## SCORING INDICATORS

SET-1

COURSE NAME : **MOBILE AND WIRELESS COMMUNICATION**
COURSE CODE : **5202** QID: **2109240235**

| Q No | Scoring Indicators | Split score | Sub Total | Total score |
|---|---|---|---|---|
| | **PART A** | | | **9** |
| I. 1 | Cell | | 1 | |
| I. 2 | Time Division Multiple Access (TDMA) | | 1 | |
| I. 3 | Home Location Register(HLR) | | 1 | |
| I. 4 | Enhanced Data Rate for GSM Evolution | | 1 | |
| I. 5 | 3rd Generation Partnership Projects (3GPP) or ITU | Both can be given 1 mark | 1 | |
| I. 6 | IEEE 802.11 | | 1 | |
| I. 7 | 2.4 GHz | | 1 | |
| I. 8 | 16QAM, 64QAM, QPSK | Any one of these | 1 | |
| I. 9 | g-NodeB | | 1 | |
| | **PART B** | | | **24** |
| II. 1 | • When distance between MS(Mobile Station) and BTS changes the power output of their signals varies.<br>• For Large distance, higher power required.<br>• When distance is less, power level has to reduced.<br>• This saves the battery life of MS<br>• The BSS controls the transmit power of both the MS and the BTS.<br>• The received MS power is monitored by the BSS and the receive BTS power is monitored by the MS and then reported to the BSS.<br>• Using these measurements the power of both MS and BTS can be adjusted accordingly | Summary of the given points can be given mark | 3 | |
| II. 2 | NTT(Nippon Telegraph And Telephone)<br>AMPS(Advanced Mobile Phone System)<br>NMT(Nordic Mobile Telephone)<br>Total Access Communication System (TACS) | One mark each | 3 | |
| II. 3 | Home Location Register(HLR),Visitor Location Register(VLR), EIR(Equipment Identity Register) | One mark Each | 3 | |

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| II. 4 | GSM air interface is also called Um interface<br>Connects Mobile Station and BTS<br>Consists of Physical Layer, Data Link Layer in OSI model<br>Featured with power control, saves the battery power of MS<br>If air distance is large, power required also higher. | | 3 | |
| II. 5 | • EDGE-Enhanced Data Rate for GSM Evolution<br>• Considered as 2.75G<br>• It provides an evolutionary migration path from GPRS to UMTS.<br>• It is standardized by 3GPP.<br>• EDGE is used for any packet switched application, like an Internet connection.<br>• It uses 8PSK modulation in order to achieve a higher data transmission rate. The modulation format is changed to 8PSK from GMSK(GMSK is used in GSM)<br>• EDGE delivers higher bit-rates per radio channel and it increase the capacity and performance.<br>• **Features**<br>• It provides an evolutionary migration path from GPRS to UMTS.<br>• It is standardized by 3GPP.<br>• EDGE is used for any packet switched application, like an Internet connection.<br>• It uses 8PSK modulation in order to achieve a higher data transmission rate. The modulation format is changed to 8PSK from GMSK(GMSK is used in GSM)<br>• EDGE delivers higher bit-rates per radio channel and it increase the capacity and performance.<br>• **Advantage**<br>• It has higher speed.<br>• It is an "always-on" connection<br>• It is more reliable and efficient<br>• It is cost efficient<br>• **Disadvantage**<br>• It consumes more battery.<br>• hardware needs upgradation.<br>• | Any 3 points. One mark for each point. | 3 | |

