CBCS SCHEME

USN

22MCA32

Third Semester MCA Degree Examination, Dec.2024/Jan.2025
Internet of Things

Time: 3 hrs. Max. Marks: 100

Note: 1. Answer any FIVE full questions, choosing ONE full question from each module.
2. M : Marks , L: Bloom's level , C: Course outcomes.

		Module – 1	M	L	C
Q.1	a.	What is IoT? Explain the evolutionary phases of the Internet.	6	L2	CO1
	b.	Discuss any two applications of IoT.	6	L3	CO1
	c.	With a neat diagram discuss the IoT World Forum (IoT WF) Standardized Architecture.	8	L2	CO1
		OR			
Q.2	a.	With a neat diagram discuss the one M2M IoT architecture.	7	L2	CO1
	b.	With a neat diagram discuss a simplified IoT architecture.	8	L2	CO1
	c.	Discuss the most significant challenges and problems that IoT is currently facing.	5	L3	CO1
		Module – 2			
Q.3	a.	Define sensors. Discuss different categories and types of sensors.	9	L2	CO2
	b.	Define smart objects. Discuss the characteristics of a smart object with diagram.	5	L2	CO2
	c.	What is LoRaWAN? Discuss about ZigBeeIp protocol stack.	6	L3	CO2
		OR			
Q.4	a.	Define Actuators. Discuss the comparison of Sensor and Actuators functionality with humans.	6	L2	CO2
	b.	Discuss 802.15.14 physical layer and MAC layer properties along with its frame format.	8	L2	CO2
	c.	List different characteristics and attributes considered when connecting smart objects. Discuss any two.	6	L1	CO2
		Module – 3			
Q.5	a.	What are the benefits of Internet Protocol?	6	L2	CO3
	b.	How optimizing IP for IoT is done? Discuss 6LOWPAN header stacks.	10	L2	CO3
	c.	What is the use of IoT Data Broker?	4	L1	CO3

		OR			
Q.6	a.	Define SCADA. Discuss the protocol stack for transporting serial DNP3 SCADA over IP.	10	L2	CO3
	b.	Why CoAP and MQTT protocols designed? Compare the differences between CoAP and MQTT.	10	L2	CO3
		Module – 4			
Q.7	a.	Discuss the following: i) Structured versus unstructured data. ii) Data in Motion versus data at rest. iii) "Three Vs" to categorize big data. iv) Types of data analysis results.	10	L1	CO4
	b.	Discuss massive parallel processing databases.	6	L2	CO4
	c.	Discuss about distributed Hadoop cluster.	4	L2	CO4
		OR			
Q.8	a.	What are the key values of edge streaming analytics? Illustrate the stages of data processing in an edge APU.	10	L1	CO4
	b.	Discuss OCTAVE Allegro steps and phases.	10	L2	CO4
		Module – 5			
Q.9	a.	With a neat diagram, explain Rasberry Pi board.	10	L2	CO5
	b.	Write a short note on smart traffic control and connected environment.	10	L2	CO5
		OR			
Q.10	a.	Discuss an IoT strategy for smarter cities.	5	L2	CO5
	b.	With a neat diagram, discuss smart city IoT architecture.	10	L2	CO5
	c.	Write a short note on Arduino.	5	L2	CO5

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Q1a) What is IoT? Explain the evolutionary phases of internet

IoT (Internet of Things) refers to the network of physical devices that are embedded with sensors, software, and connectivity to collect and exchange data over the Internet.
It enables objects to be sensed and controlled remotely, improving efficiency, automation, and decision-making.

- Goal: "Connect the unconnected"
- Example: Smart home, connected cars, health monitors

Evolutionary Phases of the Internet

(as per IoT Fundamentals – Cisco Press)

Phase	Name	Key Idea
1	Connectivity (Digitize Access)	Email, web, search – basic Internet use
2	Networked Economy (Digitize Business)	E-commerce, digital supply chains
3	Immersive Experiences (Digitize Interactions)	Social media, cloud, mobile apps
4	Internet of Things (Digitize the World)	Connects devices, sensors, machines to Internet

- Each phase builds on the previous.
- IoT = next phase focused on real-world automation and smart environments.

Q1b) Discuss any two applications of IoT

1. Smart Homes

- Definition: Smart homes use wireless IoT technology to automate and control appliances, lighting, temperature, and security systems.
- Functionality:
    - Devices like temperature sensors and HVAC controllers adjust indoor climate automatically.
    - Wireless communication makes installation easy and flexible.

- Benefits:
    - Energy efficiency
    - User convenience
    - Improved comfort and security

2. Connected Factory (Industrial IoT)

- Definition: In manufacturing, IoT is used to connect machines, workers, and systems for better control and efficiency.
- Functionality:
    - Real-time tracking with RFID tags and Wi-Fi sensors on assembly lines.
    - Sensors report on material flow, enabling dynamic adjustments.
- Benefits:
    - Reduced downtime
    - Improved production efficiency
    - Predictive maintenance and safety

Q1c) With a neat diagram explain IoT WF architecture

Introduction to IoTWF Architecture

The IoT World Forum (IoTWF) architecture, developed by Cisco and others, provides a seven-layer reference model that helps define and standardize the structure of an IoT system.

It ensures modularity, interoperability, and layered security across IoT implementations.

IoTWF 7-Layer Architecture Overview

◇ Layer 1: Physical Devices and Controllers

This layer includes all endpoint devices such as sensors, actuators, controllers, and machines.

Devices generate data or receive control commands.

◇ Layer 2: Connectivity

Provides network connectivity for data transmission.

Includes wired/wireless technologies (e.g., Wi-Fi, ZigBee, Ethernet).

- Layer 3: Edge Computing

Processes data close to the devices to reduce latency.

Filters, aggregates, and transforms data before sending to higher layers.

- Layer 4: Data Accumulation

Stores and buffers data from devices and edge nodes.

Converts real-time events into data for later processing.

- Layer 5: Data Abstraction

Ensures uniformity and compatibility across different data formats.

Applies virtualization and semantic models.

- Layer 6: Application Layer

Hosts software applications that analyze and respond to IoT data.

Supports dashboards, automation scripts, analytics, etc.

- Layer 7: Collaboration and Processes

Involves human interaction, workflows, and business processes.

Delivers business value through integration with enterprise systems.

