

## Mobile & Wireless Communication (315339)

MSBTE Diploma · K-Scheme · Model Question Paper — Set C · Model Answers

### Q.1

a) Cluster size and reuse ratio for  $i = 3, j = 1$

2 M

$$N = i^2 + ij + j^2 = 3^2 + (3)(1) + 1^2 = 9 + 3 + 1 = 13$$

$$Q = D/R = \sqrt{(3N)} = \sqrt{(3 \times 13)} = \sqrt{39} = 6.245$$

(1 M each)

b) Function of SIM and HLR

2 M

- **SIM (Subscriber Identity Module):** smart card that identifies the subscriber — stores IMSI, secret key  $K_i$ , authentication (A3) and cipher-key (A8) algorithms, PIN, contacts and SMS; makes the subscription independent of the handset.
- **HLR:** Home Location Register — permanent database of all subscribers of the operator: IMSI, MSISDN, subscribed services and current location (VLR address).

(1 M each)

c) Features of 4G LTE

2 M

- All-IP packet-switched network (voice as VoLTE).
- High data rates — up to 100 Mbps (mobile) / 1 Gbps (stationary) for 4G; LTE peak 300 Mbps DL.
- OFDMA in downlink, SC-FDMA in uplink; MIMO antennas.
- Scalable bandwidth 1.4 – 20 MHz; low latency (about 10 ms radio, 30–50 ms end-to-end).
- Flat architecture (eNodeB + EPC), seamless mobility up to 350 km/h.

(Any four, ½ M each)

d) 5G mmWave range and limitations

2 M

**Range:** 24 GHz to about 100 GHz (3GPP FR2: 24.25–52.6 GHz, extended to 71 GHz); India uses 26 GHz (24.25–27.5 GHz).

**Limitations:** very short coverage (few hundred metres) due to high path loss; poor penetration through walls, glass, foliage and rain; needs line of sight, dense small cells and beamforming, so deployment cost is high.

(Range 1 M, two limitations 1 M)

e) Features of NFC

2 M

- Operates at 13.56 MHz (HF RFID band).
- Very short range — up to 4 cm (max ~10 cm), hence secure.
- Data rates 106, 212, 424 kbps.
- Three modes: reader/writer, peer-to-peer, card emulation.
- Easy “tap to connect”, no pairing; low power — passive tags need no battery.

(Any four, ½ M each)

## f) Adjacent channel interference

2 M

**Adjacent channel interference (ACI)** is interference caused by signals whose frequencies are **adjacent (next) to the desired channel**. Due to imperfect receiver filters, energy of the neighbouring channel leaks into the pass-band of the desired channel; it is worst when the interfering mobile is much closer to the base station than the desired mobile (near–far effect).

(Definition 2 M)

## g) Two key targets of IMT-2020

2 M

- Peak data rate of 20 Gbit/s (DL) and 10 Gbit/s (UL); user experienced rate 100 Mbit/s.
- User-plane latency of 1 ms for URLLC.
- Connection density of  $10^6$  devices/km<sup>2</sup>; mobility up to 500 km/h.

(Any two, 1 M each)

## Q.2

### a) Wireless communication systems; paging system

4 M

**Wireless communication systems:** paging systems, cordless telephone systems, cellular telephone systems (1G–5G), wireless local loop (WLL), wireless LAN (Wi-Fi), WPAN (Bluetooth, NFC), Wi-MAX and satellite communication systems.

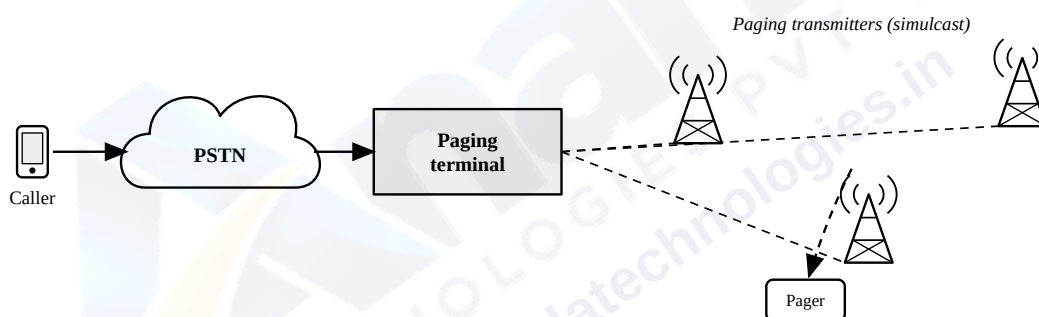


Fig.: Paging system

- A paging system sends brief messages (numeric, alphanumeric or voice) to a subscriber carrying a small receiver called a **pager**; it is a **one-way** system.
- The caller dials the paging number through PSTN; the **paging terminal** (control) accepts the message and the pager address.
- The message is transmitted by all **paging transmitters** of the service area simultaneously (simulcast) so that the pager receives it anywhere in a wide area (city/country).
- Pager alerts by beep/vibration and displays the message. Advantages: wide coverage, small low-power receiver; limitation: no reply possible.

(List 1 M, diagram 1 M, explanation 2 M)

### b) Compare N-AMPS and IS-95

4 M

| Parameter | N-AMPS | IS-95 |
|-----------|--------|-------|
|-----------|--------|-------|

| Generation        | 1G     | 2G                                     |
|-------------------|--------|----------------------------------------|
| Multiple access   | FDMA   | CDMA (direct-sequence spread spectrum) |
| Channel bandwidth | 10 kHz | 1.25 MHz                               |
| Analog / digital  | Analog | Digital                                |

(1 M each)

