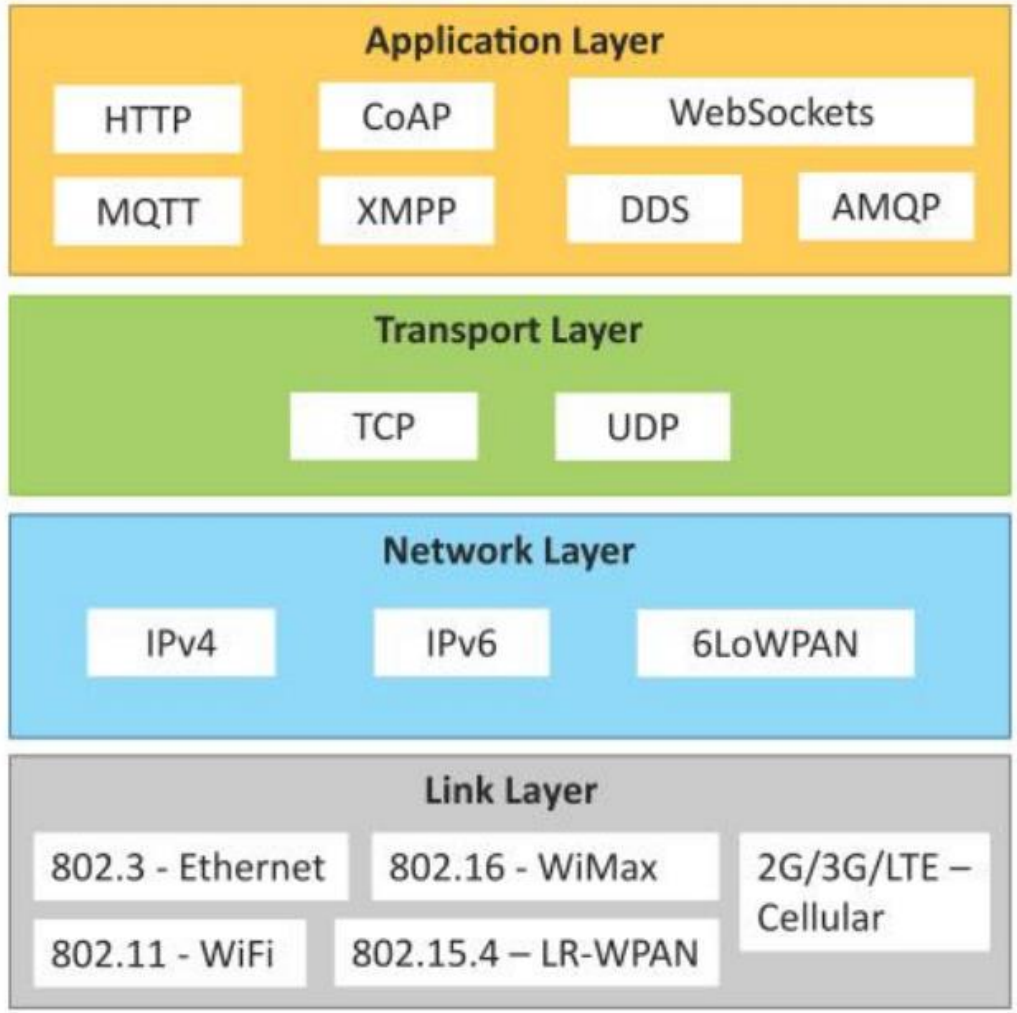
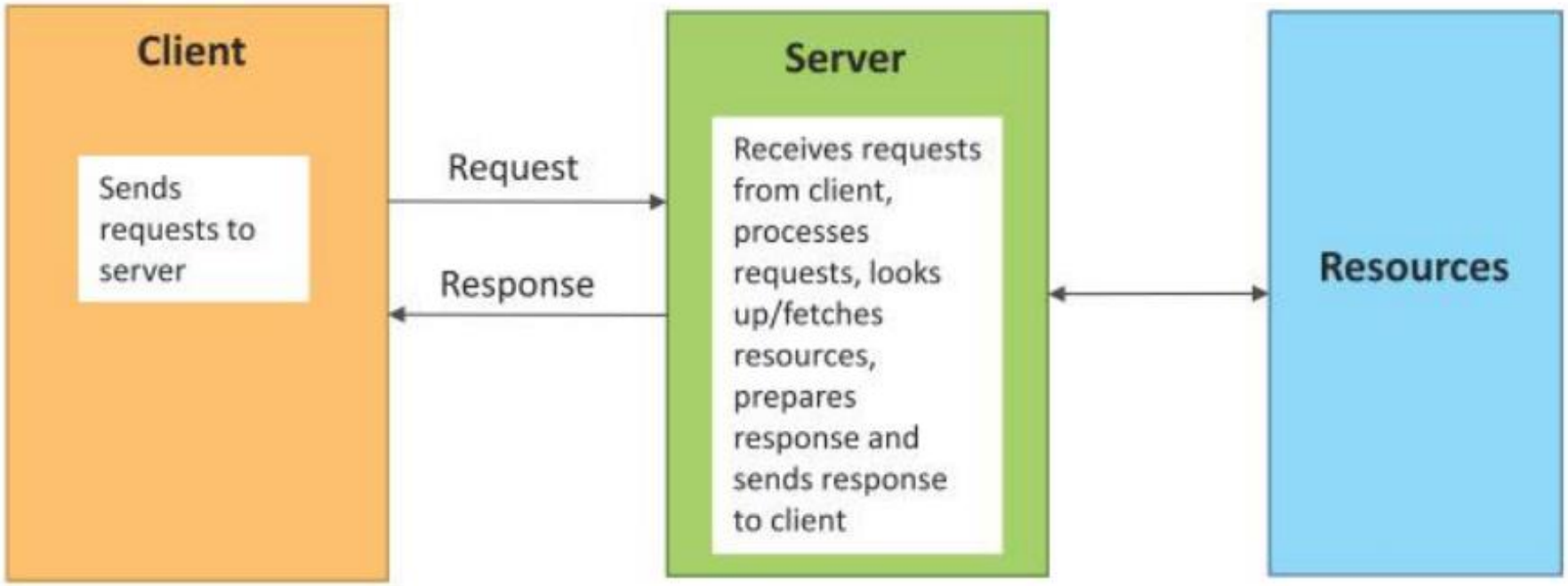
IoT Protocols