<table>
<tr>
<td>II. 6</td>
<td>
• UTRAN-UMTS Terrestrial Radio Access Network<br>
• Connects mobile user to Core network of UMTS.<br>
• Consists of NodeB and RNC.<br>
• NodeB( Same function of BTS in GSM)<br>
• RNC- Radio Network Controller- which controls a number of Node Bs.
</td>
<td>Any 3 points can be awareded mark. One mark for each</td>
<td>3</td>
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<td>II. 7</td>
<td>
Mobile WiMAX Technology (IEEE 802.16e)<br><br>
• Standard: Developed by IEEE as part of the WiMAX family for mobile broadband.<br>
• Mobility: Supports high-speed mobility, allowing users to remain connected while moving.<br>
• Frequency Bands: Operates in various frequency ranges, typically from 2.5 GHz to 3.5 GHz.<br>
• Channel Bandwidth: Offers flexible channel widths, from 1.25 MHz to 20 MHz.<br>
• Data Rates: Achieves download speeds up to 75 Mbps under optimal conditions.<br>
• OFDM: Utilizes Orthogonal Frequency Division Multiplexing (OFDM) for efficient spectrum usage.<br>
• QoS: Provides Quality of Service (QoS) for various applications, ensuring reliable performance.<br>
• Applications: Supports broadband Internet access, VoIP, and multimedia streaming.
</td>
<td>Any 3 points can be awarded mark. One mark for each.</td>
<td>3</td>
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<tr>
<td>II. 8</td>
<td>
<table>
<tr><th>Specifications</th><th>LTE</th><th>LTE Advanced</th></tr>
<tr><td>Standard</td><td>3GPP Release 8</td><td>3GPP Release 10</td></tr>
<tr><td>Bandwidth</td><td>supports 1.4MHz, 3.0MHz, 5MHz, 10MHz, 15MHz, 20MHz</td><td>70MHz Downlink(DL), 40MHz Uplink(UL)</td></tr>
<tr><td>Data rate</td><td>300 Mbps Downlink(DL) 4x4MIMO and 20MHz, 75 Mbps Uplink(UL)</td><td>1Gbps Downlink(DL), 500 Mbps Uplink(UL)</td></tr>
<tr><td>Theoretical Throughput</td><td>About 100Mbps for single chain(20MHz,100RB,64QAM), 400Mbps for 4x4 MIMO. 25% os this is used for control/signaling(OVERHEAD)</td><td>2 times than LTE</td></tr>
<tr><td>Maximum No. of Layers</td><td>2(category-3) and 4(category-4,5) in the downlink, 1 in the uplink</td><td>8 in the downlink, 4 in the uplink</td></tr>
<tr><td>Maximum No. of codewords</td><td>2 in the downlink, 1 in the uplink</td><td>2 in the downlink, 2 in the uplink</td></tr>
<tr><td>Spectral Efficiency(peak,b/s/Hz)</td><td>16.3 for 4x4 MIMO in the downlink, 4.32 for 64QAM SISO case in the Uplink</td><td>30 for 8x8 MIMO in the downlink, 15 for 4x4 MIMO in the Uplink</td></tr>
<tr><td>PUSCH and PUCCH transmission</td><td>Simultaneously not allowed</td><td>Simultaneously allowed</td></tr>
<tr><td>Modulation schemes supported</td><td>QPSK, 16QAM, 64QAM</td><td>QPSK, 16QAM, 64QAM</td></tr>
<tr><td>Access technique</td><td>OFDMA (DL),DFTS-OFDM (UL)</td><td>Hybrid OFDMA(DL), SC-FDMA(UL)</td></tr>
<tr><td>carrier aggregation</td><td>Not supported</td><td>Supported</td></tr>
<tr><td>Applications</td><td>Mobile broadband and VOIP</td><td>Mobile broadband and VOIP</td></tr>
</table>
</td>
<td>Any 3 points can be awarded mark. One mark for each.</td>
<td>3</td>
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| II.9 | **M2M vs. IoT: What's the difference?**<br>  <br>M2M: Machines; Hardware-based; Vertical applications; Deployed in a closed system; Machines communicating with machines; Uses non-IP protocol; Can use the cloud, but not required to; Machines use point-to-point communication, usually embedded in hardware; Often one-way communication; Main purpose is to monitor and control; Operates via triggered responses based on an action; Limited integration options, devices must have complementary communication standards; Structured data<br>IoT: Sensors; Software-based; Horizontal applications; Connects to a larger network; Machines communicating with machines, humans with machines, machines with humans; Uses IP protocols; Uses the cloud; Devices use IP networks to communicate; Back and forth communication; Multiple applications; multilevel communications; Can, but does not have to, operate on triggered responses; Unlimited integration options, but requires software that manages communications/protocols; Structured and unstructured data | Any 3 points can be awarded mark. One mark for each. | 3 | |
| II.10 | **. Release 15**<br>While initial specifications enabled non-standalone 5G (NSA) integrated into previous-generation LTE networks<br>**Release 16**<br>Release 16 was a major release and necessary to broaden the overall system specifications of Release 15<br>**Release 17**<br>Release 17 features already in the pipeline include new work and/or enhancements for URLLC for NR-based IIoT, NR-based NTN, MIMO<br>**Release 18**<br>Work items possible for that release may include enhancements of multimedia telephony services | | 3 | |
| | **PART C** | | | **42** |
| III. | **1. Call Initiation**<br>• **User Action:** The caller dials a number on their mobile device.<br>• **Signal Generation:** The mobile device generates a signaling message indicating a call request.<br>**2. Accessing the Network**<br>• **Cell Selection:** The mobile device connects to the nearest cell tower (base station) based on signal strength.<br>• **Channel Allocation:** The network allocates a radio channel for the call.<br>**3. Call Setup Procedure**<br>• **Signaling to the Network:** The mobile device sends a request to the base station, which forwards it to the Mobile Switching Center | | 7 | |