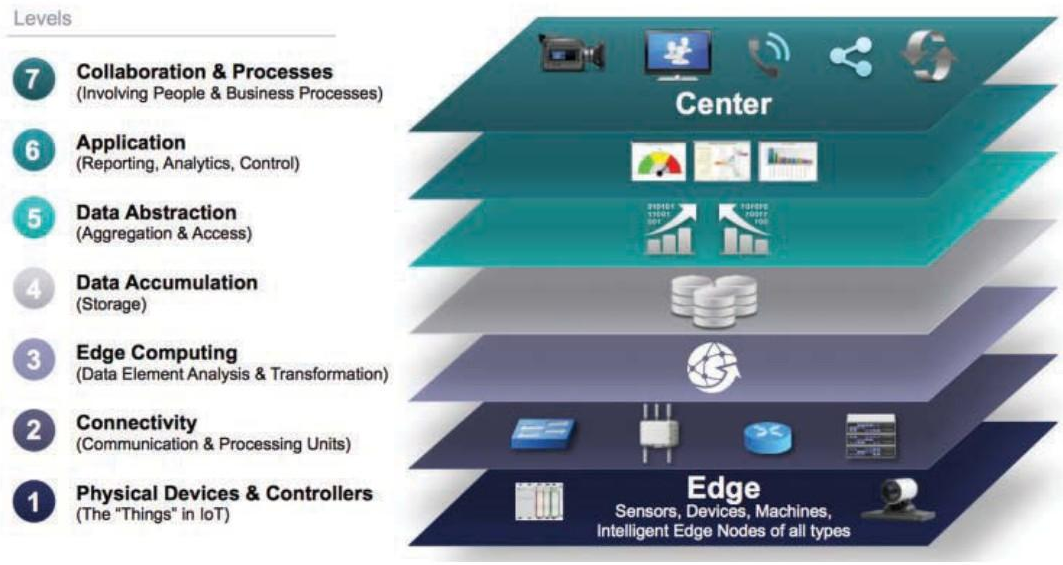


Figure 2-2 *IoT Reference Model Published by the IoT World Forum*

Security:

Spans all layers – each layer must have its own security mechanisms.

Key Benefits of IoTWF Model

Modular design helps in clear system development.

Supports multi-vendor interoperability.

Defines responsibilities across IT and OT teams.

Enables tiered security implementation.

Q2a) With a neat diagram explain one M2M architecture

The oneM2M architecture is a standardized IoT architecture developed to address the interoperability challenges in Machine-to-Machine (M2M) and Internet of Things (IoT) communications. It is structured into three major domains:

Figure 2-1 illustrates the oneM2M IoT architecture.

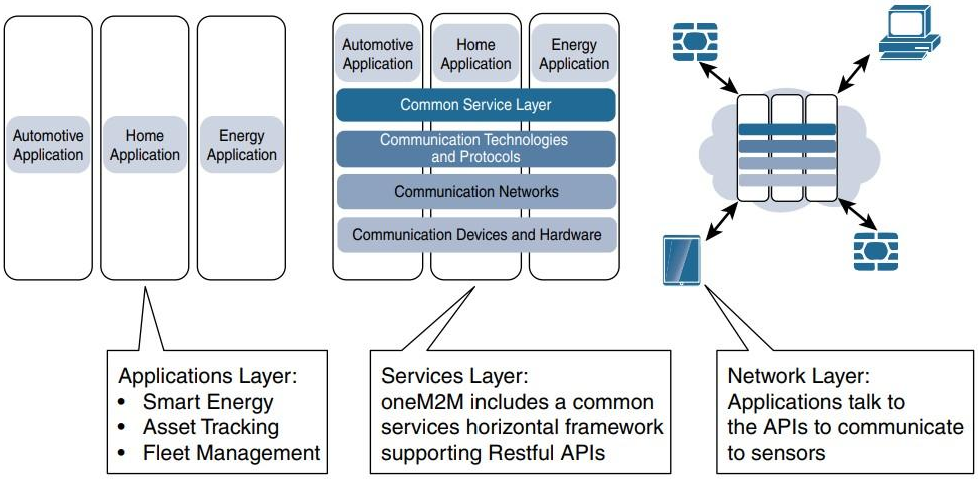


Figure 2-1 *The Main Elements of the oneM2M IoT Architecture*

Explanation:

1. Applications Layer:

- This layer focuses on the connectivity between devices and their industry-specific applications.
- It includes application-layer protocols and northbound APIs that interact with business intelligence systems.
- Applications are often vertical (e.g., smart home, automotive, energy).

2. Services Layer:

- This is a horizontal layer that supports common services required across applications.
- It includes APIs, middleware, and platform services.
- It promotes interoperability using a standardized service layer that can be embedded in various devices and software.

3. Network Layer:

- This layer handles the actual communication infrastructure, including both devices and protocols.
- It connects sensors and actuators to the network using technologies like Wi-Fi, LoRa, Zigbee, or Ethernet.

- It enables communication through field area networks (FANs) and includes gateway devices to connect legacy or non-IP devices.

Key Features of oneM2M Architecture:

- Provides interoperability across heterogeneous systems.
- Uses RESTful APIs for ease of integration.
- Facilitates horizontal communication services across vertical industries like healthcare, smart cities, and transportation.
- Supports integration of legacy systems through gateways.

Q2b) With a neat diagram explain Simplified architecture

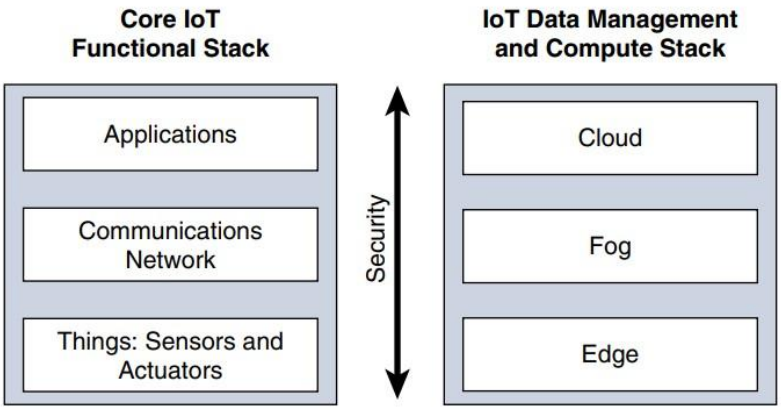


Figure 2-6 *Simplified IoT Architecture*

The Simplified IoT Architecture is presented in the form of two parallel stacks:

1. Core IoT Functional Stack
2. IoT Data Management and Compute Stack

This model simplifies understanding of IoT by organizing all components into logical layers. Though simplified, it covers all layers of complex IoT architectures in functional blocks that are easy to grasp.

Explanation of Each Layer:

1. Core IoT Functional Stack:

- Things Layer: Includes physical devices like sensors and actuators.

- Communications Layer: Responsible for transmitting data through networks such as Wi-Fi, LoRa, or Zigbee.
- Applications Layer: Analytics and business logic that utilize the collected data for insights and automation.

2. IoT Data Management and Compute Stack:

- Edge Layer: Data is processed directly on devices or nearby gateways.
- Fog Layer: Intermediate layer for processing and filtering data before it reaches the cloud.
- Cloud Layer: Centralized systems for long-term storage, advanced analytics, and global access.

Security (Spanning Both Stacks):

- Security is not confined to a single layer but is embedded across all layers, ensuring secure communication, access control, encryption, and integrity.

