Subject Name Solutions

4351602 – Winter 2024

Semester 1 Study Material

Detailed Solutions and Explanations

Question 1(a) [3 marks]

List out types of congestion control and explain any one

Solution

Type	Description
Open-Loop	Prevents congestion before it occurs
Closed-Loop	Manages congestion after detection

Open-Loop Congestion Control Explanation:

- **Prevention approach**: Takes action before congestion occurs
- **Traffic shaping**: Controls data rate at sender
- **Admission control**: Limits new connections during high traffic
- **Load shedding**: Drops packets when buffer full

Mnemonic

"Open Prevents Traffic Admission Load"

Question 1(b) [4 marks]

Explain Address Resolution Protocol briefly

Solution

ARP (Address Resolution Protocol) maps IP addresses to MAC addresses in local networks.

Working Process:

- **ARP Request**: Broadcast message asking "Who has IP X?"
- **ARP Reply**: Target device responds with its MAC address
- **ARP Cache**: Stores IP-MAC mappings for future use
- **Dynamic mapping**: Updates entries automatically

Table 1: ARP Message Types

Type	Purpose	Broadcast
ARP Request	Find MAC address	Yes
ARP Reply	Provide MAC address	No

Mnemonic

"ARP Requests Broadcast, Replies Cache Dynamic"

Question 1(c) [7 marks]

Explain TCP/IP model with all layers and functionalities of each layer

Solution

TCP/IP Model is a four-layer network protocol stack for internet communication.

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Application Layer] {-{-}{} B[Transport Layer]}
    B {-{-}{} C[Internet Layer] }
    C {-{-}{} D[Network Access Layer]}
{Highlighting}
{Shaded}
```

Layer Functions:

Layer	Function	Protocols
Application	User interface, network services	HTTP, FTP, SMTP
Transport	End-to-end communication	TCP, UDP
Internet	Routing, addressing	IP, ICMP
Network Access	Physical transmission	Ethernet, WiFi

- **Application Layer**: Provides network services to applications
- **Transport Layer**: Ensures reliable data delivery with error control
- **Internet Layer**: Routes packets across networks using IP addressing

- **Network Access Layer**: Handles physical data transmission

Mnemonic

"All Transport Internet Network"

Question 1(c OR) [7 marks]

Explain OSI model with each layer functionality

Solution

OSI Model is a seven-layer reference model for network communication.

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Application Layer 7] {-{-}{} B[Presentation Layer 6]}
    B {-{-}{} C[Session Layer 5]}
    C {-{-}{} D[Transport Layer 4]}
    D {-{-}{} E[Network Layer 3]}
    E {-{-}{} F[Data Link Layer 2]}
    F {-{-}{} G[Physical Layer 1]}
{Highlighting}
{Shaded}
```

Layer Functionalities:

Layer	Function	Examples
Physical (1)	Bit transmission	Cables, signals
Data Link (2)	Frame delivery	Ethernet, switches

Network (3)	Routing packets	IP, routers
Transport (4)	End-to-end delivery	TCP, UDP
Session (5)	Dialog management	NetBIOS
Presentation (6)	Data formatting	SSL, compression
Application (7)	User interface	HTTP, email

Mnemonic

"Physical Data Network Transport Session Presentation Application"

Question 2(a) [3 marks]

Explain subnetting in short

Solution

Subnetting divides a large network into smaller sub-networks for better management.
Key Concepts:

- **Subnet mask**: Defines network and host portions
- **Network efficiency**: Reduces broadcast traffic
- **Address conservation**: Better IP utilization
- **Security**: Isolates network segments

Example: Network: 192.168.1.0/24 $\rightarrow$ *Subnets* : 192.168.1.0/26, 192.168.1.64/26

Mnemonic

"Subnet Network Efficiency Address Security"

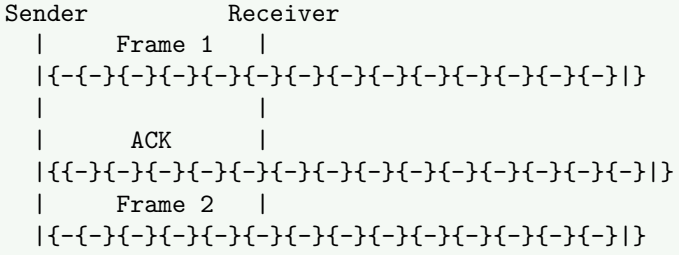
Question 2(b) [4 marks]

Explain stop and wait ARQ protocol of data link layer with example

Solution

Stop and Wait ARQ is a flow control protocol ensuring reliable data transmission.
Working Process:

- **Send frame**: Transmitter sends one frame
- **Wait for ACK**: Sender waits for acknowledgment
- **Timeout**: Retransmits if no ACK received
- **Next frame**: Sends next frame after ACK



Example: File transfer where each packet waits for confirmation before sending next.