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| | (MSC).<br>• **Authentication:** The MSC verifies the caller's identity, checking if the mobile number is valid and if the user has sufficient balance or is authorized to make the call.<br>**4. Routing the Call**<br>• **Destination Lookup:** The MSC looks up the recipient's mobile number in its database to find the corresponding MSC for the recipient.<br>• **Signal Forwarding:** The call setup request is routed through various network elements, potentially involving multiple MSCs.<br>**5. Establishing the Connection**<br>• **Ring the Recipient:** Once the recipient MSC is identified, it forwards the call request to the recipient's mobile device, which may cause it to ring.<br>• **Recipient Response:** If the recipient answers, a two-way connection is established.<br>**6. Call Connection**<br>• **Audio Channel Establishment:** A dedicated channel is set up for voice transmission between the two parties. This can be a circuit-switched connection in traditional systems or a packet-switched connection in VoIP.<br>**7. Call in Progress**<br>• **Voice Transmission:** Both parties can communicate through the established channel. Their voices are converted to digital signals and transmitted over the airwaves.<br>**8. Call Termination**<br>• **Ending the Call:** When either party hangs up, a disconnect signal is sent.<br>• **Resource Release:** The network releases the resources (channels, signaling) that were allocated for the call.<br>**9. Post-Call Handling**<br>• **Billing and Logging:** The call details are logged for billing and record-keeping purposes. Call duration, time, and other metrics may be recorded. | | | |

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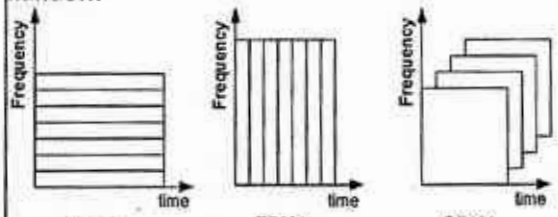
| IV. | Multiple access techniques used to access channel in a communication system.<br>**FDMA**-allots a different sub-band of frequency to each different user to access the network. In FDMA a channel is not in use, the channel is left idle instead of allotting to the other users. Continuous transmission possible.<br>**TDMA**-Used when continuous transmission not required. Time slot given for each user. Full bandwidth can be allotted to a user.<br>Handoff process simple.<br>**CDMA- Code Division Multiple Access (CDMA)**-Code division multiple access technique is an example of multiple access where several transmitters use a single channel. Full spectrum can be used by a single user. Continuous transmission possible. Provides soft handoff.<br>  <br><br>**Space Division Multiple Access (SDMA)**- Space division multiple access or spatial division multiple access is a technique which is MIMO (multiple-input multiple-output) architecture and used mostly in wireless and satellite communication<br>**Spread Spectrum Multiple Access(SSMA)**- Spread spectrum multiple access (SSMA) uses signals which have a transmission bandwidth whose magnitude is greater than the minimum required RF bandwidth. Two type Spread spectrum techniques- **FHSS, DSSS** | Figure-3<br>Explanation-4 | 7 | |
| V. | **HANDOFF**<br>In cellular communications, the handoff is the process of transferring an active call or data session from one cell in a cellular network or from one channel to another.<br>In satellite communications, it is the process of transferring control from one earth station to another.<br>Handoff is necessary for preventing loss of interruption of service to a caller or a data session user. Handoff is also called handover<br>Situations triggering Handoff<br>• If a subscriber who is in a call or a data session moves out of coverage of one cell and enters coverage area of another cell, a handoff is triggered.<br>• Each cell has a pre-defined capacity, i.e. it can handle only a specific number of subscribers. If the number of users using a particular cell reaches its maximum capacity, then a handoff occurs | Explanation-5 marks<br>Figures 2 marks<br>Explanation without figures also can give full mark if sufficient information given | 7 | |