- Link Layer
  - 802.3 – Ethernet
  - 802.11 – WiFi
  - 802.16 – WiMax
  - 802.15.4 – LR-WPAN
  - 2G/3G/4G
- Network/Internet Layer
  - IPv4
  - IPv6
  - 6LoWPAN
- Transport Layer
  - TCP
  - UDP
- Application Layer
  - HTTP
  - CoAP
  - WebSocket
  - MQTT
  - XMPP
  - DDS
  - AMQP



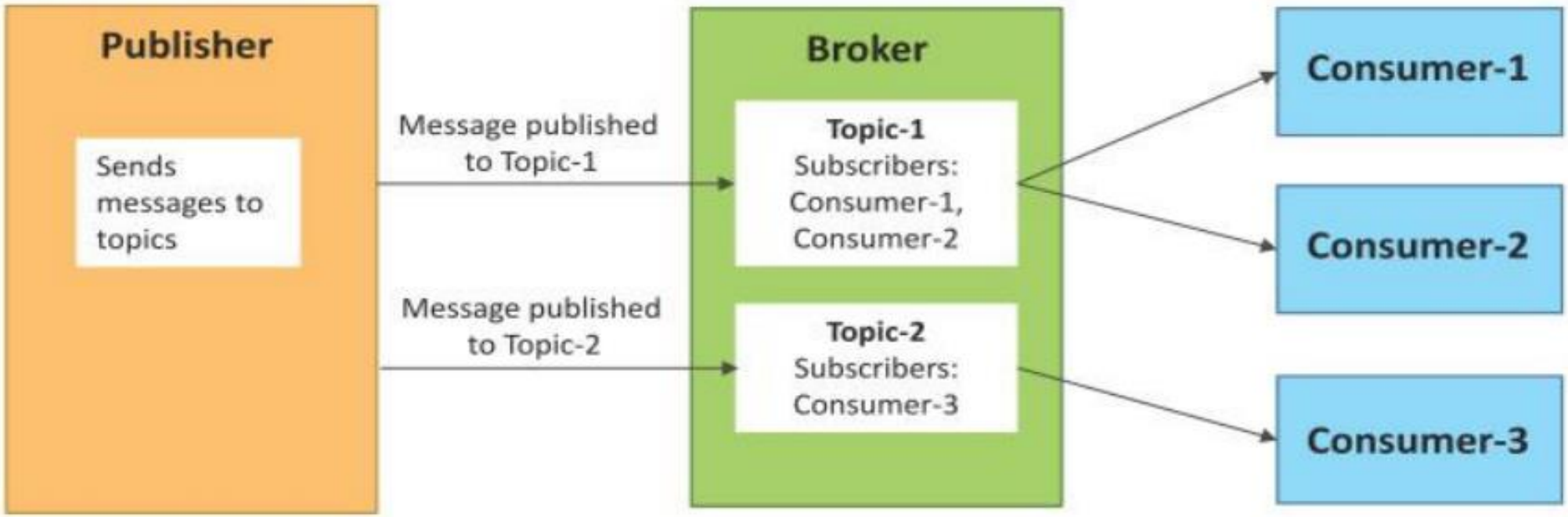
IoT communication models:

- **Request Response** :