### c) Basic cellular system — MS, BS, MSC

4 M

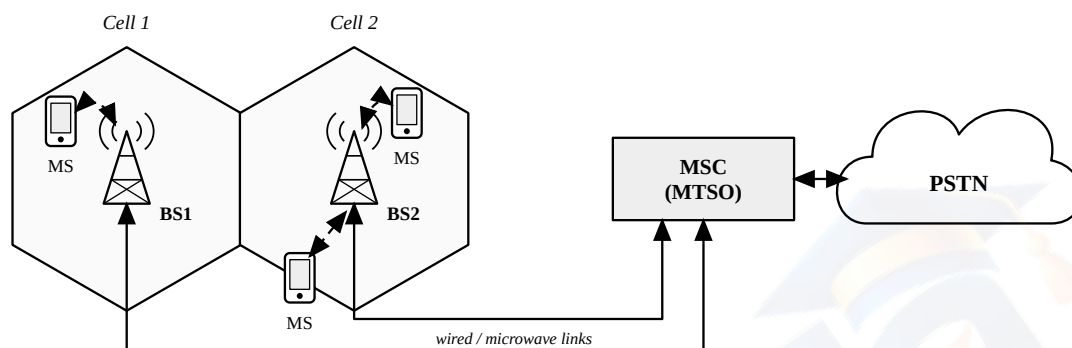


Fig.: Basic cellular system — mobiles, base stations, MSC and PSTN

- **Mobile station (MS):** the handset — transceiver, antenna and control circuit; communicates with the base station over radio, measures signal strength and transmits at the power ordered by the BS.
- **Base station (BS):** fixed transceivers and antenna tower at the centre (or corner) of each cell; serves all mobiles in the cell over forward and reverse voice and control channels; acts as a bridge between mobiles and the MSC.
- **Mobile Switching Centre (MSC/MTSO):** connects all base stations of an area and the PSTN; sets up and switches calls, allocates channels, controls handoff, keeps subscriber location and billing records.

(Diagram 1 M, functions 3 M)

## d) Mobile-terminated call procedure

4 M

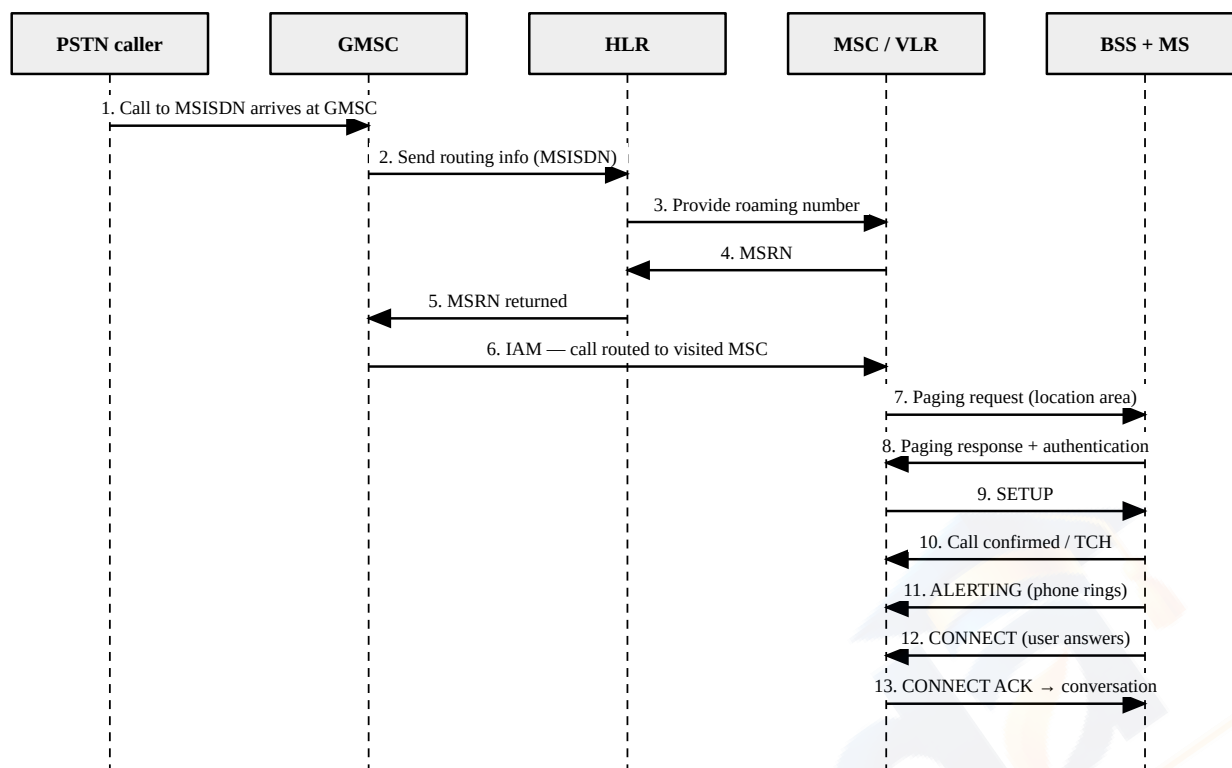


Fig.: Mobile-terminated call — signalling sequence (GSM)

- A caller dials the mobile number (MSISDN); the call reaches the **GMSC** of the home network.
- GMSC interrogates the **HLR**; HLR asks the current **VLR** for a roaming number (**MSRN**) and returns it to GMSC.
- GMSC routes the call (IAM) to the visited MSC using the MSRN; MSC/VLR finds the location area and **pages** the mobile through all BTSs of that area.
- Mobile answers the paging, gets SDCCH, is authenticated and ciphering starts; MSC sends SETUP, traffic channel is assigned.
- Mobile rings (ALERTING); when the user answers, CONNECT is sent and the conversation starts.

(Diagram 2 M, steps 2 M)

### Q.3

#### a) Co-channel interference; S/I for N = 12

4 M

**Co-channel interference** occurs between cells which use the same frequency set (co-channel cells). Since all cells of the same size transmit equal power, the S/I does not depend on transmit power but on the ratio  $Q = D/R$ ; it is reduced by increasing the reuse distance (larger N), sectoring or power control.

