver tunes to the desired frequency.

3.3 Time Division Multiple Access - TDMA

Definition: TDMA allows many users to share the same frequency by giving each user a separate time slot.

- Users transmit one after another very quickly on the same frequency.
- A frame contains a number of time slots.
- Synchronization is important; if timing is wrong, slots may overlap.
- TDMA is more flexible than FDMA for digital communication.
- GSM uses a combination of FDMA and TDMA.

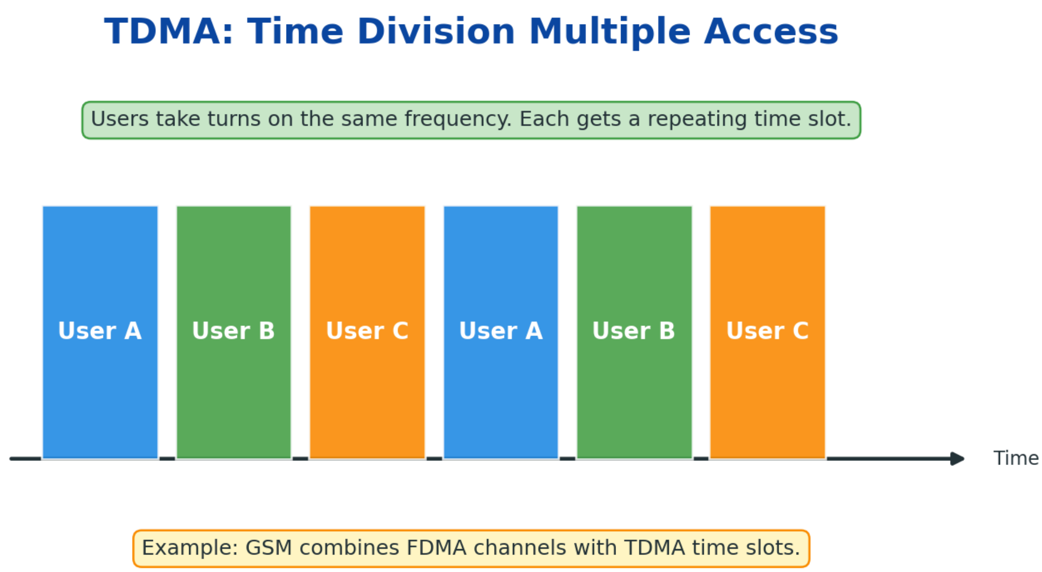

Fig. 3.3 TDMA time-slot allocation

Example: In a classroom discussion, if each student is given a fixed turn to speak, it is like TDMA. Everyone uses the same medium, but at different times.

Exam tip: FDMA separates users by frequency. TDMA separates users by time.

3.4 Code Division Multiple Access - CDMA and WCDMA

CDMA definition: CDMA allows users to use the same frequency band at the same time, but each user has a unique code. The receiver uses the correct code to recover the desired user.

WCDMA definition: WCDMA means Wideband CDMA. It is a 3G radio access technology used in UMTS and uses a wider radio channel than narrowband CDMA.

- CDMA is based on spread spectrum technique.
- The signal is spread over a wider bandwidth using a code.
- Users are separated by codes, not only by time or frequency.
- Power control is very important in CDMA because of the near-far problem.
- WCDMA supports higher data rates and better multimedia services compared with 2G systems.

