Question 1(a) [3 marks]

Define Wireless Sensor Networks (WSN) and list its key components.

Answer:

WSN Definition: A Wireless Sensor Network is a collection of spatially distributed autonomous sensors that monitor physical or environmental conditions and cooperatively pass data through the network to a main location.

Key Components Table:

Component	Function
Sensor Nodes	Collect environmental data
Base Station	Data collection and processing center
Communication Links	Wireless data transmission
Gateway	Interface between WSN and external networks

Mnemonic: "SBCG - Sensors Base Communication Gateway"

Question 1(b) [4 marks]

Explain the role of the physical layer in WSNs.

Answer:

Physical Layer Functions:

- **Signal Transmission**: Converts digital data into radio waves for wireless communication
- **Frequency Management**: Operates in ISM bands (2.4 GHz, 915 MHz, 433 MHz)
- **Power Control**: Manages transmission power to optimize battery life
- **Modulation**: Uses techniques like BPSK, QPSK for data encoding

Simple Block Diagram:

```
┌─────────────┐    ┌─────────────┐    ┌─────────────┐
│   Digital   │───▶│  Physical   │───▶│  Antenna    │
│    Data     │    │   Layer     │    │ Transmission│
└─────────────┘    └─────────────┘    └─────────────┘
```

Mnemonic: "SFPM - Signal Frequency Power Modulation"

Question 1(c) [7 marks]

Discuss the design considerations for transceivers in WSNs.

Answer:

Key Design Considerations:

- **Power Efficiency**: Ultra-low power consumption for extended battery life
- **Communication Range**: Balance between range (10m-1km) and power consumption
- **Data Rate**: Typically 20-250 kbps for sensor applications
- **Frequency Band**: ISM bands to avoid licensing requirements
- **Modulation Scheme**: Simple schemes like OOK, FSK for low power
- **Antenna Design**: Compact, omnidirectional antennas
- **Cost Factor**: Low-cost components for large-scale deployment

Transceiver Architecture:

```
┌──────────┐   ┌─────────┐   ┌────────┐   ┌────────┐
│   MCU    │◄─►│   RF    │◄─►│ PA/LNA │◄─►│Antenna │
│          │   │Frontend │   │        │   │        │
└──────────┘   └─────────┘   └────────┘   └────────┘
```

Trade-offs Table:

Parameter	High Performance	Low Power
Range	Long (1km)	Short (100m)
Power	High (100mW)	Low (1mW)
Cost	Expensive	Cheap

Mnemonic: "PCRFMAC - Power Communication Range Frequency Modulation Antenna Cost"

Question 1(c) OR [7 marks]

Explain optimization goals and figures of merit in WSN.

Answer:

Optimization Goals:

- **Energy Efficiency**: Maximize network lifetime by minimizing power consumption
- **Coverage**: Ensure complete area monitoring with minimum sensor nodes
- **Connectivity**: Maintain network connectivity even with node failures
- **Data Quality**: High accuracy and reliability of collected data
- **Scalability**: Support large number of nodes (100-10000)
- **Cost Effectiveness**: Minimize deployment and maintenance costs

Figures of Merit Table:

Metric	Description	Typical Value
Network Lifetime	Time until first node dies	1-5 years
Coverage Ratio	Area covered/Total area	>95%
Connectivity	Connected nodes/Total nodes	>90%
Latency	End-to-end delay	<1 second
Throughput	Data rate per node	1-100 kbps

Optimization Techniques:

- **Clustering**: Reduce communication overhead
- **Data Aggregation**: Minimize redundant transmissions
- **Sleep Scheduling**: Turn off nodes when not needed

Mnemonic: "ECCDC - Energy Coverage Connectivity Data Cost"

Question 2(a) [3 marks]

List the characteristics of Sensor MAC protocol in WSNs.

Answer:

S-MAC Protocol Characteristics:

Characteristic	Description
Duty Cycling	Periodic sleep and wake-up cycles
Collision Avoidance	RTS/CTS mechanism
Overhearing Avoidance	Nodes sleep during irrelevant transmissions
Message Passing	Long messages broken into fragments

Mnemonic: "DCOM - Duty Collision Overhearing Message"

Question 2(b) [4 marks]

Describe the concept of energy-efficient routing in WSNs.

Answer:

Energy-Efficient Routing Concept:

Energy-efficient routing minimizes power consumption while maintaining network connectivity and data delivery.

Key Techniques:

- **Multi-hop Communication**: Short hops consume less power than long hops
- **Load Balancing**: Distribute traffic to avoid node depletion
- **Data Aggregation**: Combine data from multiple sources
- **Geographic Routing**: Use location information for efficient paths

Energy Model:

```
E_tx = E_elec × k + ε_amp × k × d²
E_rx = E_elec × k
```

Routing Strategies Table:

Strategy	Power Saving	Implementation
Shortest Path	Medium	Simple
Min-Energy	High	Complex
Max-Lifetime	Very High	Very Complex

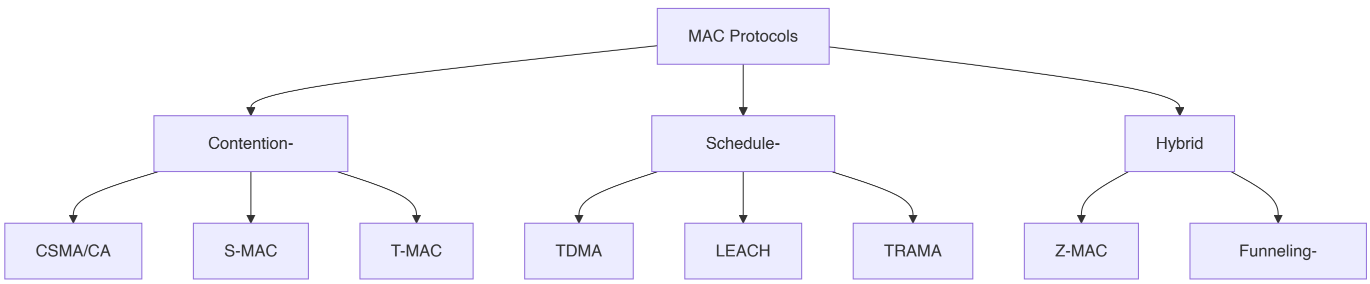
Mnemonic: "MLDG - Multi-hop Load Data Geographic"

Question 2(c) [7 marks]

Explain the classification of MAC protocols for WSNs with examples.