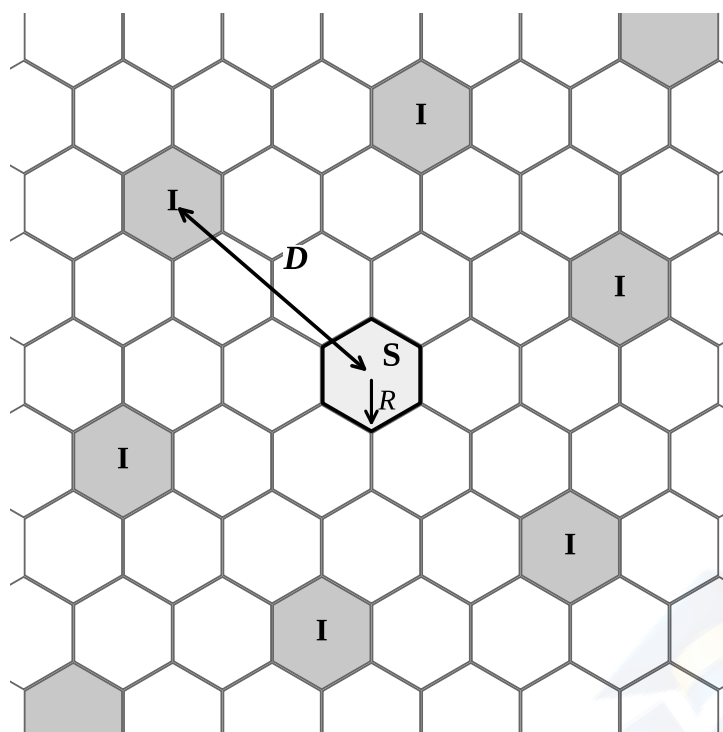


Fig.: Reference cell  $S$  and first tier of six co-channel cells  $I$  ( $N = 7$ ,  $D = 4.58 R$ )

$$S/I = (\sqrt{(3N)})^n / i_0, \text{ with } N = 12: Q = \sqrt{36} = 6, i_0 = 6$$

| $n$ | $Q^n$ | $S/I = Q^n/6$ | $S/I$ (dB) |
|-----|-------|---------------|------------|
| 3   | 216   | 36            | 15.56 dB   |
| 4   | 1296  | 216           | 23.34 dB   |

(Explanation 2 M, calculation 2 M)

### b) Compare 3G, 4G and 5G

4 M

| Parameter        | 3G                                           | 4G                                                  | 5G                                                          |
|------------------|----------------------------------------------|-----------------------------------------------------|-------------------------------------------------------------|
| Peak data rate   | 384 kbps – 2 Mbps<br>(HSPA: up to 14.4 Mbps) | 100 Mbps (high mobility)<br>– 1 Gbps (low mobility) | Up to 20 Gbps DL / 10 Gbps UL;<br>100 Mbps user experienced |
| Latency          | 100 – 500 ms                                 | 30 – 50 ms                                          | 1 ms (URLLC) – 10 ms                                        |
| Switching / core | Circuit (voice) + packet (data)              | All-IP packet switching (EPC)                       | All-IP, service-based cloud-native core (5GC), SDN/NFV      |
| Multiple access  | CDMA (WCDMA)                                 | OFDMA (DL), SC-FDMA (UL)                            | OFDMA (CP-OFDM), DFT-s-OFDM (UL)                            |

(1 M each)

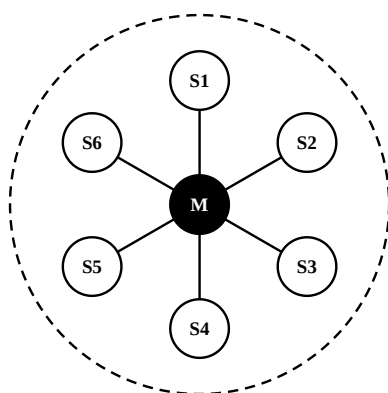
### c) Bluetooth features; piconet and scatternet

4 M

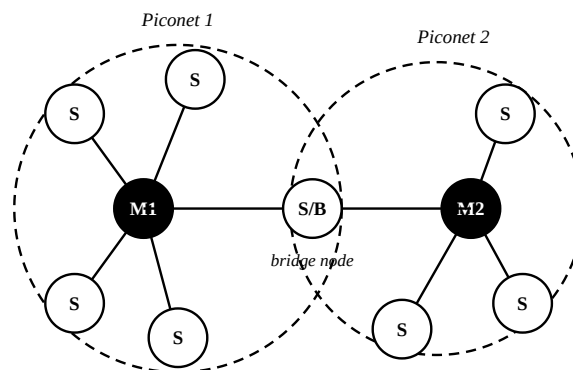
#### Features:

- Operates in 2.4 GHz ISM band (2.402–2.480 GHz), 79 channels of 1 MHz.
- Frequency hopping spread spectrum at 1600 hops/s — robust against interference.
- Range about 10 m (class 2); up to 100 m (class 1).

- Data rate 1 Mbps (basic rate, GFSK); 2–3 Mbps with EDR.



(a) Piconet: 1 master + up to 7 active slaves



(b) Scatternet: two piconets linked by a bridge node

Fig.: Bluetooth piconet and scatternet

- **Piconet:** the basic Bluetooth network formed when devices connect ad hoc. One device acts as **master** (sets the clock and hopping sequence) and up to **7 active slaves** (and up to 255 parked slaves) synchronise to it. Slaves talk only through the master.
- **Scatternet:** two or more piconets interconnected. A device that is a member of two piconets (slave in both, or master in one and slave in the other) acts as a **bridge** and forwards data, so many devices can communicate beyond one piconet.

(Features 2 M, piconet & scatternet 2 M)

#### d) Network slicing; role of NSSF

4 M

**Network slicing** is the 5G capability of running multiple isolated **logical end-to-end networks** (RAN + transport + core) over one shared physical infrastructure. Each slice is configured for a specific service with its own QoS, latency, security and capacity, using SDN and NFV.