CDMA and WCDMA: Users Separated by Codes

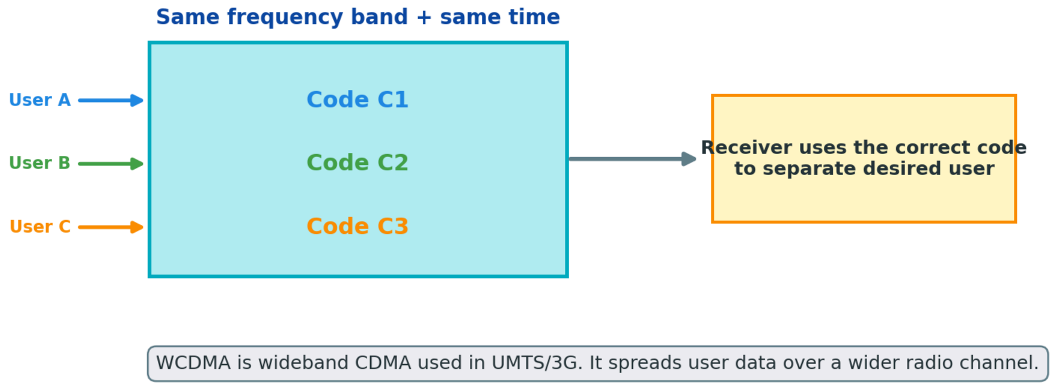

Fig. 3.4 CDMA/WCDMA concept

Point	CDMA / WCDMA meaning
Resource sharing	Same time and same frequency can be shared.
Separation method	Different spreading codes separate users.
Important requirement	Accurate power control is required.
3G relation	WCDMA is the main radio access technology of UMTS.

3.5 Introduction to OFDMA

Definition: OFDMA means Orthogonal Frequency Division Multiple Access. It divides a wide channel into many narrow orthogonal subcarriers and assigns groups of subcarriers to users.

- Orthogonal means subcarriers do not interfere with each other when correctly synchronized.
- Resources are allocated in a time-frequency grid.
- It is efficient for high-speed data services.
- It handles multipath better than single-carrier systems.
- It is used in LTE downlink, Wi-Fi and 5G NR.

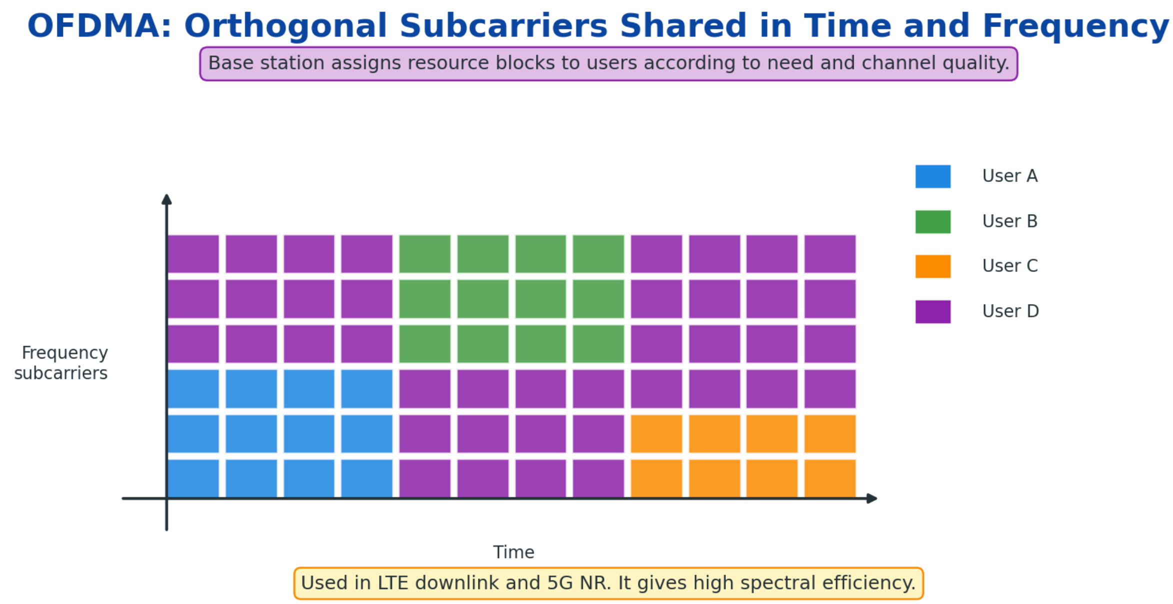

Fig. 3.5 OFDMA resource allocation grid

Example: Imagine a train with many seats. OFDMA assigns different groups of seats to different passengers. If a user needs more data, more resource blocks can be assigned.

Technique	Separated by	Typical use
FDMA	Frequency	Early mobile/radio systems
TDMA	Time	GSM
CDMA/WCDMA	Code	CDMA systems, UMTS/3G
OFDMA	Subcarriers and time	LTE, Wi-Fi, 5G NR

UNIT IV - MOBILE COMMUNICATION SYSTEMS

Topic no.	Syllabus topic
4.1	Introduction of GSM and its architecture
4.2	Introduction of GPRS, EDGE, Bluetooth and Wi-Fi

4.1 Introduction of GSM and Its Architecture

GSM: GSM stands for Global System for Mobile Communication. It is a widely used 2G digital cellular system for voice, SMS and basic data services.

