Wireless Sensor Networks and IoT (4353201) - Summer 2025 Solution

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Question 1(a) [3 marks]

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

> **Solution**
>
> **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.
>
> **Table 1.** Key Components
>
> | 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.

> **Solution**
>
> **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
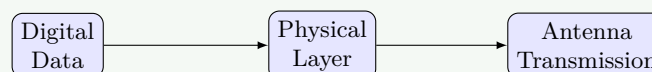>
> Digital Data → Physical Layer → Antenna Transmission
>
> **Figure 1.** Simple Block Diagram

> **Mnemonic**
>
> "SFPM - Signal Frequency Power Modulation"

Question 1(c) [7 marks]

Discuss the design considerations for transceivers in WSNs.

> **Solution**
>
> **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
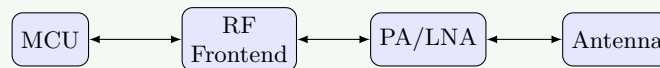>
> **Transceiver Architecture:**
>
> MCU ↔ RF Frontend ↔ PA/LNA ↔ Antenna
>
> **Figure 2.** Transceiver Architecture
>
> **Table 2.** Trade-offs
>
> | Parameter | High Performance | Low Power |
> |-----------|------------------|-----------|
> | 99: Range | Long (1km) | Short (100m) |
> | 100: Power | High (100mW) | Low (1mW) |
> | 101: 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.

> **Solution**
>
> **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
>
> **Table 3.** Figures of Merit
>
> | 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.

Solution

S-MAC Protocol Characteristics:

Table 4. 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.

Solution

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:

Listing 1. Energy Model Equations

```
E_tx = E_elec * k + e_amp * k * d^2
E_rx = E_elec * k
```

Table 5. Routing Strategies

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.
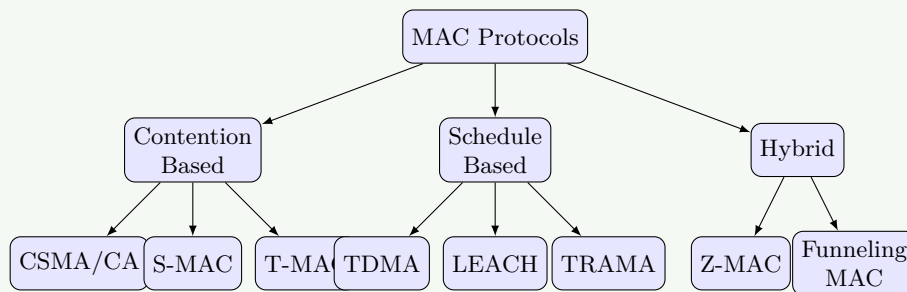
Solution

MAC Protocol Classification:

Figure 3. 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

Table 6. Comparison

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.

> **Solution**
>
> **Address Management Purpose:**
>
> **Table 7.** Purposes
>
> | 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.

> **Solution**
>
> **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:**
>
> **Listing 2.** 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
> ```
>
> **Table 8.** 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.

Solution

LEACH Protocol (Low-Energy Adaptive Clustering Hierarchy):
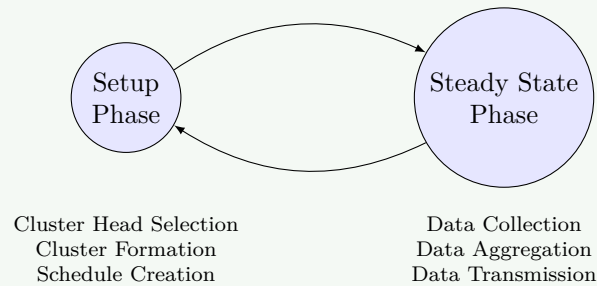**Protocol Phases:**

Figure 4. LEACH 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:

Listing 3. Cluster Head Probability

```
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

Table 9. 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 state its key sources.

Solution

IoT Definition: The Internet of Things (IoT) describes the network of physical objects (things) embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet.

Table 10. Key Sources

Source	Description
RFID Technology	Identification and tracking of objects
Sensor Networks	Data collection from environment
Mobile Computing	Ubiquitous connectivity via smartphones
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.

Solution

Modified OSI Model for IoT:
The traditional 7-layer OSI model is adapted for IoT to handle resource constraints and specific communication needs.

Table 11. Layer Comparison

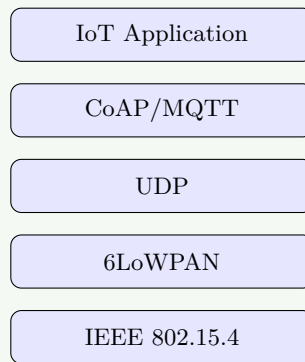| Layer	Traditional OSI	IoT/M2M Modification
Application	End-user applications	IoT Applications, Data Analytics
Presentation	Data formatting	Data Aggregation, Semantic Processing
Session	Session management	Device Management, Security
Transport	End-to-end delivery	Reliable/Unreliable delivery (UDP/TCP)
Network	Routing	IPv6, 6LoWPAN, RPL Routing
Data Link	Frame delivery	IEEE 802.15.4, WiFi, Bluetooth
Physical	Bit transmission	Radio, Optical, Wired Transmission

Protocol Stack Example:

IoT Application

CoAP/MQTT

UDP

6LoWPAN

IEEE 802.15.4

Figure 5. IoT Protocol Stack

Question 3(c) [7 marks]

Discuss the major ingredients of IoT system with diagram.

Solution

IoT System Architecture:

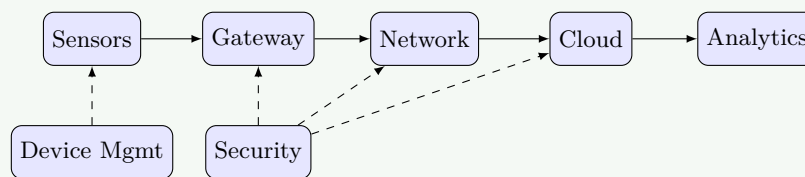Sensors → Gateway → Network → Cloud → Analytics

Device Mgmt ⇢ Sensors

Security ⇢ Gateway

Figure 6. IoT System Ingredients

Major Ingredients:
1. **Device Layer**: Sensors, Actuators, Microcontrollers (ESP32), Communication modules.
2. **Connectivity Layer**: Gateways, Network infrastructure, Protocols (MQTT, HTTP).
3. **Data Processing Layer**: Cloud platforms, Edge computing, Storage.
4. **Application Layer**: Analytics engines, Machine Learning, APIs.
5. **Business Layer**: User interfaces, Business logic, Integration.

Table 12. Ingredient Functions

Ingredient	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 Info
Applications	Processed Data	Business Logic	User Actions

Question 3(a OR) [3 marks]

List three challenges of IoT implementation.

Solution