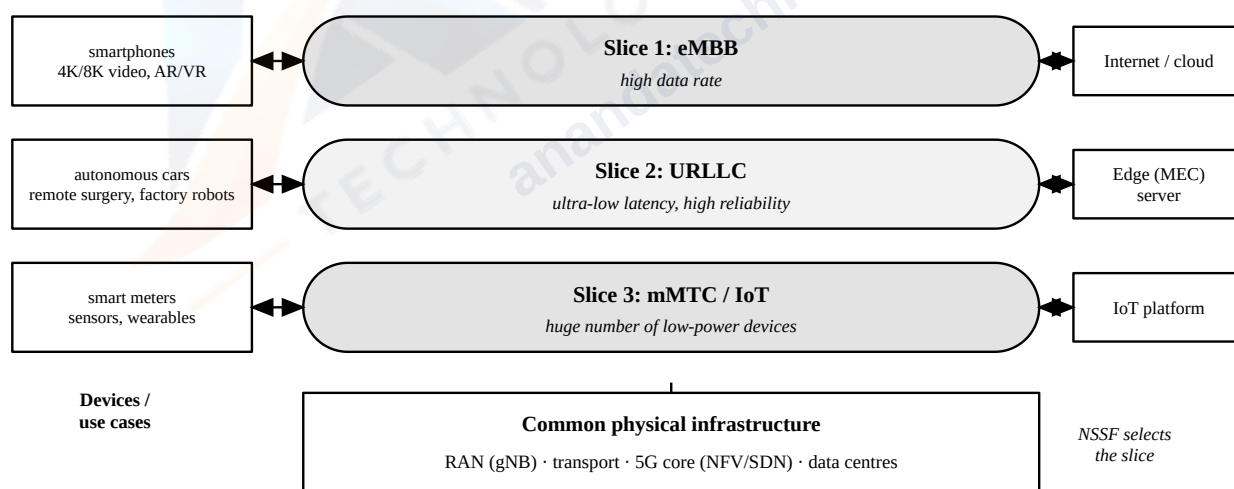


Fig.: Network slicing — several logical end-to-end networks on one physical 5G network

**Role of NSSF (Network Slice Selection Function):** when a UE registers, the AMF consults the NSSF, which selects the allowed slice(s) (S-NSSAI) for the UE based on its subscription and request, and selects the AMF set that serves those slices.

(Explanation 1 M, sketch 2 M, NSSF 1 M)

## Q.4

### a) Analog, digital and hybrid beamforming

4 M

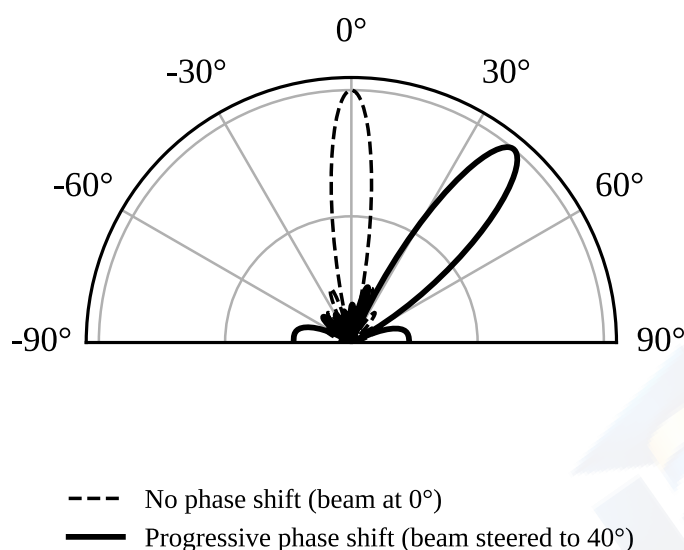


Fig.: Computed array pattern of a 8-element antenna array (spacing  $\lambda/2$ ) — beamforming

- **Analog beamforming:** one RF chain feeds all antenna elements through analog phase shifters; only one beam at a time; low cost and power — used in mmWave terminals.
- **Digital beamforming:** each antenna element has its own RF chain and ADC/DAC; weights are applied in baseband, so many simultaneous beams (multi-user MIMO) are possible; flexible but costly and power hungry — used at sub-6 GHz massive MIMO.
- **Hybrid beamforming:** few digital RF chains combined with analog phase-shifter networks; gives several beams at reasonable cost — common in 5G mmWave base stations.
- **Significance in 5G:** compensates mmWave path loss, increases coverage and capacity, reduces interference and enables massive MIMO / multi-user transmission.

(Three types 3 M, significance 1 M)

### b) Cell splitting and sectoring; S/I improvement with 120° sectors

4 M

**Cell splitting:** a congested cell is subdivided into smaller cells (microcells), each with its own base station of reduced antenna height and transmit power. Channels are reused more times in the same area, so capacity increases. If the radius is halved, about four times as many cells cover the area and transmit power reduces by  $10 \log(2^4) = 12.04$  dB ( $n = 4$ ).

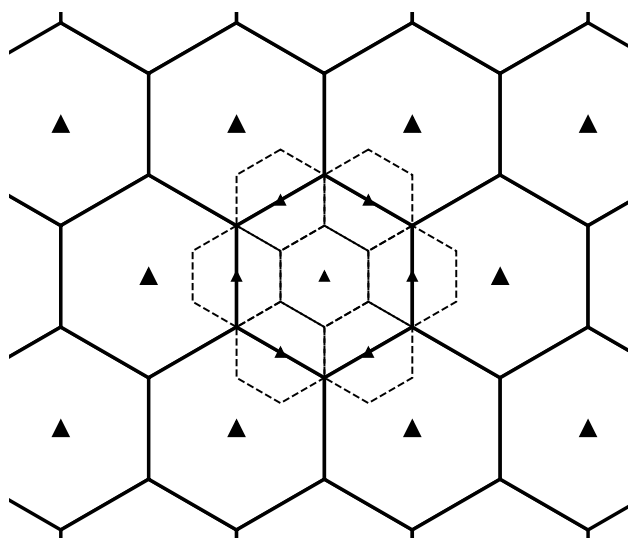


Fig.: Cell splitting — a congested cell of radius  $R$  is split into microcells of radius  $R/2$  (large  $\blacktriangle$  original BS, small  $\blacktriangle$  new microcell BS)

**Sectoring:** the omnidirectional antenna of a cell is replaced by 3 ( $120^\circ$ ) or 6 ( $60^\circ$ ) directional antennas; each sector uses a part of the channel set. A sector receives interference from fewer co-channel cells, so S/I improves and a smaller  $N$  can be used.