Key Features:

- Two Parallel Stacks: Separating core functions from data management gives better visibility and modular design.
- Layered Approach: Encourages independent development and deployment of each layer.
- Flexible and Scalable: Can adapt to various industry-specific use cases.
- Edge-Fog-Cloud: Supports distributed computing close to the data source to reduce latency.

2C) Explain the most significant challenges and problems that IoT is facing now

While the Internet of Things (IoT) promises transformational benefits, it also faces numerous significant challenges that must be addressed for successful and secure implementation. The most critical issues include:

1. Scale
   - Description: IoT deployments often operate at a scale far beyond traditional IT networks. For instance, a utility company may manage tens of millions of smart meters, creating a 1,000-fold increase in connected devices compared to its workforce.
   - Challenge: Designing and managing networks that can scale efficiently while maintaining performance and reliability.

2. Security

- Description: Each connected "thing" becomes a potential attack surface. Compromised devices can be used to attack other systems.
- Challenge: Providing end-to-end security (device, network, and cloud) while dealing with legacy systems and diverse protocols.

3. Privacy
   - Description: IoT devices collect personal and sensitive data (e.g., health, location, shopping patterns).
   - Challenge: Determining who owns the data, how it is secured, and who has access to it.
4. Big Data and Data Analytics
   - Description: IoT generates a massive volume of data in various formats from multiple sources.
   - Challenge: Storing, processing, and analyzing this data efficiently and in real time to derive useful insights.
5. Interoperability
   - Description: IoT includes a wide variety of devices and protocols, both proprietary and open.
   - Challenge: Ensuring seamless communication and integration among different vendors and standards.
6. Legacy System Integration
   - Description: Many IoT deployments must work alongside legacy industrial systems not designed for modern network environments.
   - Challenge: Ensuring compatibility, security, and reliability without costly hardware replacements.
7. Network Design Erosion
   - Description: Over time, initially secure IoT network designs degrade due to ad hoc updates and lack of centralized control.
   - Challenge: Maintaining robust network architecture and communication path integrity.
8. Data Management Bottlenecks
   - Description: Transmitting all raw data to the cloud is inefficient.
   - Challenge: Implementing fog/edge computing to handle data closer to the source and reduce latency and costs.
   -

Q3a) Define Sensor, Discuss different categories and types of sensors

A sensor is a device that measures physical quantities from the environment (such as temperature, pressure, light, motion, etc.) and converts those measurements into a digital or analog signal. This signal is then transmitted to a processing unit or device to interpret the data for meaningful use.
“A sensor does exactly as its name indicates: It senses. More specifically, a sensor measures some physical quantity and converts that measurement reading into a digital representation.”

Categories of Sensors:

Sensors can be grouped in various ways based on different criteria:

1. Active vs. Passive
    - Active: Require an external power source and generate a signal (e.g., radar sensors).
    - Passive: Operate without external power and simply receive signals (e.g., thermocouples).
2. Invasive vs. Non-invasive
    - Invasive: Become part of the environment being measured.
    - Non-invasive: Do not directly interfere with the environment.
3. Contact vs. No-contact
    - Contact: Require physical contact with the subject (e.g., thermocouple).
    - No-contact: Use radiation or waves to measure without direct contact (e.g., IR thermometer).
4. Absolute vs. Relative
    - Absolute: Measure exact values with reference to an absolute scale.
    - Relative: Measure in comparison to a reference value.
5. Area of Application
    - Sensors can also be grouped by industries like agriculture, automotive, healthcare, etc.
6. Measurement Principle
    - Thermoelectric, piezoresistive, optical, electrochemical, etc.
7. What They Measure
    - This is the most common IoT-focused classification: based on the physical variable being sensed

Sensor Type	Description	Examples
Acoustic	Detects sound waves and converts to digital signals	Microphone, Geophone
Temperature	Measures heat or cold	Thermometer, Thermocouple
Humidity	Detects moisture levels	Hygrometer, Soil moisture sensor
Pressure	Measures force applied by gases or liquids	Barometer, Piezometer
Position	Detects location or displacement	Proximity sensor, Inclinometer
Motion/Occupancy	Detects presence or movement	Radar sensor, Motion detector
Light	Detects visible/invisible light	IR sensor, Photodetector
Radiation	Detects ionizing radiation	Geiger-Müller counter

Sensor Type	Description	Examples
Chemical	Senses chemical composition or gas concentration	Smoke detector, CO2 sensor
Biosensor	Measures biological data	Glucose biosensor, Pulse oximeter
Force	Measures force or pressure	Force gauge, Tactile sensor
Flow	Measures fluid flow	Anemometer, Water meter
Velocity/Acceleration	Measures speed or change in speed	Accelerometer, Gyroscope

Q3b) Define Smart objects. Discuss the characteristics of a smart object with diagram

A smart object is a device that has, at a minimum, the following four defining characteristics: a processing unit, sensors and/or actuators, a communication device, and a power source

Key Characteristics of a Smart Object:

1. Processing Unit
    - Handles data acquisition, local processing, and decision making.
    - Commonly a microcontroller due to its low power, flexibility, and cost-effectiveness.
2. Sensors and/or Actuators
    - Sensors measure physical quantities (e.g., temperature, humidity).
    - Actuators perform actions (e.g., switch on a motor, rotate a mirror).
3. Communication Device
    - Enables interaction with other devices and cloud platforms.
    - Can use wired or wireless protocols (e.g., Wi-Fi, Bluetooth, Zigbee).
4. Power Source
    - Provides the necessary energy for operations.
    - Options include batteries, solar panels, mains power, or energy scavenging methods.

Q3c) What is LoRaWAN? Discuss about Zigbee IP Protocol Stack.

LoRaWAN (Long Range Wide Area Network) is a communication protocol and system architecture developed for low-power, long-range IoT applications. It is part of the LPWAN (Low Power Wide Area Network) technology category and is governed by the LoRa Alliance.

Key Features of LoRaWAN:

- LoRa is the physical (PHY) layer, using chirp spread spectrum modulation.
- LoRaWAN is the MAC and higher layers, defining communication protocols, architecture, and security.
- Optimized for: Low power consumption, long-range (up to 15 km in rural areas), and low data rates.
- Topology: Uses a "star of stars" network where end devices connect to gateways, which forward data to a central network server.

Security in LoRaWAN:

- Two layers of encryption: Network (NwkSKey) and Application (AppSKey)
- AES-128 encryption is used for data confidentiality and message integrity

Zigbee IP Protocol Stack

Zigbee IP is an evolution of the ZigBee protocol that incorporates open IETF standards such as IPv6, 6LoWPAN, and RPL for low-power, low-bandwidth IoT networking. It enhances interoperability and Internet integration compared to traditional ZigBee.

Key Features of Zigbee IP:

- Based on IPv6 and supports 6LoWPAN compression and fragmentation.
- Uses RPL for routing and ICMPv6 for message handling.
- Supports both UDP and TCP, making it suitable for a wider range of applications.
- Originally developed for Smart Energy (SE) 2.0, but usable in any IoT domain.