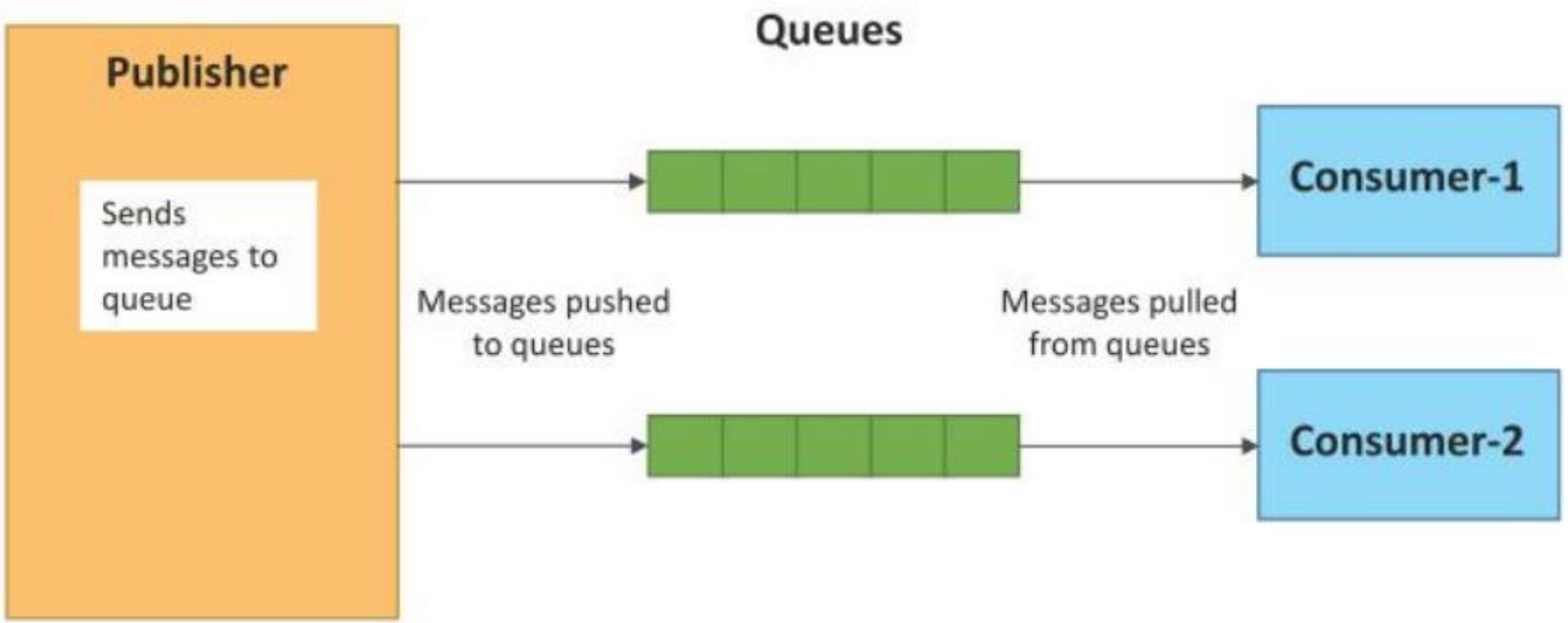


Request-Response model is a stateless communication model and each request-response pair is independent of others.

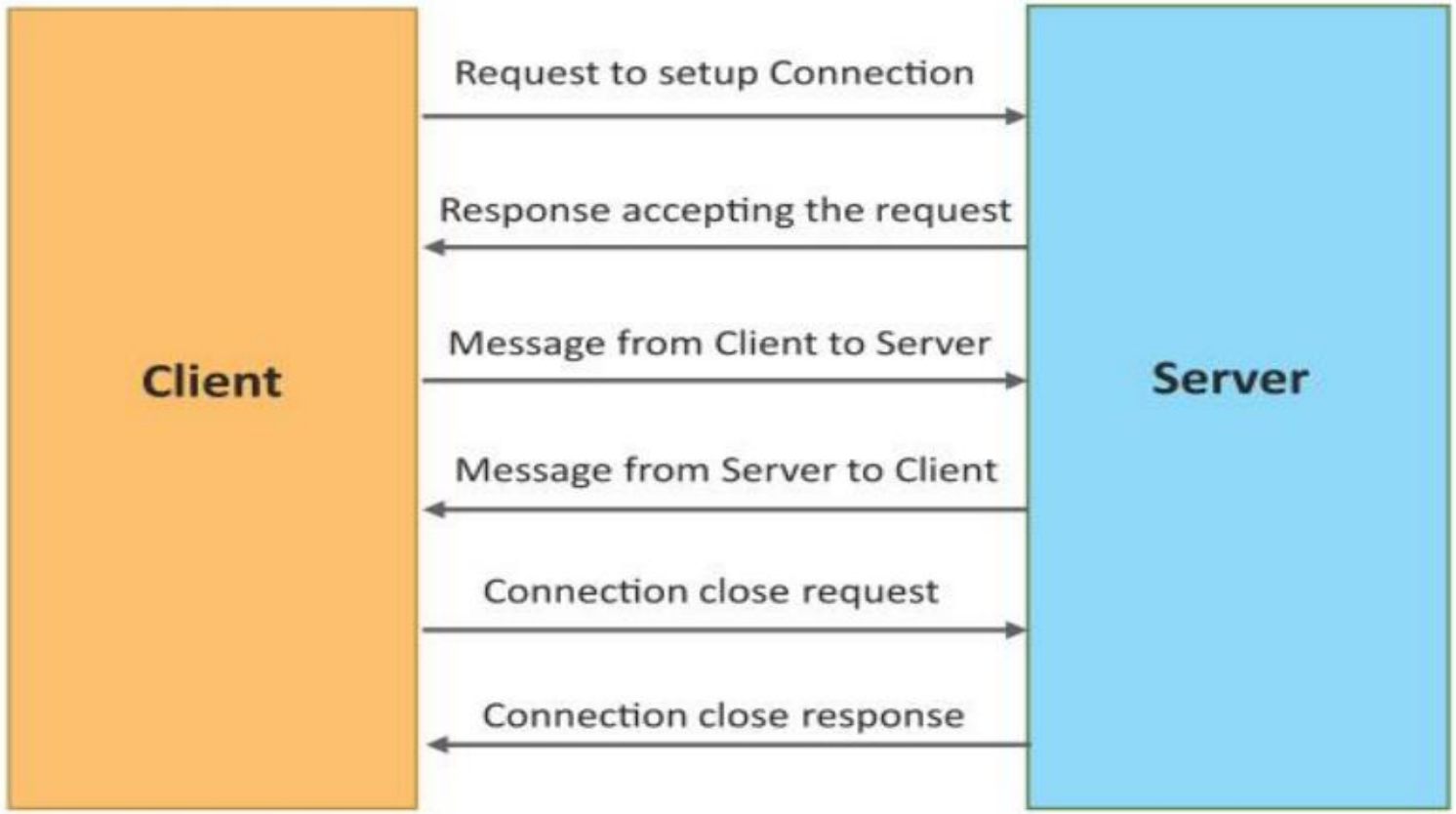
- **Publish-Subscribe**:



Push-Pull:


Queues
Publisher
Sends messages to queue
Messages pushed to queues
Messages pulled from queues
Consumer-1
Consumer-2

