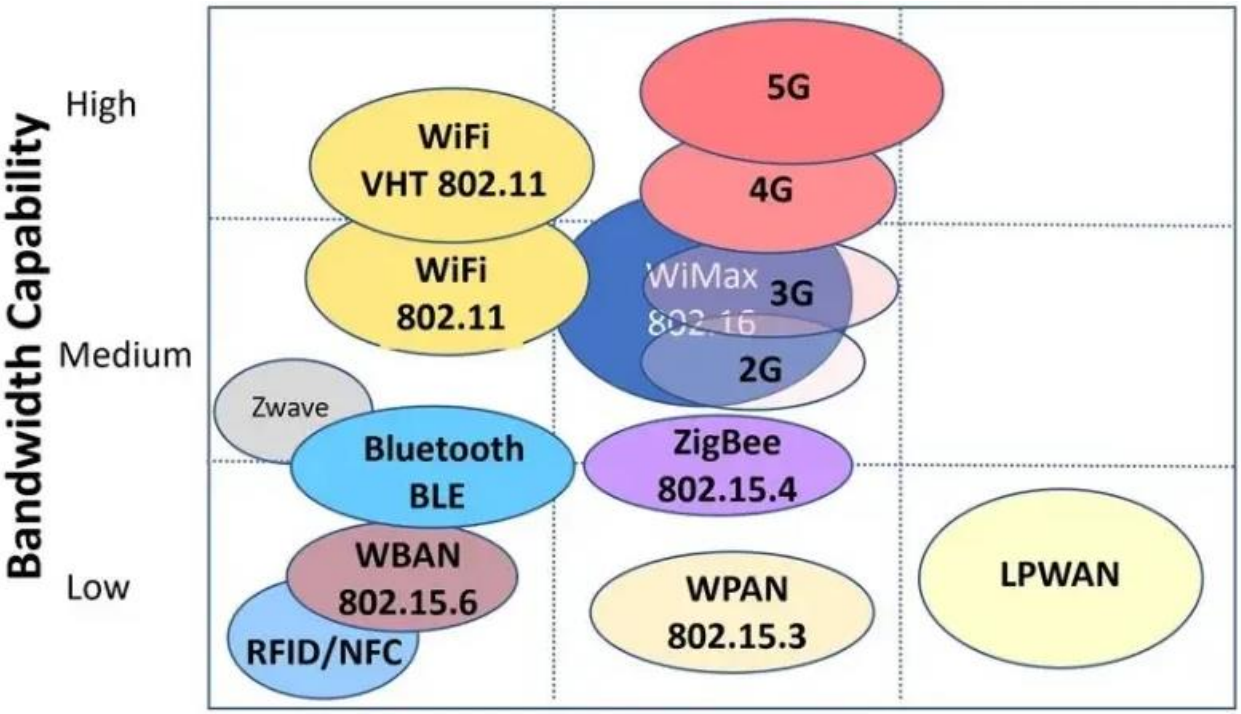
UNIT-III

Wireless Technologies for IoT

- Wireless technologies are fundamental to the operation of the IoT, as they provide the flexibility and scalability needed for devices to communicate in diverse environment.
- Unlike wired systems, which are limited by physical infrastructure, wireless solutions allow for seamless connectivity across various locations- ranging from smart homes and industrial sites to remote agriculture fields.
- Technologies such as Wi-Fi, Bluetooth, Zigbee, Z- wave and LoRa enable communication over different distances and bandwidths, depending on application requirements.



- Among these, short-range technologies like Bluetooth Low Energy (BLE), Zigbee and Z-wave are optimized for low-power, low- data rate applications in personal and homwworks.
- On the other hand, long-range options like LoRa and cellular networks (NB-IoT, LTE-M) are better suited for applications requiring wide-area coverage and infrequent, low-data transmission such as environmental monitoring (or) smart metering.

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WPAN technologies used in IoT

- A Wireless Personal Area Networks (WPAN) is a short range wireless network that connects personal electronic devices within a limited area, generally between 10 to 100 meters.
- WPANs are designed for low-power, low-cost communication between devices such as smartphones, tablets, smartwatches, fitnesstrackers and sensors.
- These networks eliminate the need for cables and allow devices to exchange data efficiently using standards like Bluetooth, Zigbee and Infrared.

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1Q. Explain the IEEE 802.15.4 standard and its role in IoT communication.

IEEE 802.15.4

- IEEE 802.15.4 is a technical standard developed by the Institute of Electrical and Eleectronics Engineers (IEEE) for Low-Rate Wireless personal Area Networks (LR-WPANs).
- designed to support simple, cost-effective and energy efficient communication among devices.
- This standard is ideal for applications where power conservation is crucial, such as battery oprated sensors and embedded systems.
- The communication range is typically ten to hundreds of meters, depending on the environment and transmission power.

Key Features of IEEE 802.15.4

Low Data rate: Designed for data rates of 250 kbits/s (Or) lower.
Low Power Consumption: Very low, suitable for battery powered IoT devices.
Short Range: Operates over short distances typically 10 to 100 meters.
Frequency Band: Primarily uses the 2.4 GHz industrial, scientific and medical (ISM) band which is widely available.
Network Topologies: Supports various network topologies including star and mesh.
Security: Provides security features like data authentication using message authentication codes (MACs).

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2Q. Write a short notes on Zigbee, NFC and Z-Wave.

Zigbee

- Zigbee is a wireless communication protocol built on the IEEE 802.15.4 standard, tailored specially for low-power, low-data rate and short-range applications. Operating in the 2.4 GHz ISM band, zigbee supports communication ranges of up to 100 meters and data rate upto 250 kbps.
- In IoT applications, zigbee is widely used for tasks like lighting control, energy monitoring, security systems and environmental sensing.
- Zigbee also supports secure communication through encryption and authentication features, making it is robust choice for both consumer and industrial applications.
- Zegbee supports 3 main topologies such as star, tree and mesh topologies.
- Technical Specifications

Feature	Description
Standard	IEEE 802.15.4
Frequency	2.4 GHz (World wide)
Range	10 – 100 meters per hop
Data Rate	Upto 250 kbps
Power Consumption	Very Low
Max. Nodes	65,000+ in mesh networks.