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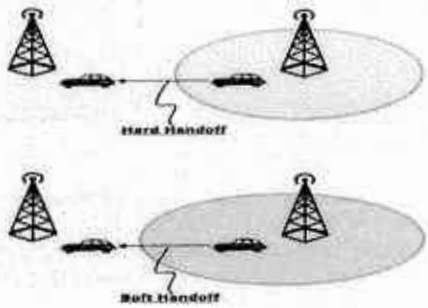
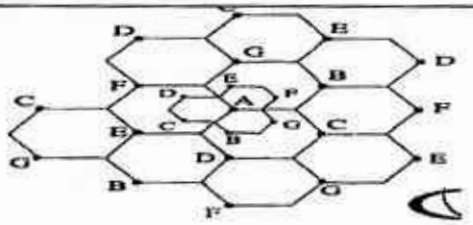
| | • Cells are often sub-divided into microcells. A handoff may occur when there is a transfer from the large cell to the smaller cell and vice versa.<br>• Handoffs may also occur when there is an interference of calls using the same frequency for communication.<br>TYPES OF HANDOFF<br>• **Hard Handoff** – In a hard handoff, an actual break in the connection occurs while switching from one cell to another. The radio links from the mobile station to the existing cell is broken before establishing a link with the next cell. It is generally an inter-frequency handoff. It is a "break before make" policy.<br>• **Soft Handoff** – In soft handoff, at least one of the links is kept when radio links are added and removed to the mobile station. This ensures that during the handoff, no break occurs. This is generally adopted in co-located sites. It is a "make before break" policy.<br>• **Mobile Assisted Handoff (MAHO)** is a technique in which the mobile devices assist the Base Station Controller (BSC) to transfer a call to another BSC. It is used in GSM cellular networks.<br>  <br> | | | |
| VI. | Capacity improvement Techniques are **splitting, sectoring, and coverage zone .**<br><br>**Cell Splitting-** Cell splitting is the process of subdividing a congested cell into smaller cells, each with its own base station and a corresponding reduction in antenna height and transmitter power. Cell splitting increases the capacity of a cellular system since it increases the number of times that channels are reused | Explanation 4 marks Figures 3 marks | 7 | |



**Cell sectoring**

Replacing a single omni-directional antenna at the base station by several directional antennas, each radiating within a specified sector. The factor by which the co-channel interference is reduced depends on the amount of sectoring used. A cell is normally partitioned into three 120 degree sectors or six 60° sectors

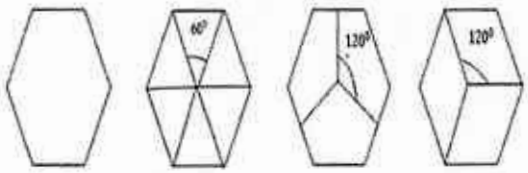
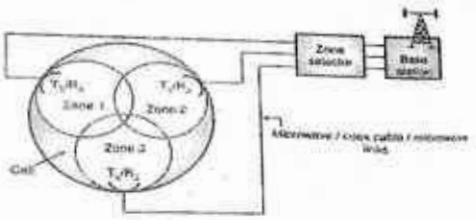



Fig: omni-directional $60^0$ sectoring $120^0$ sectoring

**Micro cell or coverage zone**

A **microcell** is a cell in a mobile phone network served by a low power cellular base station (tower), covering a limited area such as a mall, a hotel, or a transportation hub. A microcell is usually larger than a picocell, though the distinction is not always clear.