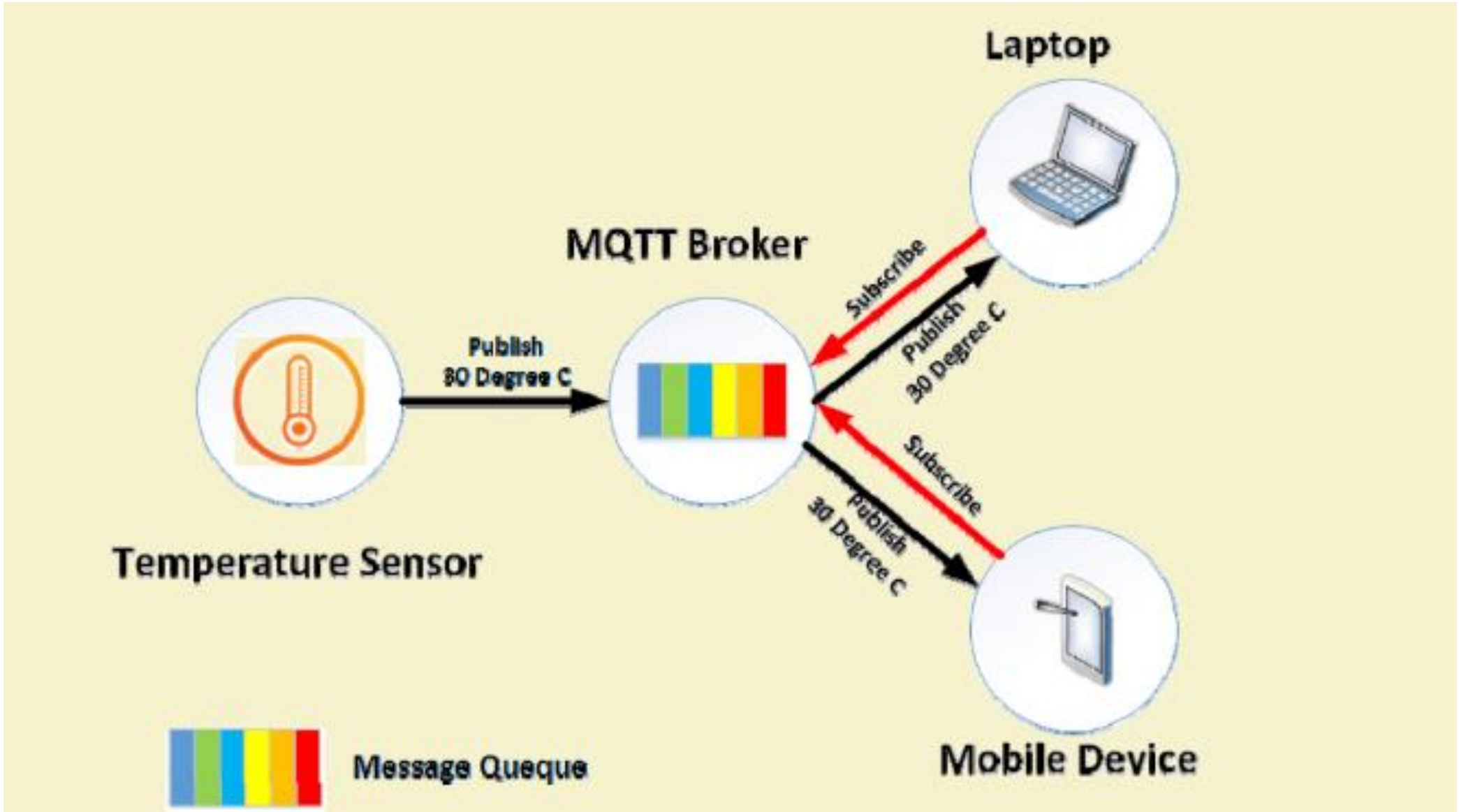
Exclusive Pair



Exclusive Pair is a bi-directional, fully duplex communication model that uses a persistent connection between the client and server.

MQTT:

- MQTT stands for **Message Queue Telemetry Transport**.
- MQTT is the most commonly used **messaging protocol** for the Internet of Things (IoT).
- MQTT is a lightweight protocol that is designed for connections with remote locations that have devices with **resource constraints** or **limited network bandwidth**.
- The protocol is **event driven** and connects devices using the **publish /subscribe** (Pub/Sub) pattern.
- The sender (Publisher) and the receiver (Subscriber) communicate via **Topics** and are **decoupled** from each other.
- A topic to which a client is subscribed is updated in the form of messages and distributed by the message **broker.**
- The connection between sender and receiver is handled by the MQTT broker.
- The MQTT broker **filters** all incoming messages and **distributes** them correctly to the Subscribers.
- An MQTT broker is **a server** that receives all messages from the clients and then routes the messages to the appropriate destination clients. An MQTT **client** is any device (from a micro controller up to a fully-fledged server) that runs an MQTT library and connects to an MQTT broker over a network.


Laptop
MQTT Broker
Subscribe
Publish
30 Degree C
Publish
30 Degree C
Subscribe
Publish
30 Degree C
Temperature Sensor
Message Queque
Mobile Device

Definition

- “MQTT is a Client Server publish/subscribe messaging transport protocol. It is light weight, open, simple, and designed so as to be easy to implement. These characteristics make it ideal for use in many situations, including constrained environments such as for communication in Machine to Machine (M2M) and Internet of Things (IoT) contexts where a small code footprint is required and/or network bandwidth is at a premium.“
- -*Citation from the official MQTT 3.1.1 specification*

- The most important aspect of pub/sub is the decoupling of the publisher of the message from the recipient (subscriber). This decoupling has several dimensions:

- **Space decoupling:** Publisher and subscriber do not need to know each other (for example, no exchange of IP address and port).
- **Time decoupling:** Publisher and subscriber do not need to run at the same time.
- **Synchronization decoupling:** Operations on both components do not need to be interrupted during publishing or receiving.