Answer:

MAC Protocol Classification:



Detailed Classification:

1. Contention-Based Protocols:

- **CSMA/CA**: Carrier sensing before transmission
- **S-MAC**: Synchronized duty cycles with sleep schedules
- **T-MAC**: Adaptive duty cycle based on traffic

2. Schedule-Based Protocols:

- **TDMA**: Time slots allocated to nodes

- **LEACH**: Cluster-based with rotating cluster heads
- **TRAMA**: Traffic-adaptive medium access

3. Hybrid Protocols:

- **Z-MAC**: Combines CSMA and TDMA benefits
- **Funneling-MAC**: Different protocols for different network regions

Comparison Table:

Protocol Type	Energy Efficiency	Latency	Scalability
Contention	Medium	Low	High
Schedule	High	Medium	Medium
Hybrid	High	Low	High

Mnemonic: "CSH - Contention Schedule Hybrid"

Question 2(a) OR [3 marks]

State the purpose of address management in WSNs.

Answer:

Address Management Purpose:

Purpose	Description
Node Identification	Unique identification of each sensor node
Routing Support	Enable efficient data forwarding
Network Organization	Hierarchical addressing for scalability

Mnemonic: "NIR - Node Identification Routing"

Question 2(b) OR [4 marks]

Explain geographic routing in Detail.

Answer:

Geographic Routing:

Geographic routing uses physical location information to make forwarding decisions without maintaining routing tables.

Key Components:

- **Location Service**: GPS or localization algorithms

- **Greedy Forwarding**: Forward to neighbor closest to destination
- **Face Routing**: Handle local minima situations
- **Coordinate System**: 2D/3D positioning

Forwarding Algorithm:

```
1. Receive packet with destination coordinates
2. Find neighbor closest to destination
3. If closer than current node, forward
4. Else use face routing or drop
```

Advantages/Disadvantages:

Aspect	Advantage	Disadvantage
Scalability	No routing tables	Location overhead
Adaptability	Handles mobility	Local minima problem

Mnemonic: "LGFC - Location Greedy Face Coordinate"

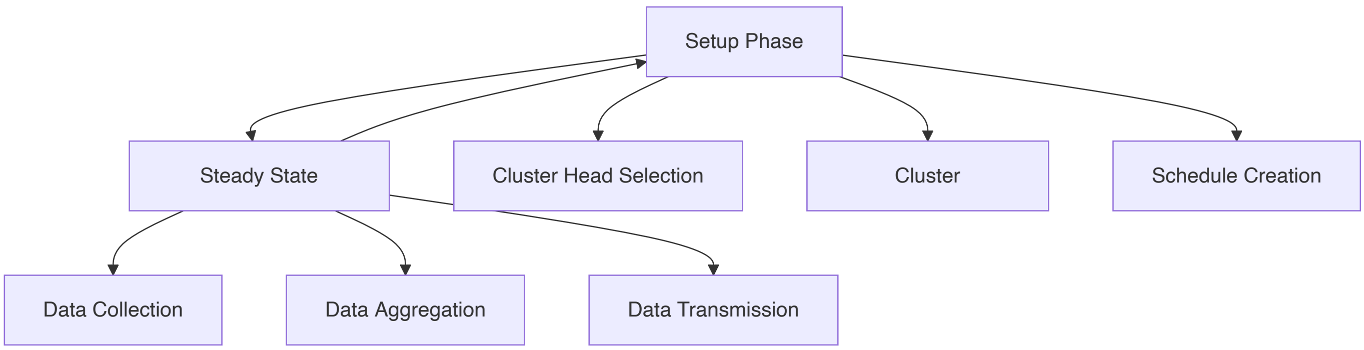
Question 2(c) OR [7 marks]

Explain the working of the LEACH protocol in WSN.

Answer:

LEACH Protocol (Low-Energy Adaptive Clustering Hierarchy):

Protocol Phases:



Detailed Working:

1. Setup Phase:

- **Cluster Head Selection**: Nodes decide to become cluster heads based on probability
- **Advertisement**: Cluster heads broadcast advertisement messages
- **Cluster Formation**: Non-cluster head nodes join nearest cluster head
- **Schedule Creation**: TDMA schedule created for cluster members

2. Steady State Phase:

- **Data Collection**: Cluster members collect and send data to cluster head
- **Data Aggregation**: Cluster head aggregates received data
- **Data Transmission**: Aggregated data sent to base station

Cluster Head Selection Formula:

```
P(n) = k / (N - k × (r mod N/k))
```

Where: k = desired cluster heads, N = total nodes, r = current round

Energy Benefits:

- **Load Distribution**: Cluster head role rotates among nodes
- **Data Aggregation**: Reduces transmissions to base station
- **Short Range Communication**: Most transmissions are within cluster

Performance Metrics:

Metric	LEACH	Direct Transmission
Network Lifetime	8x longer	Baseline
Energy Distribution	Uniform	Uneven
Scalability	High	Low

Mnemonic: "SSCADT - Setup Steady Cluster Aggregation Data Transmission"

Question 3(a) [3 marks]

Define IoT and mention its key sources.

Answer:

IoT Definition: Internet of Things is a network of interconnected physical devices embedded with sensors, software, and connectivity to collect and exchange data.

Key Sources Table:

Source	Description
RFID Technology	Radio frequency identification for object tracking
Sensor Networks	WSNs and environmental monitoring systems
Mobile Computing	Smartphones and portable devices
Cloud Computing	Scalable data storage and processing

Mnemonic: "RSMC - RFID Sensor Mobile Cloud"

Question 3(b) [4 marks]

Explain the modified OSI model for IoT/M2M systems.

Answer:

Modified OSI Model for IoT:

Layer	Traditional OSI	IoT/M2M Modification
Application	End-user applications	IoT applications, data analytics
Presentation	Data formatting	Data aggregation, semantic processing
Session	Session management	Device management, security
Transport	End-to-end delivery	Reliable/unreliable delivery (UDP/TCP)
Network	Routing	IPv6, 6LoWPAN, RPL routing
Data Link	Frame delivery	IEEE 802.15.4, WiFi, Bluetooth
Physical	Bit transmission	Radio, optical, wired transmission

IoT-Specific Modifications:

- **6LoWPAN**: IPv6 over Low-Power Wireless Personal Area Networks
- **CoAP**: Constrained Application Protocol for resource-limited devices
- **MQTT**: Message Queuing Telemetry Transport for lightweight communication

Protocol Stack Example:

```
┌─────────────────┐
│  IoT Application│
├─────────────────┤
│   CoAP/MQTT     │
├─────────────────┤
│       UDP       │
├─────────────────┤
│     6LoWPAN     │
├─────────────────┤
│  IEEE 802.15.4  │
└─────────────────┘
```

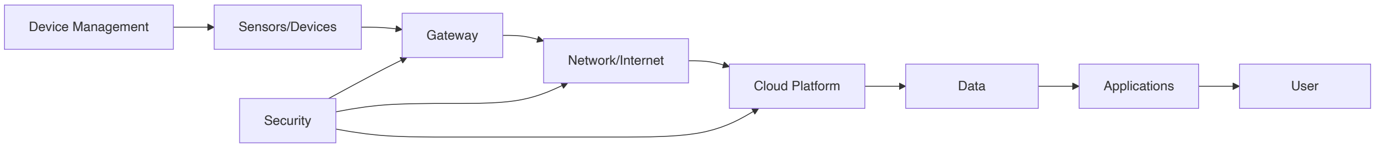
Mnemonic: "Six-Layer Low-Power WAN - 6LoWPAN"

Question 3(c) [7 marks]

Discuss the major components of an IoT system with a diagram.