VII.

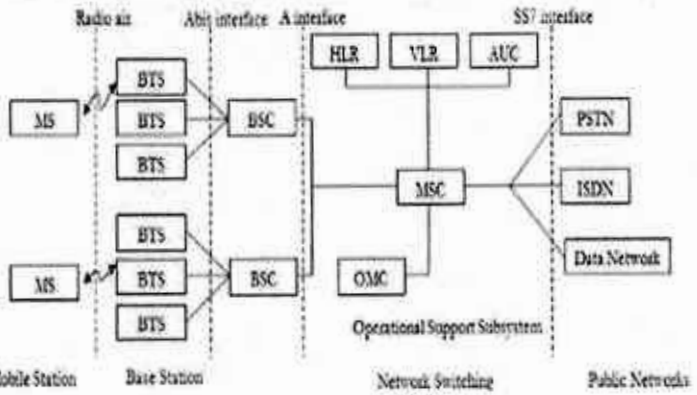



Fig: GSM Architecture

Block diagram 4 marks
Explanation 3 marks

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| | Figure shows the block diagram of architecture of GSM.<br>MS- Mobile station. Consists of mobile handset and SIM card.<br>BTS- Base Transceiver Station. MS connected to BTS through air interface called Um interface. A number of BTS connected to BSC(Base Station Controller) via Abis interface.<br>MSC-Mobile switching Center is the heart of a GSM network.<br>Registers like HLR,VLR, EIR and Authentication Center connected to MSC.<br>MSC or GMSC can connect a GSM network to other networks such as PDN or PSTN. | | | |
| VIII. | **CDMA IS-95 Concept**<br>• **Technology**: Uses Code Division Multiple Access (CDMA) for simultaneous communication.<br>• **Unique Spreading Codes**: Assigns distinct codes to each user, enabling multiple calls over the same frequency.<br>• **Signal Spreading**: Spreads the signal over a wide bandwidth, enhancing resistance to interference and improving capacity.<br>• **Higher Spectral Efficiency**: Offers better utilization of available bandwidth compared to time-division or frequency-division systems.<br>• **Data Rates**: Supports voice and data services with speeds up to 115 kbps.<br>• **Power Control**: Incorporates power control mechanisms to maintain signal quality and minimize battery usage.<br>• **Soft Handoffs**: Facilitates seamless transitions between cells, enhancing call continuity during movement.<br>• **Voice and Data**: Supports a variety of services, including voice calls, SMS, and data transmission.<br>• **Foundation for Future Technologies**: Laid the groundwork for later CDMA standards like CDMA2000 and 3G technologies.<br>• IS-95 stands for **Interim Standard 95** and is also known as **CDMAOne**.<br>• It was the first ever CDMA-based digital cellular technology and was developed by Qualcomm. It is an 2G cellular system based on DS-CDMA.(Direct Sequence CDMA)<br>• **DSSS** is Direct Sequence Spread Spectrum Technique | | 7 | |