MQTT clients

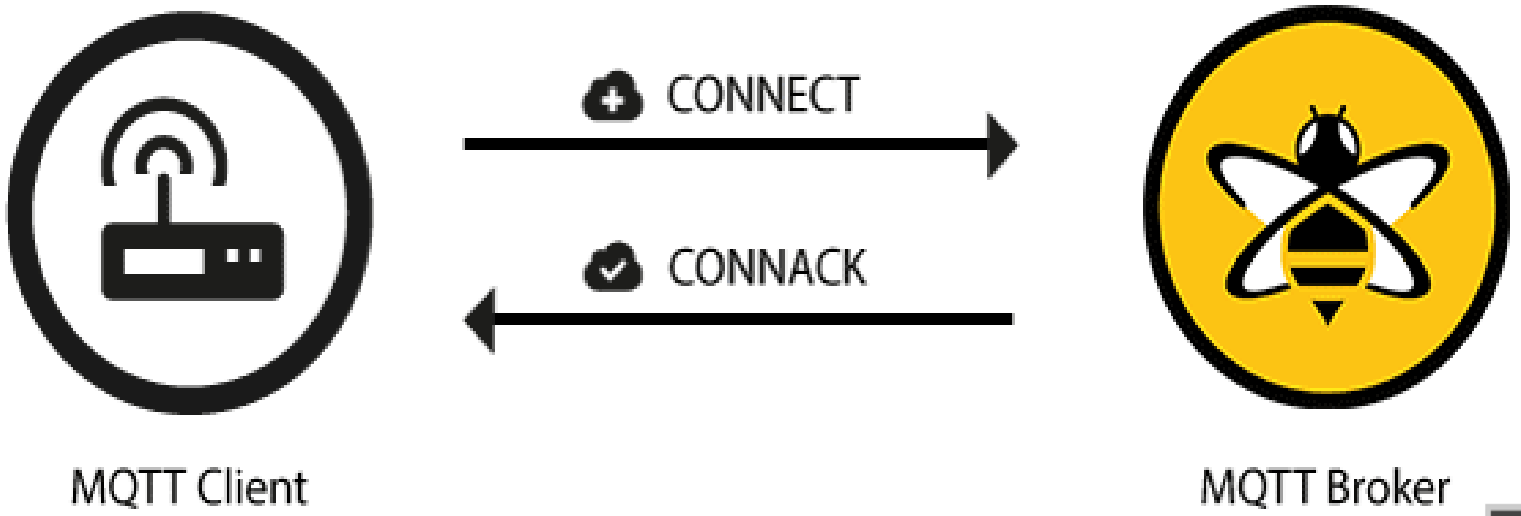
- Both publishers and subscribers are MQTT clients.
- The publisher and subscriber labels refer to whether the client is currently publishing messages or subscribed to receive messages
- publish and subscribe functionality can also be implemented in the same MQTT client

MQTT broker

- **The broker is responsible for receiving all messages, filtering the messages, determining who is subscribed to each message, and sending the message to these subscribed clients.**
- The broker also holds the session data of all clients that have persistent sessions, including subscriptions and missed messages.
- Another responsibility of the broker is the authentication and authorization of clients.

MQTT control packets:

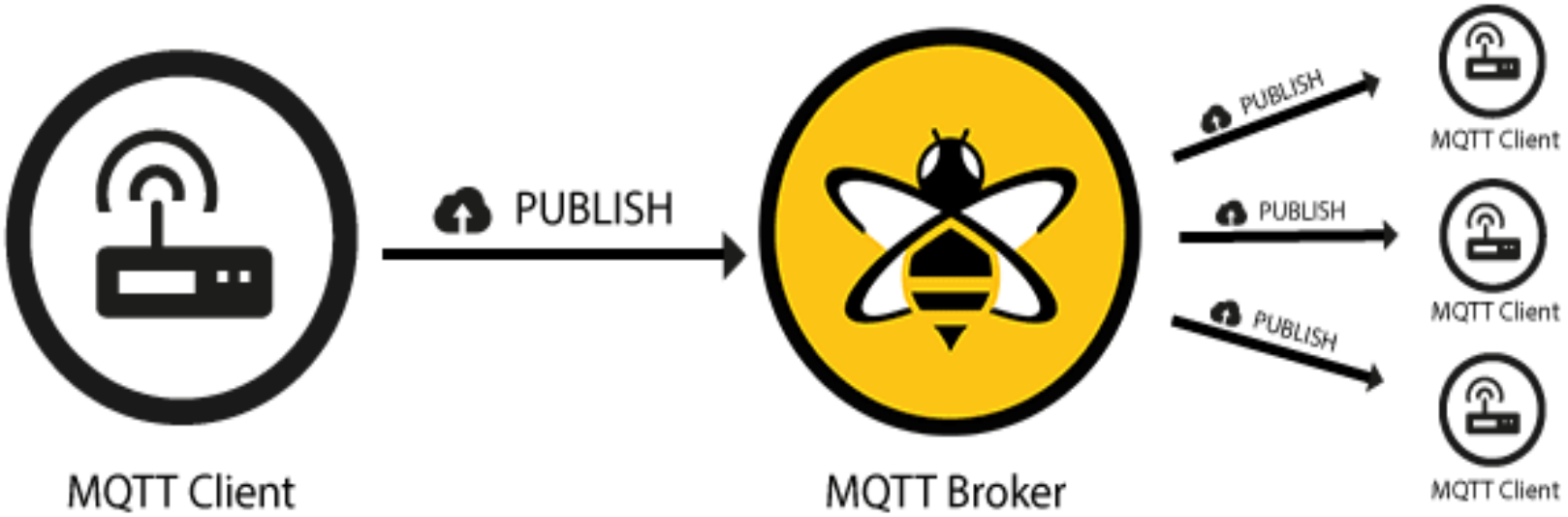
- **Connect and Connack**
- To initiate a connection, the client sends a command message to the broker.
- Connect packet includes the client identifier (ClientId) that **identifies each MQTT client** that connects to an MQTT broker.
- MQTT can send a **user name and password for client authentication and authorization** in a connect packet.
- Connect packet includes the keep alive. It is **a time interval in seconds** that the client specifies and communicates to the broker when the connection established.
- This interval defines the longest period of time that the broker and client can endure without sending a message.
- The client commits to sending regular PING Request messages to the broker. The broker responds with a PING response. This method allows both sides to determine if the other one is still available