Mnemonic

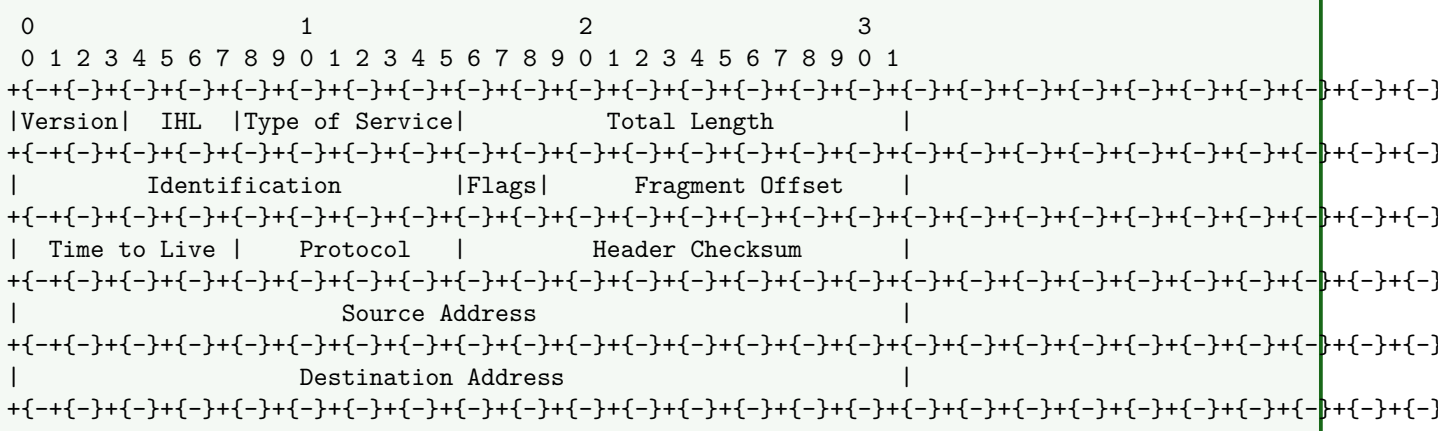
"Send Wait Timeout Next"

Question 2(c) [7 marks]

Draw diagram of IPv4 datagram Header and explain it

Solution

IPv4 Header contains control information for packet routing and delivery.



Field Explanations:

Field	Size	Function
Version	4 bits	IP version (4 for IPv4)
IHL	4 bits	Header length
Type of Service	8 bits	Quality of service
Total Length	16 bits	Packet size
TTL	8 bits	Hop limit
Protocol	8 bits	Next layer protocol
Source/Dest Address	32 bits each	IP addresses

Mnemonic

"Version IHL Service Total TTL Protocol Source Destination"

Question 2(a OR) [3 marks]

What is HTTPS? List important key features of HTTPS

Solution

HTTPS (HTTP Secure) is encrypted HTTP using SSL/TLS for secure web communication.

Key Features:

- **Encryption**: Data encrypted in transit
- **Authentication**: Verifies server identity
- **Data integrity**: Prevents data tampering
- **Trust**: SSL certificates provide validation

Security Benefits:

- Protects sensitive information
- Prevents man-in-the-middle attacks
- Search engine ranking boost

Mnemonic

"HTTPS Encrypts Authentication Data Trust"

Question 2(b OR) [4 marks]

Give Answer of any two:

Solution

1) How many bits HOST ID use by class B and C?
- **Class B**: 16 bits for Host ID (65,534 hosts)
- **Class C**: 8 bits for Host ID (254 hosts)

2) What is IP range for Class A and D?
- **Class A**: 1.0.0.0 to 126.255.255.255
- **Class D**: 224.0.0.0 to 239.255.255.255 (Multicast)