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HART (Highway Addressabe Remote Tranducer)

- HART is a wireless communication protocol widely used in idustrial automation to facilitate digital communication over traditional analog wioring.
- HART was desigmned to enable smart devices such as sensors and actuators to transmit digital data while analog signal is used for process control.
- The HART protocol enables two-way communication between field devices and control (or) monitoring systems.
- It supports multiple devices on a single communication line, enabling complex network setups in industrial plants.

- HART's compatibility with legacy systems and its features have made it populay choice for process industries such as oil and gas, chemical and manufacturing.

Feature ---------- @ @ @ ----------	Description
Communication Type	Hybrid (Analog + Digital)
Signal Type	4-20 mA current loop with superimposed digital signal.
Data Rate	1200 bps
Topology	Point-to Point and multidrop
Device Addressing	Up to 15 devices on a single mutidrop bus
Compatibility	Works with existing analog instrumentaion
Security	Basic security features, more advanced versions exist

NFC (Near Field Communication)

- NFC is a short range wireless communication technology that allows two devices to exchange data when placed very closed to each other, typically wihin 4 cm.
- NFC operates at a frequency of 13.56 MHz
- Due to its extremely close range, NFC offers secure and convenient data transfer.
- It is ideal for applications that require quick, contactless interactions such as payment systems, access control and device pairing.
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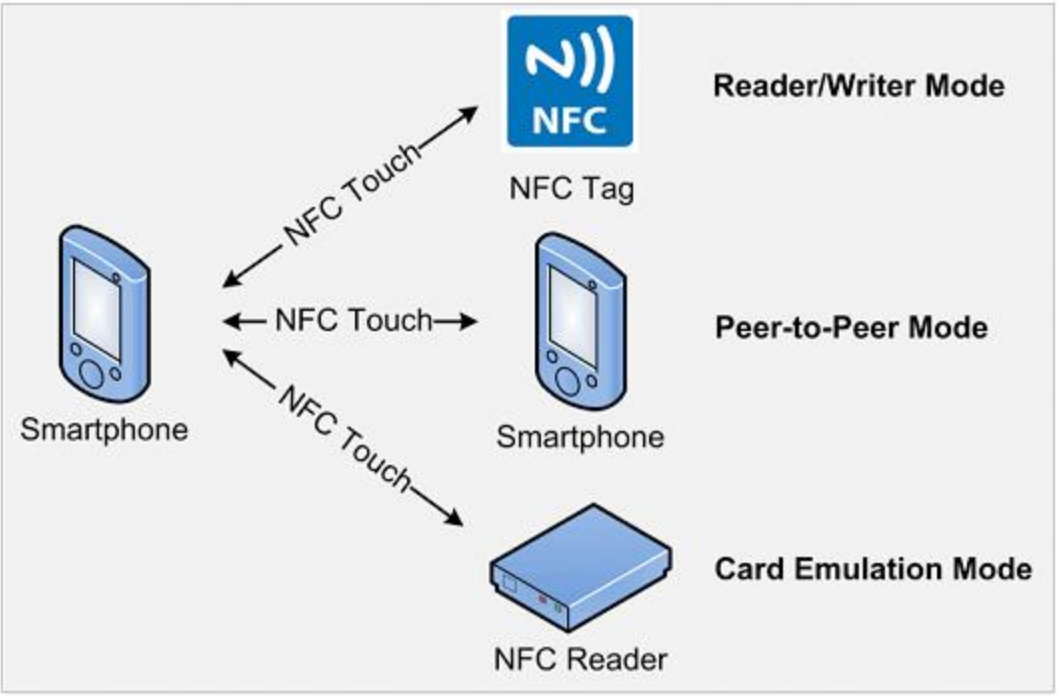

Feature	Description
Communication Range	Very Short- up to 4 cm
Freuency	13.56 MHz
Data Rate	Typically 106, 212, 424 kbps
Power	Passive (Powered by reader) or active (powered by device)
Device Addressing	Up to 15 devices on a single mutidrop bus
Communication modes	Peer-to-Peer, reader/Writer, Card Emulation
Security	Built-in encryption, short range reduces risk.

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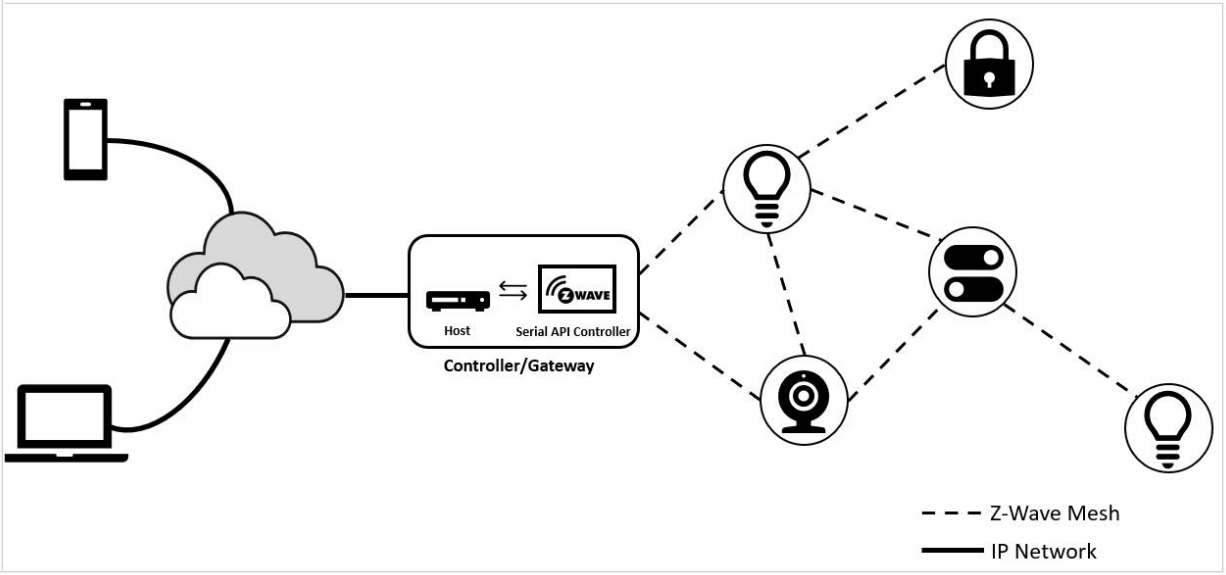
Z -Wave

- Z -wave is a short range wireless communication protocol specilly developed for home automation and smart device applications within the IoT system.
- Originally created by Zensys in 2001 and now managed by z-wave alliance.
- This protocol enabling seamless communication between various smart devices such as lighting systems, security sensors, thermostats and door locks.