- **Broker response with a CONNACK message**
- When a broker receives a CONNECT message, it is obligated to respond with a CONNACK message.
- The CONNACK message contains a connect return code that is **a return code that tells the client whether the connection attempt was successful or not**. If unsuccessful then why connection was refused.

Return Code	Return Code Response
0	Connection accepted
1	Connection refused, unacceptable protocol version
2	Connection refused, identifier rejected
3	Connection refused, server unavailable
4	Connection refused, bad user name or password
5	Connection refused, not authorized

Publish



- An MQTT client can publish messages as soon as it connects to a broker.
- **Each message must contain a topic that the broker can use to forward the message to interested clients**
- **It also contains the packet Identifier** that uniquely identifies a message as it flows between the client and broker.
- **QoS** This number indicates the Quality of Service Level (QoS) of the message. There are three levels: 0, 1, and 2.

Table 3.2 - QoS definitions

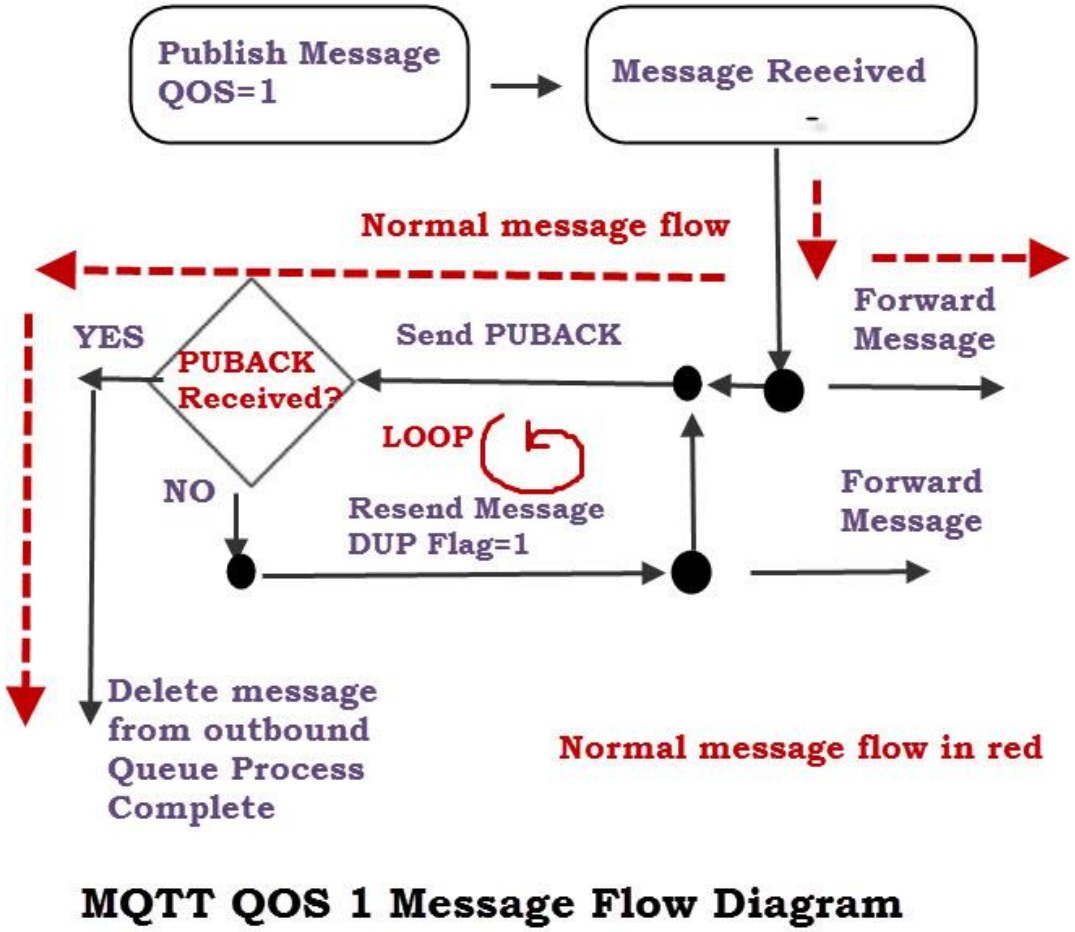
QoS value	Bit 2	bit 1	Description
0	0	0	At most once delivery
1	0	1	At least once delivery
2	1	0	Exactly once delivery
-	1	1	Reserved – must not be used

- QoS 0 - at most once
- This service level guarantees a best-effort delivery
- There is no guarantee of delivery.
- The recipient does not acknowledge receipt of the message and the message is not stored and re-transmitted by the sender.
- QoS level 0 is often called “fire and forget” and provides the same guarantee as the underlying TCP protocol.

QoS 1 - at least once

- QoS level 1 guarantees that a message is delivered at least one time to the receiver.
- The sender stores the message until it gets a **PUBACK** packet from the receiver that acknowledges receipt of the message.
- It is possible for a message to be sent or delivered multiple times.