Q4a) Define actuators. Discuss the comparison of actuator and sensor functionality with humans.

An actuator is a device that receives a control signal (usually electrical or digital) and performs a physical action, such as motion, rotation, or force application. Actuators are the action-enabling components in an IoT system, working in contrast to sensors, which gather data.

"Actuators... receive some type of control signal (commonly an electric signal or digital command) that triggers a physical effect, usually some type of motion, force, and so on." Comparison of Actuator and Sensor Functionality with Humans:

This analogy illustrates how IoT devices mimic biological systems:

Component	Human Equivalent	Function
Sensor	Human Senses (eyes, ears, skin)	Sense physical inputs (light, sound, temperature, pressure, etc.)
Processor	Human Brain	Processes sensory information and makes decisions
Actuator	Human Muscles	Acts based on brain's signals (e.g., move a limb, open mouth, etc.)

Types of Actuators (by Energy Type):

Type	Examples
Mechanical actuators	Lever, screw jack, hand crank
Electrical actuators	Transistor, diode
Electromechanical actuators	AC/DC motors, stepper motors
Electromagnetic actuators	Solenoids, electromagnets
Hydraulic/pneumatic actuators	Pistons, pressure valves
Smart material actuators	Shape memory alloys, piezoelectric devices
Micro/Nano actuators	Electrostatic motors, microvalves

4b) Discuss IEEE 802.15.4 MAC and Physical Layer along with its frame format.

IEEE 802.15.4 is a standard that defines the MAC (Medium Access Control) and PHY (Physical) layers for low-rate wireless personal area networks (LR-WPANs). It is widely used as the basis for higher-layer IoT protocol stacks such as Zigbee, 6LoWPAN, and Thread.

1. Physical (PHY) Layer:

- Function: Transmits and receives raw bits over the physical medium.
- Frequency Bands Supported:
    - 2.4 GHz (worldwide) – 16 channels, 250 kbps
    - 915 MHz (Americas) – 10 channels, 40 kbps
    - 868 MHz (Europe) – 1 channel, 20 kbps
- Preamble: Used to synchronize the receiver.
- Start of Frame Delimiter: Indicates where the frame content begins.
- Frame Length: Informs receiver of expected payload size.
- PSDU (PHY Service Data Unit): Contains MAC frame.

2. MAC (Medium Access Control) Layer:

- Function: Coordinates access to the wireless channel and data delivery.
- Responsibilities:
    - Beaconing and network synchronization
    - PAN (Personal Area Network) association and disassociation
    - Frame delivery and acknowledgments
    - Security using AES encryption

Types of MAC Frames:

1. Data Frame – Used to carry data between devices
2. Beacon Frame – Sent by coordinator to manage synchronization
3. Acknowledgment Frame – Confirms successful frame receipt
4. MAC Command Frame – Used for control messages like association requests

4c) List different characteristics and attributes to be considered for connecting smart objects. Discuss any two.

When selecting and connecting smart objects in an IoT environment, the following key characteristics and attributes must be considered:

1. Range
2. Frequency Bands
3. Power Consumption
4. Topology
5. Constrained Devices
6. Constrained-Node Networks

1. Range (Discussed)

Definition:
Range refers to the maximum distance over which a signal can be effectively transmitted between two smart objects.

Types:

- Short-range (e.g., Bluetooth, IEEE 802.15.1): Tens of meters.
- Medium-range (e.g., Zigbee, IEEE 802.15.4): Tens to hundreds of meters.
- Long-range (e.g., LoRaWAN, NB-IoT): Greater than 1 mile.

Importance:
Range is a critical factor in network planning, especially when smart objects are widely distributed, such as in agriculture or city infrastructure.

2. Power Consumption (Discussed)

Definition:
Power consumption determines the energy efficiency of a smart object, especially important for battery-operated devices.

Considerations:

- Battery-powered nodes may need to operate for 5–15 years.

- Power-efficient communication protocols and sleep modes are essential.
- Technologies like LPWAN are optimized for ultra-low power consumption.

Importance:
Reduces maintenance costs and increases device longevity, especially for inaccessible deployments like smart meters or remote sensors.

Q5a) What are the benefits of Internet Protocol?

The Internet Protocol (IP) plays a crucial role in the connectivity and communication of smart objects in IoT systems. IP provides a standardized and scalable way for devices to communicate across heterogeneous networks.

Benefits of Using Internet Protocol (IP):

1. End-to-End Communication
    - IP provides seamless, end-to-end communication between devices, regardless of the underlying hardware or network.
2. Global Addressing and Identification
    - Each device can have a unique IP address, enabling precise identification and location tracking of billions of devices.
3. Interoperability
    - IP is an open, well-established standard, making it compatible with a wide variety of devices, platforms, and vendors.
4. Scalability
    - With IPv6, the address space supports trillions of devices, which is ideal for the expanding IoT ecosystem.
5. Use of Existing Infrastructure
    - IP-based devices can utilize existing Internet infrastructure, reducing the need for new proprietary networks.
6. Proven and Mature Technology
    - IP has been in use for decades and is a robust, time-tested protocol supported by many software libraries and hardware platforms.

7. Support for Secure Communication
    - IP supports security protocols like IPsec, DTLS, and TLS, enabling data confidentiality, integrity, and authentication.
8. Mobility Support
    - Through Mobile IP and similar mechanisms, devices can change networks without losing connectivity, ideal for mobile and wearable IoT devices.
9. Protocol Reuse and Layering
    - Applications can be built using higher-layer protocols like HTTP, MQTT, CoAP over IP, leveraging familiar programming models.
10. Simplified Network Management

    IP networks support well-known tools and techniques for monitoring, troubleshooting, and managing devices, easing large-scale deployments.

Q5b) How optimizing IP for IoT is done? Discuss 6LOWPAN header stacks.

While the Internet Protocol (IP) is foundational to IoT networking, it was originally designed for resource-rich environments. IoT devices, on the other hand, are often constrained in terms of power, memory, and bandwidth. To make IP viable for such devices, various optimizations are applied.

Main Optimization Strategies:

1. Use of IPv6 over IPv4
    - IPv6 is preferred for IoT due to larger address space and better support for autoconfiguration.
2. Adaptation Layers
    - These are used to adapt full IP stacks to low-power, lossy networks (LLNs).
    - 6LoWPAN is the most prominent adaptation layer developed for IoT.
3. Header Compression
    - Standard IPv6 and UDP headers (48 bytes) are compressed to as little as 6 bytes, greatly reducing overhead.