Features of Z- wave

Feature	Description
Communication Range	Typically 30-100 mts indoor, up to 300 mts outdoor
Freuency	Sub-GHz bands (868 MHz europe, 908 MHz USA)
Data Rate	Upto 100 kbps
Power	Very low, suitable for battery operated devices
Network Topology	Mesh network
Number of Devices	Up to 232 devices on a single network
Security	AES-128 encryption for secure communication.

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3Q. Discuss the working principle of BLE and its suitability for IoT devices.

BLE (Bluetooth Low Energy)

- BLE is also known as bluetooth smart, is a wireless personal area network technplogy developed to provide short-range communication while significantly reducing power compared to classic bluetooth.
- Unlike classic bluetooth, BLE is optimized for intermittent, small data tansmissions, making it ideal for applications where energy efficiency is critical.
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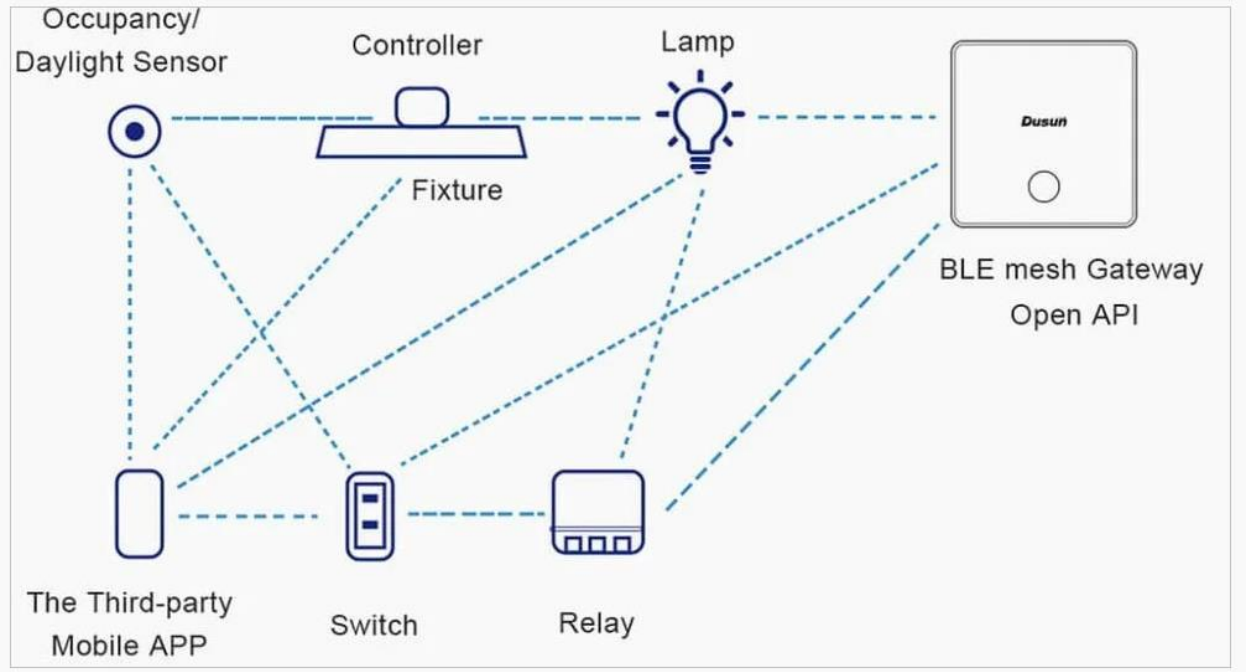


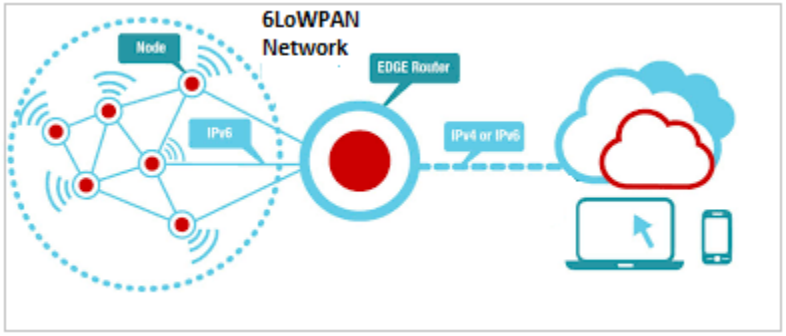
- BLE is widely used across a variety of IoT applications including wearable fitness trackers, healthcare monitoring devices, smart home products and environmental sensors.
- Additionally, BLE supports robust security features and can connect multiple devices simultaneously.
- **Features of BLE**

Feature	Description
Communication Range	Typically 10-50 meters (upto 100 meters in ideal consdition)
Freuency	2.4 GHz ISM band
Data Rate	Upto 1 Mbps (Bluetooth 4.X), upto 2 Mbps with bluetooth 5.X
Power Consumption	Extremely low compared to classic Bluetooth
Network Topology	Star Topology
Communication	Connection-oriented and connectionless (Broadcast)
Security	AES-128 encryption for secure communication.

4Q. Write a short notes on BACnet and Modbus.

BACnet

- BACnet stands for Building Automation and Control Network, is a communication protocol primily used in building automation systems.



- The primary goal of BACnet is to enable integration and efficient management of various building systems such as heating, ventilation and Air Conditioning (HVAC), lighting control, access control, fire detection and security.
- BACnet allows devices and systems within a building to share data and coordinate their functions effectively, enhancing operational efficiency, energy management and occupant comfort.
- It supports for multiple communication media including Ethernet, IP and Rs-485 further increases its flexibility.

- It is a widely adopted protocol in commercial and industrial building automation projects.