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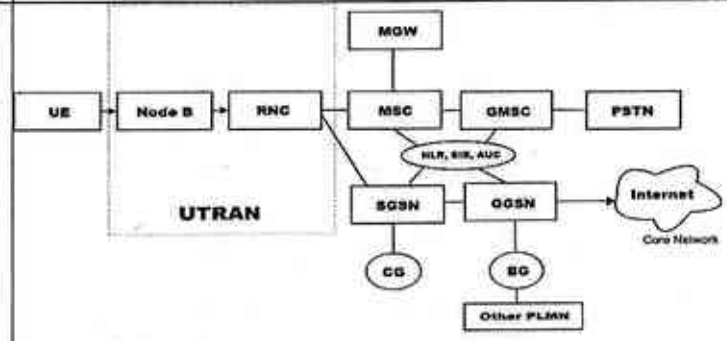
| | which is a spread spectrum technique in which the data to be transmitted is encoded using spreading code and received and then decoded using the same code.<br>– It is used to avoid interference, spying and jamming. The spreading code used is known to transmitter and receiver only. | | | |
| IX. |  <br>UE: User Equipment<br>RNC: Radio Network Controller<br>SGSN: Serving GPRS Support Node<br>GGSN: Gateway GPRS Support Node<br>CG: Charging Gateway<br>BG: Border Gateway<br>MSC: Mobile Switching Center<br>MGW:<br>GMSC: Gateway MSC<br>PSTN: Public Switched Telephone Network<br>HLR: Home Location Register<br>EIR: Equipment Identity Register<br>AUC: Authentication Center<br>Fig: UMTS Architecture<br>UE- user equipment( SIM+Handset) connected to NodeB. BTS in GSM replaced by NodeB in UMTS.<br>RNC-Radio Network Controller- Control several NodeBs and allocate radio resources. RNC-Radio Network Controller.<br>The RNC is a functional element of the UMTS RNS (Radio Network System) which controls a number of Node Bs. Responsibilities of the RNC include<br>**radio resource management and control,**<br>**air interface security,**<br>**mobility procedures and system synchronization**<br>UTRAN-(UMTS terrestrial Random Access Network) Is a collective name for NodeB and RNC. UMTS is backward compatible therefore all network elements of GSM and GPRS are there, like MSC, SGSN,GGSN etc. Gateway MSC connects UMTS networks to other Networks. | Block Diagram-4 Explanation-3 | 7 | |
| X. | WiMAX is a technology based on the IEEE 802.16 specifications to enable the delivery of last-mile wireless broadband access as an alternative to cable and DSL. Acronym for **Worldwide Interoperability for Microwave Access**. Based on Wireless MAN | Explanation 3 marks features 4 marks | 7 | |

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| | technology. A wireless technology optimized for the delivery of IP centric services over a wide area. A scalable wireless platform for constructing alternative and complementary broadband networks. A certification that denotes interoperability of equipment built to the IEEE 802.16 or compatible standard.<br>Wi-max is operated at 2.5Ghz frequency band. There will be Wi-Max antenna in the tower, and there will be customer premise equipment(CPE). CPE receives signal from the tower and then goes to a LAN network.<br>**Features of wimax are**<br>**High-Speed Data**: WiMAX offers broadband speeds, comparable to wired connections, supporting data-intensive applications like video streaming and online gaming.<br>**Long-Range Coverage**: It covers larger areas, reducing the need for numerous base stations, making it cost-effective for network providers.<br>**Scalability**: WiMAX can scale easily to accommodate more users or expand network coverage.<br>**Quality of Service (QoS)**: It supports QoS for prioritizing different types of traffic, ensuring reliable performance for voice, video, and data.<br>**Non-Line-of-Sight (NLOS) Capability**: It can work through obstacles like buildings, enhancing its reach and usability.<br>**Last-Mile Connectivity**: WiMAX bridges the digital divide by providing internet access to remote and underserved areas | | | |
| XI. | • OVSF stands for orthogonal variable spreading factor codes.<br>• The OVSF codes are used as the channelization codes in WCDMA system.<br>• These codes are orthogonal to each other.<br>• Used to spread data signal in the system.<br>• At Transmitter data multiplied with OVSF Code its bandwidth increases, that is spreading happens.<br>At receiver the spread signal multiplied by same OVSF code, therefore we will get the de-spread code | Explaining basic concepts-3 marks | 7 | |