- GSM uses SIM cards for subscriber identity.
- It supports roaming, authentication, encryption, voice calls and SMS.
- GSM architecture has three main parts: Mobile Station, Base Station Subsystem and Network Switching Subsystem.
- A call is routed through BTS, BSC and MSC. Subscriber databases help locate and authenticate the user.

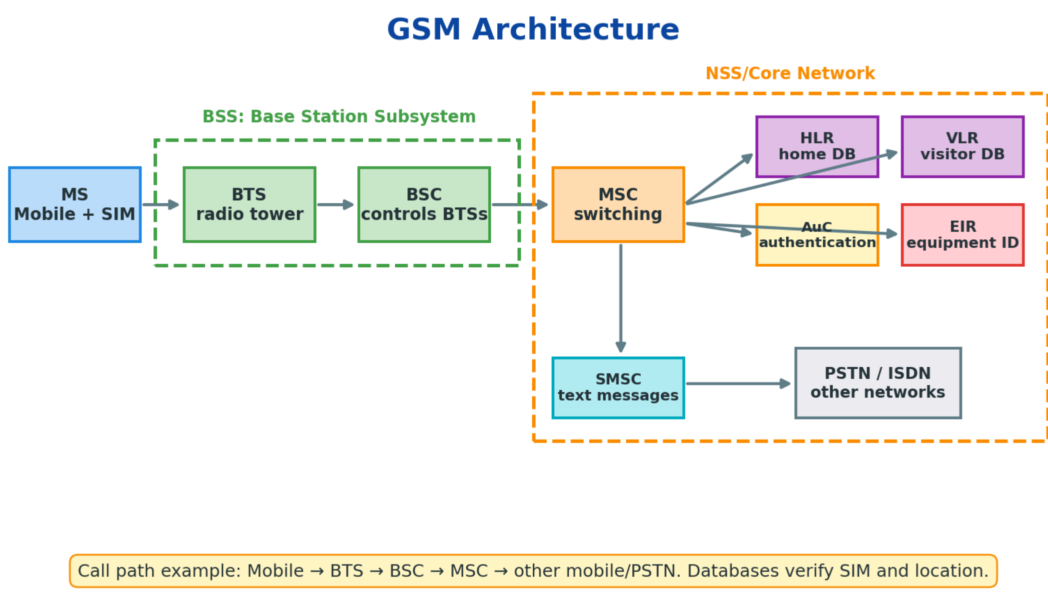

Fig. 4.1 GSM architecture

GSM block	Full form / role
MS	Mobile Station: mobile equipment + SIM.
BTS	Base Transceiver Station: radio link with mobiles.
BSC	Base Station Controller: controls many BTSs and handovers.

MSC	Mobile Switching Centre: switches calls and connects to other networks.
HLR	Home Location Register: permanent subscriber database.
VLR	Visitor Location Register: temporary location database.
AuC	Authentication Centre: security and authentication.
EIR	Equipment Identity Register: checks mobile equipment identity.

Call flow example: Mobile phone → BTS → BSC → MSC → other mobile/PSTN. The HLR/VLR databases help the network know where the user is located.

4.2 Introduction of GPRS, EDGE, Bluetooth and Wi-Fi

GPRS: GPRS stands for General Packet Radio Service. It adds packet-switched data service to GSM, so users can access e-mail, web pages and basic internet services.

EDGE: EDGE stands for Enhanced Data rates for GSM Evolution. It improves data speed in GSM networks by using improved modulation and coding.