Class	Range	Host Bits
B	128.0.0.0 - 191.255.255.255	16 bits
C	192.0.0.0 - 223.255.255.255	8 bits
A	1.0.0.0 - 126.255.255.255	24 bits
D	224.0.0.0 - 239.255.255.255	Multicast

Mnemonic

"B=16,
C=8,
A=1-126,
D=224-239"

Question 2(c OR) [7 marks]

Explain classful IPv4 addresses scheme

Solution

Classful IPv4 Addressing divides IP address space into five classes based on first octets.
Address Classes:

Class	Range	Network Bits	Host Bits	Usage
A	1-126	8	24	Large networks
B	128-191	16	16	Medium networks
C	192-223	24	8	Small networks
D	224-239	-	-	Multicast
E	240-255	-	-	Experimental

```
pie title IPv4 Address Classes
    "Class A (50\%)" : 50
    "Class B (25\%)" : 25
    "Class C (12.5\%)" : 12.5
    "Class D (6.25\%)" : 6.25
    "Class E (6.25\%)" : 6.25
```

Characteristics:
- **Class A**: 16.7 million hosts per network
- **Class B**: 65,534 hosts per network

- **Class C**: 254 hosts per network
- **Limitations**: Address wastage, inflexible allocation

Mnemonic

"A-Large, B-Medium, C-Small, D-Multicast, E-Experimental"

Question 3(a) [3 marks]

List out types of applications uses mobile computing

Solution

Mobile Computing Applications:

Type	Examples
Communication	WhatsApp, Email, Video calls
Navigation	GPS, Google Maps
E-commerce	Shopping apps, Mobile banking
Entertainment	Games, Streaming, Social media
Business	CRM, Sales tracking
Healthcare	Health monitoring, Telemedicine

- **Location-based services**: GPS navigation, location sharing
- **Mobile payments**: Digital wallets, UPI transactions
- **Social networking**: Facebook, Instagram, Twitter

Mnemonic

"Communication Navigation E-commerce Entertainment Business Healthcare"

Question 3(b) [4 marks]

Explain use of Gateways and list types of Gateways

Solution

Gateway connects networks with different protocols and architectures.
Uses of Gateways:

- **Protocol conversion**: Translates between different protocols
- **Network bridging**: Connects dissimilar networks
- **Security**: Firewall and access control
- **Data filtering**: Manages traffic flow

Types of Gateways:

Type	Function
Network Gateway	Routes between networks
Internet Gateway	Connects to internet
Protocol Gateway	Protocol translation
Application Gateway	Application-level filtering

Mnemonic

"Gateways Convert Bridge Secure Filter"

Question 3(c) [7 marks]

Draw and explain architecture of mobile computing

Solution

Mobile Computing Architecture consists of three main components working together.

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[Mobile Device] {{-}{-}{} B[Communication Network]}
    B {{-}{-}{} C[Fixed Infrastructure]}

    A1[Hardware] {-{-}{} A}
    A2[OS \& Apps] {-{-}{} A}
    A3[Data] {-{-}{} A}

    B1[Wireless Network] {-{-}{} B}
    B2[Protocols] {-{-}{} B}
    B3[Base Stations] {-{-}{} B}

