

# IoT Engineering

## 7: Messaging Protocols and Data Formats

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Slides: [tmb.gr/iot-7](https://tmb.gr/iot-7)



### Overview

These slides present the *MQTT messaging protocol*.

How to publish messages to a topic on a broker.

How to subscribe to messages about a topic.

How data formats encode the payload.

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### Prerequisites

Set up [SSH](#) access to the Raspberry Pi, install Node.js.

Check the Wiki entry on [Raspberry Pi Zero W Setup](#).

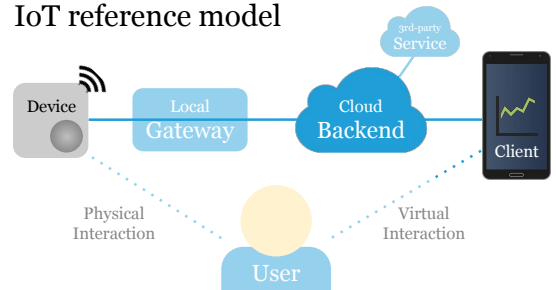
And follow the steps to [install the Node.js runtime](#).

[Set up the Feather Huzzah ESP8266](#) for Arduino.

Get access to a Wi-Fi network without a portal.

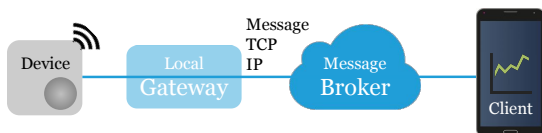
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### IoT reference model



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### Messaging protocols



Messaging protocols enable lightweight, bidirectional data exchange between devices and client apps.

We will look at the MQTT messaging protocol.

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### MQTT

[MQTT](#) is a standard protocol to transfer data packets.

In the OSI model, MQTT sits on the application layer.

It uses TCP/IP as a transport, on port 1883 and 8883.

The transferred data packets are called *messages*.

Current version is [MQTT v5.0](#), replacing [v3.1.1](#).

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## Publish/subscribe

MQTT is based on the *Publish/Subscribe* pattern.

This pattern decouples the sender and receiver.

Publishers send messages to a specific channel.

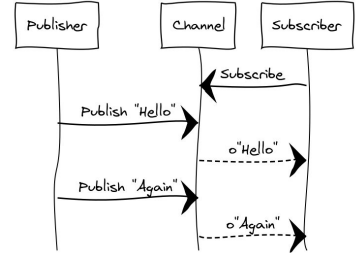
Subscribers of a channel receive the messages.

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## Pub/Sub, 1:1

Publisher sends message to a channel.

Subscriber gets the published message.

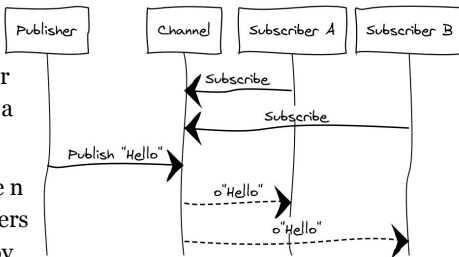


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## 1:n

Publisher sends to a channel.

All of the n subscribers get a copy.

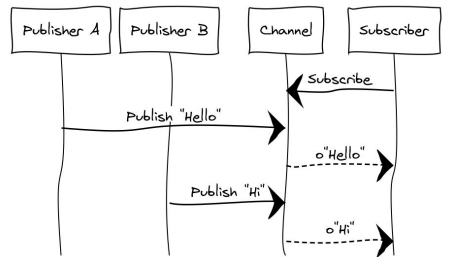


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## n:1

Publishers send to a channel.

Subscriber gets each message.

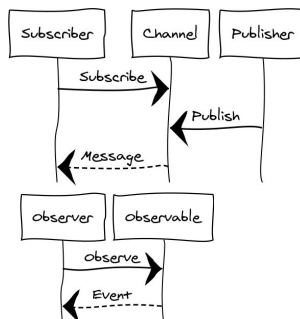


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## Decoupling

With Pub/Sub the channel decouples the two parties.

Compare this to the *Observer* pattern, where the receiver knows the sender.



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## Clients and brokers

In MQTT, *clients* exchange messages via a *broker*.

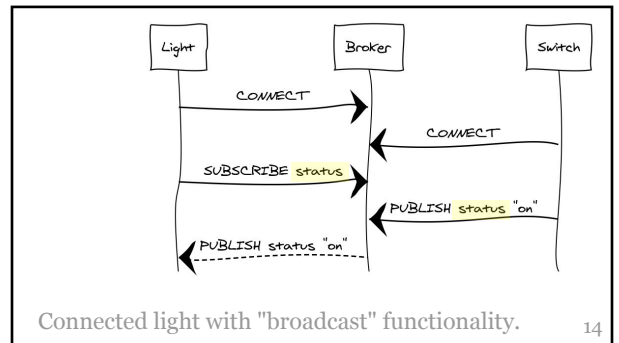
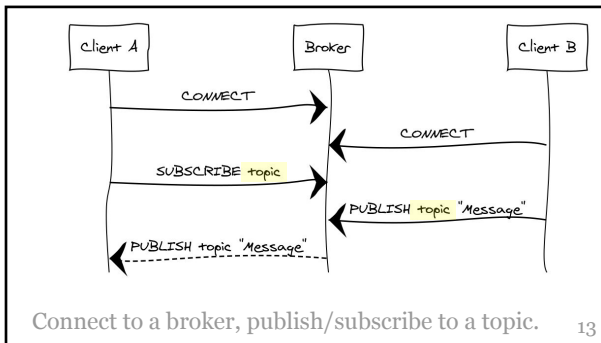
Clients can be publishers, subscribers or both.