- **Features of BACnet**

Feature	Description
Protocol Type	Open, interoperable
Standard	ANSI/ASHRAE standard 135
Communication Layers	Support several transport layers: ethernet, ARCNET,MSTP (RS-485, IP and LonTalk)
Data Model	Oject-oriented (Devices modeled as objects with properties)
Network Topology	Star, Bus, ring, and mesh topologies
Services	Read /Write properties, alarms, sheduling, trending, device management
Device types	Sensors, actuators, controllers, gateways.
Interoperability	Enables devices from multiple vendors to work together.

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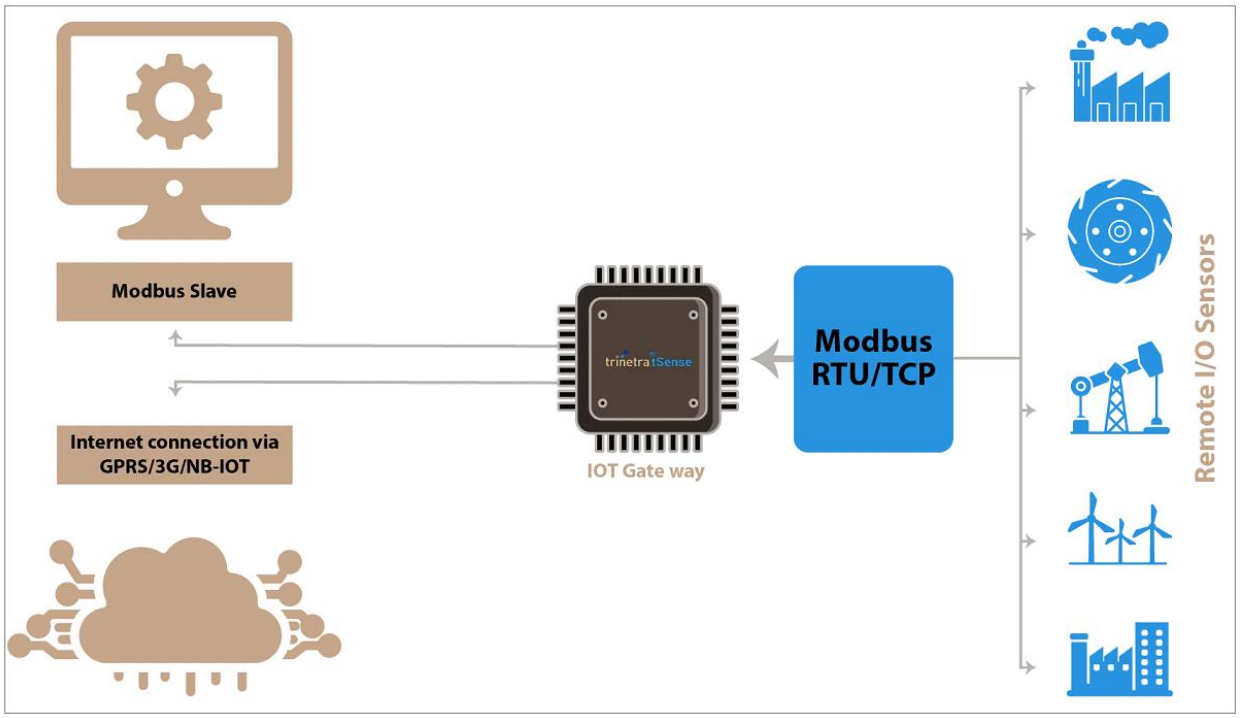
Modbus

- Modbus is a simple and widely used industrial communication protocol for connecting various industrial devices, including sensors, PLCs, and HMI systems.
- It allowing exchange data between these devices, enabling real-time monitoring, control, and automation in industrial environments.
- It allowing exchange data between these devices, enabling real-time monitoring, control, and automation in industrial environments.
- It is primarily used for Supervisory Control and Data Acquisition (SCADA) systems, connecting sensors, actuators, meters and other field devices to centralized controllers and monitoring stations.
- Modbus operates on a master –slave architecture, where the master device (PLC,PC, SCADA system) initiates communication with one (or) more slave devices (sensors, actuators).



- Features of Modbus

Feature	Description
Protocol Type	Serial and ethernet communication protocol
Communication Modes	Modbus RTU (binary), Modbus ASCII, Modbus TCP/IP
Data Model	Registers and coils (Disret bits and analog values)
Transport Media	RS-232, RS-485, Ethernet
Network Topology	Master –Slave (client-Server)
Simple Messaging	Read/Write registers and coils.
Device Limit	Up to 247 slaves in serial mode

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IP Based Protocols For IoT

IPv6: IPv6 (Internet Protocol version 6) is the latest version of the internet protocol designed for identifying and locating devices on networks and routing data across the internet. IPv6 addresses are 128 bits long, significantly largger than the 32-bit addresses used in IPv4. This vast address capacity makes IPv6 particulry crucial for the internet of thinga (IoT), where billons of devices require individual IP addresses to connect and communicate.

IPv6 offers 2^{128} addresses , particularly unlimited for IoT expansion. They are witten as eight groups of four exadecimal digits separated by colons,
Ex: **2356:2db0:0000:0000:8a2e:85a3:0370:7334)**

- **Features of IPv6**

Feature	Description
Large Address Space	Supports trillions of devices with unique global addresses
Simplifier Header	More efficient packet processing and routing
Auto-configuration	Devices can self-configure IP addresses automatically
Improved security	Built-in IP secsupport for data integrity and confidentiality
Better Mobility Support	Seamless device mobility with mobile IPv6
No NAT needed	End-to- end comunication without Network Address Translation
Multicast & Anycast	Efficient data transmission to multiple (or) nearest devices.