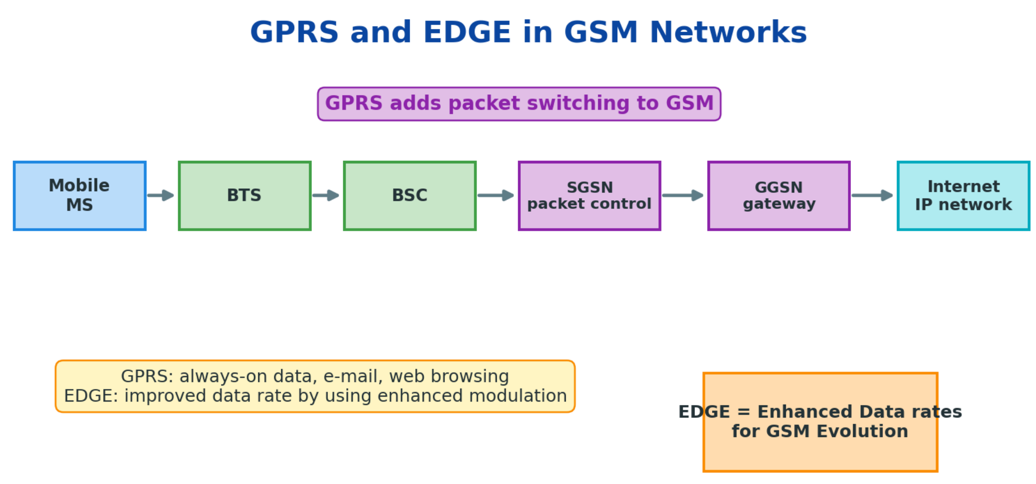

Fig. 4.2 GPRS and EDGE packet data path

System	Main idea	Example use
GPRS	Packet data added to GSM	Basic web browsing and e-mail on 2G phones
EDGE	Higher data rate version of GSM/GPRS	Faster mobile internet than GPRS
Bluetooth	Short-range, low-power wireless personal area network	Phone connected to earbuds or smartwatch

Wi-Fi	Wireless local area network using access point/router	Home or college internet access

Bluetooth: Bluetooth is used for short-range communication between nearby devices. It is low power and works well for personal devices.

Wi-Fi: Wi-Fi is used for wireless local area networks. A Wi-Fi access point connects phones, laptops and other devices to a local network or internet.

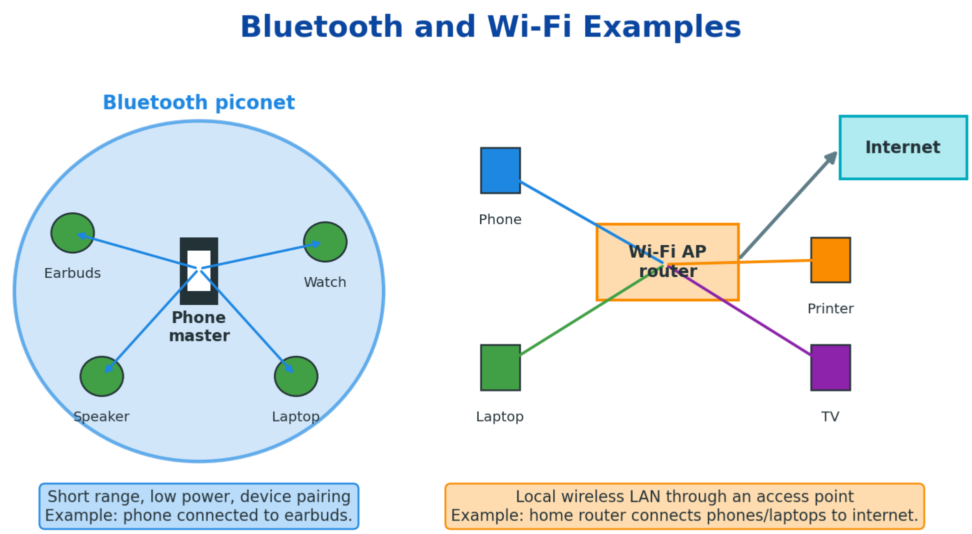

Fig. 4.3 Bluetooth piconet and Wi-Fi access point

Example: Bluetooth example: wireless earbuds connected to a phone. Wi-Fi example: a laptop connected to a home router for internet.

Exam tip: Bluetooth is for short-range personal area networking. Wi-Fi is for local area networking with higher data rate and larger range than Bluetooth.

UNIT V - INTRODUCTION TO 3G, 4G & 5G

Topic no.	Syllabus topic
5.1	Architecture and features of UMTS
5.2	Features and architecture of LTE
5.3	Introduction to 5G and concept of New Radio technology
5.4	Comparison of 4G with 5G

5.1 Architecture and Features of UMTS

Definition: UMTS stands for Universal Mobile Telecommunications System. It is a 3G mobile communication system based mainly on WCDMA radio access.

- UMTS supports voice, data, multimedia, video calling and international roaming.
- The user device is called UE, and it contains mobile equipment and USIM.
- Node B is the 3G base station.
- RNC controls multiple Node Bs and manages radio resources and handovers.
- The core network connects to voice networks and packet data networks.