Answer:

IoT System Architecture:



Major Components:

1. Device Layer:

- **Sensors**: Temperature, humidity, motion, light sensors
- **Actuators**: Motors, relays, valves for control
- **Microcontrollers**: ESP32, Arduino, Raspberry Pi
- **Communication Modules**: WiFi, Bluetooth, LoRa, Cellular

2. Connectivity Layer:

- **Gateways**: Protocol translation and data aggregation
- **Network Infrastructure**: Internet, cellular, satellite
- **Communication Protocols**: HTTP, MQTT, CoAP, WebSocket

3. Data Processing Layer:

- **Cloud Platforms**: AWS IoT, Azure IoT, Google Cloud IoT
- **Edge Computing**: Local data processing and filtering
- **Data Storage**: Time-series databases, NoSQL databases

4. Application Layer:

- **Analytics Engine**: Real-time and batch processing
- **Machine Learning**: Predictive analytics and pattern recognition
- **APIs**: RESTful services for data access

5. Business Layer:

- **User Interfaces**: Web dashboards, mobile apps
- **Business Logic**: Rules engines and workflow management
- **Integration**: ERP, CRM system integration

Component Functions Table:

Component	Input	Processing	Output
Sensors	Physical parameters	Analog to digital	Digital data
Gateway	Sensor data	Protocol conversion	Network packets
Cloud	Raw data	Storage and analytics	Processed information
Applications	Processed data	Business logic	User actions

Data Flow:

```
Sensors → Gateway → Internet → Cloud → Analytics → Applications → Users
```

Mnemonic: "DCDA-B - Device Connectivity Data Application Business"

Question 3(a) OR [3 marks]

List three challenges of IoT implementation.

Answer:

IoT Implementation Challenges:

Challenge	Description
Security and Privacy	Protecting data and device access
Interoperability	Different protocols and standards
Scalability	Managing millions of connected devices

Mnemonic: "SIS - Security Interoperability Scalability"

Question 3(b) OR [4 marks]

Describe the technology behind IoT with examples.

Answer:

Core Technologies:

1. Sensing Technology:

- **MEMS Sensors**: Accelerometers, gyroscopes
- **Environmental Sensors**: Temperature, humidity (DHT22)
- **Biometric Sensors**: Heart rate, fingerprint
- **Example**: Smart thermostat using temperature sensors

2. Communication Technology:

- **Short Range**: Bluetooth, WiFi, Zigbee
- **Long Range**: LoRaWAN, Cellular (4G/5G), Satellite
- **Example**: Smart home using WiFi for local control

3. Computing Technology:

- **Microcontrollers**: ESP32, Arduino Uno
- **Single Board Computers**: Raspberry Pi
- **Example**: Smart irrigation using NodeMCU

4. Cloud Technology:

- **Platforms**: AWS IoT Core, Microsoft Azure IoT
- **Services**: Data analytics, machine learning
- **Example**: Industrial monitoring using AWS IoT

Technology Stack Example:

```
┌──────────────────┐
│   Cloud (AWS)    │
├──────────────────┤
│  WiFi Network    │
├──────────────────┤
│    ESP32 MCU     │
├──────────────────┤
│  DHT22 Sensor    │
└──────────────────┘
```

Mnemonic: "SCCC - Sensing Communication Computing Cloud"

Question 3(c) OR [7 marks]

Explain the role of M2M communication in IoT with an example application.

Answer:

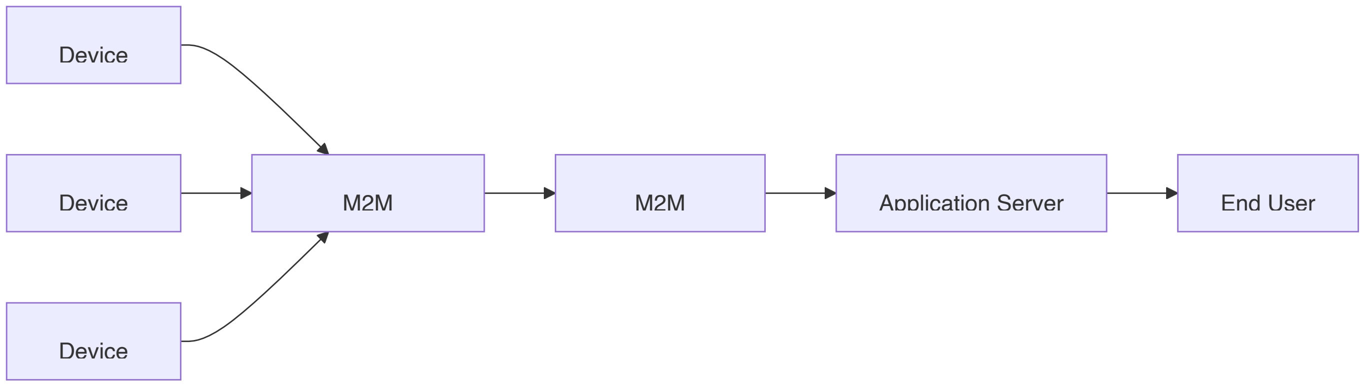
M2M Communication in IoT:

Machine-to-Machine (M2M) communication enables automated data exchange between devices without human intervention.