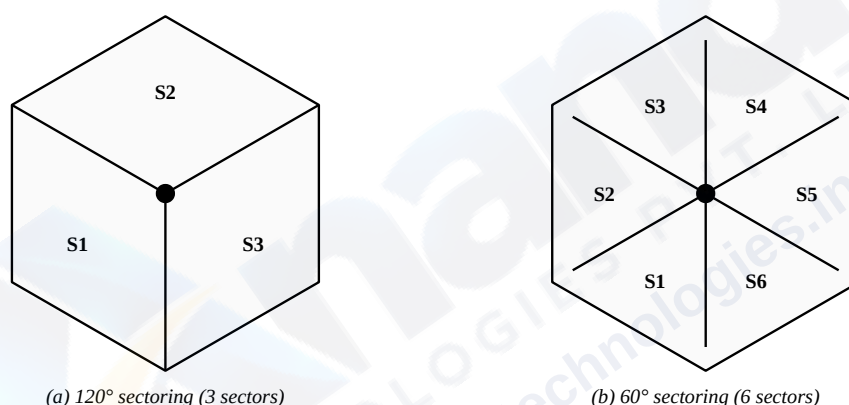


Fig.: Cell sectoring using directional antennas

**Calculation ( $N = 7$ ,  $n = 4$ ,  $Q = \sqrt{21} = 4.583$ ):** Omni (6 interferers):  $S/I = Q^4/6 = 73.5 \rightarrow 18.66$  dB.  $120^\circ$  sectoring (2 interferers):  $S/I = Q^4/2 = 220.5 \rightarrow 23.43$  dB. **Improvement = 4.77 dB** (factor 3).

(Splitting 1 M, sectoring 1 M, calculation 2 M)

### c) Vehicular communication applications; V2I

4 M

#### Applications:

- Collision avoidance and emergency brake warning (V2V)
- Traffic signal timing and green-light optimal speed advisory
- Electronic toll collection and smart parking
- Platooning, cooperative cruise control and autonomous driving
- Emergency vehicle priority and accident notification (eCall)

**V2I (vehicle-to-infrastructure):** Vehicles communicate with road-side units (RSU) mounted on traffic lights, signboards, toll plazas and street poles, using DSRC (802.11p, 5.9 GHz) or C-V2X. The RSU broadcasts signal phase and timing, speed limits, road-work and weather warnings; the

vehicle sends its position and speed. Traffic control centres use this data to optimise signals, reduce congestion and emissions, give priority to ambulances and collect tolls without stopping.

(Applications 2 M, V2I 2 M)

#### d) 3G limitations; 3G standards

4 M

##### Limitations of 3G (motivation for 4G):

- Limited data rate (2 Mbps theoretical, few hundred kbps practical).
- Two separate cores — circuit switching for voice and packet switching for data — complex and costly.
- High latency (100 ms or more); poor for real-time video and gaming.
- Fixed 5 MHz bandwidth, CDMA interference-limited capacity; incompatible standards (WCDMA vs CDMA2000) hinder global roaming.

##### 3G (IMT-2000) standards:

| IMT-2000 name | Standard                | Access technique        |
|---------------|-------------------------|-------------------------|
| IMT-DS        | UTRA-FDD / WCDMA (UMTS) | CDMA (direct spread)    |
| IMT-MC        | CDMA2000                | CDMA (multi-carrier)    |
| IMT-TC        | UTRA-TDD, TD-SCDMA      | CDMA + TDMA (time code) |
| IMT-SC        | UWC-136 / EDGE          | TDMA (single carrier)   |
| IMT-FT        | DECT                    | FDMA / TDMA             |

(Limitations 2 M, standards 2 M)

#### e) IEEE 802.11 architecture and features of Wi-Fi

4 M

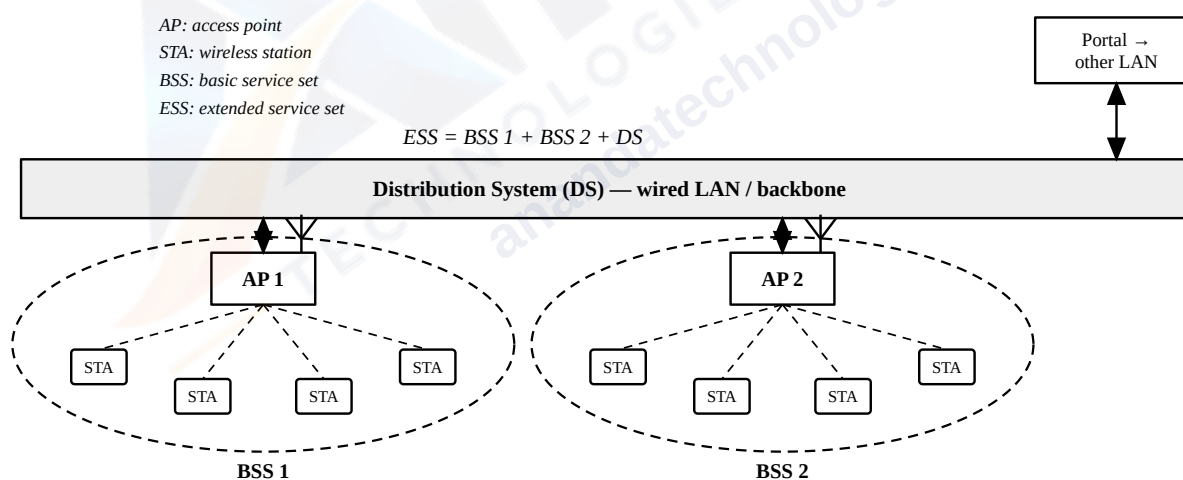


Fig.: IEEE 802.11 architecture — BSS, ESS and distribution system

Stations (STA) in a BSS communicate through the access point (AP); several BSSs are joined by the distribution system to form an ESS. Without an AP, stations form an ad hoc IBSS.

##### Features of Wi-Fi:

- Works in unlicensed 2.4 GHz and 5 GHz (and 6 GHz for Wi-Fi 6E) bands.
- Data rates from 11 Mbps (802.11b), 54 Mbps (a/g) to several Gbps (802.11ac/ax).