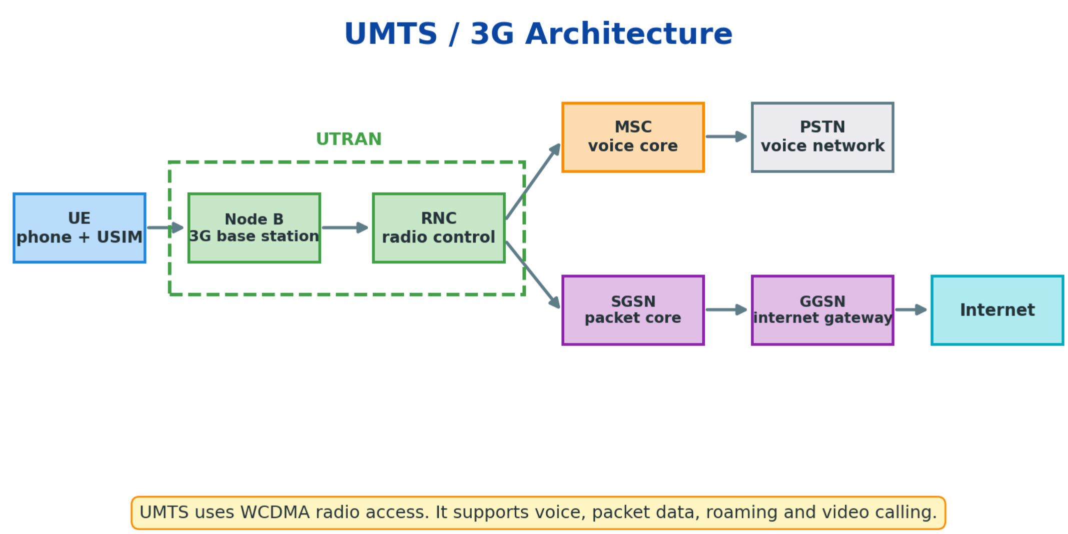

Fig. 5.1 UMTS / 3G architecture

UMTS component	Function
UE	User equipment: 3G phone or data card.
Node B	Radio base station of UMTS.

RNC	Radio Network Controller: controls radio resources and handovers.
MSC	Voice switching core.
SGSN/GGSN	Packet data core for internet access.

Features of UMTS: Higher data rate than 2G, WCDMA radio access, simultaneous voice and data support, video calling, global roaming and improved security.

5.2 Features and Architecture of LTE

Definition: LTE stands for Long Term Evolution. It is a 4G mobile communication technology designed for high-speed packet data and all-IP communication.

- LTE uses eNodeB as the radio base station. It combines many radio control functions that were separate in older systems.
- LTE core network is called EPC - Evolved Packet Core.
- Important EPC blocks are MME, HSS, Serving Gateway and Packet Gateway.
- LTE uses OFDMA in downlink and SC-FDMA in uplink.
- It supports MIMO antennas, higher data rates, lower latency and VoLTE for voice over IP.

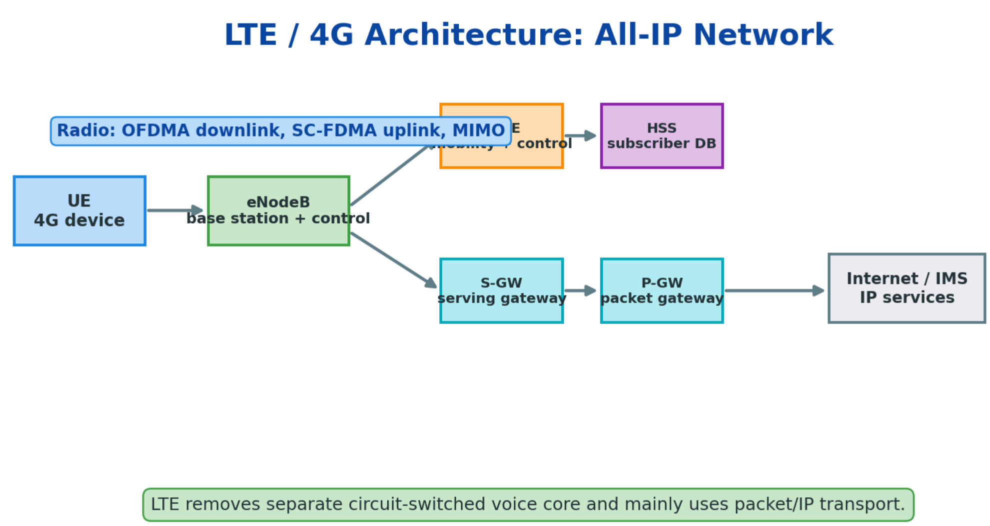

Fig. 5.2 LTE / 4G architecture

LTE block	Function
UE	4G user device.
eNodeB	LTE base station with radio and control functions.
MME	Mobility management and control signalling.
HSS	Subscriber database.