Quality of Service level 1: delivery at least once



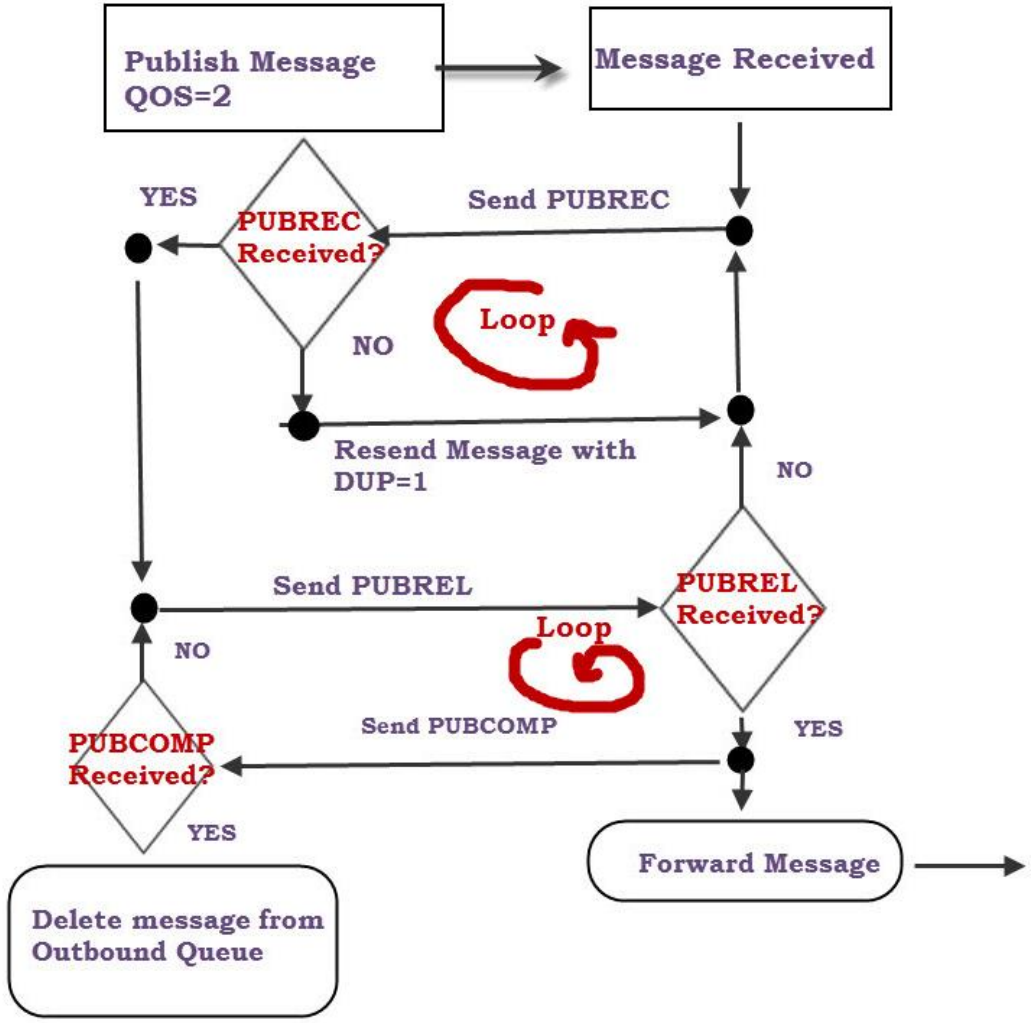
MQTT QOS 1 Message Flow Diagram

QoS-1

- The sender uses **the packet identifier** in each packet **to match** the **PUBLISH** packet to the corresponding **PUBACK** packet.
- If the sender does not receive a PUBACK packet in a **reasonable amount of time**, the sender resends the PUBLISH packet.
- When a receiver gets a message with QoS 1, it can process it immediately.
- For example, if the receiver is a broker, the broker sends the message to all subscribing clients and then replies with a PUBACK packet.
- If the publishing client sends the message again it sets a **duplicate (DUP) flag**.

QOS 2 – Only Once

- This level guarantees that the message will be delivered **only once**.
- This is the slowest method as it requires 4 messages.
- 1. The sender sends a message and waits for an acknowledgement (**PUBREC**)
- 2. The receiver sends a **PUBREC** message
- 3. If the sender doesn't receive an acknowledgement (**PUBREC**) it will resend the message with the **DUP flag** set.
- 4. When the sender receives an acknowledgement message **PUBREC** it then sends a message release message (**PUBREL**).
- 5. If the receiver doesn't receive the **PUBREL** it will resend the **PUBREC** message
- 5. When the receiver receives the **PUBREL** message it can now forward the message onto any subscribers.
- 6. The receiver then send a publish complete (**PUBCOMP**) .
- 7. If the sender doesn't receive the PUBCOMP message it will resend the **PUBREL** message.
- 8. When the sender receives the **PUBCOMP** the process is complete and it can **delete the message** from the outbound queue, and also the message state.



