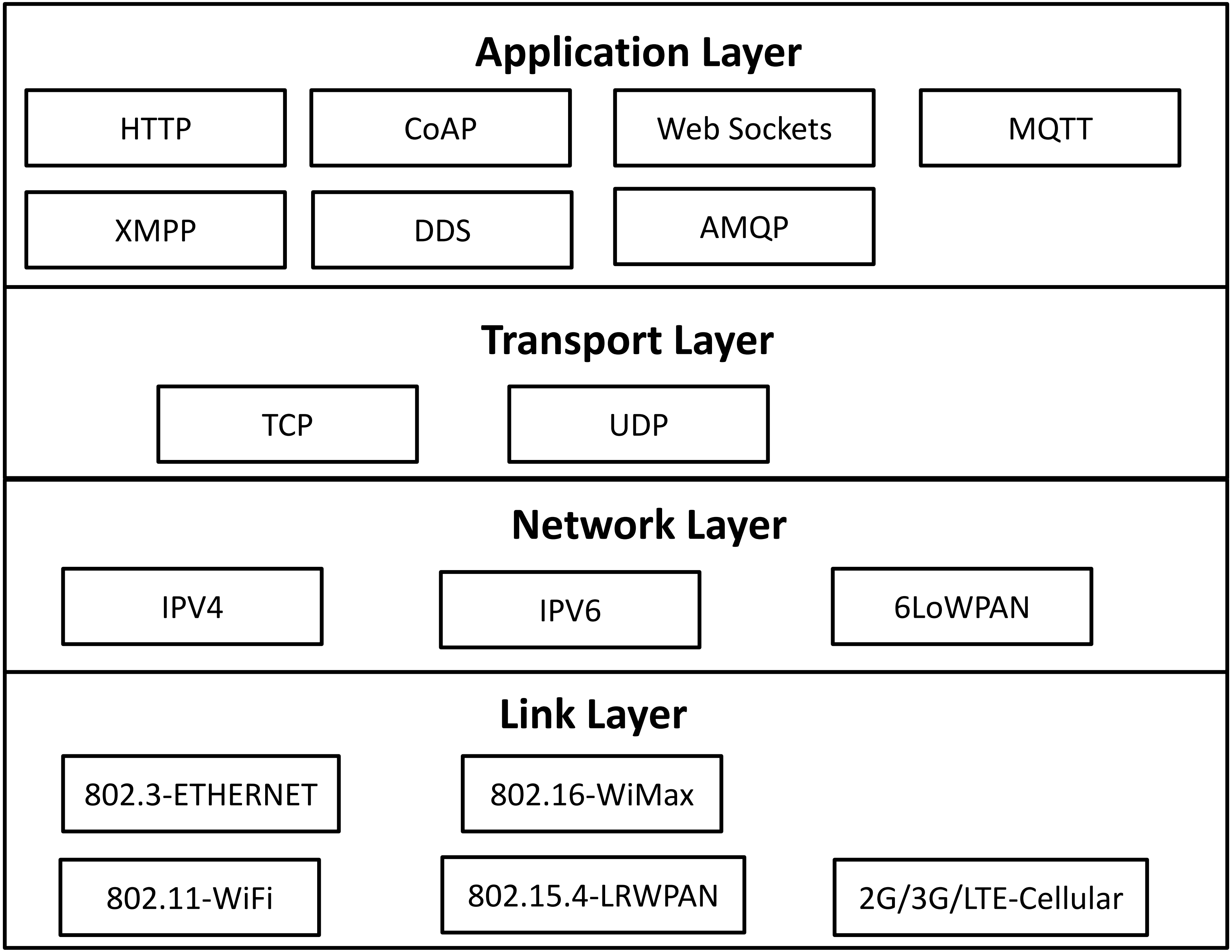
# IoT protocols

- IoT protocols are a set of rules and standards that govern communication between devices on the Internet of Things (IoT).
- The main purpose of these technologies is to ensure smooth communication between different IoT devices, regardless of manufacturer or platform.
- They are the foundation of data transmission and are critical to the successful implementation of IoT projects.
- Without these proper protocols, IoT applications would not be able to communicate properly with each other.

# Difference between conventional protocols and IoT Protocols

- While traditional protocols such as HTTP and FTP were designed for Internet applications, IoT standards are specifically tailored to the needs of IoT devices. These include range, data volume, and energy efficiency.
- Another difference is the type of communication. Traditional standards mainly use connection-oriented protocols such as TCP, however, IoT technologies support both connection-oriented and connectionless communication, allowing for flexible and adaptable data transfer in different IoT applications.
- IoT communication is based on a layered architecture that efficiently organizes data exchange across different protocols. Data exchange between devices goes through several layers from storage, to processing and to the user interface.

# IoT Protocols



## Application Layer

HTTP

CoAP

Web Sockets

MQTT

XMPP

DDS

AMQP

## Transport Layer

TCP

UDP

## Network Layer

IPV4

IPV6

6LoWPAN

## Link Layer

802.3-ETHERNET

802.16-WiMax

802.11-WiFi

802.15.4-LRWPAN

2G/3G/LTE-Cellular

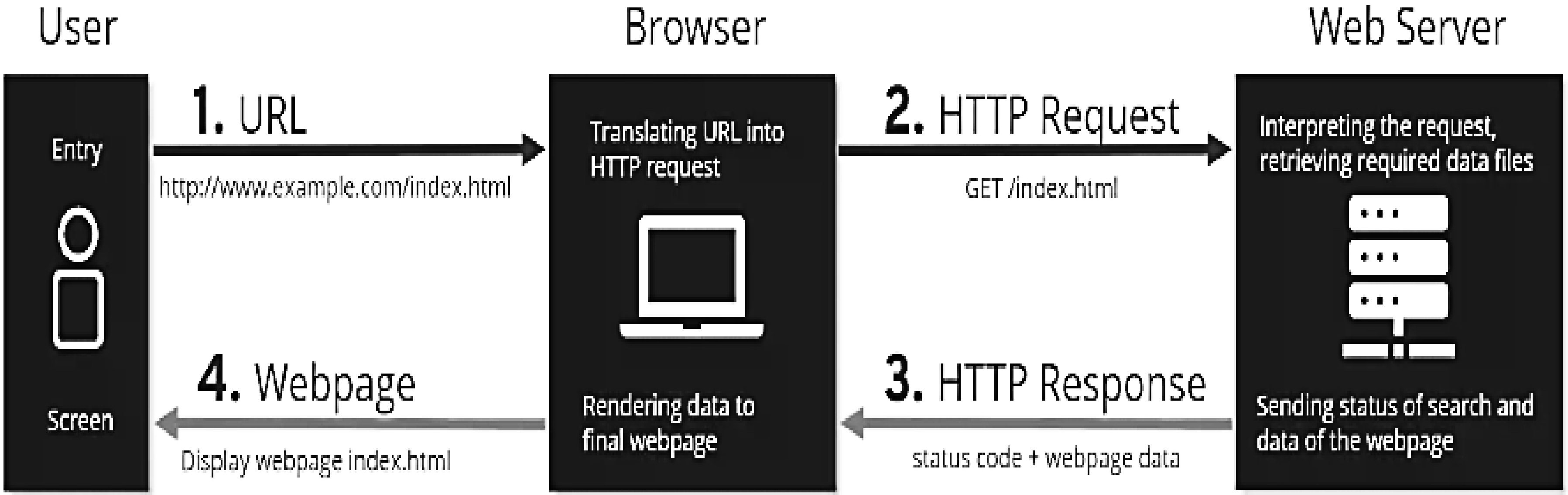
# HTTP (hyper text transfer protocol)

- It is an application layer protocol.
- It is a client server protocol also known as request response protocol.
- http requests the webpage to the server and after getting response from the server it closes the connection.
- A web browser is an http client whereas a web server is the http server.

**How HTTP Works?**

- **Open Web Browser:** First, you open your web browser and type a website URL (e.g., www.example.com).
- **DNS Lookup:** Your browser asks a Domain Name System (DNS) server to find out the IP address associated with that URL. Think of this as looking up the phone number of the website.
- **Send HTTP Request:** Once the browser has the website’s IP address, it sends an HTTP request to the server. The request asks the server for the resources needed to display the page (like text, images, and videos).
- **Server Response:** The server processes your request and sends back an HTTP response. This response contains the requested resources (like HTML, CSS, JavaScript) needed to load the page.
- **Rendering the Web Page:** Your browser receives the data from the server and displays the webpage on your screen.

- After the page is loaded, the connection between the browser and server is closed. If you request a new page, a new connection will be made.


User
Browser
Web Server
Entry
Screen
1. URL
http://www.example.com/index.html
Translating URL into HTTP request
2. HTTP Request
GET /index.html
Interpreting the request, retrieving required data files
3. HTTP Response
status code + webpage data
Sending status of search and data of the webpage
Rendering data to final webpage
4. Webpage
Display webpage index.html

# CoAP (Constrained Application Protocol)

- CoAP is an IoT protocol.
- It is designed to join IoT devices through low bandwidth restricted network.
- CoAP is designed for M2M and IoT applications.
- It is an application layer protocol so follow request response model.
- CoAP runs over UDP protocol. (i.e. at transport layer UDP is present)
- It uses few resources than HTTP.
- CoAP clients can use GET, PUT and DELETE commands.

- **GET:** when client wants to get some data it uses GET command.
- **PUT:** when client wants to upload some data it uses PUT command.
- **DELETE:** if client wants to delete some data it uses DELETE command.

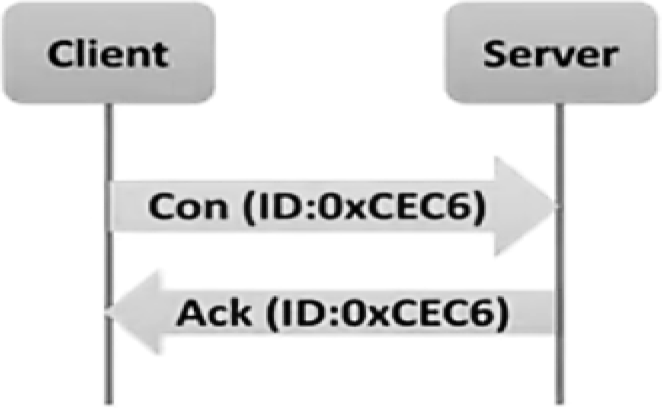
# CoAP Layers

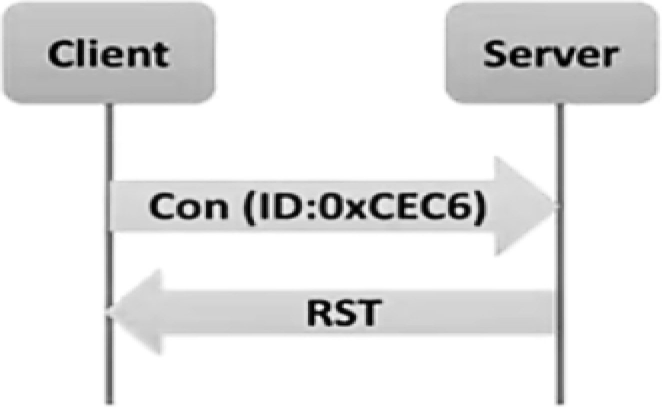
- **CoAP is divided into two layers.**

1. **Application Layer:** it is designed for communication based on request response model.
2. **UDP Layer or lower layer:** it is designed to deal with UDP and asynchronous messages.

# Types of messages in CoAP

1. **Confirmable message or reliable message (con):** the client keep on sending message until the acknowledgement is received from server or the number of request are exhausted.

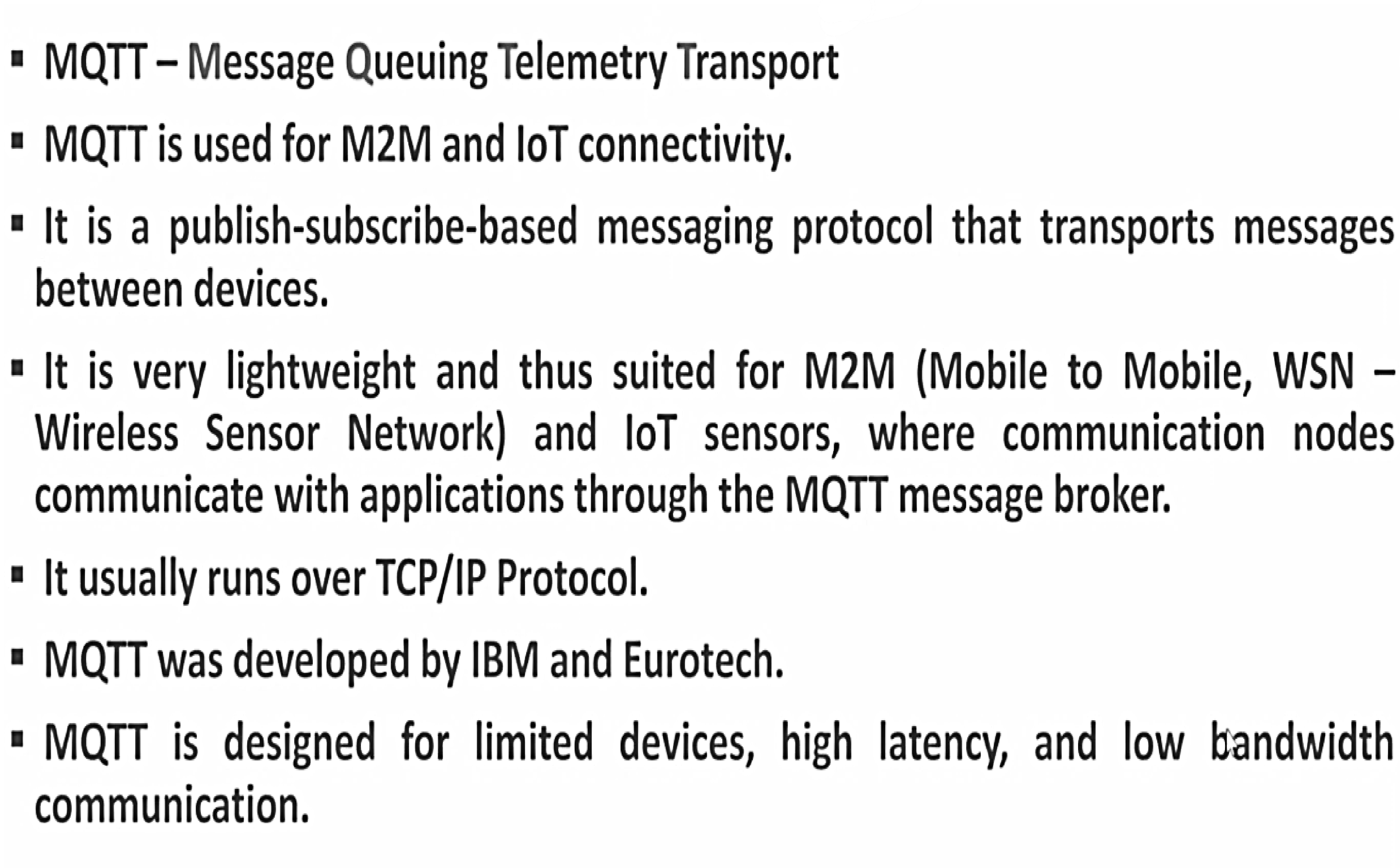




2. If server is having trouble in confirmation or receiving message it can send **Reset (RST) message.**
3. **Non-confirmable message (non):** these messages doesn't have important data so no need of acknowledgement is required.
4. **Acknowledgement message (ACK**): it is sent by the server to acknowledge the confirmable message.