- Range about 30–50 m indoor, ~100 m outdoor.
- MAC uses CSMA/CA; infrastructure and ad hoc modes; roaming within ESS.
- Security with WPA2/WPA3 encryption.

(Diagram 2 M, any four features 2 M)

## Q.5

### a) Block diagram of a 3G mobile handset

6 M

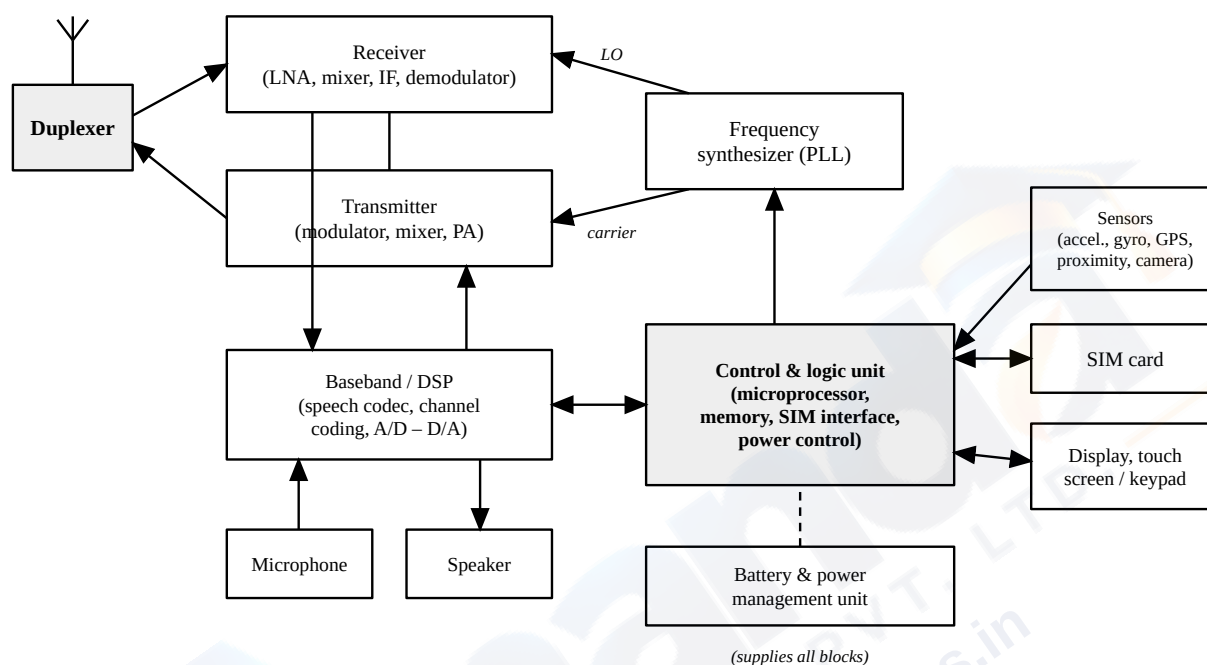


Fig.: Block diagram of a mobile (cellular) telephone unit

- **Antenna and duplexer:** one antenna for both transmit and receive; the duplexer (filters) isolates transmitter from receiver.
- **Receiver:** LNA amplifies weak RF, mixer with LO converts to IF/zero-IF, filters remove adjacent channels, demodulator/despreader recovers baseband data.
- **Transmitter:** baseband data is spread/modulated (QPSK), up-converted and amplified by the power amplifier; the output level is controlled by the logic unit (closed-loop power control).
- **Frequency synthesizer:** PLL-based; generates LO and carrier frequencies of the channel assigned by the network (divider N set by control unit).
- **Baseband / DSP:** A/D and D/A conversion, speech codec (AMR), channel coding, interleaving, spreading, encryption.
- **Control and logic unit:** microprocessor + memory run the protocol stack and applications; control all blocks, SIM, display, keypad/touch screen and sensors.
- **User interface and sensors:** microphone, speaker, display/touch screen, camera, accelerometer, GPS, proximity sensor etc.
- **Battery and power management:** supplies regulated voltages, charges battery, reduces consumption in idle mode.

(Diagram 2 M, explanation 4 M)

## b) 5G bands comparison with free-space path loss

6 M

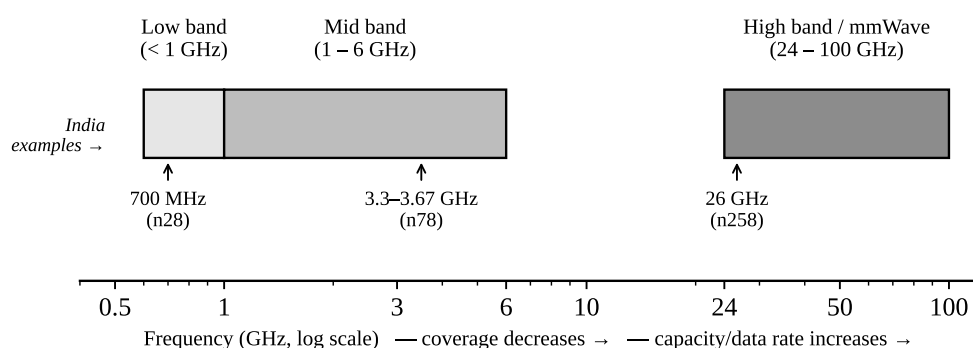


Fig.: 5G (NR) spectrum — low, mid and high (mmWave) bands

| Band                        | Advantages                                                                                       | Deployment challenges                                                                                                                         |
|-----------------------------|--------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| Low band (< 1 GHz)          | Wide-area and rural coverage, deep indoor penetration, fewer sites needed                        | Little bandwidth → modest speed; spectrum scarce and costly; large antennas for massive MIMO                                                  |
| Mid band (1–6 GHz, 3.5 GHz) | Best balance of coverage and capacity; 100 MHz channels; massive MIMO practical; 100 Mbps–1 Gbps | Coexistence with satellite/radar/altimeter users; needs denser sites than 4G; high auction price                                              |
| mmWave (24–100 GHz)         | Very large bandwidth (400–800 MHz); multi-Gbps; very low latency; high capacity hotspots         | Range of a few hundred metres; blocked by walls, foliage, rain and body; needs many small cells, fibre backhaul and beam tracking — high cost |