IoT Implementation Challenges:

Table 13. Challenges

Challenge	Description
Security & 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.

Solution

Key Technologies:
- **Sensing Technology**: MEMS, Environmental (DHT22), Biometric sensors.
- **Communication Technology**: Short range (WiFi, Zigbee), Long range (LoRaWAN, 5G).
- **Computing Technology**: Microcontrollers (ESP32), SBCs (Raspberry Pi).
- **Cloud Technology**: AWS IoT, Azure IoT, Data analytics platforms.
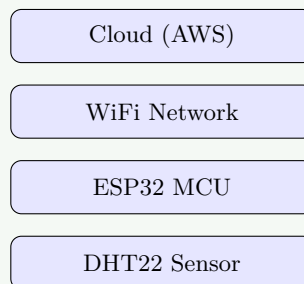
Technology Stack Example:

Cloud (AWS)

WiFi Network

ESP32 MCU

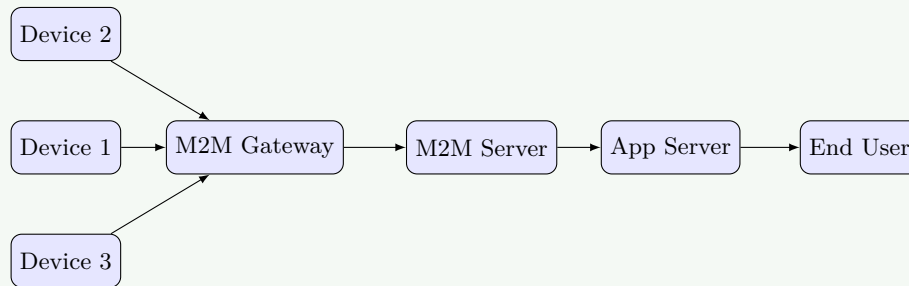DHT22 Sensor

Figure 7. Tech Stack Example

Mnemonic

"SCCC - Sensing Communication Computing Cloud"

Question 3(c OR) [7 marks]

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

Solution

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

M2M Architecture:

Figure 8. M2M Architecture

Example Application: Smart Street Lighting System
- **Motion Sensors**: Detect movement and send data via Zigbee.
- **Lights**: Communicate to create a "lighting path", adjusting brightness.
- **Controller**: Optimizes schedules via cellular connection.
- **Benefits**: Energy efficiency (60%), Predictive maintenance.

Table 14. Performance Metrics

Metric	Traditional	M2M Smart System
Energy Usage	100%	40%
Response Time	Manual (Hours)	Automated (Seconds)

Mnemonic

"ARSR - Autonomous Real-time Scalable Reliable"

Question 4(a) [3 marks]

Name three application layer protocols used in IoT.

Solution

IoT Application Layer Protocols:

Table 15. 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.

Solution

MQTT Role: MQTT (Message Queuing Telemetry Transport) is a lightweight publish-subscribe messaging protocol designed for IoT devices with limited bandwidth and power.
Architecture:

Figure 9. MQTT Architecture

QoS Levels:
- **QoS 0**: At most once (Fire and forget).
- **QoS 1**: At least once (Guaranteed delivery).
- **QoS 2**: Exactly once (Critical data).

Mnemonic

"PQPL - Publish QoS Persistent Last-will"

Question 4(c) [7 marks]

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

Solution

System Design: Temperature Monitoring System

Figure 10. System Architecture

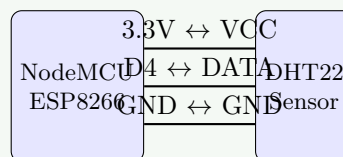**Circuit Diagram:**

Figure 11. Hardware Connections

Code Snippet:

Listing 4. Arduino Code