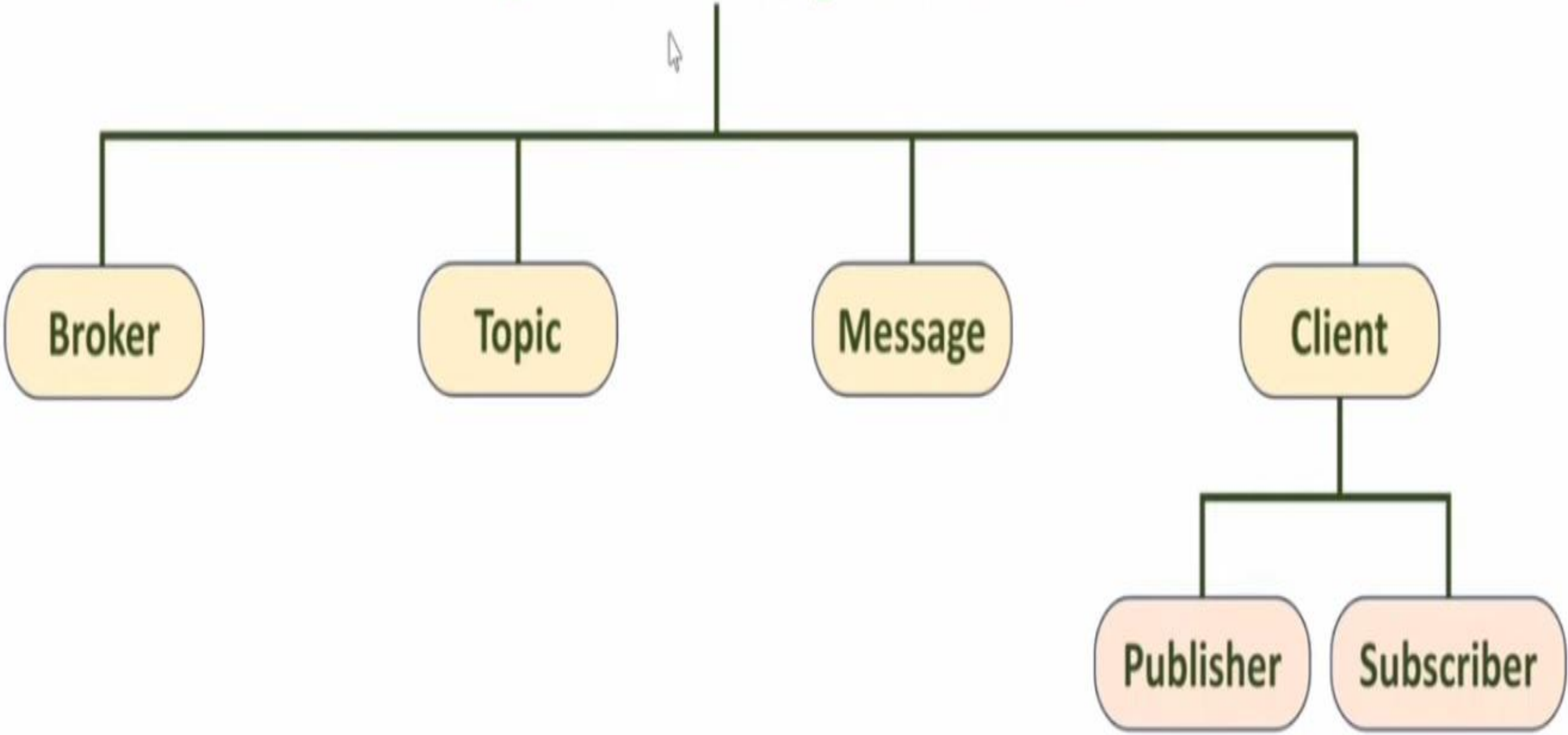
*for acknowledgement, a confirmation ID of 2 byte is sent and the same id is received as a confirmation message.

# MQTT (Message Queuing Telemetry Transport)



- MQTT – Message Queuing Telemetry Transport
- MQTT is used for M2M and IoT connectivity.
- It is a publish-subscribe-based messaging protocol that transports messages between devices.
- It is very lightweight and thus suited for M2M (Mobile to Mobile, WSN – Wireless Sensor Network) and IoT sensors, where communication nodes communicate with applications through the MQTT message broker.
- It usually runs over TCP/IP Protocol.
- MQTT was developed by IBM and Eurotech.
- MQTT is designed for limited devices, high latency, and low bandwidth communication.

# MQTT Components



Broker

Topic

Message

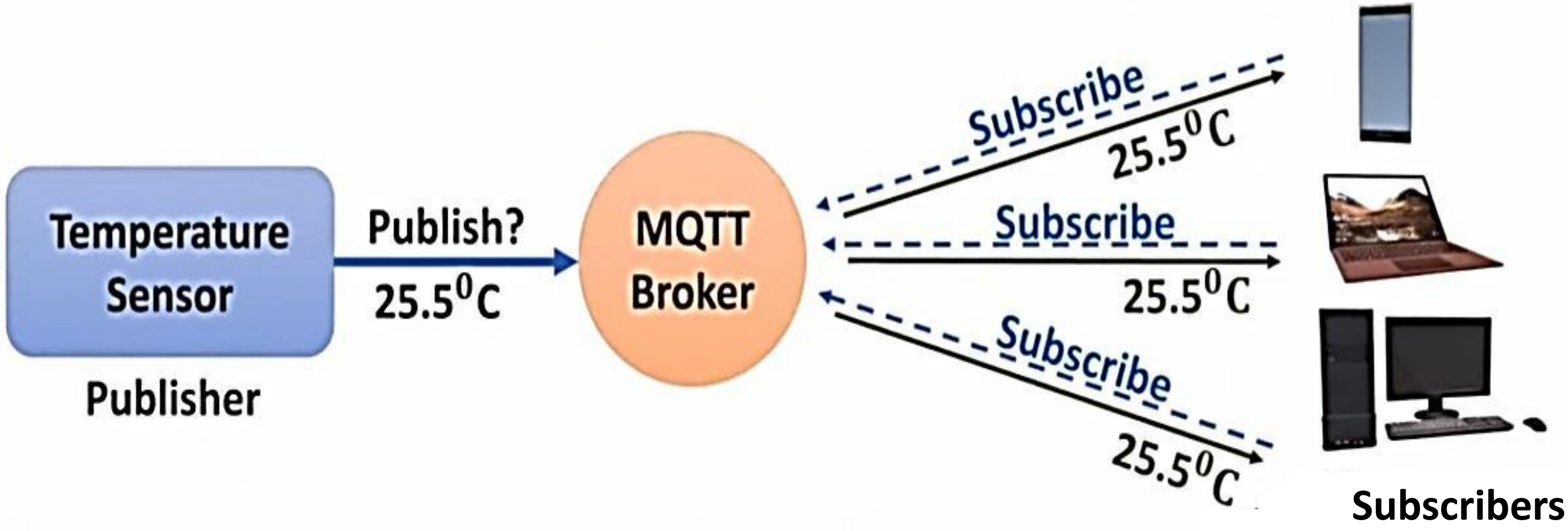
Client

Publisher

Subscriber

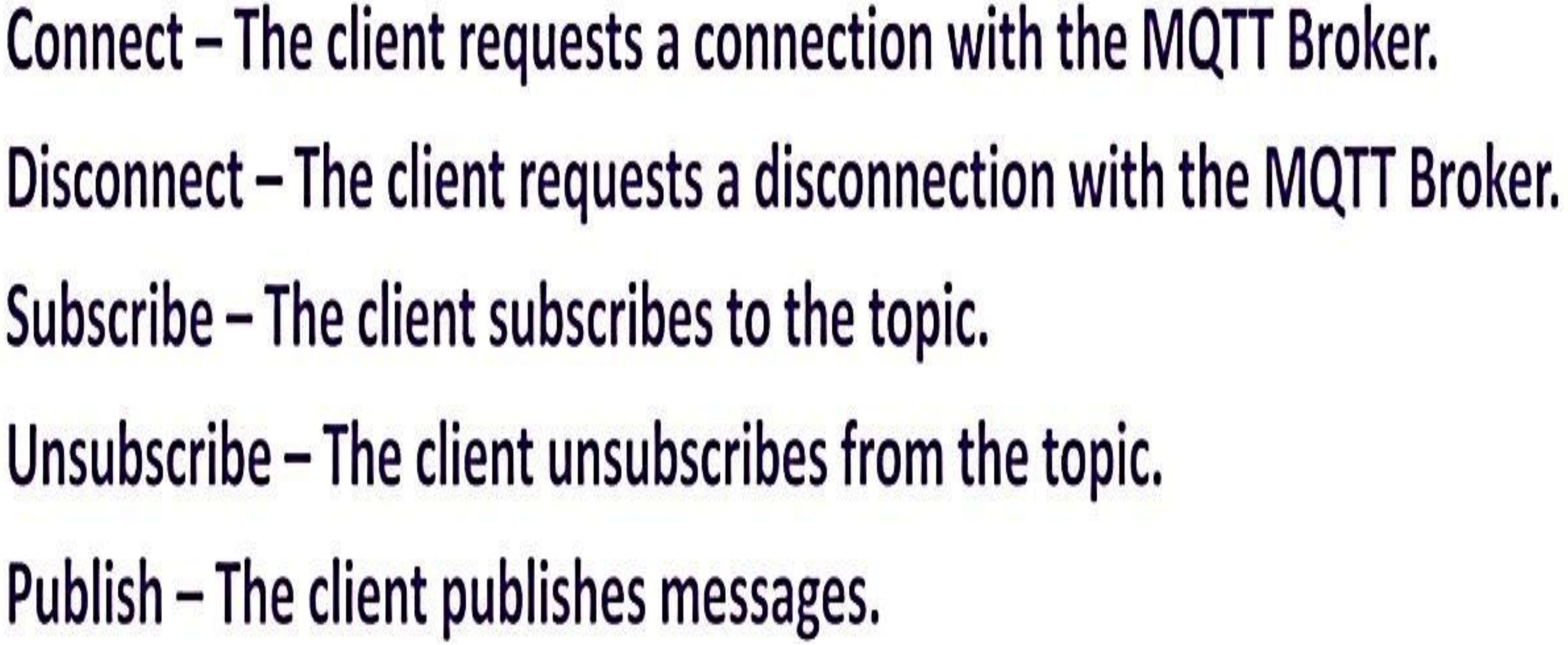
- **MQTT Client:** A client can be either the publisher or the subscriber. Subscriber can subscribe to topics and receive messages. Publishers can publish the topics.
- **MQTT Broker:** It is a central point of communication. It is responsible for dispatching all messages between clients. It receives subscription from clients on topics and based on subscriptions it forwards the messages to clients.
- **Topic:** Topic is an identifier for subscribers (temperature, pressure, humidity, gases etc.).
- **Message:** Subscribers receives messages based on topics of subscription from broker.

# Working of MQTT



- **Step – 1:** Publishers can publish topics. {Ex. Temperature}
- **Step – 2:** Subscribers can subscribe to one or more topics.
- **Step – 3:** Publisher gives messages on topics to MQTT Broker.
- **Step – 4:** MQTT Broker publishes the messages to subscribed users.

# MQTT Methods



Connect – The client requests a connection with the MQTT Broker.

Disconnect – The client requests a disconnection with the MQTT Broker.

Subscribe – The client subscribes to the topic.

Unsubscribe – The client unsubscribes from the topic.

Publish – The client publishes messages.