Key Characteristics:

- **Autonomous Operation**: Devices communicate without human input
- **Real-time Response**: Immediate action based on data exchange
- **Scalable Architecture**: Support for thousands of connected devices
- **Reliable Communication**: Guaranteed message delivery

M2M Architecture:



Communication Protocols:

- **MQTT**: Lightweight publish-subscribe messaging
- **CoAP**: Constrained Application Protocol for limited devices
- **HTTP/REST**: Web-based communication
- **WebSocket**: Real-time bidirectional communication

Example Application: Smart Street Lighting System

System Components:

- **Smart LED Lights**: Individual controllable street lights
- **Motion Sensors**: Detect pedestrian and vehicle movement
- **Light Sensors**: Measure ambient light levels
- **Central Controller**: Manages entire lighting network

M2M Communication Flow:

```
1. Motion sensor detects movement
2. Sensor sends data to nearby lights via Zigbee
3. Lights communicate with each other to create "lighting path"
4. Lights automatically adjust brightness based on traffic
5. Usage data sent to central controller via cellular
6. Controller optimizes lighting schedules
```

M2M Benefits in this Application:

- **Energy Efficiency**: Lights dim when no activity detected
- **Predictive Maintenance**: Lights report their health status
- **Adaptive Control**: System learns traffic patterns
- **Cost Reduction**: 60% energy savings compared to traditional lighting

Communication Protocol Stack:

```
┌─────────────────┐
│   Application   │ ← Smart Lighting Control
├─────────────────┤
│      MQTT       │ ← Message Protocol
├─────────────────┤
│      TCP        │ ← Transport Layer
├─────────────────┤
│   Cellular/WiFi │ ← Network Layer
└─────────────────┘
```

Performance Metrics:

Metric	Traditional	M2M Smart System
Energy Consumption	100%	40%
Maintenance Cost	High	Low (predictive)
Response Time	Manual (hours)	Automatic (seconds)
Flexibility	Fixed schedule	Adaptive

Mnemonic: "ARSR - Autonomous Real-time Scalable Reliable"

Question 4(a) [3 marks]

Name three application layer protocols used in IoT.

Answer:

IoT Application Layer Protocols:

Protocol	Purpose
MQTT	Lightweight publish-subscribe messaging
CoAP	Constrained Application Protocol for resource-limited devices
HTTP/HTTPS	Web-based RESTful communication

Mnemonic: "MCH - MQTT CoAP HTTP"

Question 4(b) [4 marks]

Explain the role of MQTT in IoT systems.

Answer:

MQTT (Message Queuing Telemetry Transport) Role:

MQTT is a lightweight publish-subscribe messaging protocol designed for IoT devices with limited resources.

Key Features:

- **Publish-Subscribe Model**: Decoupled communication between devices
- **Quality of Service**: Three levels (0, 1, 2) for message delivery
- **Persistent Sessions**: Maintains connection state
- **Last Will Testament**: Automatic notification when device disconnects

MQTT Architecture:

```
┌─────────────┐    ┌─────────────┐    ┌─────────────┐
│  Publisher  │───▶│   Broker    │◀───│ Subscriber  │
│  (Sensor)   │    │  (Server)   │    │ (Display)   │
└─────────────┘    └─────────────┘    └─────────────┘
```

QoS Levels:

Level	Description	Use Case
QoS 0	At most once delivery	Non-critical data
QoS 1	At least once delivery	Important data
QoS 2	Exactly once delivery	Critical commands

Benefits in IoT:

- **Low Bandwidth**: Minimal protocol overhead
- **Battery Efficient**: Optimized for low-power devices
- **Scalable**: Supports thousands of concurrent connections

Mnemonic: "PQPL - Publish QoS Persistent Last-will"

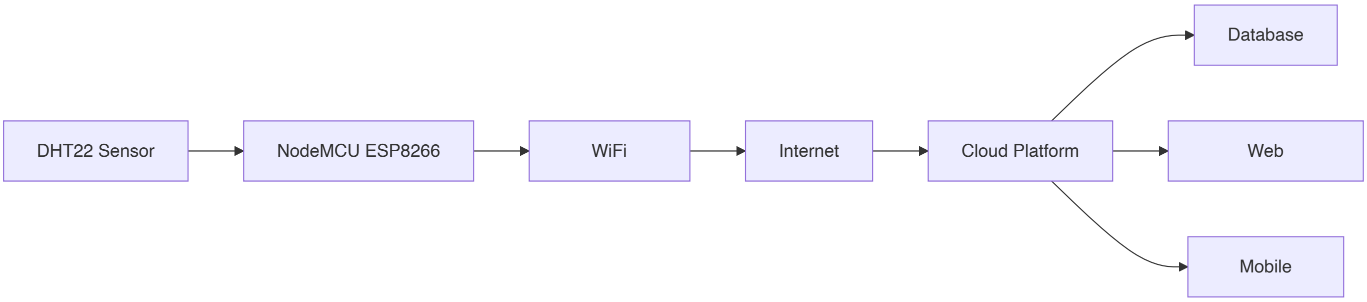
Question 4(c) [7 marks]

Design a system to read temperature sensor data using NodeMCU and transmit it to a cloud platform.

Answer:

System Design: Temperature Monitoring System

System Architecture:



Hardware Components:

- **NodeMCU ESP8266**: Microcontroller with WiFi capability
- **DHT22 Sensor**: Digital temperature and humidity sensor
- **Breadboard and Jumper Wires**: For connections
- **Power Supply**: USB or external 5V supply

Circuit Diagram:

```
NodeMCU ESP8266        DHT22 Sensor
┌─────────────┐       ┌─────────────┐
│    3.3V     │──────▶│     VCC     │
│     GND     │──────▶│     GND     │
│     D4      │──────▶│    DATA     │
└─────────────┘       └─────────────┘
```

Software Implementation:

Arduino Code (Simplified):

```
#include <ESP8266WiFi.h>
#include <DHT.h>
#include <PubSubClient.h>

#define DHT_PIN D4
#define DHT_TYPE DHT22

DHT dht(DHT_PIN, DHT_TYPE);
WiFiClient espClient;
PubSubClient client(espClient);

void setup() {
  Serial.begin(115200);
  dht.begin();
  WiFi.begin("SSID", "PASSWORD");
  client.setServer("mqtt.broker.com", 1883);
}

void loop() {
  float temp = dht.readTemperature();
```

```
  float hum = dht.readHumidity();

  String payload = "{\"temperature\":" + String(temp) +
                   ",\"humidity\":" + String(hum) + "}";

  client.publish("sensor/data", payload.c_str());
  delay(30000); // Send every 30 seconds
}
```

Cloud Platform Setup (AWS IoT):

1. **Device Registration**: Create IoT device certificate
2. **Topic Configuration**: Set up MQTT topics for data
3. **Rules Engine**: Process and route incoming data
4. **Database Storage**: Store data in DynamoDB/TimeStream
5. **API Gateway**: Create REST APIs for data access

Data Flow:

```
DHT22 → NodeMCU → WiFi → Internet → AWS IoT → Database → Dashboard
```

System Features:

- **Real-time Monitoring**: Temperature data every 30 seconds
- **Historical Data**: Store data for trend analysis
- **Alerts**: Email/SMS when temperature exceeds thresholds
- **Remote Access**: View data from anywhere via web/mobile

Performance Specifications:

Parameter	Specification
Accuracy	±0.5°C temperature, ±2% humidity
Range	-40°C to 80°C
Update Rate	30 seconds
Power Consumption	70mA active, 20μA deep sleep
WiFi Range	50-100 meters

Cost Analysis:

Component	Cost (USD)
NodeMCU ESP8266	$3
DHT22 Sensor	$5
Miscellaneous	$2
Total Hardware	$10
Cloud Service	$5/month

Mnemonic: "HSCDP - Hardware Software Cloud Data Platform"

Question 4(a) OR [3 marks]

List the types of sensors used in IoT applications.