**Free-space path loss:**  $FSPL \text{ (dB)} = 20 \log d(\text{km}) + 20 \log f(\text{MHz}) + 32.44$ , with  $d = 1 \text{ km}$ :

| Frequency | 20 log d(km) | 20 log f(MHz) | FSPL = sum + 32.44 |
|-----------|--------------|---------------|--------------------|
| 700 MHz   | 0.00         | 56.90         | 89.34 dB           |
| 3500 MHz  | 0.00         | 70.88         | 103.32 dB          |
| 26000 MHz | 0.00         | 88.30         | 120.74 dB          |

At 26 GHz the loss is 31.40 dB more than at 700 MHz (and 17.42 dB more than at 3.5 GHz) — this is why mmWave cells are small and need high-gain beamforming, while low band gives coverage.

(Comparison 4 M, calculation 2 M)

### c) GSM architecture, call routing; VLR, AuC, EIR

6 M

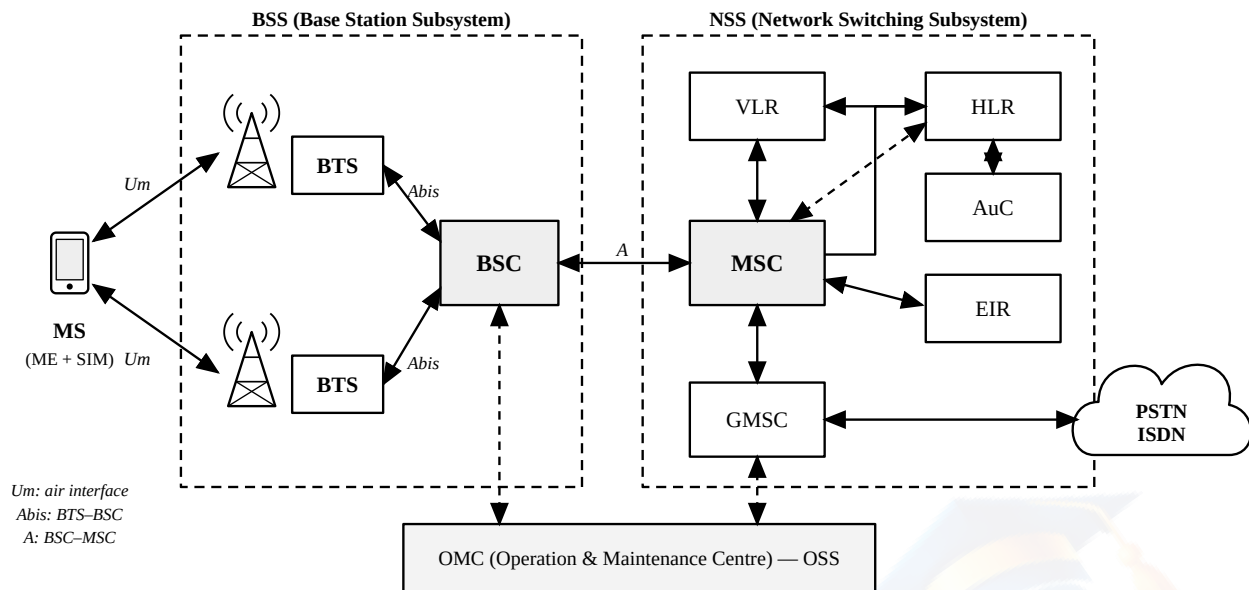


Fig.: GSM network architecture

#### Routing of a call to a mobile user:

- Call for the MSISDN reaches the GMSC of the subscriber's home network.
- GMSC queries the HLR; HLR knows the serving VLR and obtains a temporary roaming number (MSRN) from it.
- GMSC routes the call to the visited MSC using the MSRN.
- MSC/VLR pages the mobile in its location area through BSC and BTSs; after paging response, authentication and channel assignment, the call is connected.
- **VLR:** Visitor Location Register — temporary database of subscribers currently roaming in the MSC area; stores TMSI, location area; reduces queries to HLR.
- **AuC:** Authentication Centre — stores secret key  $K_i$  of every SIM and generates triplets (RAND, SRES,  $K_c$ ) for authentication and ciphering.
- **EIR:** Equipment Identity Register — list of IMEIs: white (valid), grey (monitored) and black (stolen/barred) handsets.

(Diagram 2 M, routing 2 M, functions 2 M)

## Q.6

### a) IMT-2020 usage scenarios and spectrum requirement

6 M

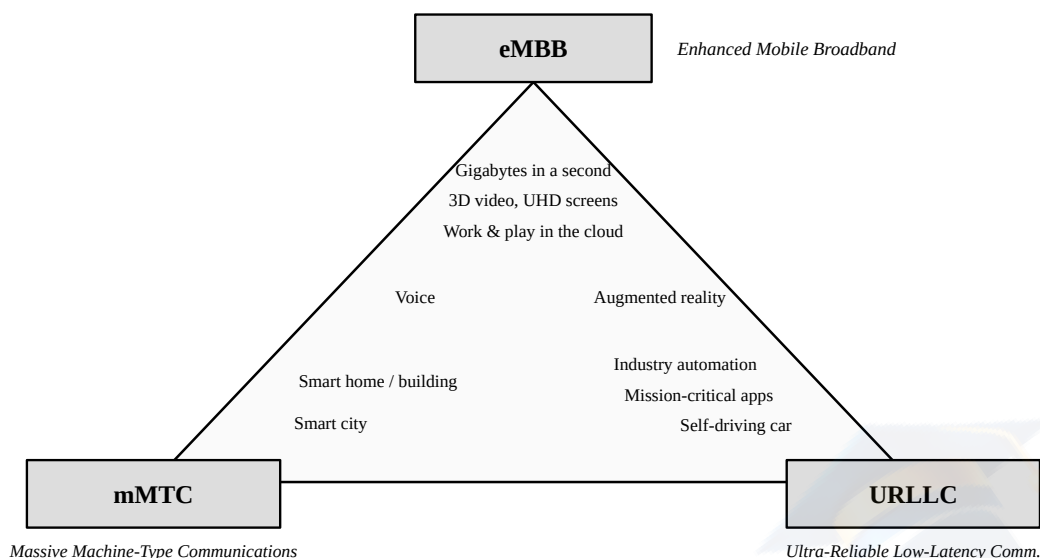


Fig.: IMT-2020 usage scenarios (ITU-R M.2083)