S-GW	Serving gateway for user data path.
P-GW	Packet gateway connecting to external IP networks.

Example: Streaming HD video on a smartphone using a 4G data connection is a common LTE service example.

5.3 Introduction to 5G and Concept of New Radio Technology

5G: 5G is the fifth generation mobile communication system. It is designed for very high data rates, massive device connectivity and low-latency applications.

New Radio: 5G NR means 5G New Radio. It is the radio access technology used by 5G networks. It supports flexible bandwidth, flexible subcarrier spacing, massive MIMO and beamforming.

- 5G can work in sub-6 GHz bands and also in higher mmWave bands depending on network deployment.
- Massive MIMO uses many antenna elements to improve capacity and coverage.
- Beamforming focuses radio energy toward the user instead of radiating equally in all directions.
- Network slicing allows one physical network to support different virtual networks for different services.
- 5G use cases are usually grouped as eMBB, URLLC and mMTC.

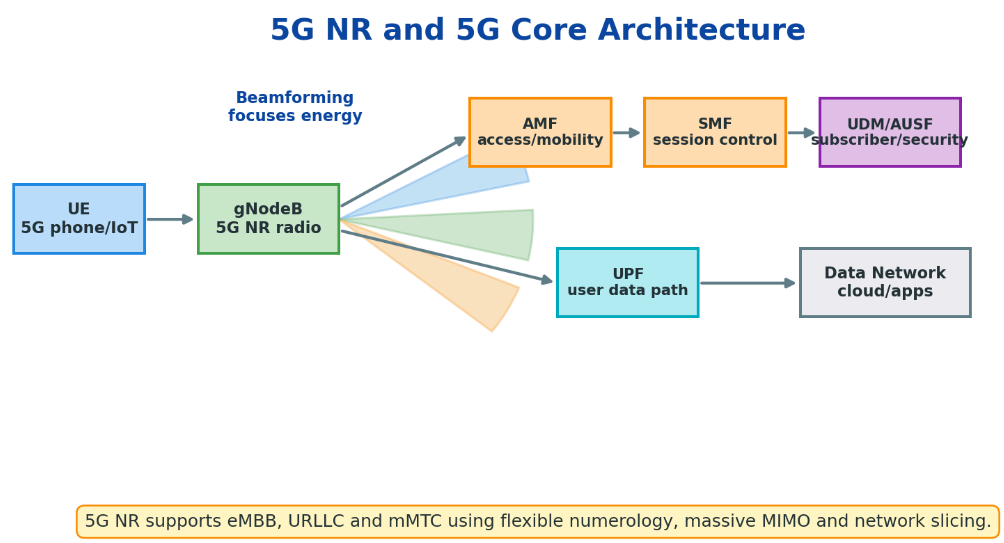

Fig. 5.3 5G NR and 5G Core concept

Term	Easy meaning
eMBB	Enhanced Mobile Broadband: very high data rate, video, AR/VR.
URLLC	Ultra-Reliable Low-Latency Communication: industrial control, critical applications.
mMTC	Massive Machine-Type Communication: many IoT sensors and smart devices.

Beamforming	Antenna technique that focuses signal energy toward the user.

Example: A 5G smart factory can use high-speed video inspection, low-latency robot control and thousands of sensors in the same network through different service designs.

5.4 Comparison of 4G with 5G

Main difference: 4G mainly improved mobile broadband and IP data. 5G further improves speed, latency, connection density and flexibility for many different applications.