Brokers offer multiple channels, or *topics*.

Brokers can cache or store messages.

MQTT is session-based.

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## Node.js MQTT with *mqtt*

Install the [mqtt](#) Node.js library & command line tool:

```
$ npm install mqtt # installs Node.js library
$ sudo npm install mqtt -g # adds tool to path
```

To publish/subscribe with the command line tool, try:

```
$ mqtt sub -t 'mytopic' -h 'test.mosquitto.org'
$ mqtt pub -t 'mytopic' \
-h 'test.mosquitto.org' \
-m 'Hello, world!'
```

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## Hands-on, 10': MQTT command line

Install the *mqtt* CLI tool on the Raspberry Pi.

Connect to the broker `test.mosquitto.org`

Subscribe to the topic `fnhw-iot/names`

Send\* your name to the same topic.

\*Open a second terminal.

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## Node.js MQTT subscriber client

.js

```
const mqtt = require("mqtt");

const broker = "mqtt://test.mosquitto.org/";
const client = mqtt.connect(broker);
client.on("connect", () => {
  client.subscribe("hello"); // topic "hello"
});
client.on("message", (topic, message) => {
  console.log(message.toString());
});
```

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## Node.js MQTT publisher client

.js

```
const mqtt = require("mqtt");

const broker = "mqtt://test.mosquitto.org/";
const client = mqtt.connect(broker);
client.on("connect", () => {
  const topic = "hello";
  const message = "Hello, World!";
  client.publish(topic, message);
});
```

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## Hands-on, 10': MQTT pub/sub clients

Install the [mqtt](#) Node.js library on the Raspberry Pi.

Run the previous MQTT pub/sub\* client examples.

Use the [.js](#) link on each page or check the main repo.

To run a Node.js program *my.js*, type: `$ node my.js`

\*Open a second terminal.

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## ESP8266 MQTT publisher client [.ino](#)

```
#include <ESP8266WiFi.h> // v2.4.2
#include <ESP8266MQTTClient.h> // v1.0.4

MQTTClient client;

void handleConnected() {
    client.publish("hello", "Hello, World!");
}

client.onConnect(handleConnected);
client.begin("mqtt://test.mosquitto.org/");
```

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## ESP8266 MQTT subscriber client [.ino](#)

```
#include <ESP8266WiFi.h> // v2.4.2
#include <ESP8266MQTTClient.h> // v1.0.4

MQTTClient client;

void handleC...() { client.subscribe("hello"); }
void handleD...(String topic, String data,...) {...}

client.onConnect(handleConnected);
client.onData(handleDataReceived);
client.begin("mqtt://test.mosquitto.org/");
```

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## Topics

The broker organises messages into multiple topics.

Clients send each message to a specific topic.

Clients subscribe to one or more topics.

Topics are hierarchical, like paths.

Wildcards replace topic levels.

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## Home

```
home
  /room
    /light
      /status      "on"
      /color       "255,0,64"
    /sensor
      /temperature "23.0"
      /humidity    "42"
home/room/light/status "off"
```

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## mqtt+json

```
home
  /room
    /light
      {
        "status": "on",
        "color": "255,0,64"
      }
    /sensor ...
home/room/light/status {"status":"off"}
```

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## Broker

`$SYS`

```
/broker
/load
/bytes
  /received/+  "1024", "3280", "31415"
  /sent/1min   "2048" (5min) (15min)
/clients
  /connected   "3"
  /total       "99"
```

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## Hands-on: 15' local MQTT broker

Install and run the *mosquitto* broker on Raspberry Pi:

```
$ sudo apt-get update
```

```
$ sudo apt-get install mosquitto # port 1883
```

Test with the ESP8266 publisher/subscriber clients.

Use the *.ino* link on the page or check the main repo.

Check `$SYS/broker/clients/connected` on the Pi.

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## Quality of Service

Clients indicate desired QoS when publishing.

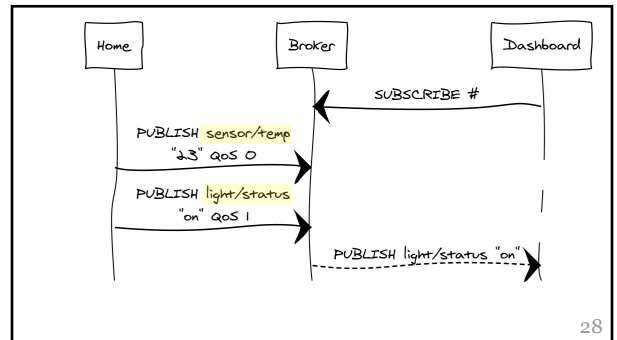
QoS 0 — At most once delivery

QoS 1 — At least once delivery

QoS 2 — Exactly once delivery\*

\*QoS 2 is hard to implement reliably, [in practice](#).