4. Fragmentation Support
    - IPv6 requires 1280 bytes minimum MTU, while IEEE 802.15.4 supports only 127 bytes per frame. Fragmentation is essential.
5. Mesh Addressing
    - Supports multi-hop routing at the link layer for more flexible network topologies

6LoWPAN Header Stacks:

6LoWPAN introduces modular headers that can be stacked in various combinations to enable:

- Header compression

  802.15.4 Header → IPv6 Header Compression → IPv6 Payload

- Fragmentation

  802.15.4 Header → Fragment Header → IPv6 Header Compression → IPv6 Payload

- Mesh addressing

  802.15.4 Header → Fragment Header → Mesh Addressing Header → IPv6 Header Compression → IPv6 Payload

Benefits of 6LoWPAN Optimization:

Reduced Packet Size: Makes IPv6 viable over constrained links like IEEE 802.15.4.

Improved Payload Efficiency: Increases usable data per frame (e.g., from 53 bytes to 108 bytes).

Supports Routing and Scalability: Through mesh addressing and fragmentation.

Low Power Operation: Critical for battery-powered IoT devices.

Q5c) What is the use of IoT Data broker?

An IoT Data Broker is a middleware component that facilitates data exchange between sensors and applications by standardizing and translating data from diverse sources into a uniform, usable format. It plays a critical role in handling interoperability, data management, and commercial distribution of IoT data.

Key Uses of IoT Data Broker:

1. Standardization of Sensor Data

- IoT devices from different manufacturers often produce data in different formats.
- An IoT data broker decodes and translates various sensor data into a common, standardized format that can be easily consumed by any application.

Example: Temperature values from three sensors—2-byte, 4-byte, and 8-byte encoded—are all normalized into a standard format by the broker.

2. Simplifies Application Development

- Applications do not need to understand or handle vendor-specific data formats.
- They simply connect to the broker's API to retrieve standardized data, reducing complexity and development time.

3. Enables Scalability

- As IoT networks grow to include hundreds or thousands of sensors, managing direct integration becomes difficult.
- A data broker offers a centralized solution to manage and scale these interactions efficiently.

4. Supports Commercialization

- Organizations can use data brokers to monetize IoT data.
- Access to data can be granted to third-party applications or businesses for a fee, turning the broker into a revenue-generating service.

5. Enhances Interoperability and Flexibility

The data broker acts as a translation layer between heterogeneous sensor systems and unified applications, improving system interoperability.

Q6 a) Define SCADA. Discuss the Protocol stack for transporting serial DNP3 SCADA over IP

SCADA stands for Supervisory Control and Data Acquisition. It is a centralized system used to monitor and control remote devices such as sensors and actuators across industrial environments like utilities, manufacturing, and energy.

- SCADA enables real-time data acquisition from remote devices such as RTUs (Remote Terminal Units) and IEDs (Intelligent Electronic Devices).

- These devices gather data (e.g., voltage, current, switch status) and send it to a central SCADA server (master), which may also send control commands back.

“SCADA is a system by which remote devices can be monitored and controlled by a central server... typically used in substations and automation systems.”

SCADA with DNP3 over IP:

DNP3 (Distributed Network Protocol) is a commonly used SCADA protocol in North America, operating on a master/slave model, where:

- Master = Central SCADA server (usually located in a control center)
- Slave = Remote devices (referred to as Outstations) such as RTUs

The protocol supports communication in either event-driven (asynchronous) or poll-response (synchronous) modes.

Protocol Stack for Transporting Serial DNP3 SCADA over IP:

To support modern IP networks, legacy serial-based DNP3 was updated under IEEE 1815-2012, allowing it to be used over TCP or UDP, typically on port 20000.

Stack Layer Descriptions:

- DNP3 Application Layer: Handles control commands and data retrieval (e.g., status of a breaker).
- DNP3 Transport Function: Manages segmentation of larger messages into smaller parts for transmission.
- DNP3 Data Link Layer: Ensures message integrity with checksums and link-layer acknowledgments.
- TCP/UDP Layer: Provides reliable (TCP) or lightweight (UDP) transport.
- IP Layer: Enables routing and addressing across the network.
- Data Link/Physical Layer: Physical network medium (e.g., Ethernet).

Operational Features:

- Connection management is defined for establishing TCP sessions (e.g., TCP active/passive opens).
- Keepalive mechanisms: DNP3 uses link-layer status requests to ensure session continuity.
- UDP Constraints: DNP3 frames cannot span across multiple UDP datagrams.

Q6b) Why were CoAP and MQTT protocols designed? Compare the difference between CoAP and MQTT.

Purpose of CoAP and MQTT Protocols:

1. CoAP (Constrained Application Protocol)

- Designed by: IETF CoRE (Constrained RESTful Environments) working group.
- Purpose: To provide a lightweight RESTful protocol for constrained devices and networks.
- Use Case: Suited for low-power, lossy networks (LLNs) with limited bandwidth, where HTTP is too heavy.
- Design Goals: Simplicity, support for multicast, asynchronous communication, minimal overhead.

2. MQTT (Message Queuing Telemetry Transport)

- Originally Developed by: IBM and Arcom for oil and gas industries.
- Purpose: To enable reliable, low-overhead publish/subscribe communication between sensors and servers.
- Use Case: Ideal for remote monitoring with unreliable or high-latency networks.
- Design Goals: Reliability, simplicity, low bandwidth usage, TCP-based connectivity, message queuing

Aspect	CoAP	MQTT
Transport Protocol	UDP	TCP
Messaging Model	Request/Response (Client–Server)	Publish/Subscribe
Suitability for LLNs	Excellent (designed for constrained nodes)	Low to Fair (unless paired with UDP)

Aspect	CoAP	MQTT
Security	DTLS (Datagram Transport Layer Security)	TLS/SSL
Communication Model	One-to-One	Many-to-Many
Strengths	Lightweight, RESTful, supports multicast, easy for constrained devices	Robust communication, supports QoS levels, scalable with broker model
Weaknesses	Less reliable than TCP (requires app-level retry logic)	Heavier on constrained devices, no multicast support
Multicast Support	Yes	No
Example Use Case	Smart meters, environmental monitoring	Smart building management, messaging systems, telemetry systems

Q7a) Discuss the following:

Structured versus unstructured data

Data in motion and data at rest

3 Vs to categories bigdata

Types of data analysis results

Structured vs. Unstructured Data

Aspect	Structured Data	Unstructured Data
Format	Organized in rows and columns (tables)	No predefined format or structure
Storage	Stored in relational databases (RDBMS)	Stored in data lakes, NoSQL databases, files, emails, etc.
Examples	SQL databases, spreadsheets	Audio, video, images, emails, social media posts

Aspect	Structured Data	Unstructured Data
Ease of Analysis	Easy to search, query, and analyze	Requires advanced tools (NLP, ML, etc.) for processing
Schema	Fixed schema	No fixed schema

Data in Motion vs. Data at Rest

Type	Description	Examples
Data in Motion	Data actively moving between devices, networks, or systems	Sensor readings, streaming video, IoT
Data at Rest	Data stored and not currently being transmitted	Databases, data warehouses, hard drives
Security Focus	Encryption in transit, secure transmission protocols	Encryption at rest, access control

The 3 Vs to Categorize Big Data

- Volume
  - Refers to the amount of data generated (terabytes to zettabytes).
  - Example: Data from millions of IoT sensors.
- Velocity
  - Refers to the speed of data generation and processing.
  - Example: Real-time traffic updates from GPS-enabled devices.
- Variety
  - Refers to the different types and formats of data (structured, unstructured, semi-structured).
  - Example: Combining video, images, text, and sensor logs.