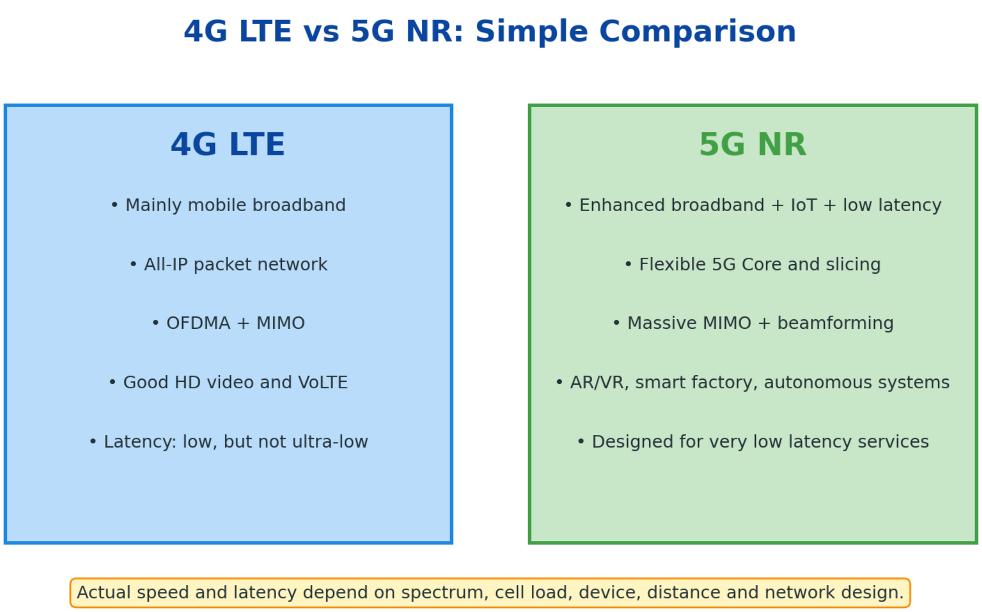

Fig. 5.4 Simple comparison of 4G LTE and 5G NR

Point	4G LTE	5G NR
Main aim	High-speed mobile broadband	Broadband + low latency + massive IoT
Radio access	LTE radio, OFDMA downlink	New Radio with flexible numerology
Core network	EPC, all-IP packet core	5G Core with service-based architecture
Antenna technology	MIMO support	Massive MIMO and beamforming emphasized
Latency	Low latency for normal internet services	Designed for very low-latency services
Use cases	HD video, VoLTE, mobile internet	AR/VR, smart factory, IoT, autonomous systems

Exam tip: Do not only write speed. A good 4G vs 5G answer should include latency, massive IoT, beamforming, network slicing and new radio technology.

QUICK REVISION SHEET

Topic	One-line answer
Wireless communication	Information transfer without wires using electromagnetic waves.
Cell	Small coverage area served by one base station.
Frequency reuse	Using the same channels again in far-away cells.
Co-channel interference	Interference from another cell using the same frequency.
Adjacent channel interference	Interference from nearby frequency channels.
Power control	Adjusting transmit power to reduce interference and save battery.
Cell splitting	Dividing a large cell into smaller cells to increase capacity.
Sectoring	Using directional antennas to divide a cell into sectors.
FDMA	Different users get different frequencies.
TDMA	Different users get different time slots.
CDMA	Different users get different codes.
OFDMA	Users get groups of orthogonal subcarriers in a time-frequency grid.
GSM	2G digital cellular system with SIM, voice and SMS.
GPRS	Packet data service added to GSM.
EDGE	Enhanced data rate version of GSM/GPRS.
UMTS	3G system using WCDMA radio access.
LTE	4G all-IP high-speed mobile broadband system.
5G NR	5G New Radio for high speed, low latency and massive connectivity.

IMPORTANT FORMULAS AND MEMORY POINTS

- Electromagnetic wave relation: $c = f \times \lambda$.
- Channels per cell = total available channels S / cluster size N.
- Frequency reuse factor = $1/N$.
- Reuse distance for hexagonal cells: $D = R\sqrt{3N}$.
- Smaller cluster size gives more capacity but more interference.
- Power control reduces the near-far problem and saves mobile battery.
- OFDMA is important for LTE and 5G because it uses subcarriers efficiently.

SUGGESTED DIAGRAMS TO PRACTICE

- Basic wireless communication link.
- Electromagnetic wave showing λ.
- Cellular network with cells and base stations.
- Frequency reuse cluster and reuse distance.
- Co-channel and adjacent channel interference.
- Power control concept.
- Cell splitting and sectoring.
- FDMA, TDMA, CDMA and OFDMA diagrams.
- GSM architecture.
- UMTS, LTE and 5G architecture diagrams.