Answer:

IoT Sensor Types:

Sensor Type	Measurement
Temperature	Ambient and surface temperature
Motion/PIR	Movement and presence detection
Light/LDR	Ambient light intensity

Mnemonic: "TML - Temperature Motion Light"

Question 4(b) OR [4 marks]

Discuss the security challenges in IoT systems.

Answer:

IoT Security Challenges:

1. Device-Level Security:

- **Weak Authentication**: Default passwords and poor access control
- **Firmware Vulnerabilities**: Unpatched security flaws
- **Physical Security**: Device tampering and theft
- **Resource Constraints**: Limited processing power for encryption

2. Network-Level Security:

- **Data Transmission**: Unencrypted communication channels
- **Network Protocols**: Vulnerabilities in wireless protocols

- **Man-in-the-Middle**: Interception of communication
- **DDoS Attacks**: Overwhelming network infrastructure

3. Cloud-Level Security:

- **Data Privacy**: Unauthorized access to stored data
- **API Security**: Vulnerabilities in application interfaces
- **Identity Management**: Poor user authentication and authorization
- **Data Breaches**: Large-scale data theft

Security Solutions Table:

Challenge	Solution
Weak Authentication	Strong passwords, multi-factor authentication
Data Transmission	End-to-end encryption (TLS/SSL)
Firmware Updates	Secure OTA update mechanisms
Access Control	Role-based permissions

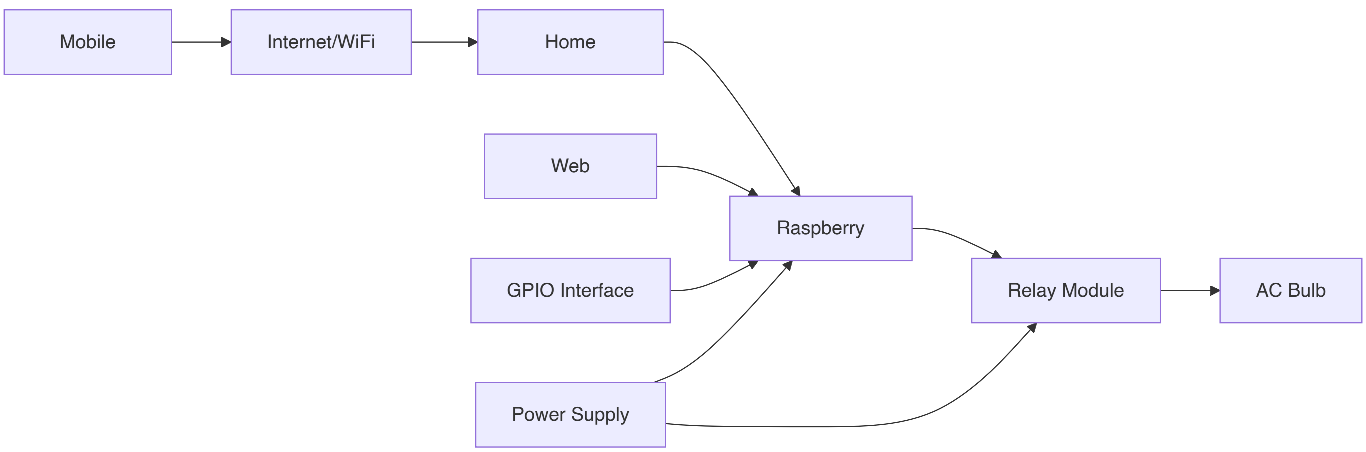
Mnemonic: "DNCI - Device Network Cloud Identity"

Question 4(c) OR [7 marks]

Draw a block diagram for controlling a bulb using Raspberry Pi via a mobile app. Explain the blocks in detail.

Answer:

Smart Bulb Control System:



Detailed Block Explanation:

1. Mobile Application:

- **Platform**: Android/iOS native app or web app

- **Interface**: ON/OFF buttons, dimming slider, scheduling
- **Communication**: HTTP requests to Raspberry Pi web server
- **Features**: Real-time status, timer controls, voice commands

2. Internet/WiFi Network:

- **Local Network**: Home WiFi router for local control
- **Internet**: Remote access via port forwarding or VPN
- **Protocols**: HTTP/HTTPS for web communication
- **Security**: WPA2/WPA3 encryption

3. Home Router:

- **Function**: Network gateway and DHCP server
- **Port Forwarding**: External access to Raspberry Pi
- **Firewall**: Security for home network
- **QoS**: Traffic prioritization

4. Raspberry Pi Controller:

- **Model**: Raspberry Pi 4B with WiFi capability
- **OS**: Raspberry Pi OS (Linux-based)
- **Web Server**: Flask/Apache serving control interface
- **GPIO Control**: Python libraries for hardware control

5. Relay Module:

- **Type**: 5V single-channel relay module
- **Function**: Electrical isolation and AC switching
- **Control Signal**: 3.3V GPIO from Raspberry Pi
- **Safety**: Optocoupler isolation

6. AC Bulb:

- **Type**: Standard 230V AC incandescent/LED bulb
- **Power**: Up to 100W capacity
- **Control**: ON/OFF switching via relay
- **Connection**: Series connection through relay contacts

System Operation Flow:

```
Mobile App          Raspberry Pi         Relay Module        AC Bulb

┌─────────┐        ┌─────────────┐      ┌─────────────┐     ┌─────────┐
│ Tap ON  │───────▶│ Web Server  │─────▶│  GPIO=HIGH  │────▶│ Bulb ON │
│         │        │   Process   │      │             │     │         │
│ Tap OFF │───────▶│   Request   │─────▶│  GPIO=LOW   │────▶│ Bulb OFF│
└─────────┘        └─────────────┘      └─────────────┘     └─────────┘
```

Software Components:

Python Code (Simplified):

```python
import RPi.GPIO as GPIO
from flask import Flask, request, jsonify

app = Flask(__name__)
RELAY_PIN = 18
GPIO.setmode(GPIO.BCM)
GPIO.setup(RELAY_PIN, GPIO.OUT)

@app.route('/bulb/<state>')
def control_bulb(state):
    if state == 'on':
        GPIO.output(RELAY_PIN, GPIO.HIGH)
        return jsonify({'status': 'Bulb ON'})
    elif state == 'off':
        GPIO.output(RELAY_PIN, GPIO.LOW)
        return jsonify({'status': 'Bulb OFF'})

if __name__ == '__main__':
    app.run(host='0.0.0.0', port=5000)
```

Mobile App Interface:

- **Connection**: HTTP requests to Pi's IP address
- **URL Format**: `http://192.168.1.100:5000/bulb/on`
- **Response**: JSON status confirmation
- **UI Elements**: Toggle switch, status indicator

Hardware Connections:

Raspberry Pi	Relay Module	AC Circuit
GPIO 18	IN	-
5V	VCC	-
GND	GND	-
-	COM	Live Wire
-	NO	Bulb Live

Safety Considerations:

- **Electrical Isolation**: Relay provides galvanic isolation
- **Proper Wiring**: Follow electrical safety codes
- **Enclosure**: Protect connections from moisture
- **Circuit Breaker**: Include in AC circuit for safety

System Advantages:

- **Remote Control**: Access from anywhere with internet
- **Scheduling**: Automated ON/OFF timers
- **Energy Monitoring**: Track power consumption
- **Voice Control**: Integration with Alexa/Google Assistant
- **Multiple Bulbs**: Expandable to control multiple devices

Cost Breakdown:

Component	Cost (USD)
Raspberry Pi 4B	$35
Relay Module	$3
Jumper Wires	$2
Enclosure	$5
Total	$45

Mnemonic: "MIHRBA - Mobile Internet Home-router Raspberry-pi Relay Bulb"

Question 5(a) [3 marks]

Classify IoT applications into broad categories.

Answer:

IoT Application Categories:

Category	Description
Consumer IoT	Smart homes, wearables, entertainment
Industrial IoT	Manufacturing, supply chain, predictive maintenance
Infrastructure IoT	Smart cities, transportation, utilities

Mnemonic: "CII - Consumer Industrial Infrastructure"

Question 5(b) [4 marks]

Explain the working of a smart home automation system using IoT.

Answer:

Smart Home Automation System:

Smart home automation integrates various IoT devices to provide centralized control and intelligent automation of home functions.

System Components:

- **Central Hub**: Smart home controller (like Amazon Echo, Google Home)
- **Sensors**: Motion, temperature, light, door/window sensors
- **Actuators**: Smart switches, thermostats, door locks, cameras
- **Communication**: WiFi, Zigbee, Z-Wave protocols

Working Principle:

```
┌─────────────┐    ┌─────────────┐    ┌─────────────┐
│   Sensors   │───▶│ Central Hub │───▶│  Actuators  │
│  (Input)    │    │ (Process)   │    │  (Output)   │
└─────────────┘    └─────────────┘    └─────────────┘
       ▲                  │                  │
       │                  ▼                  │
┌─────────────┐    ┌─────────────┐           │
│ Mobile App  │◀───│    Cloud    │           │
│   Control   │    │  Services   │           │
└─────────────┘    └─────────────┘           │
       ▲                                     │
       └─────────────────────────────────────┘
```

Automation Examples:

- **Security**: Motion sensors trigger lights and cameras
- **Energy Management**: Temperature sensors control HVAC systems
- **Convenience**: Voice commands control multiple devices
- **Safety**: Smoke detectors trigger alarms and notifications

Benefits:

- **Energy Efficiency**: 20-30% reduction in power consumption
- **Security**: Real-time monitoring and alerts
- **Convenience**: Remote control and automation
- **Cost Savings**: Reduced utility bills and insurance premiums

Mnemonic: "HCSA - Hub Communication Sensors Actuators"

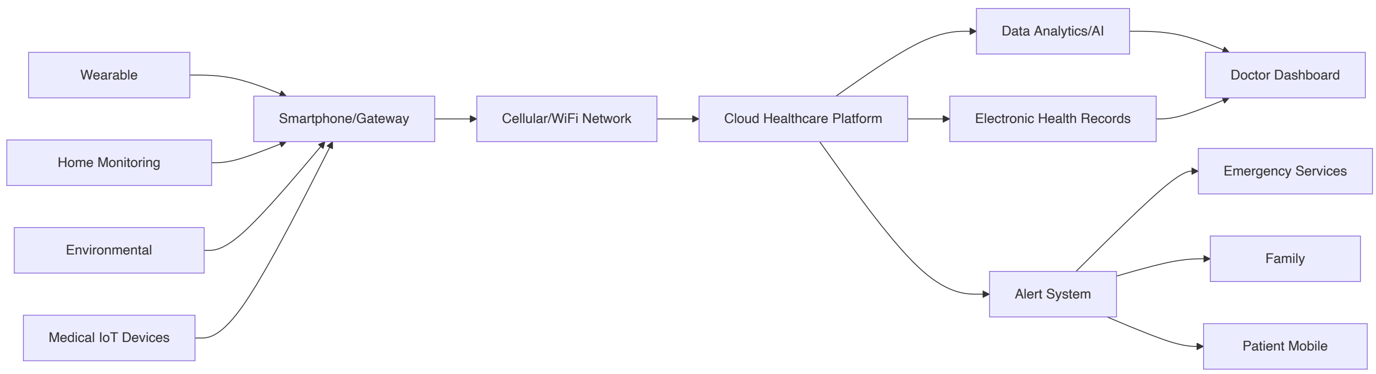
Question 5(c) [7 marks]

Propose a block diagram and working principle for an IoT-based healthcare monitoring system.

Answer:

IoT Healthcare Monitoring System:

System Architecture:



Detailed Components:

1. Patient-Side Devices:

Wearable Sensors:

- **Smartwatch**: Heart rate, activity tracking, ECG
- **Fitness Bands**: Steps, sleep patterns, calories
- **Smart Patches**: Continuous glucose monitoring, temperature
- **Smart Clothing**: Respiratory rate, posture monitoring

Home Monitoring Devices:

- **Smart Blood Pressure Monitor**: Automatic readings with timestamps
- **Smart Weighing Scale**: Body composition analysis
- **Smart Thermometer**: Non-contact temperature measurement
- **Smart Pill Dispenser**: Medication adherence tracking

Environmental Sensors:

- **Air Quality Monitor**: PM2.5, CO2, humidity levels

- **Smart Bedroom**: Sleep quality analysis
- **Fall Detection**: Accelerometer-based emergency detection

2. Communication Layer:

- **Smartphone Gateway**: Data aggregation and transmission
- **Bluetooth LE**: Low-power device connectivity
- **WiFi/4G/5G**: Internet connectivity for data upload
- **Edge Processing**: Local data filtering and analysis

3. Cloud Infrastructure:

- **Healthcare Cloud Platform**: HIPAA-compliant data storage
- **Real-time Data Processing**: Stream processing for vital signs
- **Machine Learning Models**: Anomaly detection and prediction
- **API Gateway**: Secure data access for applications

4. Analytics and Intelligence:

- **Vital Signs Analysis**: Trend detection and threshold monitoring
- **Predictive Analytics**: Early warning system for health issues
- **Personalized Insights**: Individual health recommendations
- **Population Health**: Aggregate health statistics