Types of Data Analysis Results

Analysis Type	Purpose	Example
Descriptive	Describes what has happened	Monthly sales report
Diagnostic	Explains why something happened	Root cause of website traffic drop
Predictive	Forecasts what is likely to happen	Predicting customer churn
Prescriptive	Suggests actions based on predictions	Recommending inventory restocking strategies

Q7b) Discuss Massively Parallel Processing (MPP).

Massively Parallel Processing (MPP) refers to a computing architecture in which many independent processors (often in the hundreds or thousands) work simultaneously on different parts of a task or data set to perform high-speed processing.

Key Characteristics of MPP:

1. Multiple Processors/Nodes:
    - Each processor has its own memory and operating system.
    - Processors work on independent pieces of the overall problem.
2. Parallel Execution:
    - Tasks are divided and distributed across processors to be executed simultaneously, dramatically improving performance.
3. Scalability:
    - MPP systems can scale horizontally by adding more nodes, making them suitable for handling big data workloads.
4. Shared Nothing Architecture:
    - Each node operates independently and does not share memory or disk, reducing contention and bottlenecks.
5. Used in Big Data Analytics:

- Common in data warehouses and platforms like Teradata, Amazon Redshift, Google BigQuery, and Hadoop-based ecosystems.

Advantages of MPP:

- High performance: Enables faster processing of large datasets.
- Scalability: Easily expanded by adding more nodes.
- Fault isolation: Node failure does not affect others.
- Optimized for analytics: Well-suited for executing complex queries over big data.

Disadvantages of MPP:

- Complex system management due to multiple nodes.
- High cost of setup and maintenance.
- Requires careful data distribution to avoid processing skew.

Example Use Case:

In a retail business, an MPP system might:

- Use hundreds of processors to simultaneously analyze sales data from stores worldwide.
- Deliver insights in real-time to support marketing, inventory, and sales decisions

Q7c) Discuss Distributed Hadoop Cluster.

A Distributed Hadoop Cluster is a network of computers (nodes) configured to work together using the Apache Hadoop framework to store and process large volumes of data across multiple machines in a scalable, fault-tolerant, and cost-effective manner.

Key Components of a Hadoop Distributed Cluster:

1. HDFS (Hadoop Distributed File System):

- Responsible for storage.
- Divides files into blocks (typically 128 MB or 256 MB).
- Stores each block across multiple nodes for fault tolerance.

2. YARN (Yet Another Resource Negotiator):

- Manages cluster resources and schedules jobs.
- Coordinates execution of MapReduce and other applications.

3. MapReduce Framework:

- Processing engine that breaks down computation into Map and Reduce tasks.
- Runs tasks in parallel across the cluster.

Node Type	Function
NameNode	Manages metadata for HDFS (file locations, permissions).
DataNode	Stores actual data blocks and handles read/write requests.
ResourceManager	Coordinates and allocates cluster resources for running applications.
NodeManager	Runs on each node, manages the execution of tasks assigned by YARN.
JobTracker/TaskTracker	(In older Hadoop versions) managed MapReduce jobs.

Advantages of a Distributed Hadoop Cluster:

Scalability: Add more nodes easily to handle growing data.

- Fault Tolerance: Data is replicated across nodes for recovery.
- Cost-Effective: Runs on commodity hardware.
- Parallel Processing: Breaks large tasks into smaller pieces processed simultaneously.

Use Cases:

- Big data analytics
- Log processing
- Social media analysis
- Real-time recommendations
- Genomic data analysis

Q8a) What are the key values of edge streaming analytics? Illustrate the stages of data processing in Edge APU.

Key Values of Edge Streaming Analytics:

Edge streaming analytics provides real-time processing capabilities at the edge of the network, near the data source. Its main values include:

1. Reducing Data at the Edge
    - IoT devices generate huge volumes of data. Processing and filtering it at the edge reduces bandwidth, storage, and processing needs in the cloud.
2. Analysis and Response at the Edge
    - Some data, such as industrial control signals, are only meaningful in real-time. Edge analytics allows decisions to be made instantly, where the data is generated.
3. Time Sensitivity
    - For time-critical operations (e.g., detecting hazards), waiting for cloud processing introduces unacceptable latency. Edge analytics ensures immediate reaction.

Stages of Data Processing in Edge APU (Analytics Processing Unit):

The edge APU processes real-time data through the following stages:

1. Raw Input Data

- Data streams coming from sensors and smart devices.

2. Edge Analytics Processing

- The APU performs real-time functions such as:
    - Filter: Removes irrelevant or redundant data (e.g., regular status polls).
    - Transform: Formats the data for analysis.
    - Time Contextualization: Applies time windows (e.g., averages over 2 minutes).
    - Correlate: Combines data from multiple streams or with historical data.
    - Pattern Matching: Detects predefined or learned anomalies and trends.

- Decision Logic: May trigger alerts or local action based on analysis.

3. Output Streams

- The processed, relevant, and actionable data is output to:
  - Smart objects for real-time response.
  - Cloud systems (via MQTT or similar) for long-term storage or deeper analysis.

Q8b) Describe OCTAVE Allergo Steps and Phases

OCTAVE Allegro (Operationally Critical Threat, Asset, and Vulnerability Evaluation) is a risk assessment framework developed by the Software Engineering Institute at Carnegie Mellon University. It is a lightweight, structured methodology designed to help organizations identify, evaluate, and mitigate cybersecurity risks, particularly where resources are limited.

OCTAVE Allegro: Steps and Phases

The methodology includes eight structured steps, grouped into four main phases:

Phase 1: Establish Drivers

Step 1: Establish Risk Measurement Criteria

- Define how risk will be assessed and measured.
- Focus on impact, value, and prioritization.
- Serves as a reference for later steps in evaluating threats and risks.

Phase 2: Profile Assets

Step 2: Develop Information Asset Profile

- Identify and list critical information assets.
- Include owners, custodians, technology components, and business processes.

Step 3: Identify Information Asset Containers

- Identify where information resides—in physical, digital, or human containers.
- Focus is on container-level vulnerabilities, not just data.

Phase 3: Identify Threats

Step 4: Identify Areas of Concern

- Analyze business processes and use cases to spot security concerns.
- Introduces subjective analysis and creativity based on historical incidents.

Step 5: Identify Threat Scenarios

- Define potential threat events, including both accidental and intentional causes.
- Model threats using threat trees.

Phase 4: Identify and Mitigate Risks

Step 6: Identify Risks

- Determine specific risks from threat scenarios.
- Evaluate how risks impact the organization.