MQTT QOS 2 Message Flow Diagram

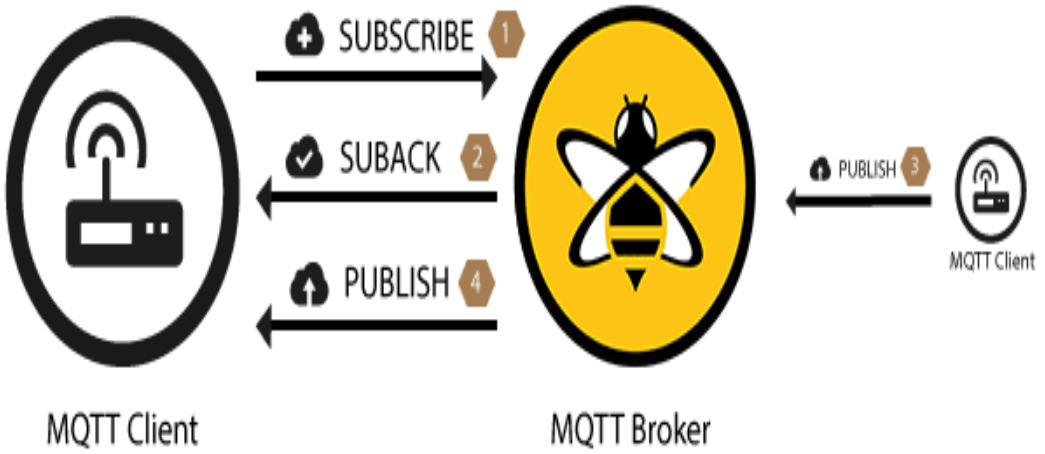
Client to Client or End to End QOS

- The Quality of service between **two clients** connected to a broker is determined by the QOS of the published message, and the QOS of the subscribing client.

- If a subscribing Client has been granted maximum QoS 1 for a particular Topic Filter, then a QoS 0 Application Message matching the filter is delivered to the Client at QoS 0.
- This means that at most one copy of the message is received by the Client.
- On the other hand a QoS 2 Message published to the same topic is downgraded by the Server to QoS 1 for delivery to the Client, so that Client might receive duplicate copies of the Message.

QOS PUBLISH	QOS SUBSCRIBE	OVERALL QOS
0	0 or 1 or 2	0
1	0	0
1	1 or 2	1
2	0	0
2	1	1
2	2	2

- To receive messages on topics of interest, the client sends a **SUBSCRIBE** message to the MQTT broker.
- This subscribe message is very simple, it contains **a unique packet identifier and a list of subscriptions.**
- To confirm each subscription, the broker sends a **SUBACK** acknowledgement message to the client.
- This message contains **the packet identifier of the original Subscribe message (to clearly identify the message) and a list of return codes.**
- **Return Code** The broker sends one return code for each topic/QoS-pair that it receives in the SUBSCRIBE message.
- For example, if the SUBSCRIBE message has five subscriptions, the SUBACK message contains five return codes.
- The return code acknowledges each topic and shows the QoS level that is granted by the broker.
- If the broker **refuses** a subscription, the SUBACK message contains a failure return code for that specific topic
- After a client successfully sends the SUBSCRIBE message and receives the SUBACK message, it gets every published message that matches a topic in the subscriptions that the SUBSCRIBE message contained.



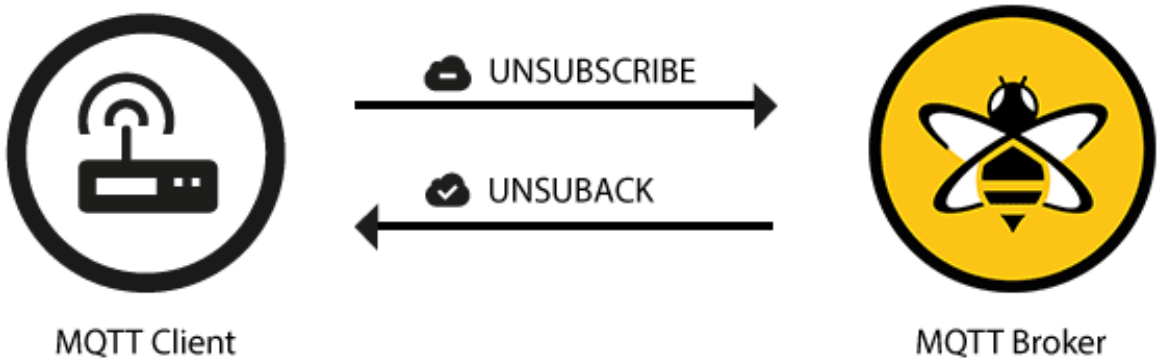
Return Code	Return Code Response
0	Success - Maximum QoS 0
1	Success - Maximum QoS 1
2	Success - Maximum QoS 2
128	Failure

Unsubscribe

- The counterpart of the SUBSCRIBE message is the **UNSUBSCRIBE** message. This message deletes existing subscriptions of a client on the broker.
- The UNSUBSCRIBE message is similar to the SUBSCRIBE message and **has a packet identifier and a list of topics.**

Unsuback

- To confirm the unsubscribe, the broker sends an **UNSUBACK** acknowledgement message to the client.
- This message contains **only the packet identifier** of the original UNSUBSCRIBE message (to clearly identify the message).



MQTT Topics

- In MQTT, the word topic refers to an UTF-8 string that the broker uses to filter messages for each connected client.
- The topic consists of one or more topic levels. Each topic level is separated by a forward slash (topic level separator).

MQTT Wildcards

When a client subscribes to a topic, it can subscribe to the exact topic of a published message or it can use wildcards to subscribe to multiple topics simultaneously.
A wildcard can only be used to subscribe to topics, not to publish a message.

There are two different kinds of wildcards: *single-level* and *multi-level*.

Single Level: +

- As the name suggests, a single-level wildcard replaces one topic level. The plus symbol represents a single-level wildcard in a topic.

- Any topic matches a topic with single-level wildcard if it contains an arbitrary string instead of the wildcard. For example a subscription to *myhome/groundfloor/+/temperature* can produce the following results:

Multi Level:

- The multi-level wildcard covers many topic levels. The hash symbol represents the multi-level wild card in the topic. For the broker to determine which topics match, the multi-level wildcard must be placed as the last character in the topic and preceded by a forward slash.
- When a client subscribes to a topic with a multi-level wildcard, it receives all messages of a topic that begins with the pattern before the wildcard character, no matter how long or deep the topic is.
- If you specify only the multi-level wildcard as a topic (#), you receive all messages that are sent to the MQTT broker.