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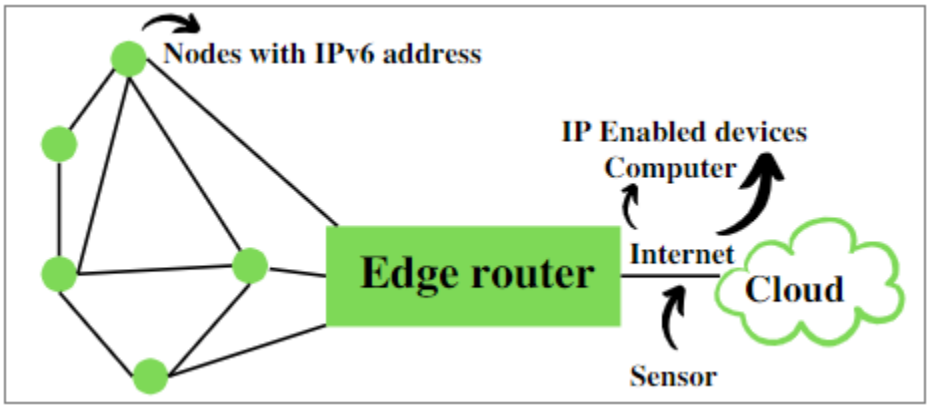
5Q. Describe how 6LoWPAN enables over low-power wireless networks.

6LowPAN: 6LowPAN (IPv6 over Low Power wireless Personal Area Network) is a network protocol designed to enable the efficient transmission of IPv6 packets over low power, low-band width wireless networks. Typically, these networks based on the IEEE 802.15.4 standard, which supports short range, low-data rate communication.

The key function of 6LowPAN us to act as an adaption layer berween the IPv6 network layer and the IEEE 802.25.4 physial and MAC layers. It compresses and fragments IPv6 packets so they can fit within the small maximum payload size of 802.15.4 frames, ensuring efficient and reliable tyransmission.



- **Features of 6LowPAN**

Feature	Description
Adaptation Layer	Compresses IPv6 headers anfd fragments packets as needed
Header Compression	Reduces IPv6 header size from 40 bytes to just a few bytes.
Fragmentation	Split IPv6 header size into smaller fragments for IEEE 802.15.4
Mesh Routing Support	Supports multi-hop routing within the low-power network
Low power consumption	Designed for battery oprated devices with minimal energy use.
End-to-end IP connectivity	Allow direct internet access to sensor nodes.
Interoperability	Enables seamless communication with other IP based networks.

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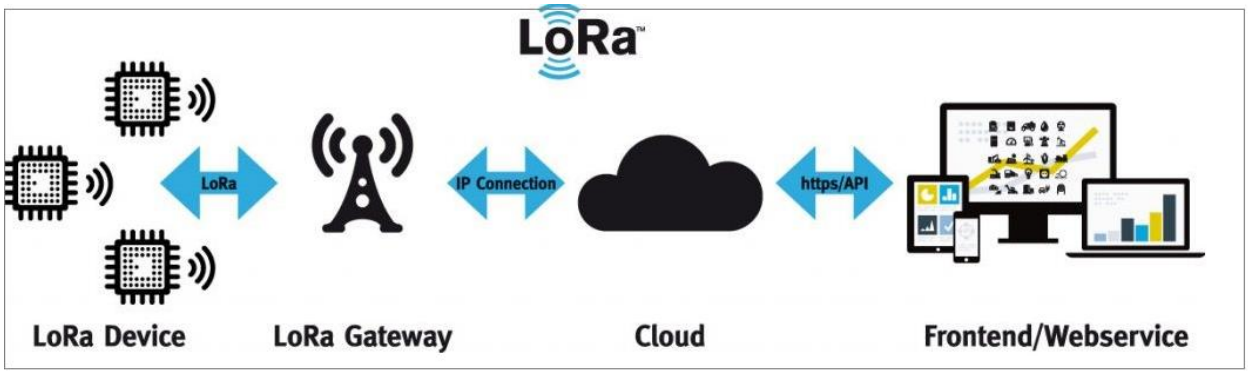
6Q. Explain the role of LoRA in long-range communication for IoT applications.

LoRa : LoRa stands for Long Range, is a proprietary wireless communication technology developed for long-range, low-power and low -data rate communication. It is particularly well-suited for IoT applications that require devices to transmit small amount of data over long distances while conderving battery life.

The key strength of LoRa lies in its ability to enable IoT devices to communicate over distances ranging from about 2 Kilometers to 15 kilometers. This long range capability, combined with its low power consumption, supports a wide range of IoT applications. LoRa network uses a star topology, where devices communicate directly with gateways that connect to cloud servers, enabling scalable, reliable and cost effective IoT developments over large geographic areas.



Features of LoRa

Feature	Description
Long Range	Can communicate over several kilimeters even through obstacles
Low Power Consumption	Designed for battery operated devices to last years
Low Data Rate	Suitable for small, infrequent data packets (up to 50 kbps)
Robustness	Uses chirp Spread Spectrum (CSS) modiulation for interference resistance.
Star Topology	Devices communicate directly with gateways
Unlicensed Spectrum	Operates in ISM bands without needing a license

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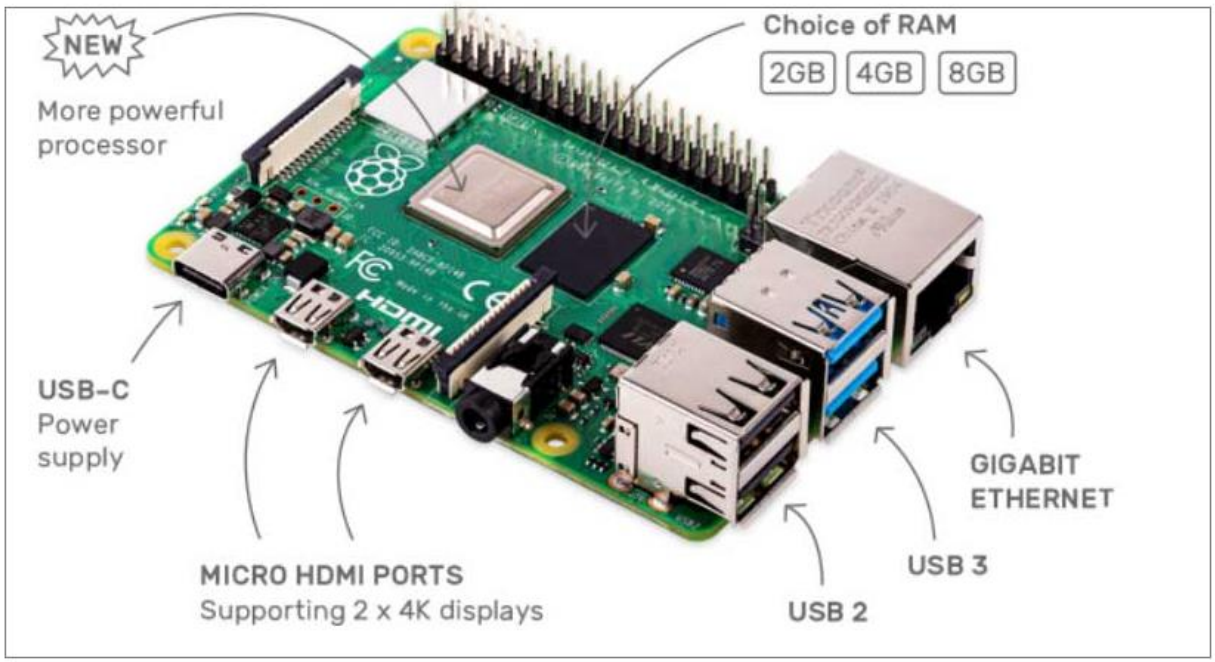
RPi : Raspberry Pi (RPi) is a compact, affordable single- board computer developed by the Raspberry Pi foundation. It is very popular for DIY electronics projects and IoT development due to its compact size, low cost and robust functionality