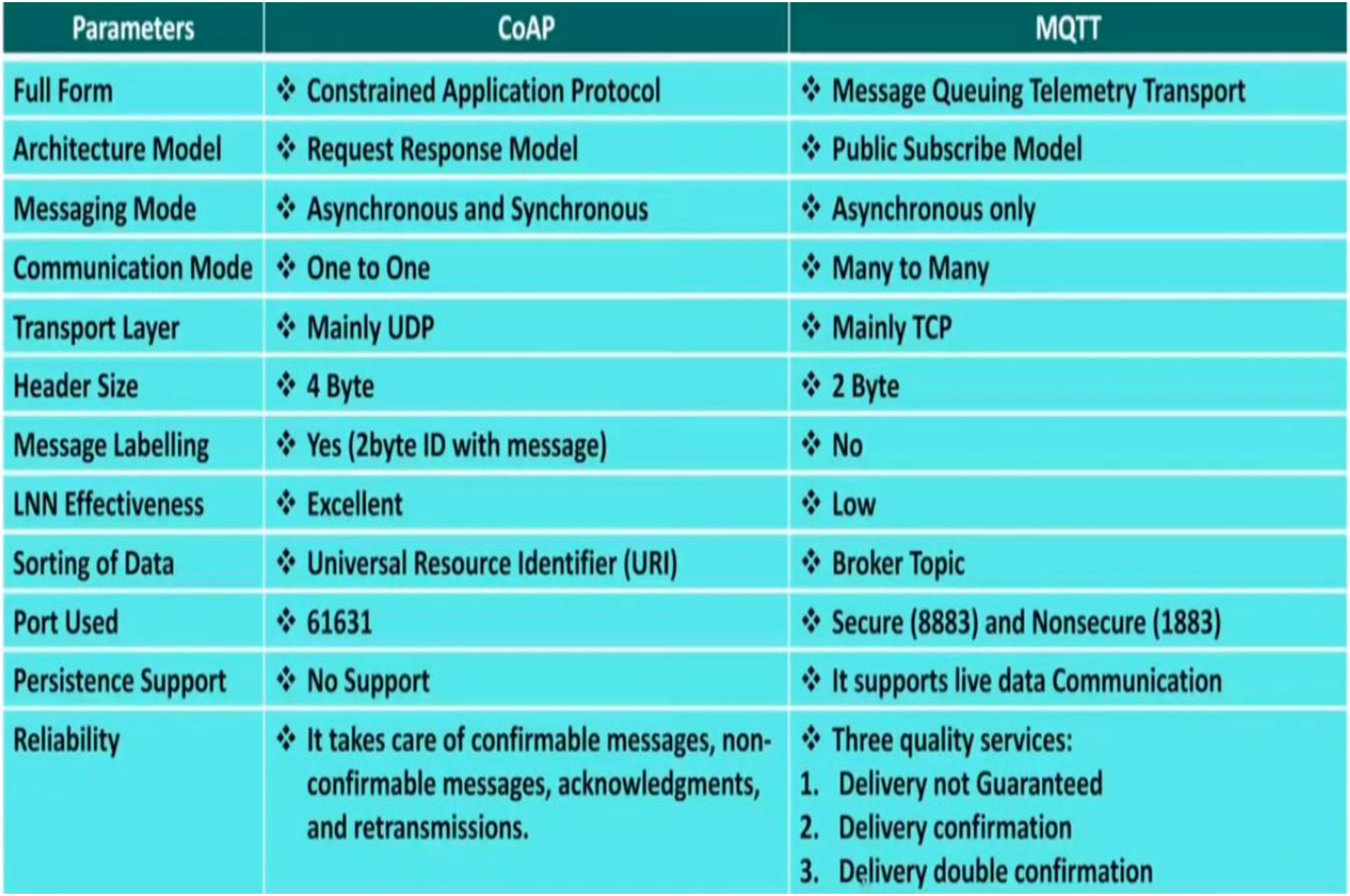
# MQTT Advantages

- It is a simple protocol for IoT devices.
- It is a lightweight protocol, so it is easy to implement in software.
- Low Network usage.
- Low Power usage.
- Lower data rate for protocol implementation.

# MQTT Applications

- Home Automation
- Factory Automation
- Medical & Healthcare
- Transport & Logistics

# Comparison b/w CoAP & MQTT



| Parameters | CoAP | MQTT |
|---|---|---|
| Full Form | ❖ Constrained Application Protocol | ❖ Message Queuing Telemetry Transport |
| Architecture Model | ❖ Request Response Model | ❖ Public Subscribe Model |
| Messaging Mode | ❖ Asynchronous and Synchronous | ❖ Asynchronous only |
| Communication Mode | ❖ One to One | ❖ Many to Many |
| Transport Layer | ❖ Mainly UDP | ❖ Mainly TCP |
| Header Size | ❖ 4 Byte | ❖ 2 Byte |
| Message Labelling | ❖ Yes (2byte ID with message) | ❖ No |
| LNN Effectiveness | ❖ Excellent | ❖ Low |
| Sorting of Data | ❖ Universal Resource Identifier (URI) | ❖ Broker Topic |
| Port Used | ❖ 61631 | ❖ Secure (8883) and Nonsecure (1883) |
| Persistence Support | ❖ No Support | ❖ It supports live data Communication |
| Reliability | ❖ It takes care of confirmable messages, non-confirmable messages, acknowledgments, and retransmissions. | ❖ Three quality services:<br>1. Delivery not Guaranteed<br>2. Delivery confirmation<br>3. Delivery double confirmation |

# Web Sockets

- Unlike http, Web Socket is a persistent connection between the client and the server. It is a bi-directional full-duplex connection.
- It is used for real time live data communication.
- A web browser can upgrade its connection from http to Web Socket connection but for that the browser has to send an http request and if request agreed the client server will handshake to establish a Web Socket connection. E.g.. Fetching trading data in browser.

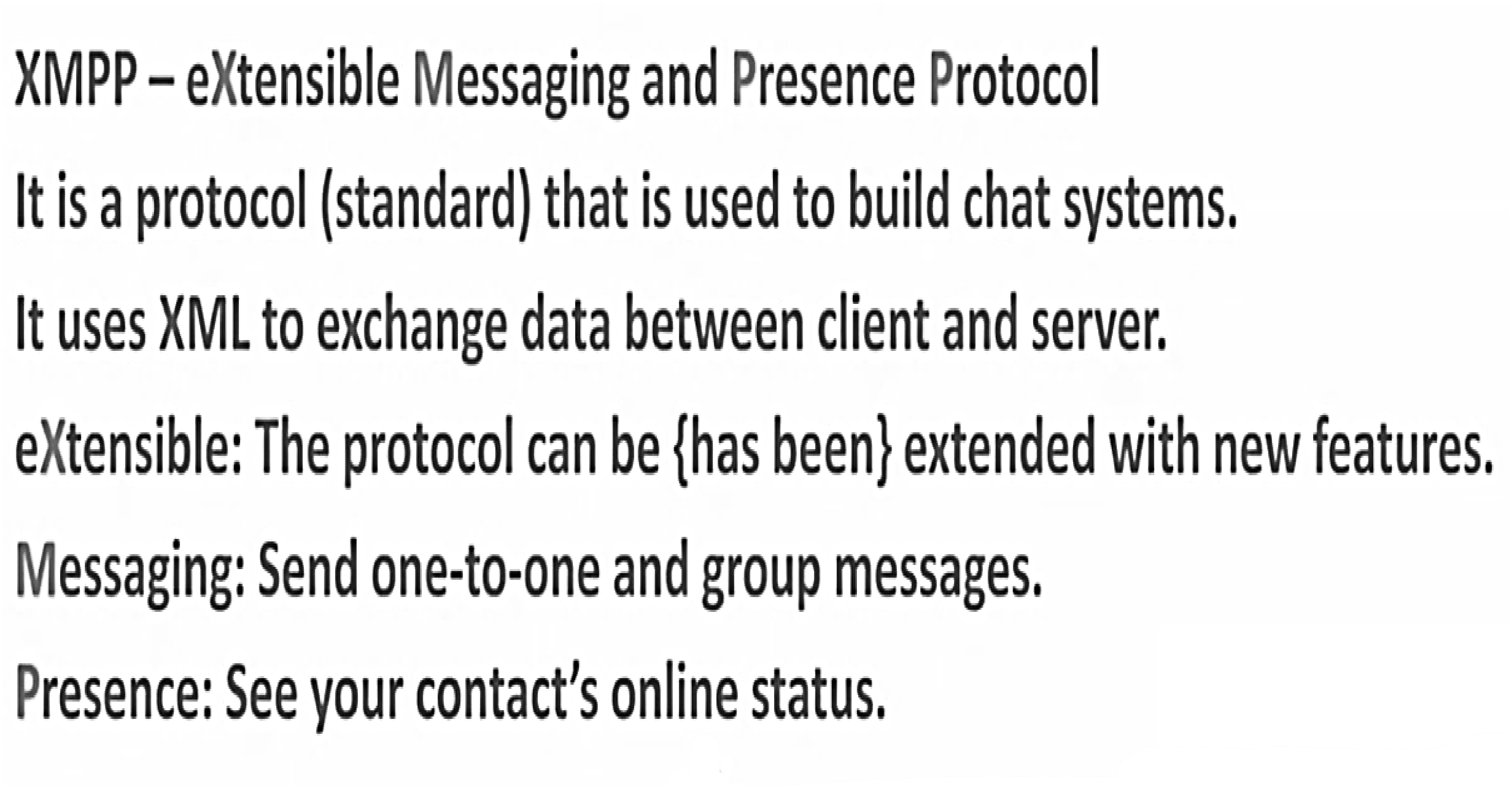
# HTTP vs Web Sockets

- HTTP is stateless whereas Web Socket is stateful.
- HTTP is unidirectional whereas Web Socket is Bidirectional.
- HTTP is half-duplex and Web Socket is full-duplex.

VS

|  | HTTP | WebSockets |
|---|---|---|
| **Duplex** | Half | Full |
| **Messaging pattern** | Request-response model | Request-response model |
| **Protocol** | Stateless | Stateful |
| **Overhead** | Each request and response has a moderate overhead (headers, cookies, etc.) | Low |
| **Scalability** | Stateless protocols tend to scale well horizontally, although it depends on your situation. | WebSockets are challenging to scale horizontally due to their stateful nature. |
| **Use cases** | Retrieving static content and resources, implementing REST APIs. | Implementing realtime updates like live news updates or bidirectional communication such as chat or multiplayer collaboration. |
| **Built-in features** | Compression, multiplexing, authentication, and more. | None |
| **Event-driven** | No | Yes |
| **Realtime updates** | No | Purpose built for realtime updates. |
| **Bidirectional updates** | No | Yes |

# XMPP (eXtensible Messaging and Presence Protocol)



XMPP – eXtensible Messaging and Presence Protocol

It is a protocol (standard) that is used to build chat systems.

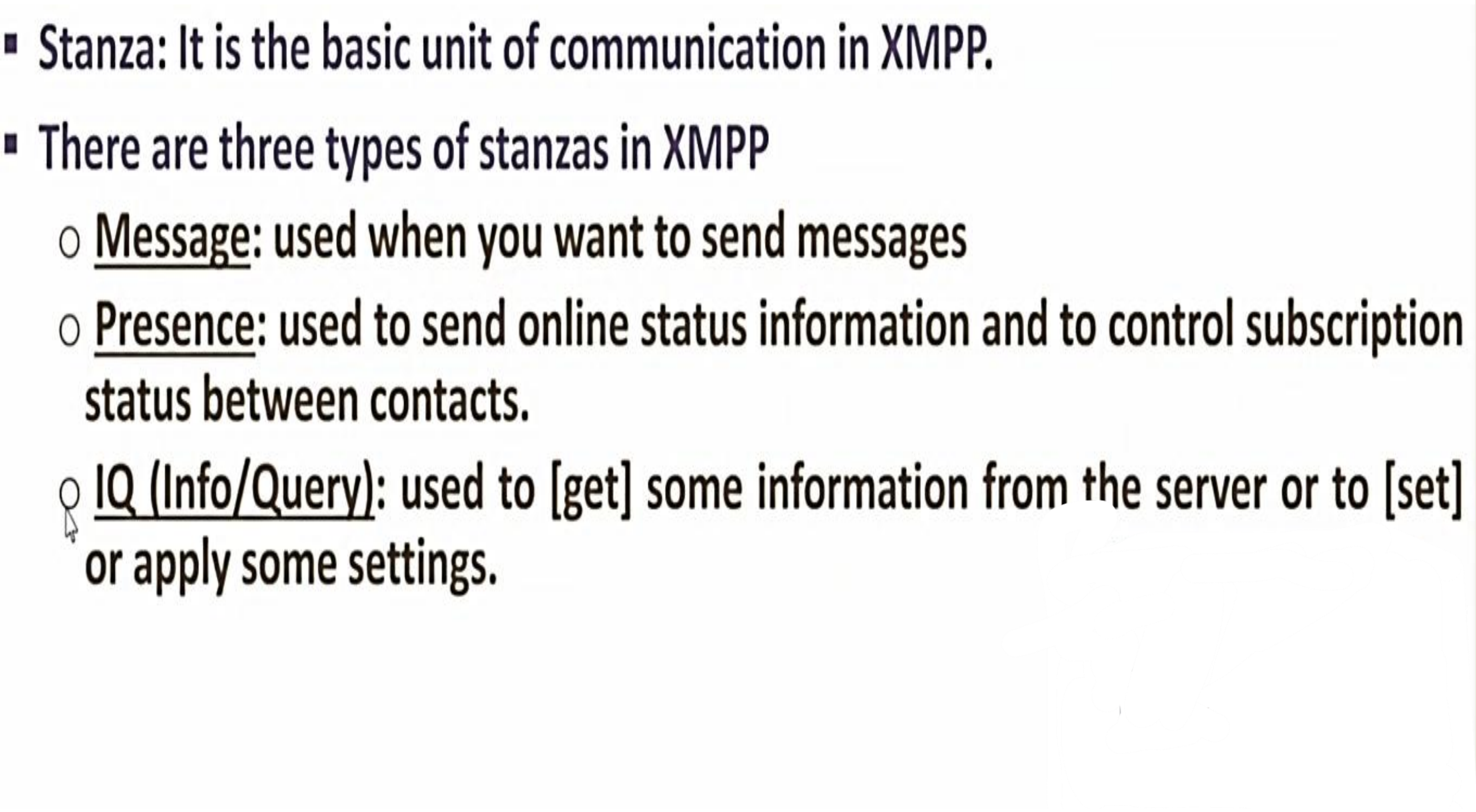
It uses XML to exchange data between client and server.

eXtensible: The protocol can be {has been} extended with new features.

Messaging: Send one-to-one and group messages.