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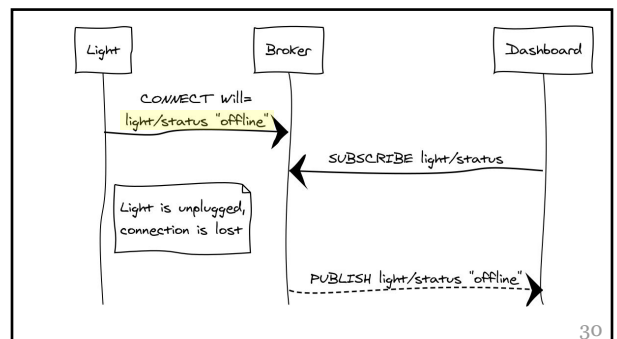
## Will message

MQTT allows to set a "last will" when connecting.

The client specifies a will topic and a will message.

The will is published as soon as the client is offline.

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## Client libraries and tools

[Paho](#) is an open source library in Java, Python, ...  
[MQTT.js](#) is Node.js library and command line tool.  
[Node-RED](#) is a dataflow-based, rule-based client.  
[HiveMQ](#) is a MQTT client with Websocket support.  
There are many other clients/libraries at [mqtt.org](#).

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## Broker software

[Shiftr.io](#) visualises topics and messages in real-time.  
[Mosquitto](#) is small and runs on the Raspberry Pi.  
[VerneMQ](#) supports clustering and it's open source.  
[AWS](#) and [Azure](#) IoT are scalable and highly reliable.  
Additional broker software is listed on [mqtt.org](#).

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## MQTT security

MQTT over TCP/IP can rely on (point-to-point) TLS.  
For testing with TLS, see <http://test.mosquitto.org/>  
End-to-end encryption is offered, e.g. by [Taserakt](#)\*.

\*See also [Is MQTT Secure?](#)

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## Reasons to use MQTT

Clients don't have to know each other, just the broker.  
Messages can be cached, while a client stays offline.  
Subscribing to hierarchies of topics with wildcards.  
Last-will message, as soon as a client goes offline.

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## New features in MQTT v5.0

[Reason code](#) in the case of errors (on CONNACK).  
[Payload format](#) and [content type](#) (MIME type).  
[Session expiry](#) interval (from disconnect).  
Optional broker feature availability.

There is a detailed [summary in the v5.0 spec](#).

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## Data formats

Two parties need to agree on what is valid content.  
Parsing means reading individual "content tokens".  
Record-based formats, e.g. CSV, are good for tables.  
Text-based formats, e.g. JSON are easily readable.  
Binary formats, e.g. Protobuf, take less space.

Data formats are often specified in [EBNF](#).

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## CSV

Comma Separated Values (CSV), defined in [RFC4180](#).

```
file = record *(CRLF record) [CRLF];
record = field *(COMMA field);
field = *TEXTDATA;
CRLF = CR LF;
COMMA = %x2C; CR = %x0D; LF = %x0A;
TEXTDATA = %x20-21 / %x23-2B / %x2D-7E;
```

Header and escaped fields omitted for shortness.

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## JSON

[JSON](#) is a simple data format based on Unicode text:  
`{"temp": 23}` // try [ddg.co/?q=json+validator](http://ddg.co/?q=json+validator)

On the Raspberry Pi, Node.js offers the [JSON object](#):

```
const obj = JSON.parse("{\"temp\": 23}");
const data = JSON.stringify(obj);
```

On Arduino, use e.g. the [Arduino\\_JSON](#) library:

```
JSONVar obj = JSON.parse("{\"temp\": 23}");
String data = JSON.stringify(obj);
```

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## Protobuf

[Protocol Buffers](#) (Protobuf) is a binary data format:

```
message Measurement {
  required int32 temp = 1;
  optional int32 humi = 2;
}
```

Message schemas are compiled to a target language,  
i.e. a parser is generated, re-generated upon changes.

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## Hands-on, 15': Data formats

Choose one of the [Grove sensors](#) listed in the Wiki.

Define a suitable JSON format to transmit its data.

Translate the format into a [Protobuf .proto file](#).

Done? Build the parser for Node.js or Arduino.

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## Summary

MQTT is a messaging protocol based on pub/sub.

Clients exchange messages by topic, via a broker.

Advantages are decoupled clients, will message.

Data formats allow to write and read payloads.

Next: Long Range Connectivity with LoRaWAN.

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## Feedback or questions?

Write me on <https://fhnw-iot.slack.com/>

Or email [thomas.amberg@fhnw.ch](mailto:thomas.amberg@fhnw.ch)

Thanks for your time.

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