Raspberry Pi typically runs on a full Linux-based operating system such as Raspberry Pi OS, providing users with a familiar desktop like environment and access to a wide range of software tools and libraries. It offers features commonly found in traditional computers, including USB ports, HDMi output, GPIO pins for hardware interfacing, and networking capabilities.



- **Features of Raspberry Pi**

Feature	Description
Processor	ARM- based CPU, multi core (varies by model)
Memory (RAM)	Ranges from 256 MB to 8 GB depending on model
Storage	MicroSD card slot for OS and data storage.
GPIO	General Purpopse Input/Output pins for connecting sensors, actuators and other devices.
Connectivity	Ethernet, Wi-Fi, Bluetooth
Ports	USB ports, HDMI, audio output, Camera interface,Display Interface
Power	Powered via micro USB (or) USB-C, typically 5V supply.

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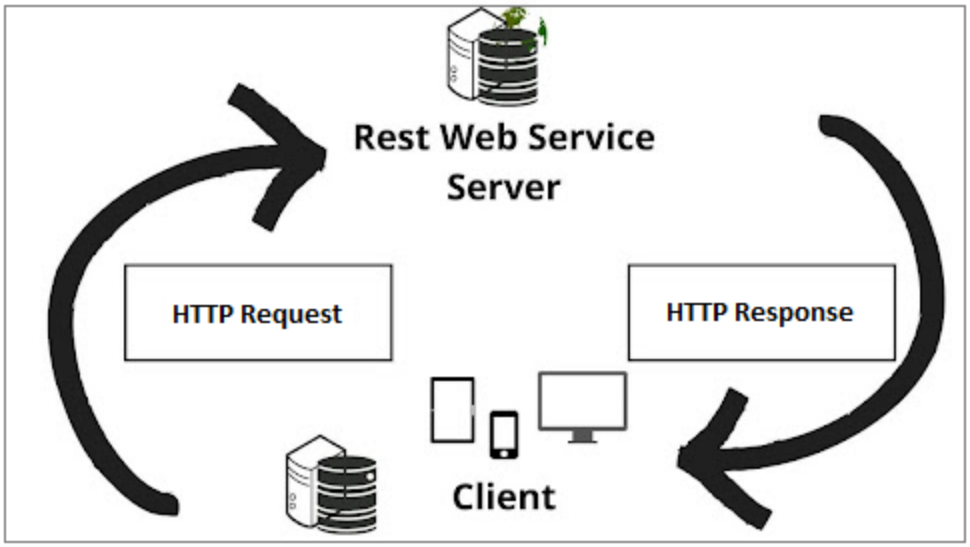
7Q. Discribe the RESTful architecture and its uses in IoT services.

REST : REST(REpresentational State Transfer) is not a specific IoT protocol, but rather an architectural style (or) a set of guidelines for building web services, including those used in IoT applications.



It emphasizes a stateless client-server interaction model, where each request from a client to a server contains all the information needed to understand and process the request, enabling better scalability and reliability. It uses standard HTTP methods such as GET, POST, PUT and DELETE to perform operations on resources, which are identified by URLs.

Principles of REST

Statelessness: Each request from a client to the server must contain all the information.
Client-Server Architecture: Client and server are separate entities, allowing each to evolve independently.
Uniform Interface: REST uses a uniform and consistent way to access resources.
Resource Based: Resources are identified by URIs (Uniform Resource Identifiers).
Representation: resources are manipulated through their representations usually in JSON (or) XML formats.
Cacheability: Responses must explicitly state if they are cacheable (or) not to improve network efficiency.
Layered System: Architecture can have layers (Proxy, firewall, gateway) , allowing scalability and security.

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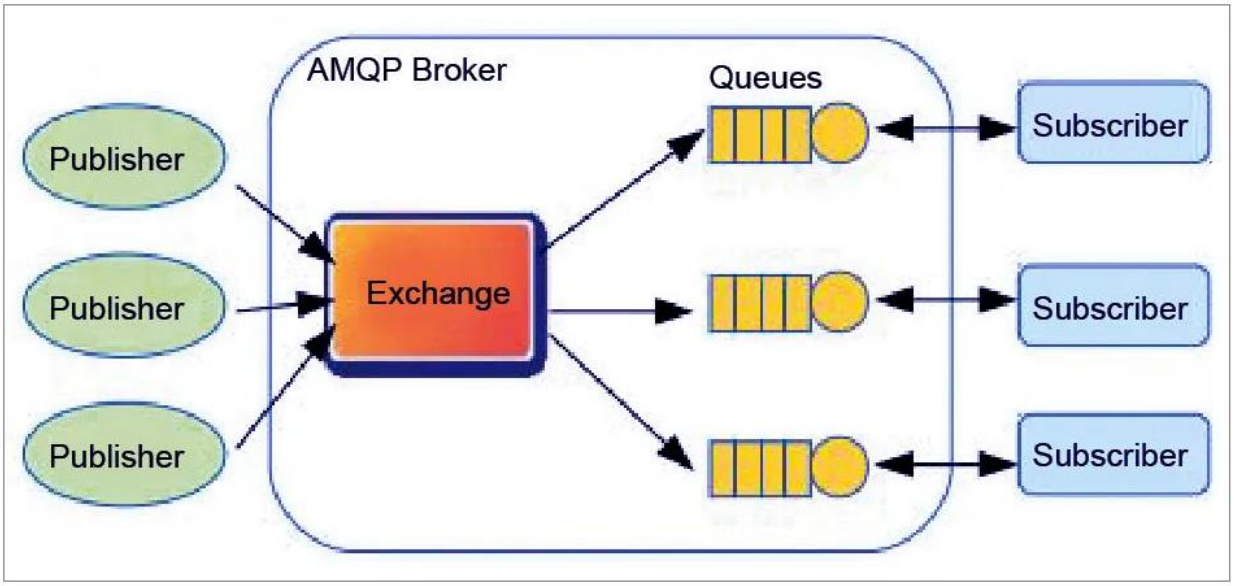
8Q. Discuss about AMQP in IoT messaging system