Presence: See your contact's online status.

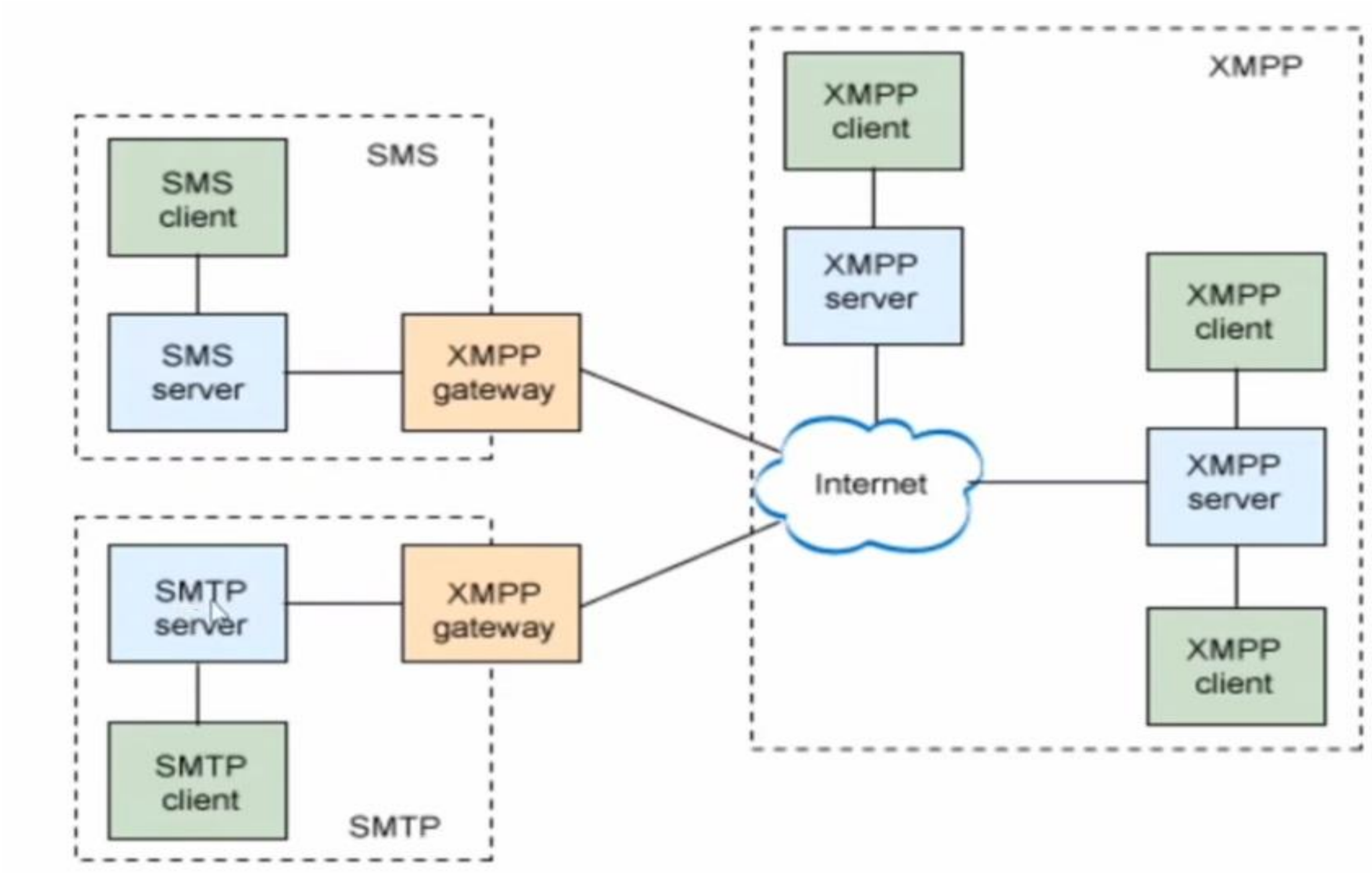
# XMPP Stanzas



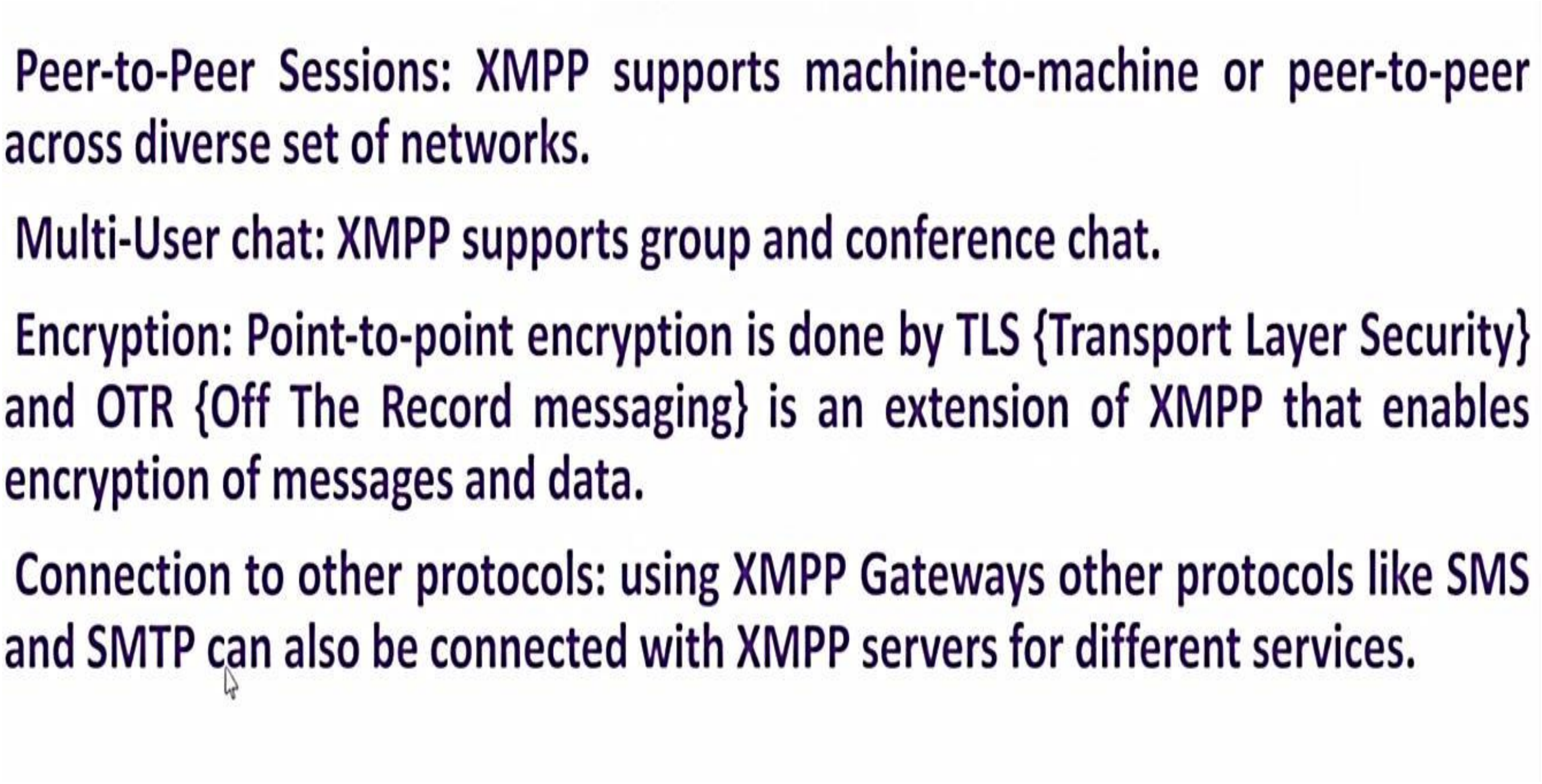
- Stanza: It is the basic unit of communication in XMPP.
- There are three types of stanzas in XMPP
  - Message: used when you want to send messages
  - Presence: used to send online status information and to control subscription status between contacts.
  - IQ (Info/Query): used to [get] some information from the server or to [set] or apply some settings.

Stanzas are the fundamental data structures for exchanging information, such as messages, presence information, and structured data requests.

# XMPP Architecture



# XMPP Features



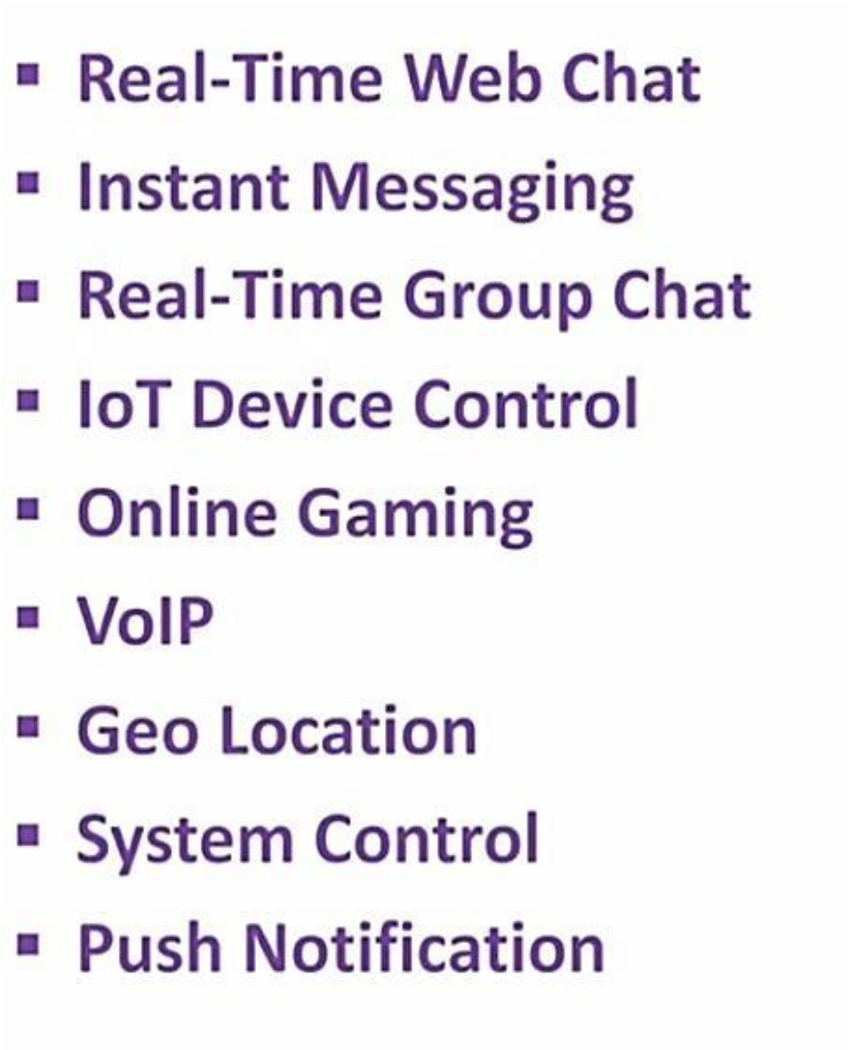
Peer-to-Peer Sessions: XMPP supports machine-to-machine or peer-to-peer across diverse set of networks.

Multi-User chat: XMPP supports group and conference chat.

Encryption: Point-to-point encryption is done by TLS {Transport Layer Security} and OTR {Off The Record messaging} is an extension of XMPP that enables encryption of messages and data.

Connection to other protocols: using XMPP Gateways other protocols like SMS and SMTP can also be connected with XMPP servers for different services.

# XMPP use cases

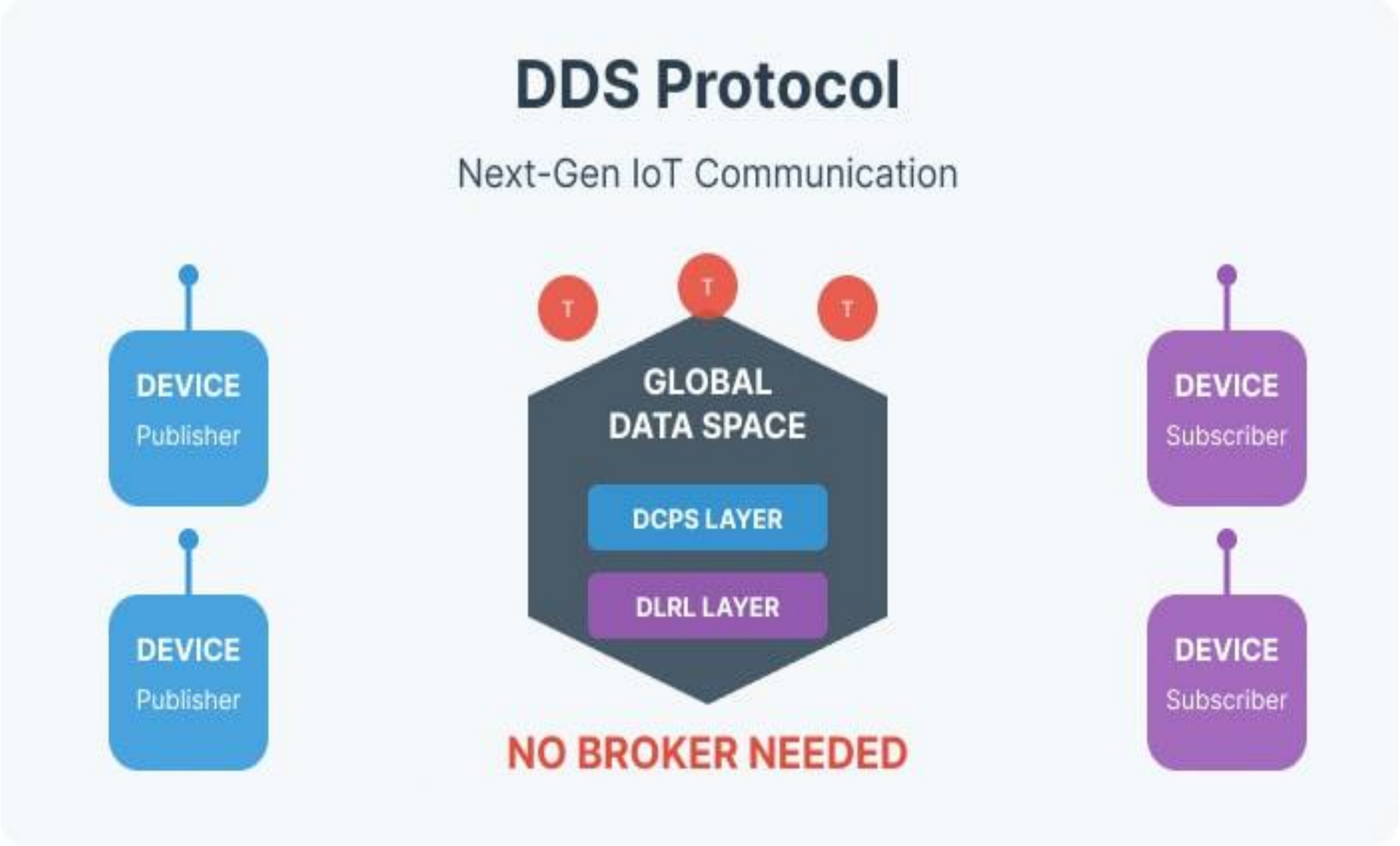


- Real-Time Web Chat
- Instant Messaging
- Real-Time Group Chat
- IoT Device Control
- Online Gaming
- VoIP
- Geo Location
- System Control
- Push Notification

# DDS (Data Distribution Service)

- It is an IoT protocol developed for M2M communication developed by OMG (object management group).
- DDS is a standard protocol for real-time, reliable, and scalable data exchange between devices and systems.
- It enables efficient communication in distributed IoT environments, particularly where low latency and high throughput are critical.
- It enables data exchange via publish-subscribe methodology.
- It develops a broker-less architecture unlike MQTT.