5. User Interfaces:

- **Patient Mobile App**: Personal health dashboard
- **Doctor Web Portal**: Patient monitoring and management
- **Emergency Dashboard**: Critical alerts and response coordination
- **Family App**: Caregiver notifications and updates

Working Principle:

Data Collection Phase:

```
Sensors → Smartphone → Data Validation → Cloud Upload
```

Processing Phase:

```
Raw Data → Preprocessing → ML Analysis → Alert Generation
```

Response Phase:

```
Alerts → Classification → Notification → Action Taken
```

Detailed Workflow:

1. **Continuous Monitoring**: Wearable devices collect vital signs every 15-30 seconds
2. **Data Aggregation**: Smartphone app aggregates data from multiple sensors
3. **Quality Check**: Data validation and error correction algorithms
4. **Secure Transmission**: Encrypted data sent to cloud via cellular/WiFi
5. **Real-time Analysis**: ML algorithms analyze incoming data streams
6. **Pattern Recognition**: Identify normal vs abnormal health patterns
7. **Alert Generation**: Automated alerts for threshold violations
8. **Notification Dispatch**: Alerts sent to patients, doctors, and family
9. **Emergency Response**: Critical alerts trigger emergency services
10. **Data Storage**: Historical data stored for long-term analysis

Clinical Use Cases:

Chronic Disease Management:

- **Diabetes**: Continuous glucose monitoring with insulin recommendations
- **Hypertension**: Blood pressure tracking with medication reminders
- **Heart Disease**: ECG monitoring with arrhythmia detection
- **COPD**: Respiratory rate and oxygen saturation monitoring

Emergency Detection:

- **Cardiac Events**: Heart rate anomalies trigger immediate alerts
- **Falls**: Accelerometer data detects falls in elderly patients
- **Medication Non-compliance**: Smart pill dispensers track adherence
- **Sleep Apnea**: Respiratory monitoring during sleep

Performance Metrics:

Metric	Target Value	Current Achievement
Data Accuracy	>95%	97%
False Alarm Rate	<5%	3%
Response Time	<30 seconds	15 seconds
Battery Life	7 days	5 days
User Adoption	>80%	75%

Technical Specifications:

Sensor Specifications:

- **Heart Rate**: ±2 BPM accuracy

- **Blood Pressure**: ±3 mmHg accuracy
- **Temperature**: ±0.1°C accuracy
- **Activity**: >95% step counting accuracy

Communication Specifications:

- **Data Rate**: 1-10 Kbps per device
- **Latency**: <100ms for critical alerts
- **Range**: 10m Bluetooth, unlimited cellular
- **Security**: AES-256 encryption

Privacy and Security:

- **Data Encryption**: End-to-end encryption for all communications
- **Access Control**: Role-based permissions for healthcare providers
- **Compliance**: HIPAA, GDPR compliant data handling
- **Audit Trails**: Complete logging of data access and modifications

Cost-Benefit Analysis:

Implementation Costs:

- **Hardware per Patient**: $200-500
- **Cloud Infrastructure**: $10-20 per patient per month
- **Development**: $500K-1M initial investment
- **Maintenance**: 15-20% of development cost annually

Benefits:

- **Hospital Readmission Reduction**: 25-30%
- **Emergency Response Time**: 50% improvement
- **Healthcare Cost Savings**: $1000-2000 per patient annually
- **Patient Satisfaction**: 85% improvement in care quality

Challenges and Solutions:

Challenge	Solution
Data Privacy	End-to-end encryption, data anonymization
Device Battery Life	Low-power protocols, energy harvesting
False Alarms	AI-based pattern recognition, adaptive thresholds
User Compliance	Gamification, family involvement
Interoperability	Standard protocols (HL7 FHIR, MQTT)

Future Enhancements:

- **AI-Powered Diagnosis**: Advanced machine learning for disease prediction
- **Telemedicine Integration**: Video consultations based on sensor data
- **Blockchain**: Secure, distributed health record management
- **5G Connectivity**: Ultra-low latency for real-time monitoring

Mnemonic: "WHDCA-UI - Wearables Home-devices Data Communication Analytics User-interface"

Question 5(a) OR [3 marks]

List three real-world IoT applications.

Answer:

Real-World IoT Applications:

Application	Description
Smart Agriculture	Soil moisture monitoring and automated irrigation
Industrial Monitoring	Predictive maintenance of manufacturing equipment
Smart Transportation	Traffic management and vehicle tracking systems

Mnemonic: "AIT - Agriculture Industrial Transportation"

Question 5(b) OR [4 marks]

Describe the role of IoT in a smart parking system.

Answer:

IoT in Smart Parking System:

IoT enables intelligent parking management by providing real-time information about parking space availability and automating payment processes.

System Components:

- **Parking Sensors**: Ultrasonic/magnetic sensors detect vehicle presence
- **Gateway Devices**: Collect data from multiple sensors
- **Cloud Platform**: Process and store parking data
- **Mobile Application**: User interface for parking information

IoT Benefits:

Traditional Parking	IoT Smart Parking
Manual space searching	Real-time availability
Cash/card payments	Mobile payments
No data analytics	Usage analytics
High fuel wastage	30% fuel savings

Working Process:

1. **Detection**: Sensors detect empty/occupied spaces
2. **Data Collection**: Gateway aggregates sensor data
3. **Cloud Processing**: Real-time space availability calculation
4. **User Notification**: Mobile app shows available spaces
5. **Navigation**: GPS-guided parking assistance
6. **Payment**: Automated mobile payment processing

Key Features:

- **Real-time Updates**: Space availability updated every 30 seconds
- **Predictive Analytics**: Parking demand forecasting
- **Dynamic Pricing**: Rates adjusted based on demand
- **Violation Detection**: Overstay and illegal parking alerts