AMQP : AMQP(Advanced Message QueuingProtocol) is an open standard application layer protocol designed for reliable and secure message transmission between distributed systems. AMQP is very popular for IoT applications due to its ability to provide assured message delivery, flexible routing and security controls.



Features of AMQP

Feature	Description
Message Orientation	Data is exchanged as messages, not just raw data steams.
Broker based	User message brokers (Servers) to route and manage messages.
Reliable delivery	Guarantees that messages are delivered with ACK.
Interoperability	Works across different platforms and languages.
Flexible Messaging Patterns	Supports point-to-point, pblish/subsribe and request/reply
Security	Supports encryption, authentication and access control

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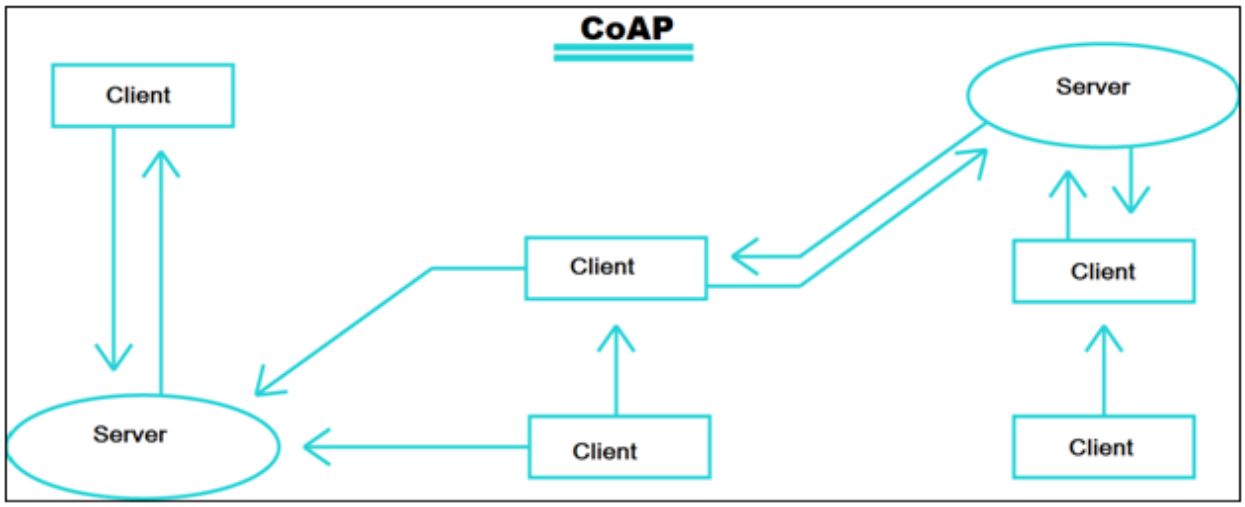
9Q. Discuss about CoAP and MQTT protocols

- **CoAP :** CoAP(Constrained Application Protocol) is a specialized web transfer protocol for resource constrained devices in the IoT. It enables these devices, like sensors and actuators, to communicate efficiently with the internet, even over networks with limited bandwidth and power.
- CoAP is a lightweight protocol that leverages a request/response interaction model, similar to HTTP, but optimized for low-power, low-resource environments.



- Following a RESTful architecture like HTTP, CoAP supports methods such as GET, POST, PUT and DELETE allowing IoT devices to interact with web services in a familiar way. It also includes features such as multicast support, asynchronous message exchanges and built-in reliability mechanisms tailored to the challenges of constrained networks.
- **Features of CoAP**

Feature	Description
Light Weight Protocol	Low header overhead (4 bytes), ideal for small devices.
RESTful architecture	Uses standard HTTP methods: GET, POST, PUT, DELETE
Reliable Messaging	Provides confirmable (ACK-based) and non-confirmable messages type.
Multicast support	Enables group communication to multiple devices at once.
Resources Descovery	Devices can discover resources dynamically using the .well known/ core URI
Asynchronous Communication	Supports delayed responses and separate acknowledgements.
Security	Supports Datagram Transport Layer Security (DTLS) for encryption and authentication.
Low Power Consumption	Designed to minimize power use, critical for battery operated devices.