# DDS Architecture

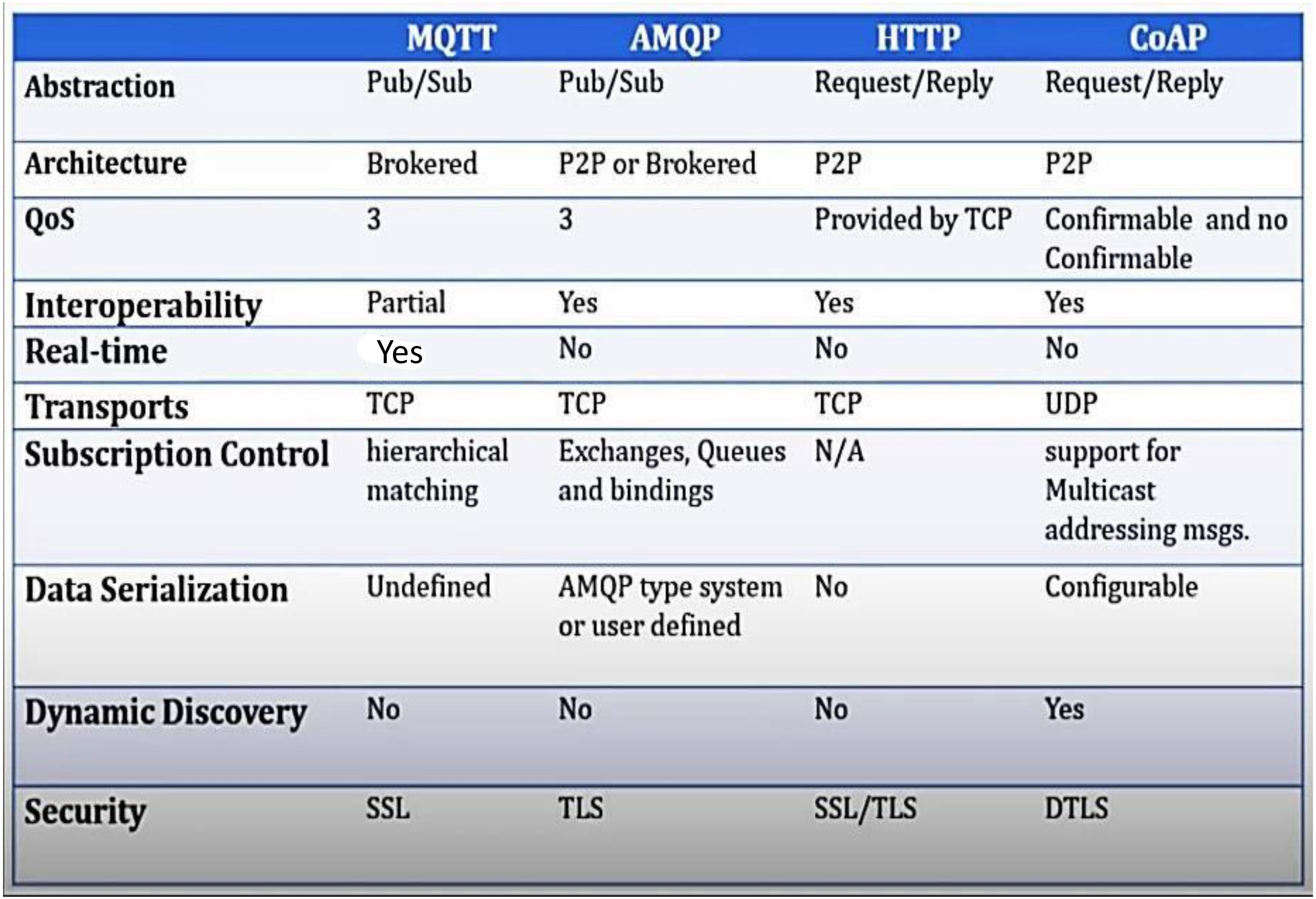


https://store.outrightcrm.com/blog/dds-protocol-in-iot/

# AMQP (Advanced Message Queuing Protocol)

- AMQP is more advanced protocol than MQTT.
- It is more reliable and have better security support.
- AMQP enables encrypted and interoperable messaging between organizations and applications.
- Used to send banking transaction messages between servers and users.
- At the other end there will be an acknowledgment of message acceptance so it is a reliable.
- The protocol is used in client/server messaging and IoT device management.

# Comparison Chart



| | MQTT | AMQP | HTTP | CoAP |
|---|---|---|---|---|
| Abstraction | Pub/Sub | Pub/Sub | Request/Reply | Request/Reply |
| Architecture | Brokered | P2P or Brokered | P2P | P2P |
| QoS | 3 | 3 | Provided by TCP | Confirmable and no Confirmable |
| Interoperability | Partial | Yes | Yes | Yes |
| Real-time | Yes | No | No | No |
| Transports | TCP | TCP | TCP | UDP |
| Subscription Control | hierarchical matching | Exchanges, Queues and bindings | N/A | support for Multicast addressing msgs. |
| Data Serialization | Undefined | AMQP type system or user defined | No | Configurable |
| Dynamic Discovery | No | No | No | Yes |
| Security | SSL | TLS | SSL/TLS | DTLS |

# Network Layer Protocols

# IPV4

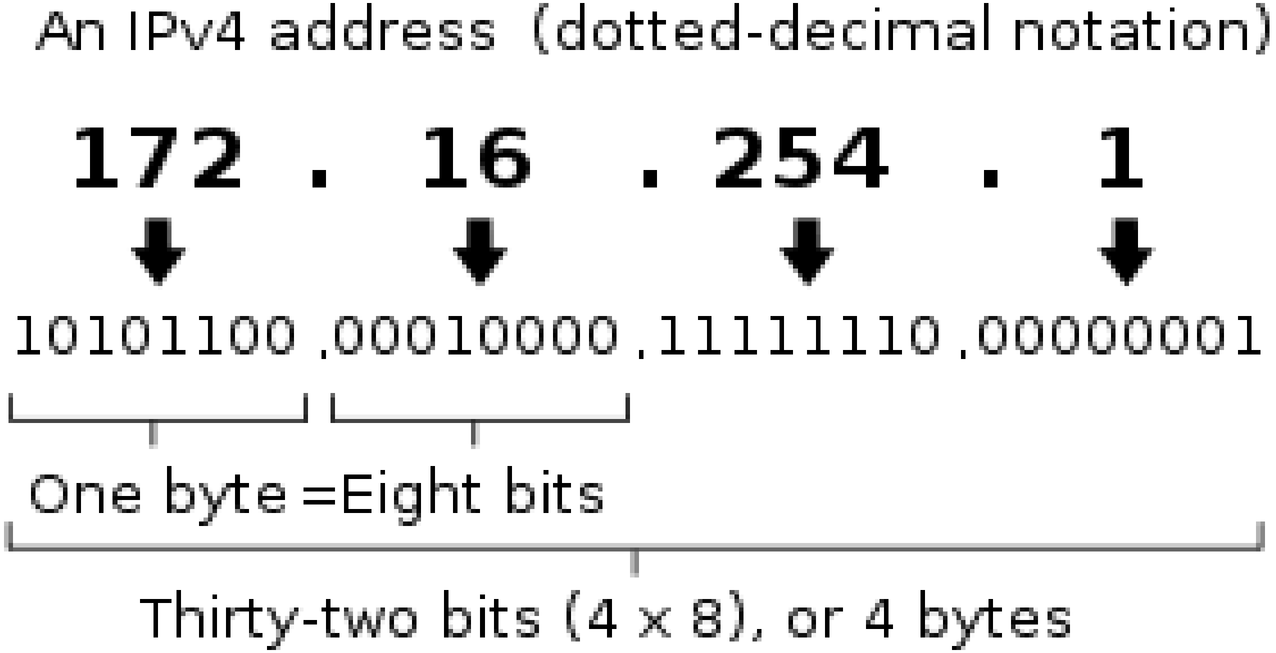
- **IP** stands for **Internet Protocol version v4** stands for **Version Four** (IPv4), is the most widely used system for identifying devices on a network.
- IP version four addresses are 32-bit integers which will be expressed in decimal notation.
- With 32 bit address we can have 4.29 Billion different nodes on a network.

## Parts of IPv4

**IPv4 addresses consist of three parts:**

- **Network Part**: The network part indicates the distinctive variety that's appointed to the network. The network part conjointly identifies the category of the network that's assigned.
- **Host Part**: The host part uniquely identifies the machine on your network. This part of the IPv4 address is assigned to every host. **Subnet Number**: This is the non-obligatory part of IPv4. Local networks that have massive numbers of hosts are divided into subnets and subnet numbers are appointed to that

# IPV4 Representation

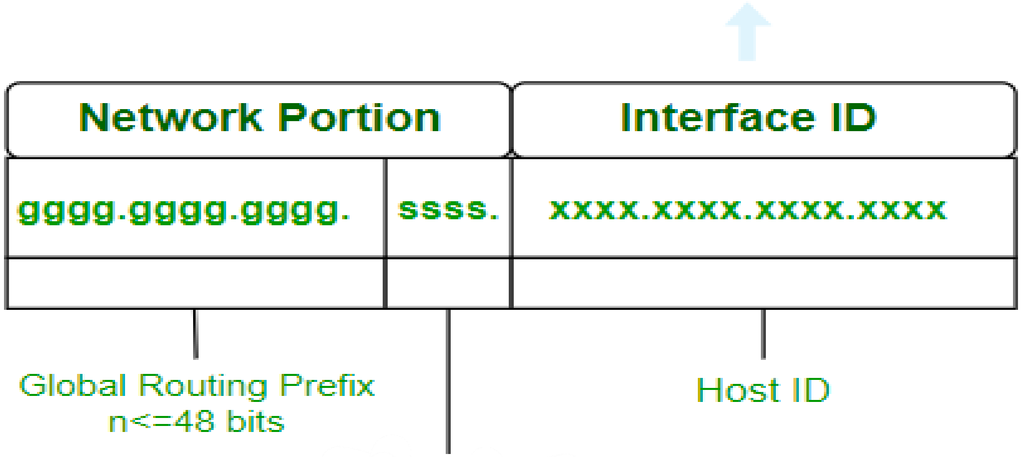

An IPv4 address (dotted-decimal notation)
172 . 16 . 254 . 1
10101100 ,00010000 ,11111110 ,00000001
One byte =Eight bits
Thirty-two bits (4 x 8), or 4 bytes

