IoT Data Collection (idb) Messaging Protocols and Data Formats

Slides: tmb.gr/idb-mp

Prerequisites

Set up SSH access to the Raspberry Pi, install Node.js:

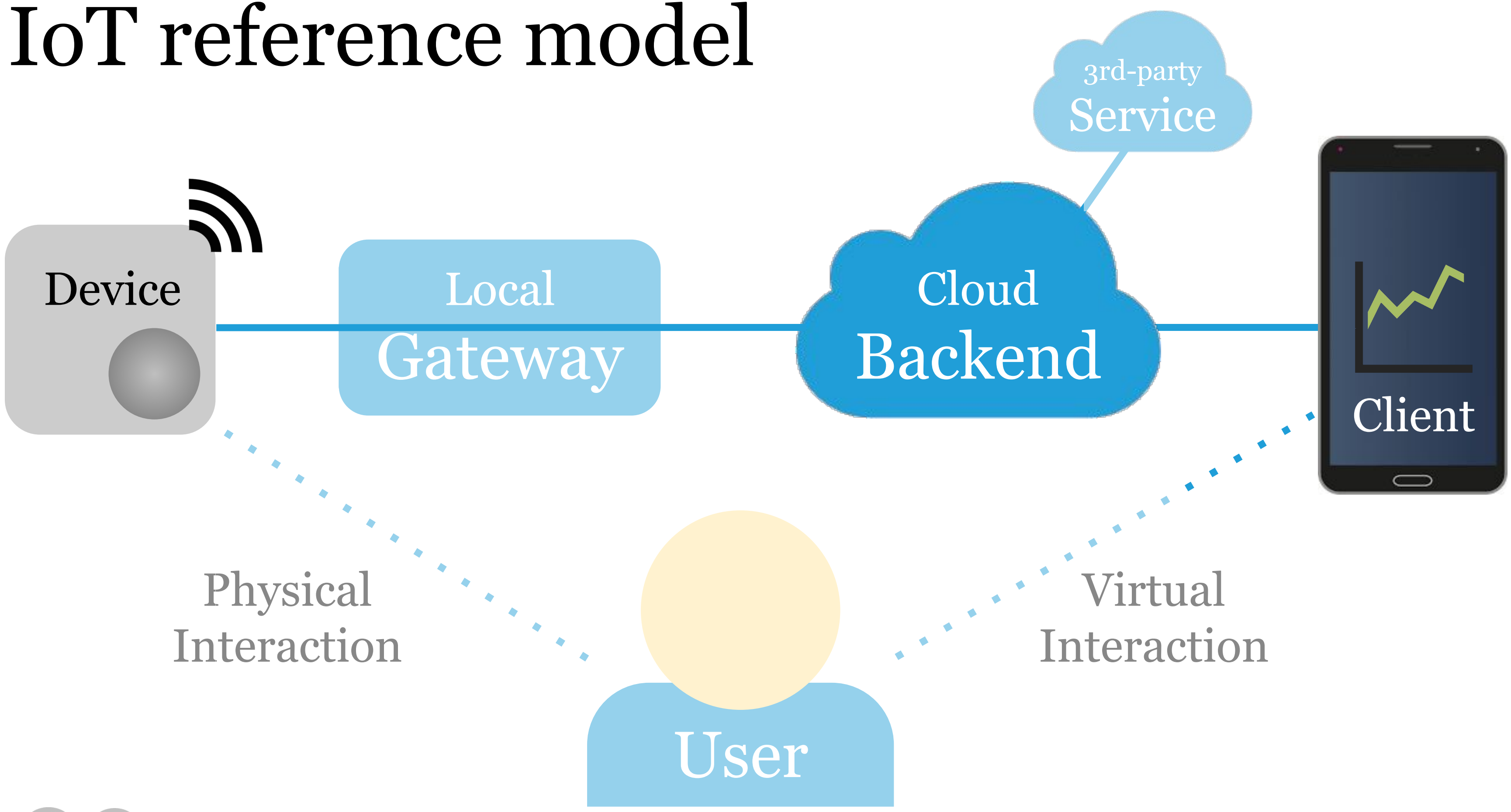
Check the Wiki entry on Raspberry Pi Zero W Setup.

And follow the steps to install the Node.js runtime.