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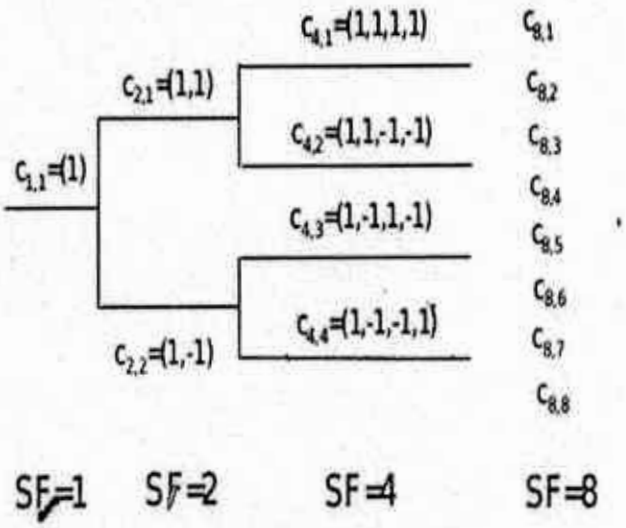
| | Spreading Factor) codes<br>$H_1=[1]$<br>$H_2=\begin{bmatrix} H_1 & H_1 \\ H_1 & -H_1 \end{bmatrix}$ $\quad H_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$<br>$H_4 = \left[\begin{array}{cc\|cc} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ \hline 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{array}\right]$<br>  <br> | Figure-4 marks | | |
| XII. | . WLAN-IEEE 802.11 (specification)<br>Wireless Local Area Network (WLAN) technology enables wireless data transmission between devices within a limited geographic area, typically a home, office, or public hotspot. WLAN uses radio waves to create a network, allowing devices like laptops, smartphones, and tablets to connect to the internet and each other without physical cables. WLANs are commonly implemented using Wi-Fi technology, offering convenience, mobility, and scalability. They have become ubiquitous in modern computing, powering wireless internet access in homes, businesses, airports, and public spaces, fostering connectivity and enabling seamless access to online resources.<br>Advantages<br>• They provide clutter-free homes, offices and other | Overall Explanation-3<br>Advantage, disadvantage 3 points-4 | 7 | |

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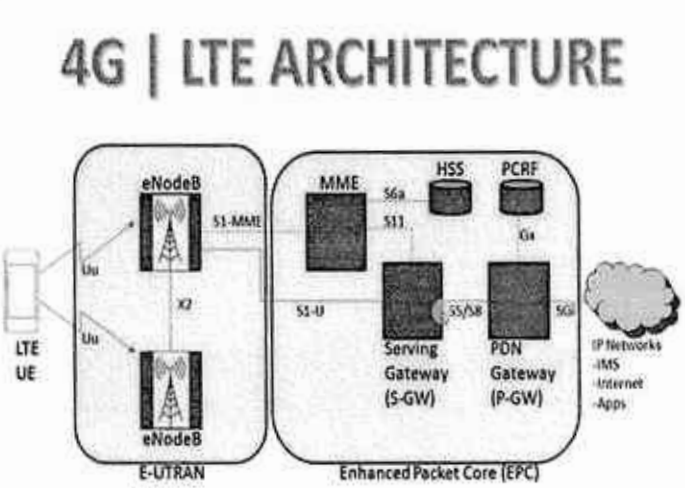
| | networked places.<br>• The LANs are scalable in nature, i.e. devices may be added or removed from the network at greater ease than wired LANs.<br>• The system is portable within the network coverage. Access to the network is not bounded by the length of the cables.<br>• Installation and setup are much easier than wired counterparts.<br>• The equipment and setup costs are reduced.<br><br>Disadvantages<br><br>• Since radio waves are used for communications, the signals are noisier with more interference from nearby systems.<br>• Greater care is needed for encrypting information. Also, they are more prone to errors. So, they require greater bandwidth than the wired LANs.<br>• WLANs are slower than wired LANs. | | | |
| XIII. | LTE (Long-Term Evolution) is a 4G wireless communication standard known for its high-speed data transmission and low latency. Its architecture can be represented by a simplified block diagram, which typically consists of the following key components<br><br>  <br><br><br>**User Equipment (UE):**<br><br>• Represents the end-user device, such as a smartphone, tablet, or modem.<br>• Contains the LTE modem and the antenna for wireless communication.<br><br>• **eNodeB (Evolved NodeB):** | Block diagram 4 marks<br><br>Explanation 3 marks | 7 | |