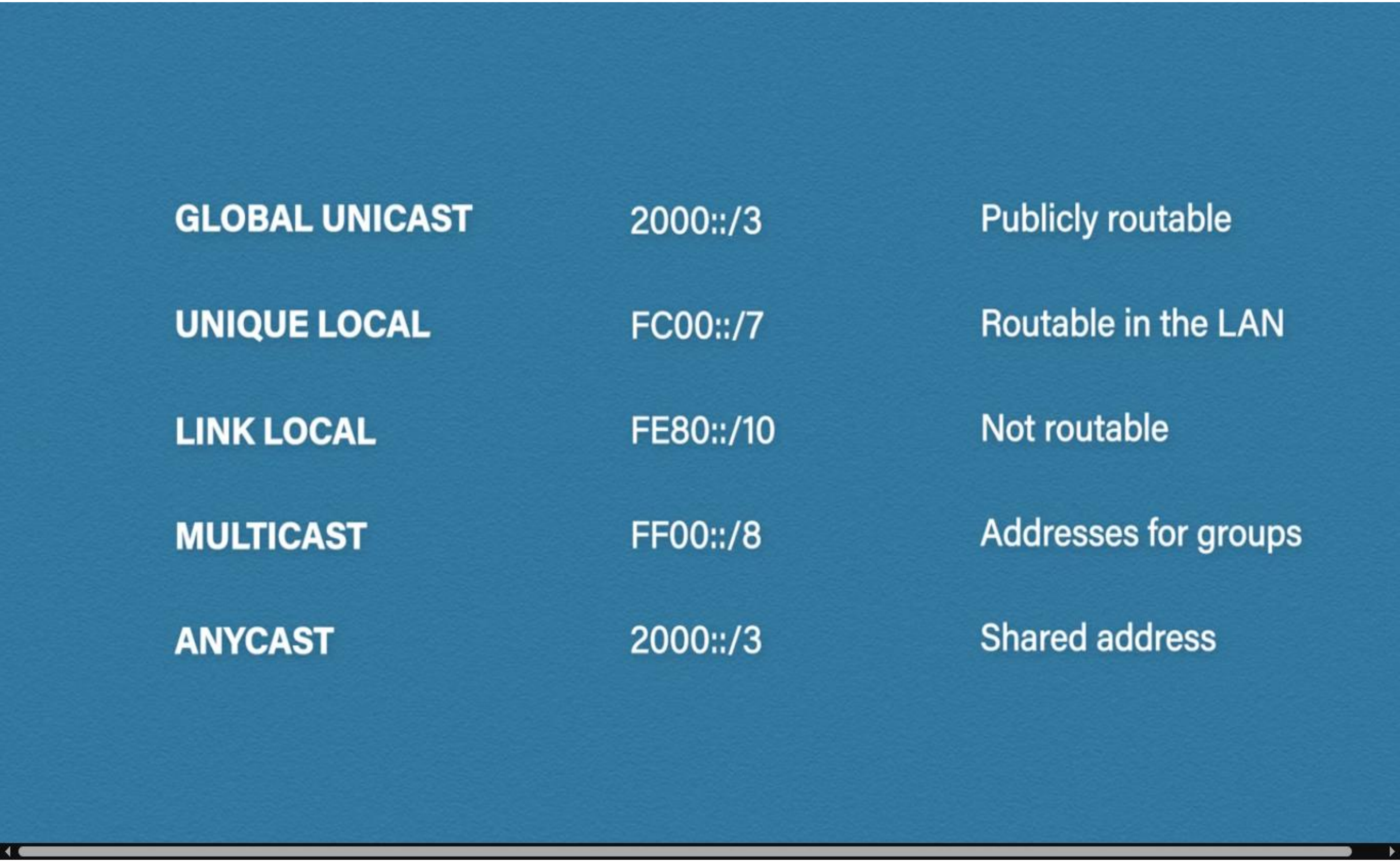
# IPV6

- The most common version of the Internet Protocol currently in use, IPv4, will soon be replaced by IPv6, a new version of the protocol.
- Because so many connected devices are being used, the original IP address scheme, known as IPv4, is running out of addresses.
- An IPv6 address consists of eight groups of four hexadecimal digits.

**for e.g.., 3001:0da8:75a3:0000:0000:8a2e:0370:7334**

- With 128-bit address space, it allows 340 undecillion ($340 \times 10^{36}$) unique address space.





| | | |
|---|---|---|
| **GLOBAL UNICAST** | 2000::/3 | Publicly routable |
| **UNIQUE LOCAL** | FC00::/7 | Routable in the LAN |
| **LINK LOCAL** | FE80::/10 | Not routable |
| **MULTICAST** | FF00::/8 | Addresses for groups |
| **ANYCAST** | 2000::/3 | Shared address |

- **Global Routing Prefix:** The Global Routing Prefix is the portion of an IPv6 address that is used to identify a specific network or subnet within the larger IPv6 internet.
- **Student Id:** The portion of the address used within an organization to identify subnets. This usually follows the Global Routing Prefix.
- **Host Id:** The last part of the address, is used to identify a specific host on a network.

- **Types of IPv6 Address**
- Now that we know about what is IPv6 address let’s take a look at its different types.
- **Unicast Addresses :** Only one interface is specified by the unicast address. A packet moves from one host to the destination host when it is sent to a unicast address destination.
- **Multicast Addresses:** It represents a group of IP devices and can only be used as the destination of a datagram.
- **Anycast Addresses:** The multicast address and the anycast address are the same. The way the anycast address varies from other addresses is that it can deliver the same IP address to several servers or devices. Keep in mind that the hosts do not receive the IP address. Stated differently, multiple interfaces or a collection of interfaces are assigned an anycast address.

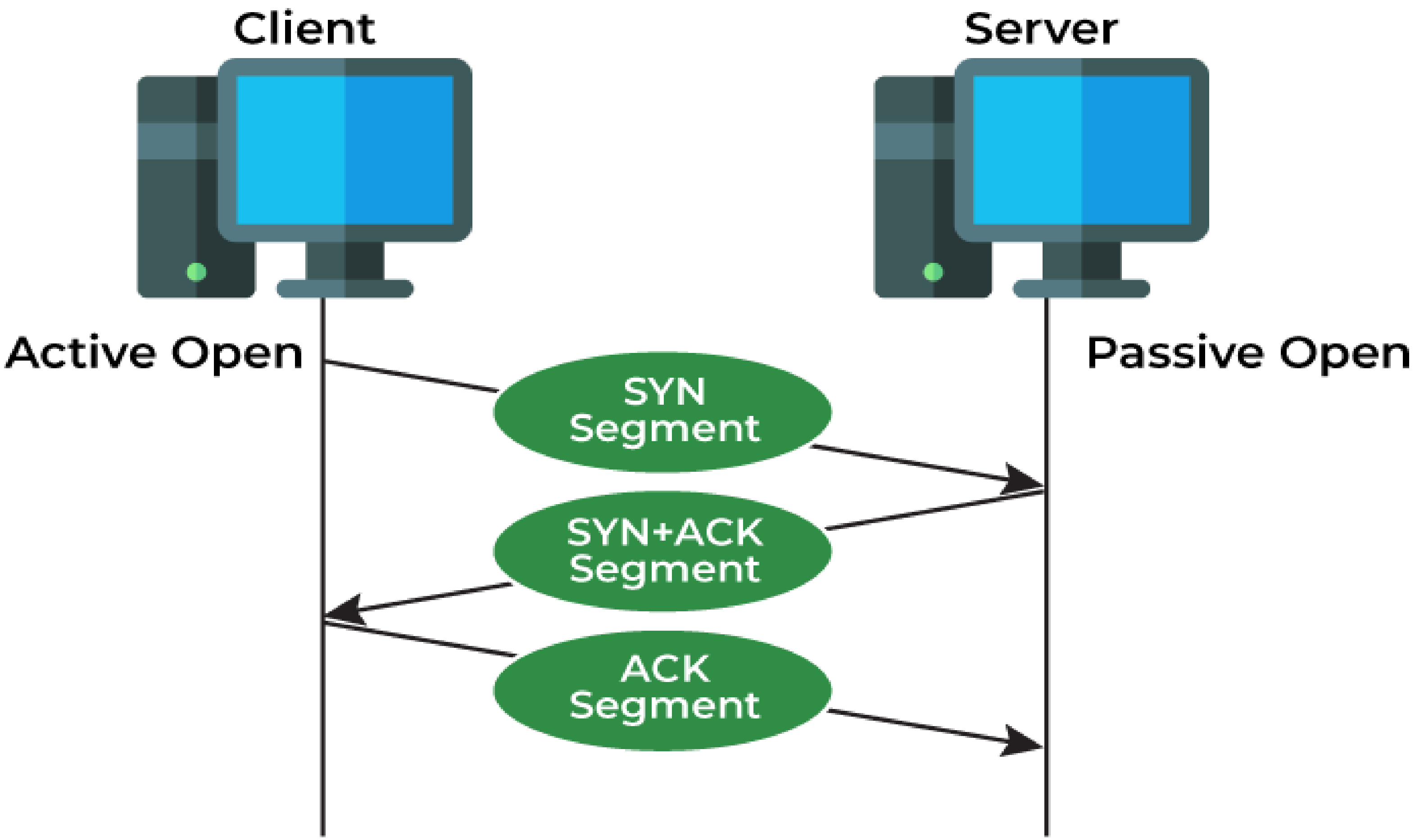
- **Advantages**
- **Faster Speeds:** IPv6 supports multicast rather than broadcast in IPv4.This feature allows bandwidth-intensive packet flows (like multimedia streams) to be sent to multiple destinations all at once.
- **Stronger Security:** IPSecurity, which provides confidentiality, and data integrity, is embedded into IPv6.
- Routing efficiency
- Reliability
- Most importantly it's the final solution for growing nodes in Global-network.
- The device allocates addresses on its own.
- Internet protocol security is used to support security.
- Enable simple aggregation of prefixes allocated to IP networks; this saves bandwidth by enabling the simultaneous transmission of large data packages.

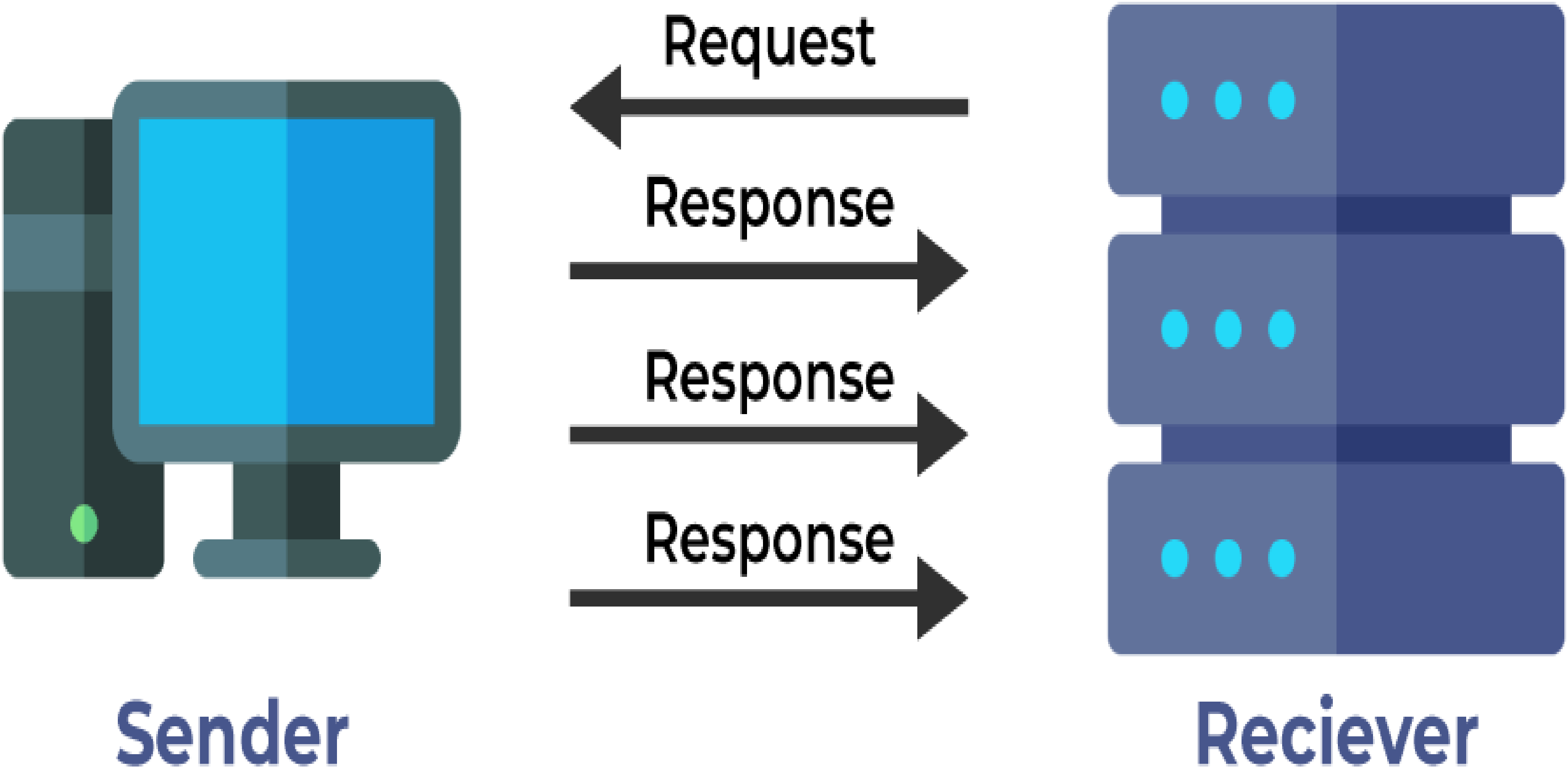
# IP4 & IPV6

| IPv6 | IPv4 |
|---|---|
| IPv6 has a 128-bit address length | IPv4 has a 32-bit address length |
| It supports Auto and renumbering address configuration | It Supports Manual and DHCP address configuration |
| The address space of IPv6 is quite large it can produce $3.4\times10^{38}$ address space | It can generate $4.29\times10^{9}$ address space |
| Address Representation of IPv6 is in hexadecimal | Address representation of IPv4 is in decimal |
| In IPv6_checksum field is not available | In IPv4 checksum field is available |
| IPv6 has a header_of 40 bytes fixed | IPv4 has a header of 20-60 bytes. |
| IPv6 does not support VLSM | IPv4 supports VLSM(Variable Length subnet mask). |

# TCP & UDP

- TCP and UDP both are protocols of the Transport Layer.
- TCP is a connection-oriented protocol (It requires a logical connection to be established between the two processes before data is exchanged) whereas UDP is a connectionless protocol (IT allows data to be exchanged without setting up a link between processes.
- Unlike TCP, it is an unreliable and connectionless protocol.


Client
Server
Active Open
Passive Open
SYN Segment
SYN+ACK Segment
ACK Segment


Request
Response
Response
Response
Sender
Reciever

- **Advantages of UDP**
- It does not require any connection for sending or receiving data.
- Broadcast and Multicast are available in UDP.
- UDP can operate on a large range of networks.
- UDP has live and real-time data.
- UDP can deliver data if all the components of the data are not complete.

- **Disadvantages of UDP**
- We can not have any way to acknowledge the successful transfer of data.
- UDP cannot have the mechanism to track the sequence of data.
- UDP is connectionless, and due to this, it is unreliable to transfer data.
- In case of a Collision, UDP packets are dropped by Routers in comparison to TCP.
- UDP can drop packets in case of detection of errors.