- **eMBB (enhanced Mobile Broadband):** very high data rates and capacity for human-centric use — 4K/8K video, AR/VR, cloud gaming, hotspots and wide-area coverage.
- **URLLC (Ultra-Reliable Low-Latency Communications):** 1 ms latency and very high reliability — autonomous vehicles, remote surgery, industrial robot control, smart grid protection.
- **mMTC (massive Machine-Type Communications):** a very large number ( $10^6/\text{km}^2$ ) of low-cost, low-power devices sending small data — smart meters, sensors, wearables, smart agriculture.

#### Spectrum requirement:

- IMT-2020 needs spectrum in all three ranges — low (< 1 GHz) for coverage, mid (1–6 GHz) for capacity and high (> 24 GHz) for very high data rates.
- Contiguous bandwidth of at least 100 MHz per carrier, and up to 1 GHz in bands above 6 GHz.
- WRC-19 identified new mmWave bands for IMT: 24.25–27.5, 37–43.5, 45.5–47, 47.2–48.2 and 66–71 GHz.
- Support for both FDD and TDD, and for licensed, shared and unlicensed spectrum.

(Diagram 1 M, three scenarios 3 M, spectrum 2 M)

## b) LTE architecture — eNodeB, MME, S-GW, P-GW, HSS

6 M

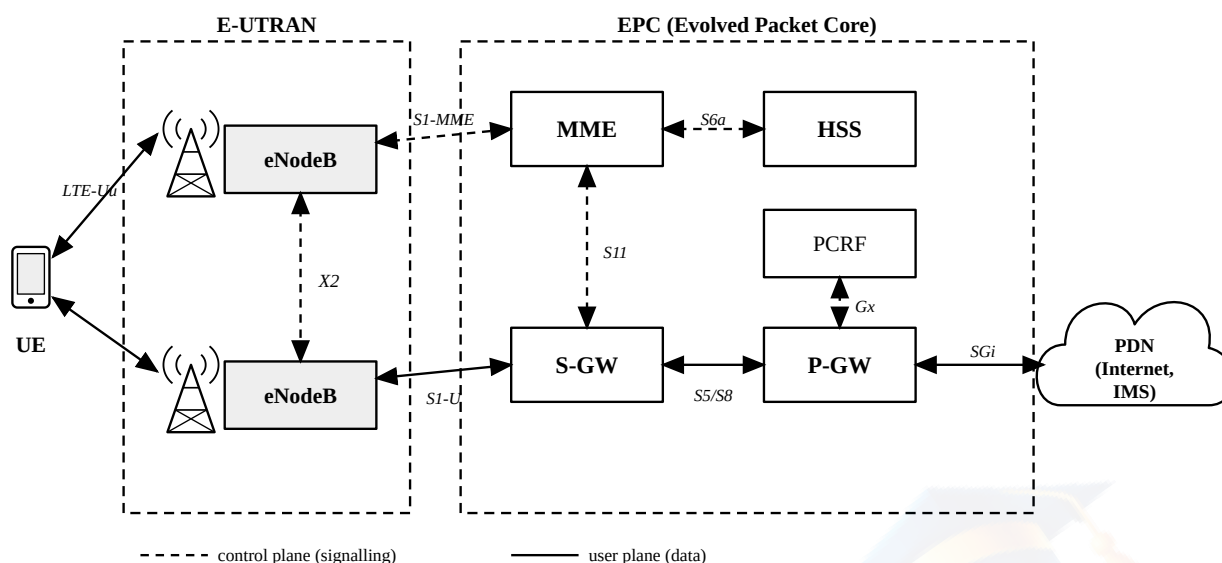


Fig.: LTE (4G) network architecture — EPS = E-UTRAN + EPC

LTE has a flat, all-IP architecture called EPS: **E-UTRAN** (eNodeBs) + **EPC** (MME, S-GW, P-GW, HSS, PCRF).

- **eNodeB:** base station with radio resource management, scheduling, admission control, ciphering and handover; eNodeBs connect to each other by X2 and to EPC by S1.
- **MME:** control node — attach, authentication (with HSS), tracking area update, paging, bearer management, gateway selection.
- **S-GW:** forwards user packets between eNodeB and P-GW; mobility anchor during handover; buffers downlink data for idle UE.
- **P-GW:** gateway to Internet/IMS (SGi); allocates IP address to UE; QoS/policy enforcement and charging.
- **HSS:** master subscriber database — profiles, authentication keys and current MME of the user.

(Diagram 2 M, five functions 4 M)

## c) Applications — industrial automation, smart cities, media and entertainment

6 M

### i) Industrial automation (Industry 4.0):

- Private 5G / Wi-Fi networks connect machines, robots, AGVs and sensors without cables — easy re-layout of production lines.
- URLLC gives millisecond control loops for robot arms and motion control; wireless PLC communication.
- IIoT sensors (vibration, temperature) send data for predictive maintenance and digital twins.
- AR glasses help technicians with remote expert guidance.

### ii) Smart cities:

- Smart traffic management — connected signals, V2X, adaptive timing, smart parking.
- Smart metering of electricity, water and gas (NB-IoT, LoRa, 5G mMTC).
- Smart street lighting, waste-bin level monitoring, air-quality and flood sensors.
- Public safety — HD CCTV surveillance and emergency communication.

### iii) Media and entertainment:

- 4K/8K video streaming and live broadcasting from 5G cameras without satellite vans.
- Cloud gaming and AR/VR experiences with low latency.
- Immersive 360° stadium and concert viewing; multi-angle replays on phones.
- Wi-Fi/Bluetooth home entertainment — smart TVs, wireless speakers, casting.

*(2 M each application area)*

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