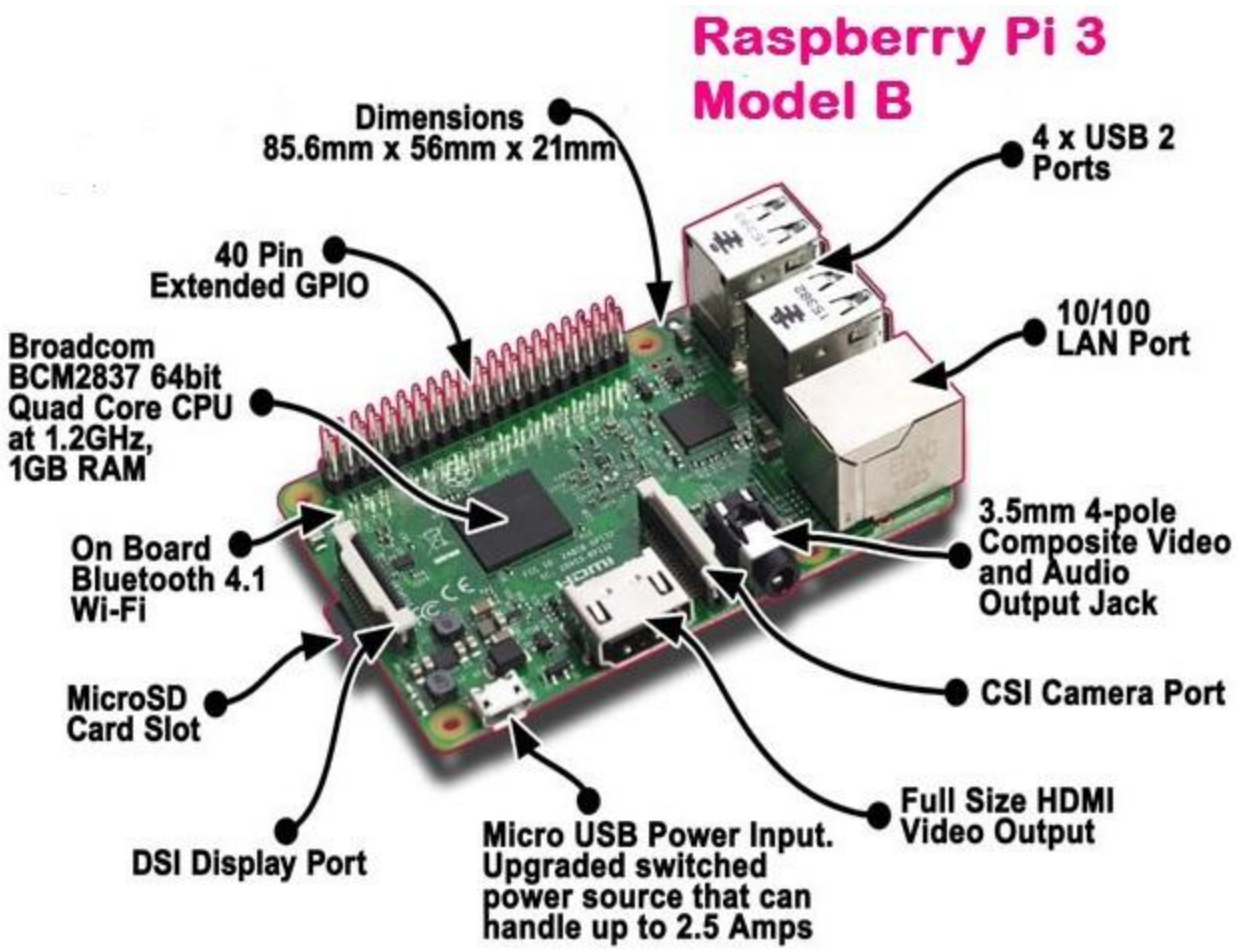
Step 7: Analyze Risks

- Perform qualitative analysis using criteria from Step 1.
- Prioritize risks based on impact severity and likelihood.

Step 8: Define Mitigation Approach

- Decide on actions:
    1. Accept the risk
    2. Mitigate the risk
    3. Defer the decision for further investigation

Q9a) With a neat diagram explain raspberry board



Q9b) Write a short note on smart traffic control and connected environment

Smart Traffic Control:

Smart traffic control systems leverage Internet of Things (IoT) technologies, sensors, cameras, and real-time analytics to efficiently manage and optimize traffic flow in urban areas.

Key Components:

- Sensors and Cameras: Detect vehicle presence, speed, and congestion levels.
- Adaptive Traffic Signals: Change signal timing dynamically based on traffic density.
- Connected Vehicles: Communicate with traffic infrastructure (Vehicle-to-Infrastructure, V2I).
- Traffic Management Centers (TMC): Analyze data to monitor traffic patterns and respond to incidents.

Functions and Benefits:

- Real-time Traffic Monitoring: Enables authorities to detect and respond to congestion and accidents instantly.
- Reduced Travel Time: Signals adapt to actual traffic conditions, minimizing wait times.
- Environmental Impact: Lower idling reduces vehicle emissions, contributing to greener cities.
- Priority Management: Emergency vehicles and public transport can be prioritized.
- Data-Driven Planning: Traffic data aids in urban planning and infrastructure development.

Example: In smart cities, traffic signals may turn green for ambulances or fire trucks approaching an intersection, ensuring faster response times.

Connected Environment:

A connected environment integrates smart devices, infrastructure, and systems using IoT and communication technologies to enable seamless data exchange and automation.

Key Features:

- Interconnected Devices: Streetlights, traffic systems, vehicles, and buildings are networked.
- Communication Technologies: Utilizes Wi-Fi, 5G, Zigbee, LoRa, and Bluetooth for real-time connectivity.
- Edge and Cloud Computing: Data is processed locally (edge) or in the cloud for large-scale analytics.
- Context Awareness: Systems respond based on location, time, and user behavior.

Applications and Benefits:

- Smart Mobility: Integrates public transport, shared mobility, and pedestrian management.
- Energy Efficiency: Smart lighting adjusts based on presence, saving energy.
- Urban Safety: Real-time alerts and surveillance improve city safety.
- Environmental Monitoring: Sensors track air quality, noise, and pollution levels.

Q10a) Discuss IoT strategy for smarter city

A smart city leverages Internet of Things (IoT) technologies to improve infrastructure, enhance public services, promote sustainability, and increase the overall quality of life for citizens. An effective IoT strategy is essential to integrate and manage diverse systems and data streams in urban environments.

Key Components of IoT Strategy for a Smarter City:

1. Infrastructure and Connectivity

- Deploy high-speed communication networks such as 5G, LPWAN, and fiber optics to support millions of connected devices.
- Ensure city-wide coverage and real-time communication between devices, systems, and users.

2. Sensor and Device Deployment

- Install IoT-enabled sensors across the city to monitor:
    - Traffic flow
    - Air and water quality
    - Waste levels
    - Energy usage
    - Structural health of buildings and bridges

3. Data Collection and Integration

- Centralize data from different sources into a smart city data platform.
- Use data lakes and APIs to share information across departments and services.