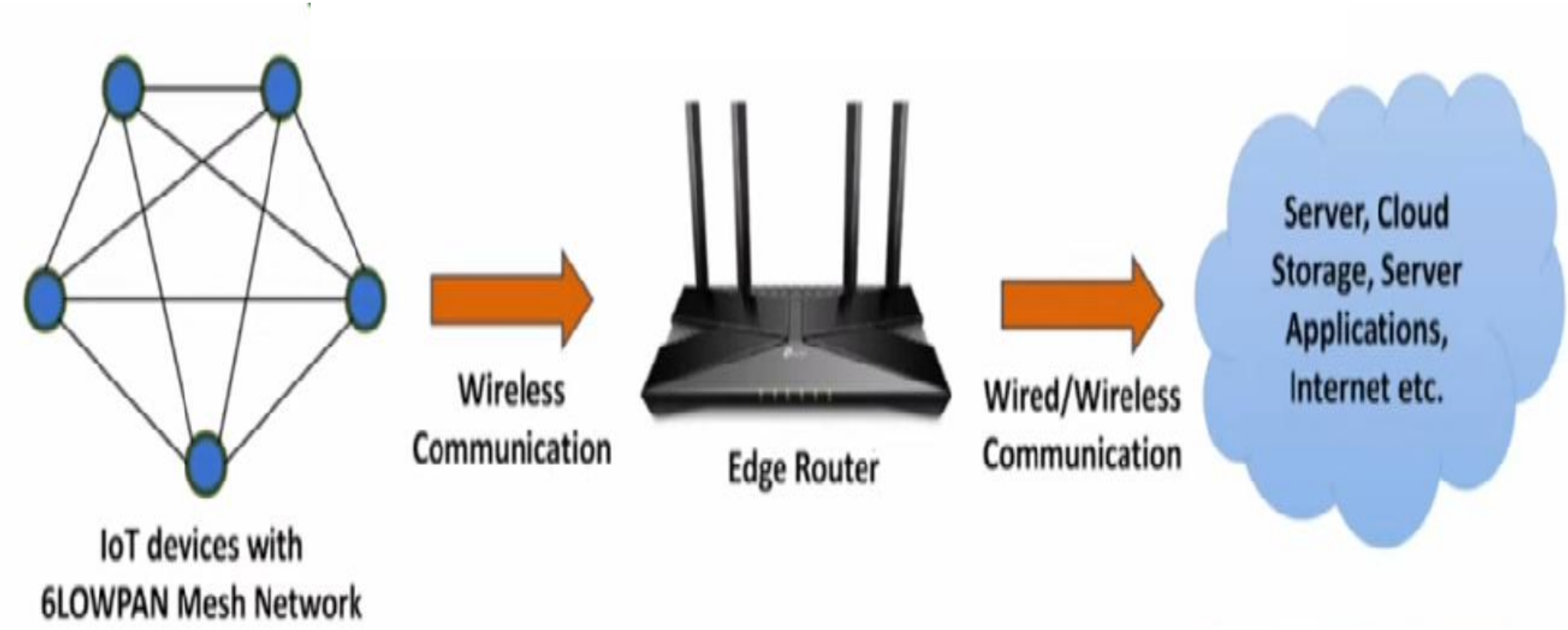
- Where TCP is Used?
- Sending Emails
- Transferring Files
- Web Browsing
- Where UDP is Used?
- Gaming
- Video Streaming
- Online Video Chats

TCP offers dependable, orderly, and error-free data transmission, making it ideal for operations that require precision, such as file transfers and web browsing. UDP, on the other hand, provides quicker, connectionless communication that is excellent for real-time applications such as gaming and video streaming, when speed is critical and minor data loss is acceptable.

# 6LoWPAN
# (IPV6 over Low power Wireless Personal Area Network)

- Low power IP driven nodes in large mesh network support makes this technology a great option for internet of things applications.
- It’s a communication protocol designed to enable small, low-power devices to connect over wireless networks.
- 6LoWPAN is an IPv6 protocol, and It’s extended from IPv6 over Low Power Personal Area Network.
- 6LoWPAN came to exist from the idea that the Internet Protocol could and should be applied even to the smallest devices, and that low-power devices with limited processing capabilities should be able to participate in the Internet of Things.
- 6lowpan uses AES 128 (Advanced Encryption Standard) link layer security.
- E.g.., LED streetlights.

# Architecture of 6LoWPAN



# Requirements of 6LoWPAN

- The device must have sleep mode to support battery saving.
- Minimal RAM and ROM requirements (in kb) must be there.
- Data rate should be lower.
- Low computations are required with 6LoWPAN.

# Features of 6 LoWPAN

- It is used with 802.15.4 (ZigBee) in ISM (industrial, scientific and medical) 2.4 Ghz band.
- Maximum 100 nodes can be connected in a 6lowpan network.
- Maximum range 200mts.
- Max. data rate is 200kbps.

# Advantages of 6LoWPAN

6LOWPAN is a Mesh Network that is robust, scalable, and self-healing.

6LOWPAN delivers low-cost, and secure communication in IoT devices.

6LOWPAN uses IPV6 protocol, so data can be routed directly to the cloud.

6LOWPAN offers one-to-many, and many-to-one routing.

6LOWPAN works efficiently with open IP standards like TCP, UDP, CoAP, HTTP, MQTT, and WebSocket.

For power saving, leaf nodes can stay in sleep mode for a longer duration.

6LOWPAN offers a large network, which can be used by millions of IoT devices.

6LOWPAN doesn’t need Gateway, with the use of edge router data can be routed to the cloud.

# Applications of 6LoWPAN

**Applications:**

- **Smart Homes and Buildings:** Controlling lighting, temperature control temperature, and security systems.
- **Industrial Automation:** Monitoring and controlling industrial processes.
- **Environmental Monitoring:** Tracking air and water quality, temperature, and other environmental factors.
- **Healthcare:** Remote patient monitoring and wearable devices.
- **Smart Agriculture:** Monitoring soil conditions, irrigation, and other agricultural parameters. , and security systems.

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# Link Layer Protocols

## IEEE 802.3- ETHERNET

- It specifies the physical layer and data link layer's media access control (MAC) for wired Ethernet networks.
- Ethernet is widely used in local area networks (LANs) and is also adaptable for Metropolitan Area Networks (MANs) and Wide Area Networks (WANs).
- It is constantly evolving technology and speed ranges up-to 400 Gbps till now started from 2.94 Mbps.
- It uses star topology and bus topology.
- MAC uses CSMA/CD method which works on collision detection so no acknowledgement of data is required.
- Physical layer uses Manchester encoding.

## Physical Layer and MAC:

IEEE 802.3 defines the physical characteristics of Ethernet, including the types of cables (copper and fiber), data rates (from 10 Mbps to 400 Gbps and beyond), and how devices share the network medium (CSMA/CD, auto-negotiation). It also specifies the MAC sub-layer, which handles addressing and access to the network.

## Data Frames:

Ethernet uses data frames to transmit information. These frames contain source and destination MAC addresses, data, and a Frame Check Sequence (FCS) for error detection.

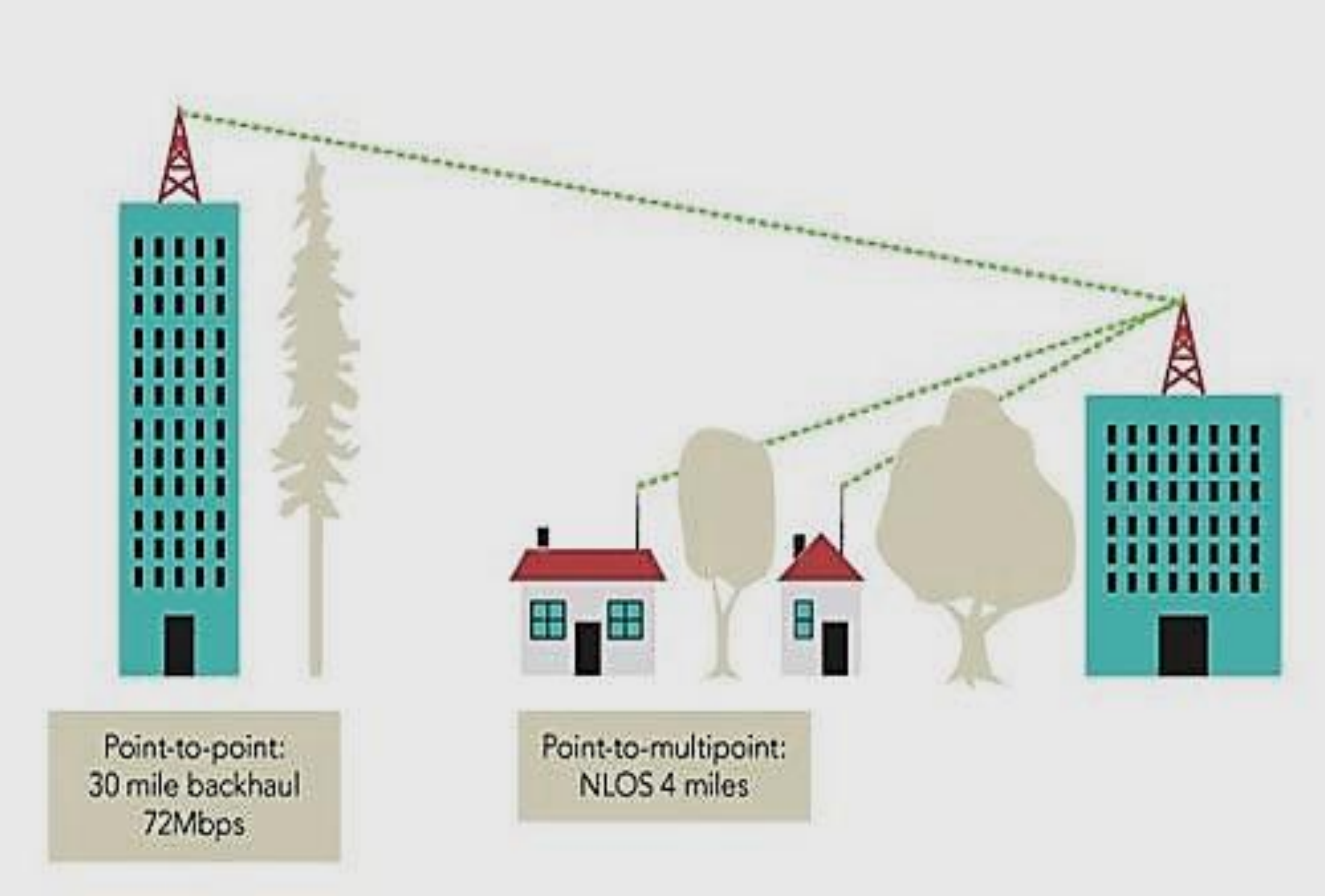
## Key Features:

IEEE 802.3 includes features like auto-negotiation (for determining optimal connection settings), flow control (to manage data flow), and support for different duplex modes (half-duplex and full-duplex)

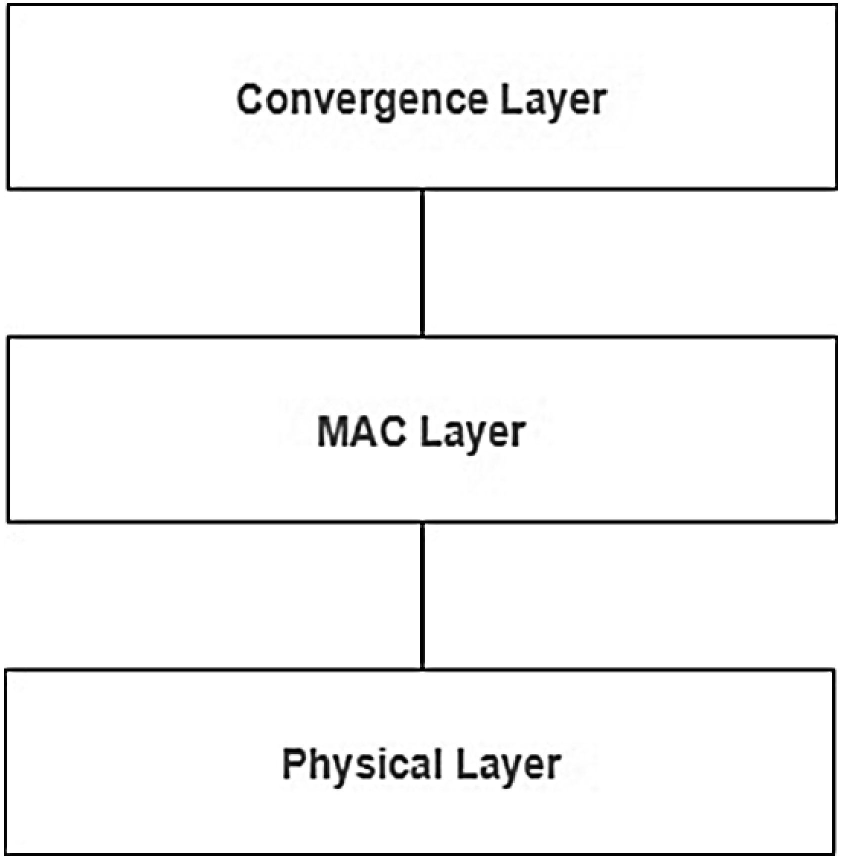
# 802.16 Wi-Max

- Wireless/worldwide interoperability for microwave access.
- This wireless communication standard designed to provide high-speed internet access over a wide area.
- It is based on MAN (metropolitan area network)
- Its range is up to 50km with Non-Line-of-Sight speed of about 70 mbps.