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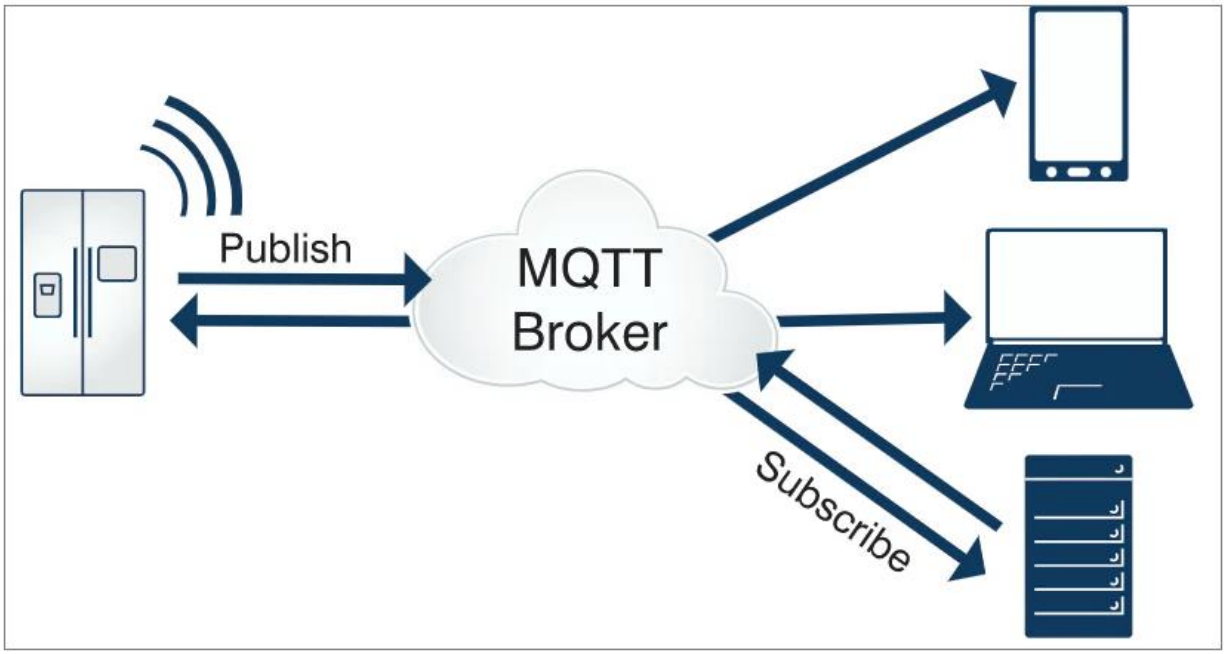
- **MQTT:** MQTT (Message Queuing Telemetry Transport) is a lightweight publish-subscribe messaging protocol designed specifically for constrained devices and networks with low bandwidth, high latency (or) unreliable connections.



How MQTT Works in IoT:

1. Publishing:

An IoT device (publisher) sends a message to a specific topic on the MQTT broker.

2. Subscribing:

Another IoT device (subscriber) subscribes to the same topic on the MQTT broker.

3. Broker Routing:

The MQTT broker receives the message from the publisher and forwards it to all subscribers of that topic.

4. Receiving:

The subscriber receives the message from the broker.

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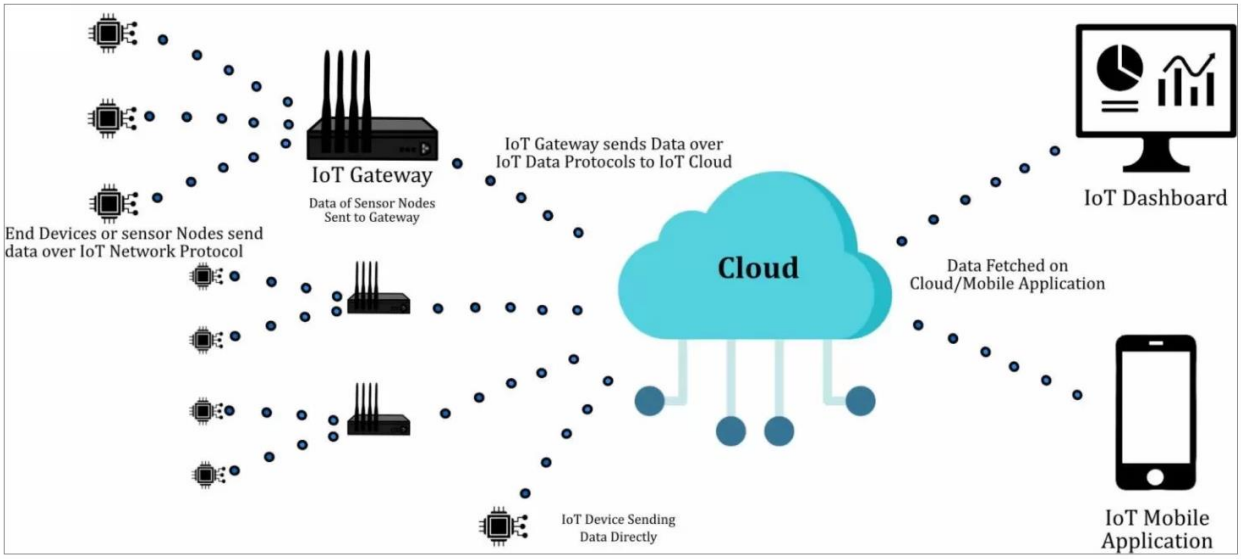
10Q. What is the significance of edge connectivity in IoT system and how do edge protocols support it?

Edge connectivity and Protocols

- Edge connectivity in IoT refers to establishing communication links between IoT devices, edge devices like gateways, and the cloud (or) other central systems. This connectivity encompasses both the physical transmission media, which can be wireless (Wi-Fi, Bluetooth, Zigbee) (Or) wired (Ethernet) and the communication protocols that govern how data is formatted, transmitted and received.
- Effective connectivity ensures that devices, regardless of their location (or) type.
- Fundamentally, connectivity is the backbone of any IoT ecosystem.
- It also plays a crucial role in maintaining data integrity, managing network traffic and securing communication channels against unauthorized access.
- It supports overall performance, scalability and reliability in IoT deployments.



Types of connectivity in IoT

- **Wired Connectivity**
  Examples: Ethernet, power Line Communication (PLC)
  Pros: Stable, High bandwidth, Secure
  Cons: Limited mobility
- **Wireless Connectivity**
  Examples: Wi-Fi (802.11), Bluetooth, BLE, Zigbee, LoRaWAN, Cellular (3G/4G/5G), NFC.
  Pros: Device mobility, ease of Installation and Scalability.

Categories of IoT protocols

Layer	Protocol Examples	Purpose/ Function
Physical / Link Layer	Zigbee, Bluetooth, LoRa, Wi-Fi	Wireles Connectivity and media access control
Network Layer	IPv6, 6LowWPAN	Routing and Addressing
Transport Layer	TCP, UDP	Reliable and fast data transport
Session/ Application Layer	MQTT, CoAP, HTTP, AMQP	Messaging, data exchange, devicemanagement

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