    C1[Servers] {-{-}{} C}
    C2[Databases] {-{-}{} C}
    C3[Internet] {-{-}{} C}
{Highlighting}
{Shaded}
```

Architecture Components:

Component	Elements	Function
Mobile Unit	Devices, OS, Apps	User interface, processing
Communication Network	Wireless links, protocols	Data transmission
Fixed Infrastructure	Servers, databases	Backend services

Key Features:

- **Mobility**: Users can move while maintaining connectivity
- **Wireless communication**: Radio waves for data transmission
- **Distributed computing**: Processing across multiple devices
- **Location independence**: Access services from anywhere

Challenges:

- **Limited bandwidth**: Wireless networks have capacity constraints
- **Battery life**: Mobile devices have power limitations
- **Security**: Wireless transmission vulnerable to attacks

Mnemonic

"Mobile Communication Fixed - Mobility Wireless Distributed Location"

Question 3(a OR) [3 marks]

List security standards in mobile computing

Solution

Mobile Computing Security Standards:

Standard	Purpose
WPA3	WiFi security protocol
SSL/TLS	Secure data transmission
IPSec	IP layer security

EAP	Authentication framework
802.11i	Wireless LAN security
FIPS 140-2	Cryptographic module standards

- **Authentication protocols**: Verify user identity
- **Encryption standards**: Protect data confidentiality
- **Access control**: Manage resource permissions

Mnemonic

"WPA SSL IPSec EAP 802.11i FIPS"

Question 3(b OR) [4 marks]

Explain key functions of communication gateway

Solution

Communication Gateway manages data exchange between different network systems.
Key Functions:

Function	Description
Protocol Translation	Converts between protocols
Data Format Conversion	Changes data formats
Routing	Directs messages to destinations
Security	Access control and filtering

Detailed Functions:

- **Message routing**: Determines optimal path for data
- **Error handling**: Manages transmission errors and recovery
- **Traffic management**: Controls data flow and congestion
- **Authentication**: Verifies sender and receiver identity

Benefits:

- Enables interoperability between different systems
- Centralizes network management
- Provides security checkpoint

Mnemonic

"Protocol Data Routing Security - Message Error Traffic Authentication"

Question 3(c OR) [7 marks]

Explain use of middleware and list types of middleware

Solution

Middleware provides software layer between applications and operating system for distributed computing.
Uses of Middleware:

- **Connectivity**: Links distributed applications
- **Interoperability**: Enables different systems to work together
- **Abstraction**: Hides complexity of underlying systems
- **Scalability**: Supports system growth and expansion

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Applications] {-{-}{} B[Middleware Layer]}
    B {-{-}{} C[Operating System]}
    B {-{-}{} D[Network Services]}
    B {-{-}{} E[Database Services]}
{Highlighting}
{Shaded}
```

Types of Middleware:

Type	Function	Examples
Message-Oriented	Asynchronous communication	IBM MQ, RabbitMQ
Remote Procedure Call	Synchronous communication	gRPC, XML-RPC
Object Request Broker	Object communication	CORBA
Database Middleware	Database connectivity	ODBC, JDBC
Transaction Processing	Transaction management	Tuxedo
Web Middleware	Web services	Apache, IIS

Benefits:

- **Reduced complexity**: Simplifies application development
- **Reusability**: Common services for multiple applications
- **Maintainability**: Centralized management of services
- **Platform independence**: Works across different systems

Mnemonic

"Message RPC Object Database Transaction Web"

Question 4(a) [3 marks]

Explain working phases of Mobile IP

Solution

Mobile IP Working Phases enable seamless mobility for mobile devices across networks.
Three Main Phases:

Phase	Function
Agent Discovery	Find home/foreign agents
Registration	Register with foreign agent
Tunneling	Forward packets to mobile node

Phase Details:

- **Agent Discovery**: Mobile node detects available agents through advertisements
- **Registration**: Mobile node registers current location with home agent
- **Tunneling**: Home agent encapsulates and forwards packets to foreign agent

Mnemonic

"Agent Registration Tunneling"

Question 4(b) [4 marks]

Explain Handover management in Mobile IP

Solution

Handover Management maintains connectivity when mobile node moves between networks.
Handover Process:

- **Movement detection**: Identifies change in network attachment
- **New agent discovery**: Finds new foreign agent
- **Registration update**: Updates location with home agent
- **Data forwarding**: Redirects traffic to new location

Types of Handover:

Type	Description
Hard Handover	Break-before-make
Soft Handover	Make-before-break
Horizontal	Same technology
Vertical	Different technology

Challenges:

- **Packet loss**: During handover transition
- **Delay**: Registration and tunneling setup time
- **Resource management**: Efficient use of network resources

Mnemonic

"Movement Discovery Registration Forwarding"

Question 4(c) [7 marks]

Explain Registration and Tunneling in Mobile IP

Solution

Registration and Tunneling are core mechanisms enabling Mobile IP functionality.
Registration Process:

```
sequenceDiagram
    participant MN as Mobile Node
    participant FA as Foreign Agent
    participant HA as Home Agent

    MN{-FA: Registration Request}
    FA{-HA: Forward Request}
    HA{-FA: Registration Reply}
    FA{-MN: Forward Reply}
```

Registration Steps:

- **Request**: Mobile node sends registration request to foreign agent
- **Forward**: Foreign agent forwards request to home agent
- **Authentication**: Home agent verifies mobile node identity
- **Reply**: Home agent sends registration reply confirming registration

Tunneling Mechanism:

Component	Function
Encapsulation	Wraps original packet
Tunnel Endpoint	Home and foreign agents
Decapsulation	Unwraps packet at destination
Routing	Directs traffic through tunnel

Tunneling Process:

- **Packet arrival**: Data arrives at home agent for mobile node
- **Encapsulation**: Home agent wraps packet with foreign agent address
- **Tunnel transmission**: Packet travels through tunnel to foreign agent
- **Decapsulation**: Foreign agent unwraps and delivers to mobile node

Benefits:

- **Transparency**: Applications unaware of mobility
- **Connectivity**: Maintains communication during movement
- **Scalability**: Supports multiple mobile nodes

Security Considerations:

- **Authentication**: Prevents unauthorized registration
- **Encryption**: Protects data in tunnels

Mnemonic

"Registration Request Forward Authentication - Tunneling Encapsulation Transmission Decapsulation"

Question 4(a OR) [3 marks]

Explain snooping TCP

Solution

Snooping TCP improves TCP performance over wireless networks by handling wireless link errors.

Working Mechanism:

- **Base station monitoring**: Observes TCP packets
- **Local retransmission**: Handles wireless link errors locally
- **Cache management**: Stores copies of transmitted packets
- **Error recovery**: Retransmits lost packets without involving sender

Key Features:

Feature	Benefit
Transparent	No changes to TCP endpoints
Local recovery	Faster error correction
Reduced timeouts	Prevents unnecessary retransmissions

Mnemonic

"Snooping Monitors Local Cache Recovery"

Question 4(b OR) [4 marks]

Explain Packet delivery in Mobile IP

Solution

Packet Delivery in Mobile IP ensures data reaches mobile nodes regardless of location.

Delivery Process:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Correspondent Node] {-{-}{} B[Home Network]}
    B {-{-}{} C\{Mobile Node Location?\}}
```

```
    C {-{-}{}|Home| D[Direct Delivery]}
    C {-{-}{}|Away| E[Home Agent]}
    E {-{-}{} F[Tunnel to Foreign Agent]}
    F {-{-}{} G[Mobile Node]}
{Highlighting}
{Shaded}
```

Delivery Scenarios:

Scenario	Path	Method
At Home	Direct	Normal IP routing
Away	Via HA/FA	Tunneling
Roaming	Triangle routing	Indirect path

Packet Flow Steps:

- **Address resolution**: Determine mobile node location
- **Route selection**: Choose direct or tunneled delivery
- **Encapsulation**: Wrap packet if tunneling required
- **Forwarding**: Send to appropriate destination
- **Decapsulation**: Unwrap packet at foreign agent
- **Final delivery**: Deliver to mobile node

Optimization Techniques:

- **Route optimization**: Direct communication when possible
- **Binding cache**: Store location information
- **Smooth handover**: Minimize packet loss during movement

Mnemonic

"Address Route Encapsulation Forward Decapsulation Delivery"

Question 4(c OR) [7 marks]

Describe how DHCP working with diagram

Solution

DHCP (Dynamic Host Configuration Protocol) automatically assigns IP addresses and network configuration to devices.

DHCP Working Process:

```
sequenceDiagram
    participant C as Client
    participant S as DHCP Server

    C{-S: 1. DHCP Discover (Broadcast)}
    S{-C: 2. DHCP Offer}
    C{-S: 3. DHCP Request}
    S{-C: 4. DHCP ACK}