- **Although WiMAX towers can broadcast to a wide area, obstacles can weaken or stop the signal from traveling past it.**
- **To compensate for this and further expand their coverage, WiMAX towers use the process of backhauling.**
- **In WiMAX backhauling, a tower sends wireless signal to a second tower in its line of sight, enabling the second tower to operate as a base station without having to physically connect to the Internet.**


Point-to-point:
30 mile backhaul
72Mbps
Point-to-multipoint:
NLOS 4 miles

- It is a 3 layer Architecture.
- It ranges up to 50km and non line of sight speed of up to 70mbps.



Convergence Layer

MAC Layer

Physical Layer

- **Physical layer:** This layer specifies frequency band, synchronization between transmitter and receiver, data rate and multiplexing scheme. This layer is responsible for encoding and decoding of signals. It converts MAC layer frames into signals to be transmitted. It provides point-to-multipoint communication and is based on CSMA/CD.
- The **MAC layer** is responsible for transmitting data in frames and controlling access to shared wireless media. The MAC protocol defines how and when a subscriber may initiate a transmission on the channel.
- **Convergence layer** provides the specific function regarding the service like multimedia, ATM or telephony service.

# Advantages of Wi-MAX

- **Wide Coverage Area:** WiMAX can cover an area of up to 50 kilometers, making it suitable for providing broadband access in rural and underserved areas.
- **High Data Rates:** WiMAX can provide data rates of up to 75 Mbps, which is higher than many other wireless technologies.
- **Scalability:** WiMAX can be easily scaled to support a large number of users and devices.
- **Interoperability:** WiMAX is based on an international standard, which allows for interoperability between different vendors, equipment.
- **Cost-effective:** WiMAX is a cost-effective solution for providing broadband access in areas where it is not economically feasible to deploy wired infrastructure.

# Disadvantages of WiMAX

- **Limited Mobility:** WiMAX is designed for fixed or nomadic (semi-fixed) use, not for mobile use.
- **Interference:** WiMAX operates in the same frequency range as other wireless technologies, which can lead to interference.
- **Security Concerns:** WiMAX uses a shared spectrum, which can make it vulnerable to security threats such as eavesdropping and jamming.
- **Limited device availability:** WiMAX devices are not as widely available as devices for other wireless technologies, such as Wi-Fi.
- **Limited penetration:** WiMAX signals may have trouble penetrating through walls, buildings and other obstacles.

**Source: https://illumin.usc.edu/wimax-the-next-generation-of-wireless-technology/**

# 802.11 Wi-Fi

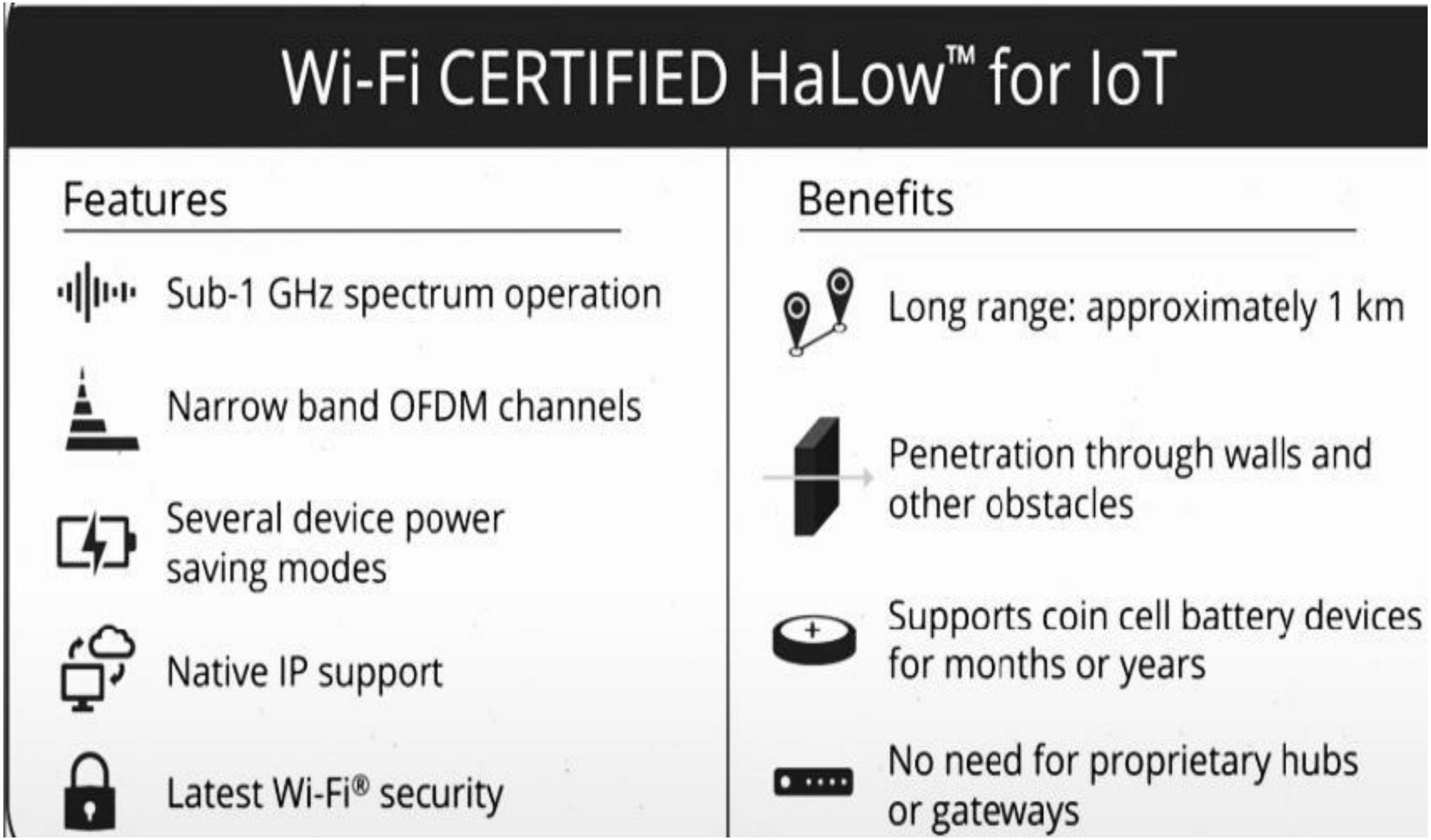
- Wi-Fi uses high-frequency radio waves instead of cables for connecting the devices in LAN.
- The term 802.11x is also used to denote the set of standards. Various specifications and amendments include 802.11a, 802.11b, 802.11e, 802.11g, 802.11n etc.

| 802.11 Protocol | Frequency | Modulation | Bandwidth | Data Rates (Mb/s) | # MIMO Streams | Comments |
|---|---|---|---|---|---|---|
| a | 5 GHz | OFDM | 20 MHz | 6, 9, 12, 18, 24, 36, 48, 54 | 1 | High frequency reduces effective range. |
| b | 2.4 GHz | DSSS | 20 MHz | 1, 2, 5.5, 11 | 1 | Many IT departments are turning off "b" access points. |
| g | 2.4 GHz | OFDM<br>&<br>DSSS | 20 MHz | 6, 9, 12, 18, 24, 36, 48, 54 | 1 | Only *universal* mo dule scheme. Access points auto-adjust rate to minimize the packet error rate. |
| n | 2.4 GHz<br>&<br>5 GHz | OFDM | 20 MHz<br>&<br>40 MHz | 7.2, 14.4, 21.7, 28.9, 43.3, 57.8, 65, 72.2 (per stream) | 4 | Must implement MIMO and 40 MHz bandwidth to get maximum data rates (600 Mb/s). |

**Source * https://developerhelp.microchip.com/xwiki/bin/view/applications/wifi/802-11-abgn-explained/**

# 802.11ah

- It is an IoT centric Wi-Fi protocol also known as Wi-Fi HaLow (comes from Hey-Low).
- The Wi-Fi HaLow operates at 900Mhz frequency which allows it to achieving range of upto 1km.



Wi-Fi CERTIFIED HaLow™ for IoT

Features

- Sub-1 GHz spectrum operation
- Narrow band OFDM channels
- Several device power saving modes
- Native IP support
- Latest Wi-Fi® security

Benefits

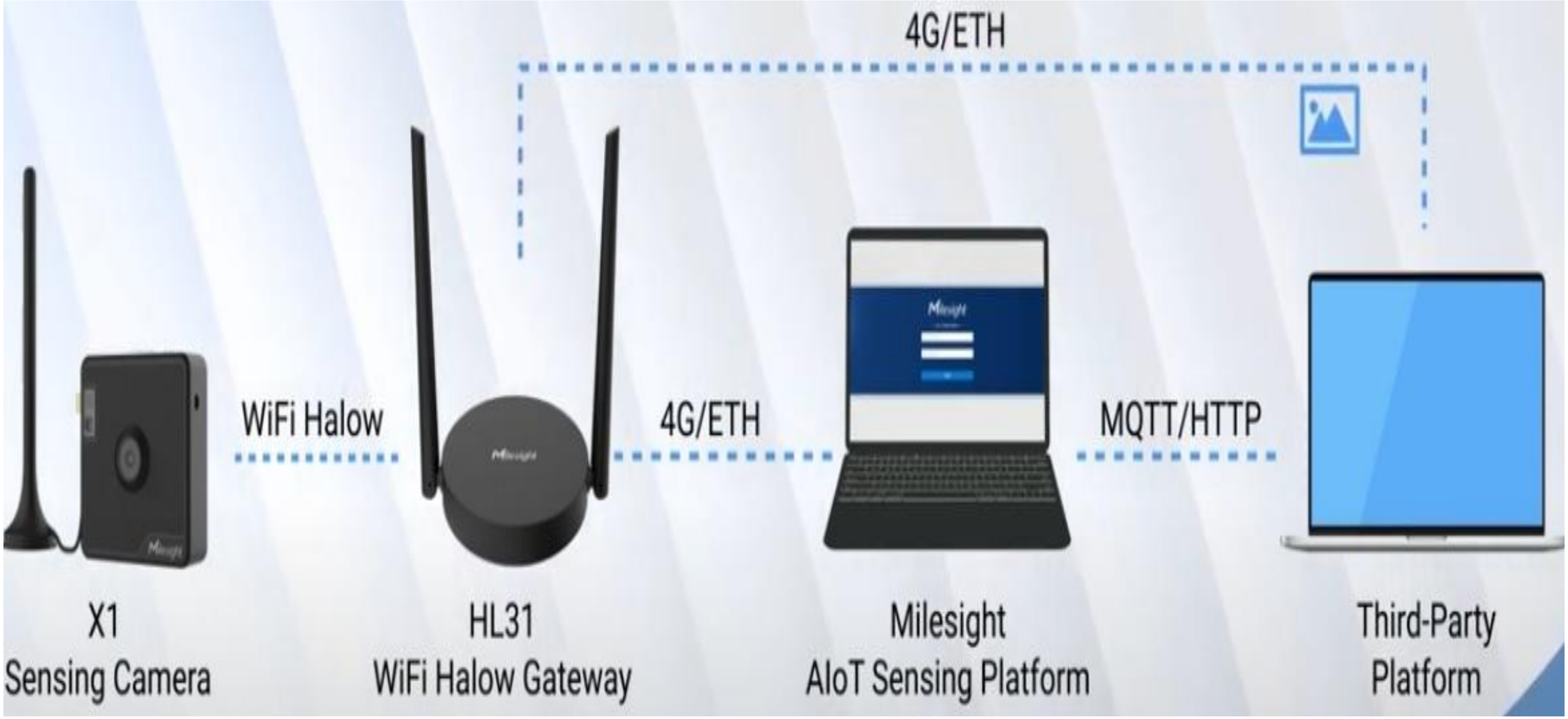
- Long range: approximately 1 km
- Penetration through walls and other obstacles
- Supports coin cell battery devices for months or years
- No need for proprietary hubs or gateways

# Applications of Halow

- **Home and building automation:** Wi-Fi Halow is low-power solution to connect door locks, cameras, appliances, and heating, ventilation, and air conditioning components.
- **Agriculture:** The range and ability of Wi-Fi HaLow to connect multiple sensors across a network over vast areas allows this technology to be used to track and monitor crops and livestock. Sensors based on coin cell batteries can operate on the farm for years.
- **Industrial:** Wi-Fi HaLow enables the connection of sensor devices and actuators across large distances in factories and refineries. It offers robust WPA3 security and built-in support for IPv6.
- **Logistics and transportation:** The sub-1 GHz radio frequency offers significant advantages that enhance planning and efficiency in the logistics of moving goods from suppliers to factories, warehouses, and points of sale.

*** In Wi-Fi halow longer battery life can be achieved by restricted access window and target wake time.**

# Working of Wi-Fi halow



# LRWPAN(Low Rate Wireless Personal Area Network)

- In this network nodes are communicated at low data rate.
- It comes under 802.15.4 IEEE standard.
- IEEE 802.15.4 is used for low power wireless connectivity solutions like zigbee, 6LowPAN and many more.
- Generally it is operated at 2.4 GHz ISM band but in Europe it uses 868 and in US it uses 915 MHz.
- At 2.4 GHz frequency its max. speed is 250kbps and at 868-915 MHz its speed lies between 20 to 40kbps
- Operates at low data rate with good performance and better battery life (upto multiple year).
- Operates at lower distance lesser than 100 mtr. (approx. 15-20 mtr.).
- IEEE 802.15.4 standard defines the characteristics of physical layer and MAC (at data link layer).
- The 802.15.4 uses Direct Sequence Spread Spectrum (DSSS) communication scheme.

# Protocol Stack of 802.15.4

- This protocol defines physical layer and data link layer.
- At physical layer devices operate at 2.4 GHz and max. speed of 250 kbps. It also defines transmission power and modulation scheme used.
- MAC is done using CSMA-CA at the second layer that is data link layer.
- Although ZigBee and 6LowPAN also uses 802.15.4 standard but only at data link layer and physical layer.

*https://www.a1.digital/knowledge-hub/iot-protocols-a-comprehensive-guide/#:~:text=Ethernet%20technology%20is%20a%20common,NFC%20(Near%20Field%20Communication)