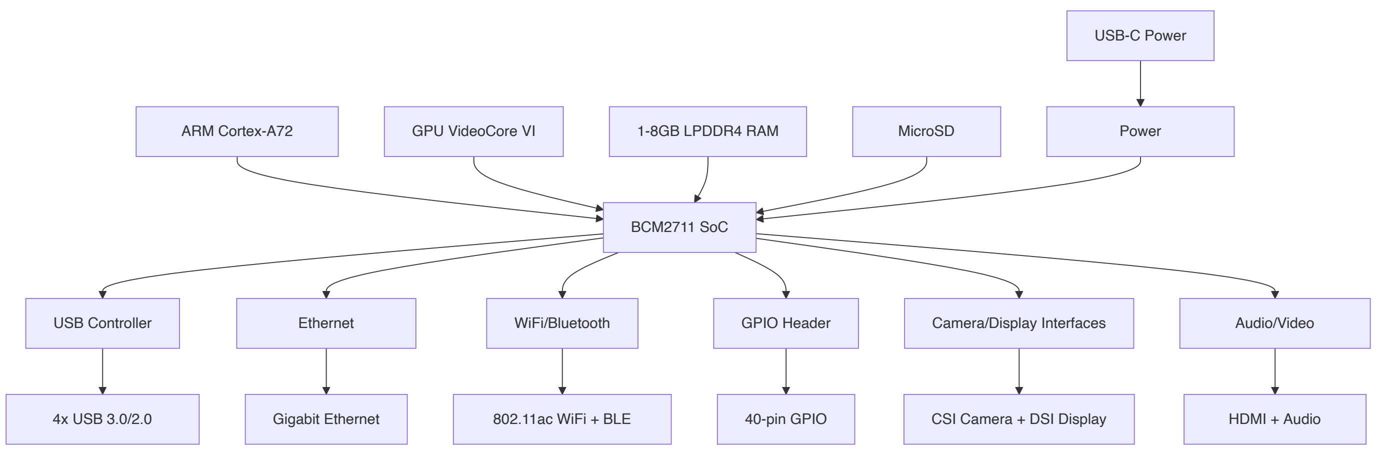
Mnemonic: "DCPN - Detection Collection Processing Notification"

Question 5(c) OR [7 marks]

Draw Architecture block diagram of Raspberry Pi and explain it.

Answer:

Raspberry Pi 4B Architecture:



Detailed Architecture Explanation:

1. Central Processing Unit (CPU):

- **Processor**: Quad-core ARM Cortex-A72 64-bit
- **Clock Speed**: 1.5 GHz (can be overclocked to 2.0 GHz)
- **Architecture**: ARMv8-A with NEON SIMD support
- **Cache**: L1: 32KB instruction + 32KB data per core, L2: 1MB shared
- **Performance**: ~4x faster than Raspberry Pi 3B+

2. Graphics Processing Unit (GPU):

- **Model**: Broadcom VideoCore VI
- **Features**: OpenGL ES 3.0, Hardware video decode
- **Video**: 4K60 HEVC decode, 1080p60 H.264 encode
- **Display**: Dual 4K display support via micro-HDMI

3. System on Chip (SoC):

- **Chip**: Broadcom BCM2711
- **Process**: 28nm technology
- **Integration**: CPU, GPU, memory controller, I/O controllers
- **Thermal Management**: Heat spreader and thermal throttling

4. Memory Subsystem:

- **RAM**: LPDDR4-3200 (1GB, 2GB, 4GB, or 8GB variants)
- **Memory Controller**: 64-bit wide bus
- **Bandwidth**: Up to 25.6 GB/s theoretical
- **Storage**: MicroSD card slot (UHS-I support)

5. Connectivity Options:

USB Connectivity:

- **USB 3.0**: 2 ports with 5 Gbps speed
- **USB 2.0**: 2 ports with 480 Mbps speed
- **Power**: Bus-powered devices supported up to 1.2A total

Network Connectivity:

- **Ethernet**: Gigabit Ethernet (1000 Mbps) via USB 3.0
- **WiFi**: 802.11ac dual-band (2.4GHz + 5GHz)
- **Bluetooth**: Bluetooth 5.0 with Low Energy support

6. Input/Output Interfaces:

GPIO (General Purpose Input/Output):

- **Pins**: 40-pin header (26 GPIO + power + ground)
- **Protocols**: SPI, I2C, UART, PWM support
- **Voltage**: 3.3V logic levels
- **Current**: 16mA per pin, 50mA total

Specialized Interfaces:

- **Camera Serial Interface (CSI)**: 15-pin connector for camera modules
- **Display Serial Interface (DSI)**: 15-pin connector for touch displays
- **Audio**: 3.5mm TRRS jack (audio + composite video)
- **HDMI**: 2x micro-HDMI ports supporting 4K60

7. Power Management:

- **Input**: USB-C connector, 5V 3A minimum
- **Power Consumption**: 2.7W idle, 6.4W under stress
- **Power Management IC**: Efficient voltage regulation
- **GPIO Power**: 3.3V and 5V rails available

8. Boot and Storage:

- **Boot Options**: MicroSD card, USB storage, network boot
- **File Systems**: Supports ext4, FAT32, NTFS
- **OS Support**: Raspberry Pi OS, Ubuntu, Windows 10 IoT

Performance Comparison:

Specification	RPi 3B+	RPi 4B
CPU Cores	4	4
CPU Speed	1.4 GHz	1.5 GHz
RAM Options	1GB	1/2/4/8GB
Ethernet	300 Mbps	1 Gbps
USB	2.0 only	3.0 + 2.0
WiFi	802.11n	802.11ac

GPIO Pinout (Key Pins):

Pin	Function	Pin	Function
1	3.3V Power	2	5V Power
3	GPIO 2 (SDA)	4	5V Power
5	GPIO 3 (SCL)	6	Ground
7	GPIO 4	8	GPIO 14 (TXD)
9	Ground	10	GPIO 15 (RXD)

Software Architecture:

```
┌─────────────────────────────────────┐
│           Applications              │
├─────────────────────────────────────┤
│      Python/C++/Java Libraries      │
├─────────────────────────────────────┤
│          Raspberry Pi OS            │
├─────────────────────────────────────┤
│           Linux Kernel              │
├─────────────────────────────────────┤
│          Hardware (BCM2711)         │
└─────────────────────────────────────┘
```

Typical IoT Use Cases:

- **IoT Gateway**: Collect data from sensors via GPIO/USB
- **Edge Computing**: Local data processing and ML inference
- **Home Automation**: Control devices via GPIO and network
- **Industrial Monitoring**: Interface with industrial sensors
- **Robotics**: Motor control and sensor integration

Advantages in IoT:

- **Full Linux OS**: Complete development environment
- **Rich I/O**: Multiple communication protocols supported
- **Community Support**: Extensive documentation and libraries
- **Cost-Effective**: $35-75 depending on RAM configuration
- **Power Efficient**: Can run on battery with proper power management

Limitations:

- **Real-time Performance**: Not suitable for hard real-time applications
- **Industrial Temperature**: Consumer-grade temperature range
- **GPIO Drive**: Limited current output per pin

- **Analog Input**: No built-in ADC (requires external ADC)

Development Tools:

- **Programming Languages**: Python, C/C++, Java, Node.js
- **IDEs**: Thonny, Visual Studio Code, Eclipse
- **Libraries**: RPi.GPIO, gpiozero, OpenCV, TensorFlow Lite
- **Remote Development**: SSH, VNC, VS Code Remote

Mnemonic: "CPU-GPU-SoC-MEM-CONN-IO-PWR-BOOT - Complete Pi Architecture"