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| | • Also known as the base station or cell tower.<br>• Responsible for radio communication with the UE.<br>• Handles tasks like radio resource management and handover procedures.<br>• Connected to the EPC (Evolved Packet Core) via an interface called S1 (for user plane) and X2 (for control plane) for communication with other eNodeBs.<br><br>• **Evolved Packet Core (EPC):**<br><br>• The core network of LTE, responsible for handling data and signaling traffic.<br>• Comprises several functional elements:<br>o **MME (Mobility Management Entity):** Handles UE tracking and signaling for mobility.<br>o **SGW (Serving Gateway):** Routes data packets between the UE and the PDN (Packet Data Network).<br>o **PGW (Packet Data Network Gateway):** Connects the EPC to external networks, like the internet or private networks.<br><br>o **HSS (Home Subscriber Server):** Stores user subscription and authentication data.<br>o **PCRF (Policy and Charging Rules Function):** Enforces QoS policies and handles charging for data usage.<br>o **DNS (Domain Name System):** Resolves domain names to IP addresses.<br><br>• **Public Data Network (PDN):**<br><br>• Represents the external networks, such as the internet or enterprise networks, that the UE accesses.<br>• Data traffic between the UE and PDN is routed through the EPC.<br><br>• **Backhaul Network:**<br><br>• Connects eNodeBs to the core network and may include optical fibers, microwave links, or other high-capacity links. | | | |
| XIV. | **5G NR (New Radio)** is a new radio access technology (RAT) developed by the 3rd Generation Partnership Project (3GPP) for the 5G (fifth generation) mobile network. It was designed to be the global standard for the air interface of 5G networks. It is based on orthogonal frequency-division multiplexing (OFDM), as is the 4G (fourth generation) long-term evolution (LTE) standard. | Explanation- 3 marks<br>Any 4 features- 4 marks | 7 | |

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| | 5G NR employs a raft of new engineering techniques that move more data through the core network faster and revolutionize the discrete operations of the air interface, which is the client device's interaction with the network provider radio hardware. Some of the improvements that 5G NR introduces are the following<br>diversity of spectrum that ranges from several hundred kilohertz to millimeter wave to enable various use cases, cell sizes and data rates;<br>modulation -- new orthogonal frequency-division multiplexing methods -- and channel-coding techniques;<br>frequency reuse algorithms, even in dense environments;<br>massive multiple input, multiple output and evolved beamforming capabilities; and slot time operations developed to deliver ultralow-latency communications.<br><br>1. **Higher Data Rates**: Data rates upto 20Gbps<br>2. **Low Latency**: ultra-low latency,critical for applications like real-time gaming, autonomous vehicles, and remote surgery.<br>3. **Massive Device Connectivity**: It supports a massive number of connected devices (IoT), offering efficient use of network resources for diverse applications.<br>4. **Enhanced Mobile Broadband (eMBB)**<br>5. **Ultra-Reliable Low Latency Communications (URLLC)**: It offers highly reliable connections for mission-critical applications such as industrial automation and public safety.<br>6. **Network Slicing**: 5G enables the creation of virtual network slices<br>7. **Beamforming and MIMO**: 5G utilizes advanced antenna technologies like beamforming and massive MIMO to enhance coverage, capacity, and overall network performance.<br>8. **Millimeter Wave (mmWave)**: Utilizes higher-frequency spectrum, such as mmWave bands, to achieve ultra-fast speeds, but with shorter propagation distances requiring more base stations.<br>9. **Dynamic Spectrum Sharing (DSS)**: Allows for more efficient spectrum utilization by sharing spectrum resources with existing 4G LTE networks during the transition to 5G.<br>10. **Network Function Virtualization (NFV)** and **Software-Defined Networking (SDN)**: 5G networks leverage virtualization and software-defined approaches to enhance network flexibility and scalability. | | | |

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| | 11. **Security Enhancements**: 5G incorporates improved security measures, including stronger encryption and authentication protocols, to protect data and user privacy.<br>12. **Global Standardization**: 5G NR is developed following global standards, ensuring compatibility and interoperability across different networks and devices. | | | |