```
1  #include <ESP8266WiFi.h>
2  #include <DHT.h>
3  #define DHT_PIN D4
4  // Setup and Loop to read temp and publish via MQTT
5  float temp = dht.readTemperature();
6  client.publish("sensor/data", String(temp).c_str());
```

Question 4(a OR) [3 marks]

List types of sensors used in IoT applications.

Solution

IoT Sensor Types:

Table 16. 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 security challenges in IoT systems.

Solution

IoT Security Challenges:
- **Device-Level**: Weak authentication, firmware vulnerabilities.
- **Network-Level**: Unencrypted communication, Man-in-the-Middle.
- **Cloud-Level**: Data privacy, API security, Data breaches.
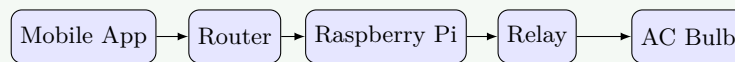
Table 17. Solutions

Challenge	Solution
Weak Authentication	Strong passwords, Multi-factor auth
Data Transmission	End-to-end encryption (TLS/SSL)
Firmware	Secure OTA updates

Mnemonic

"DNCI - Device Network Cloud Identity"

Question 4(c OR) [7 marks]

Draw block diagram to control bulb using Raspberry Pi via mobile app and explain blocks.

Solution

Smart Bulb Control System:

Mobile App → Router → Raspberry Pi → Relay → AC Bulb

Figure 12. Control Flow

System Operation Flow:
- **Tap ON**: App sends HTTP request -> Web Server (Pi) -> GPIO HIGH -> Relay ON -> Bulb ON.
- **Tap OFF**: App sends HTTP request -> Web Server (Pi) -> GPIO LOW -> Relay OFF -> Bulb OFF.

Hardware Connections:
- **Raspberry Pi**: GPIO 18, 5V, GND connected to Relay.
- **Relay**: Controls Live wire of AC circuit.
- **Safety**: Optocoupler isolation in relay module.

Mnemonic

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

Question 5(a) [3 marks]

Classify IoT applications into broad categories.

Solution

IoT Application Categories:

Table 18. 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.

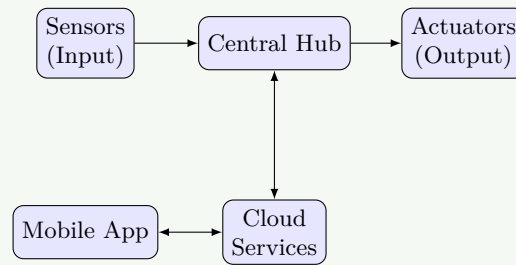**Solution**

Smart Home Automation System:

Figure 13. Automation System

Benefits:
- **Energy Efficiency**: 20-30% reduction.
- **Security**: Real-time alerts.
- **Convenience**: Voice commands.

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.

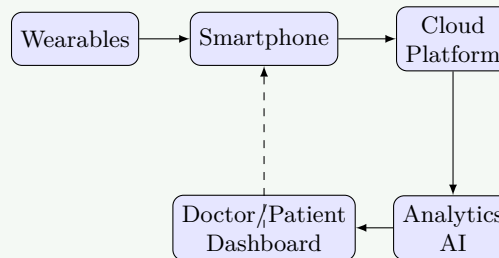**Solution**

IoT Healthcare Monitoring System:

Figure 14. Healthcare Architecture

Detailed Components:
1. **Patient Devices**: Smartwatch, BP Monitor, Smart Patches.
2. **Communication**: BLE to Phone, WiFi/Cellular to Cloud.
3. **Cloud Infrastructure**: HIPAA compliant storage, Real-time processing.
4. **Analytics**: Vital signs analysis, predictive alerts.
5. **Interfaces**: Patient App, Doctor Portal, Emergency Dashboard.

Working Principle:
- **Collection**: Vital signs every 15-30s.
- **Analysis**: ML algorithms check for anomalies.
- **Response**: Alerts sent to doctors/family if critical.

Mnemonic

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

Question 5(a OR) [3 marks]

List three real-world IoT applications.

> **Solution**
>
> **Real-World IoT Applications:**
>
> **Table 19.** Applications
>
> | Application | Description |
> |---|---|
> | **Smart Agriculture** | Automated irrigation |
> | **Industrial Monitoring** | Predictive maintenance |
> | **Smart Transportation** | Traffic management |

> **Mnemonic**
>
> "AIT - Agriculture Industrial Transportation"

Question 5(b OR) [4 marks]

Describe the role of IoT in a smart parking system.

> **Solution**
>
> **Smart Parking System:**
> - **Sensors**: Detect vehicle presence.
> - **Cloud**: Calculates availability.
> - **App**: Shows empty spots to drivers.
>
> **Benefits:**
> - Real-time availability updates.
> - Automated payments.
> - Reduced fuel consumption (searching).

> **Mnemonic**
>
> "DCPN - Detection Collection Processing Notification"

Question 5(c OR) [7 marks]

Draw Architecture block diagram of Raspberry Pi and explain it.
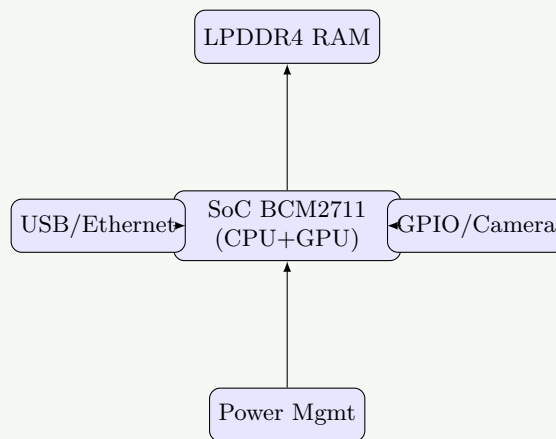
> **Solution**
>
> **Raspberry Pi 4B Architecture:**

Figure 15. Simplified Architecture

Detailed Components:
1. **CPU**: Quad-core ARM Cortex-A72 (1.5 GHz).
2. **GPU**: VideoCore VI (4K video support).
3. **RAM**: 1GB - 8GB LPDDR4 options.
4. **Connectivity**: Gigabit Ethernet, dual-band WiFi, BT 5.0.
5. **I/O**: 40-pin GPIO, 2x Micro-HDMI, CSI/DSI ports.

Advantages:
- Full Linux OS support.
- Rich community ecosystem.
- Cost-effective ($35+).

Mnemonic

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