    Note over C,S: Lease Time

    C{-S: 5. DHCP Renewal Request}
    S{-C: 6. DHCP ACK}
```

Four-Step Process:

Step	Message	Function
1	DISCOVER	Client broadcasts request for IP

2	OFFER	Server offers available IP address
3	REQUEST	Client requests specific IP address
4	ACK	Server confirms IP assignment

DHCP Components:

- **DHCP Server**: Manages IP address pool and assignments
- **DHCP Client**: Requests and uses assigned configuration
- **DHCP Relay**: Forwards DHCP messages across subnets
- **Address Pool**: Range of available IP addresses

Configuration Information Provided:

- **IP Address**: Unique network identifier
- **Subnet Mask**: Network boundary definition
- **Default Gateway**: Route to other networks
- **DNS Servers**: Domain name resolution
- **Lease Time**: Duration of IP assignment

Benefits:

- **Automatic configuration**: No manual IP assignment needed
- **Centralized management**: Single point for network configuration
- **Efficient utilization**: Dynamic allocation prevents waste
- **Reduced errors**: Eliminates manual configuration mistakes

DHCP Message Types:

- **DISCOVER**: Locate available DHCP servers
- **OFFER**: Response with configuration offer
- **REQUEST**: Accept specific server offer
- **ACK**: Confirm configuration assignment
- **NAK**: Reject configuration request
- **RELEASE**: Return IP address to pool
- **RENEW**: Extend current lease

Mnemonic

"Discover Offer Request ACK - Server Client Relay Pool"

Question 5(a) [3 marks]

Give types of WLAN and explain any one

Solution

WLAN Types:

Type	Standard	Frequency
Infrastructure	802.11	2.4/5 GHz
Ad-hoc	IBSS	2.4/5 GHz
Mesh	802.11s	Multiple

Infrastructure WLAN Explanation:

- **Access Point (AP)**: Central coordinator for all communications
- **BSS (Basic Service Set)**: Network coverage area of single AP
- **ESS (Extended Service Set)**: Multiple interconnected BSSs
- **Distribution System**: Backbone connecting multiple APs

Characteristics:

- All communication goes through access point
- Centralized network management
- Better security and performance control

Mnemonic

"Infrastructure Ad-hoc Mesh - AP BSS ESS Distribution"

Question 5(b) [4 marks]

Solution

Solution

1) List Uses of Ad hoc Network:

Use Case	Application
Emergency	Disaster recovery, rescue operations
Military	Battlefield communications
Conferences	Temporary meeting networks
Home	Device-to-device communication
Vehicular	Car-to-car networks

2) Enlist entities and terminology of mobile computing:
Entities:

- **Mobile Node (MN)**: Moving device
- **Home Agent (HA)**: Permanent network representative
- **Foreign Agent (FA)**: Temporary network coordinator
- **Correspondent Node (CN)**: Communication partner

Terminology:

- **Handover**: Network switching process
- **Roaming**: Moving between networks
- **Care-of Address**: Temporary IP address

Mnemonic

"Emergency Military Conference Home Vehicular - MN HA FA CN"

Question 5(c) [7 marks]

Explain architecture of WLAN with neat diagram

Solution

WLAN Architecture consists of wireless stations communicating through access points.

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    subgraph "BSS 1"
        A[Laptop] {-{-}{} AP1[Access Point 1]}
        B[Phone] {-{-}{} AP1}
        C[Tablet] {-{-}{} AP1}
    end

    subgraph "BSS 2"
```

```
        D[Desktop] {-{-}{} AP2[Access Point 2]}
        E[Printer] {-{-}{} AP2}
    end

    AP1 {-{-}{} DS[Distribution System]}
    AP2 {-{-}{} DS}
    DS {-{-}{} F[Wired Network/Internet]}

    subgraph "Ad{-hoc Network"}
        G[Device A] {{-}{-}{} H[Device B]}
        H {{-}{-}{} I[Device C]}
    end
{Highlighting}
{Shaded}
```

Architecture Components:

Component	Function	Coverage
STA (Station)	Wireless device	Point
AP (Access Point)	Network coordinator	BSS area
BSS (Basic Service Set)	Single AP coverage	~100m radius
ESS (Extended Service Set)	Multiple connected BSS	Large area
DS (Distribution System)	AP interconnection	Building/campus

Types of WLAN Architecture:

1. **Infrastructure Mode:**
   - **Centralized**: All traffic through access points
   - **Managed**: Network administration and security
   - **Scalable**: Easy to expand coverage area
2. **Ad-hoc Mode (IBSS):**
   - **Peer-to-peer**: Direct device communication
   - **Decentralized**: No central coordinator
   - **Temporary**: Quick setup for specific needs

Key Features:

- **Mobility**: Users can move within coverage area
- **Wireless medium**: Radio waves for communication
- **Shared bandwidth**: Multiple users share channel capacity
- **Security**: WPA/WPA2/WPA3 protocols for protection

Standards and Frequencies:

- **802.11a**: 5 GHz, up to 54 Mbps
- **802.11b**: 2.4 GHz, up to 11 Mbps
- **802.11g**: 2.4 GHz, up to 54 Mbps
- **802.11n**: 2.4/5 GHz, up to 600 Mbps
- **802.11ac**: 5 GHz, up to 6.93 Gbps

Mnemonic

"STA AP BSS ESS DS - Infrastructure Ad-hoc"

Question 5(a OR) [3 marks]

Write features of 5G

Solution

5G Key Features:

Feature	Specification
Speed	Up to 10 Gbps
Latency	$<$ 1 millisecond
Connectivity	1 million devices/km^2
Reliability	99.999% availability
Bandwidth	100x increase
Energy	90% reduction

Advanced Capabilities:

- **Enhanced Mobile Broadband (eMBB)**: Ultra-fast data speeds
- **Ultra-Reliable Low Latency (URLLC)**: Mission-critical applications
- **Massive Machine Type Communication (mMTC)**: IoT connectivity

Mnemonic

"Speed Latency Connectivity Reliability Bandwidth Energy"

Question 5(b OR) [4 marks]

Solution

Solution

1) List Type of communication middleware:

Type	Function
Message-Oriented	Asynchronous messaging
RPC-based	Remote procedure calls
Object-Oriented	Distributed objects
Service-Oriented	Web services
Database	Data access layer

2) Define the term "Home Agent" in the context of Mobile IP:

Home Agent (HA) is a router on mobile node's home network that:

- **Maintains registration**: Tracks mobile node's current location
- **Tunnels packets**: Forwards data to mobile node's foreign location
- **Address management**: Manages mobile node's permanent IP address
- **Authentication**: Verifies mobile node identity during registration

Functions:

- Acts as proxy for mobile node when away from home
- Intercepts packets destined for mobile node
- Creates tunnels to foreign agents

Mnemonic

"Message RPC Object Service Database - HA Maintains Tunnels Address Authentication"

Question 5(c OR) [7 marks]

Explain Bluetooth protocol stack with diagram

Solution

Bluetooth Protocol Stack provides layered architecture for short-range wireless communication.

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Applications] {-{-}{} B[Application Layer]}
    B {-{-}{} C[OBEX/SDP/TCS]}
    C {-{-}{} D[RFCOMM]}
    D {-{-}{} E[L2CAP]}
    E {-{-}{} F[HCI {-} Host Controller Interface]}
    F {-{-}{} G[Link Manager Protocol {-} LMP]}
    G {-{-}{} H[Baseband]}
    H {-{-}{} I[Radio Layer]}
{Highlighting}
{Shaded}
```

Protocol Stack Layers:

Layer	Function	Protocols
Application	User applications	Audio, File transfer
Middleware	Services	OBEX, SDP, TCS
Transport	Data delivery	RFCOMM
Network	Packet management	L2CAP
Interface	Host-Controller	HCI
Management	Link control	LMP
Data Link	Channel access	Baseband
Physical	Radio transmission	2.4 GHz ISM

Layer Details:
Upper Layers:
- **OBEX**: Object Exchange Protocol for file transfers
- **SDP**: Service Discovery Protocol finds available services
- **TCS**: Telephony Control Specification for voice calls
- **RFCOMM**: Serial port emulation over Bluetooth

Lower Layers:
- **L2CAP**: Logical Link Control manages multiple connections
- **HCI**: Host Controller Interface standardizes communication
- **LMP**: Link Manager Protocol handles connection setup
- **Baseband**: Manages time slots and frequency hopping

Key Features:
- **Frequency Hopping**: 1600 hops/second across 79 channels
- **Piconet**: Network of up to 8 devices
- **Scatternet**: Multiple overlapping piconets
- **Power Classes**: Class 1 (100m), Class 2 (10m), Class 3 (1m)

Advantages:
- **Low power consumption**: Suitable for battery devices
- **Automatic pairing**: Easy device connection
- **Interference resistance**: Frequency hopping spread spectrum
- **Cost effective**: Low implementation cost

Applications:
- **Audio streaming**: Headphones, speakers
- **Data transfer**: File sharing between devices
- **Input devices**: Keyboards, mice
- **IoT devices**: Sensors, smart home devices

Mnemonic

"Application Middleware Transport Network Interface Management DataLink Physical"