4. Analytics and Artificial Intelligence

- Apply AI and machine learning to analyze sensor data for:
    - Predictive maintenance
    - Traffic pattern analysis
    - Demand forecasting
- Enable automated decision-making and dynamic resource allocation.

5. Citizen-Centric Services

- Provide real-time information through mobile apps and public dashboards (e.g., bus arrival times, parking availability).
- Enable two-way communication between citizens and city authorities (e.g., reporting potholes or issues).

6. Smart Governance and Policy

- Develop data governance policies for security, privacy, and transparency.
- Encourage public-private partnerships and open data initiatives for innovation.

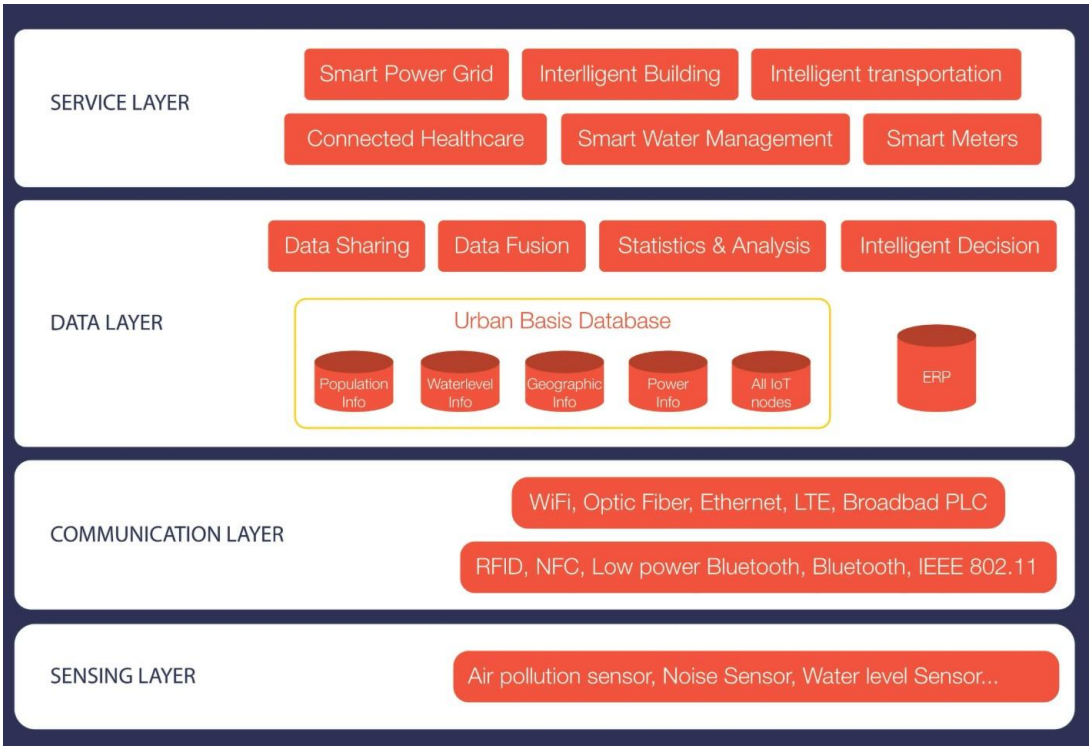
7. Security and Privacy

- Implement end-to-end encryption, secure authentication, and role-based access control.
- Ensure compliance with privacy regulations (e.g., GDPR) and protect citizen data.

8. Sustainability and Scalability

- Integrate renewable energy, smart grids, and electric vehicle infrastructure.
- Ensure the IoT ecosystem can scale as the population and technology usage grow.

Q10b) With a neat diagram, discuss smart city IoT architecture



A Smart City IoT Architecture is designed to efficiently collect, process, and act on data from a wide range of sensors and devices deployed across urban areas. This architecture supports real-time decision-making, sustainability, efficient resource usage, and improved citizen services.

Smart City IoT Architecture – Four-Layer Model:

According to the reference model, the architecture includes four key layers:

1. Street Layer

- Contains sensors, actuators, cameras, and smart meters installed in city infrastructure.
- Examples: Smart lights, parking sensors, environmental sensors, surveillance systems.
- These devices collect raw data and forward it to the next layer.

2. City Layer (Network Layer)

- Composed of gateways, switches, and routers to carry data.
- Ensures resilient, secure transport of real-time data from the field to data centers or cloud.
- Handles multiple protocols (e.g., MQTT, CoAP, Zigbee, LoRaWAN).

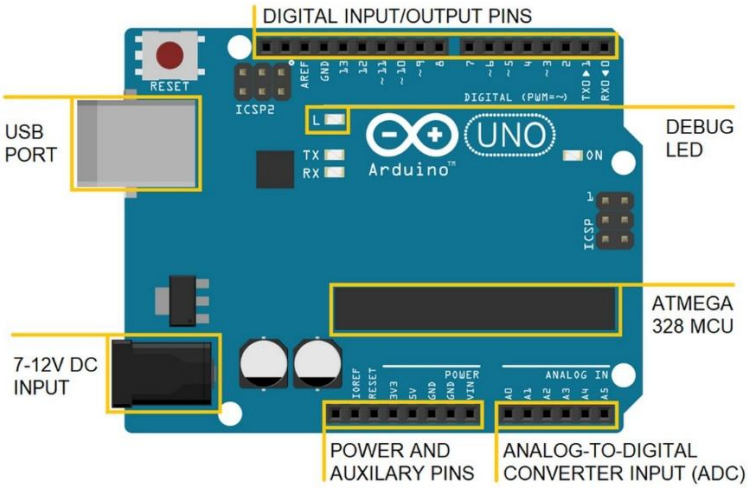
3. Data Center Layer

- Responsible for data aggregation, storage, normalization, and analytics.
- Supports cloud and fog computing to process both global and local data.
- Provides interfaces for application developers to use structured and normalized data.

4. Services Layer

- Hosts smart city applications like traffic control, waste management, public safety, and energy optimization.
- Provides dashboards, mobile apps, and APIs for city operators, citizens, and developers.
- Ensures data is visualized and consumed by multiple stakeholders.

Q10c) Write a short note on Arduino



Arduino is an open-source electronics platform based on simple microcontroller boards and a user-friendly Integrated Development Environment (IDE). It is widely used for building digital devices and interactive projects involving sensors, actuators, and communication modules.

Key Features:

- Built around Atmel microcontrollers (e.g., ATmega328).
- Programs are written in C/C++ using the Arduino IDE.
- Supports easy USB programming and power.
- Comes in multiple variants (e.g., Arduino Uno, Nano, Mega).

Applications:

- Home automation
- IoT prototypes
- Robotics
- Wearable devices
- Educational kits

Advantages:

- Low cost and easy to use
- Extensive community support
- Compatible with a wide variety of sensors and shields