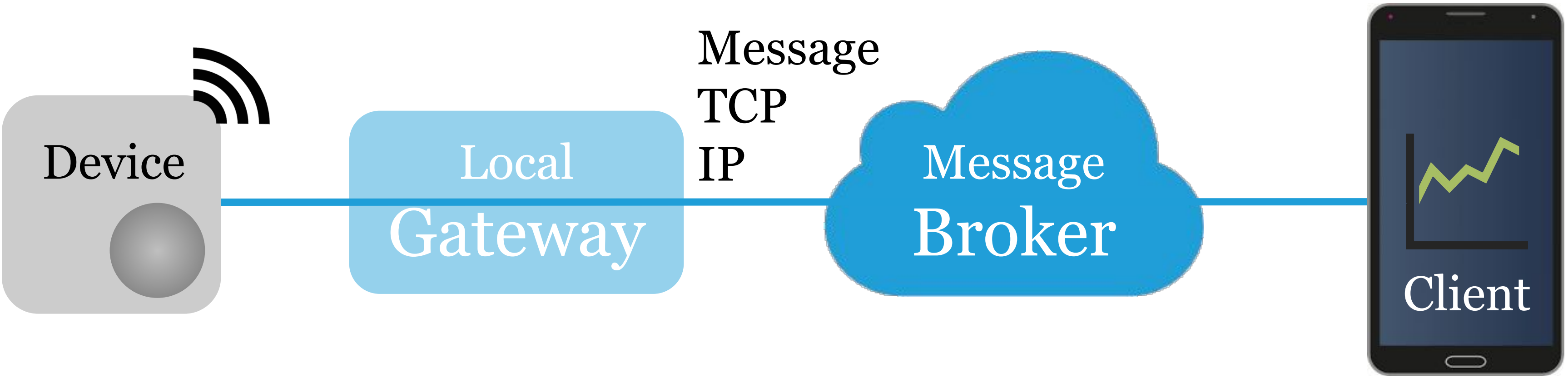
Then, also Set up the Feather nRF52840 Express.

And add a FeatherWing ESP32 AirLift module.

IoT reference model



Messaging protocols



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

We will look at the MQTT messaging protocol.

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.

Publish/subscribe

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

This pattern decouples the sender and receiver.

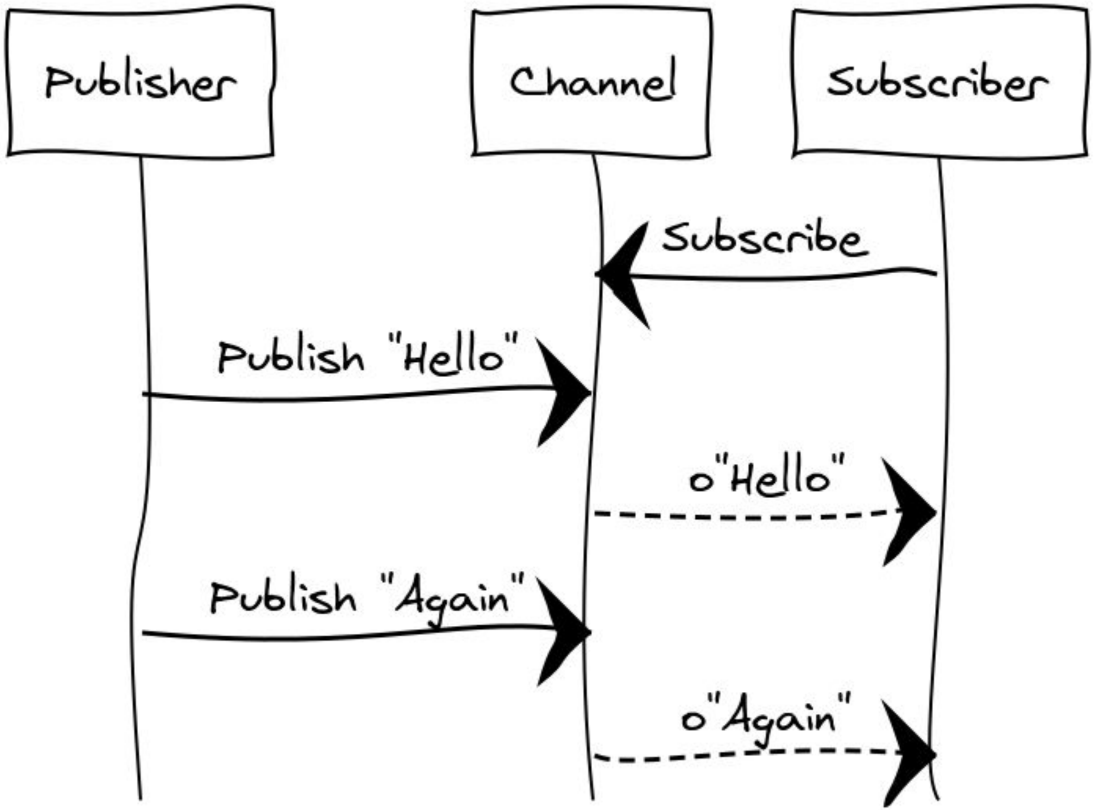
Publishers send messages to a specific channel.

Subscribers of a channel receive the messages.

Pub/Sub, 1:1

Publisher sends message to a channel.

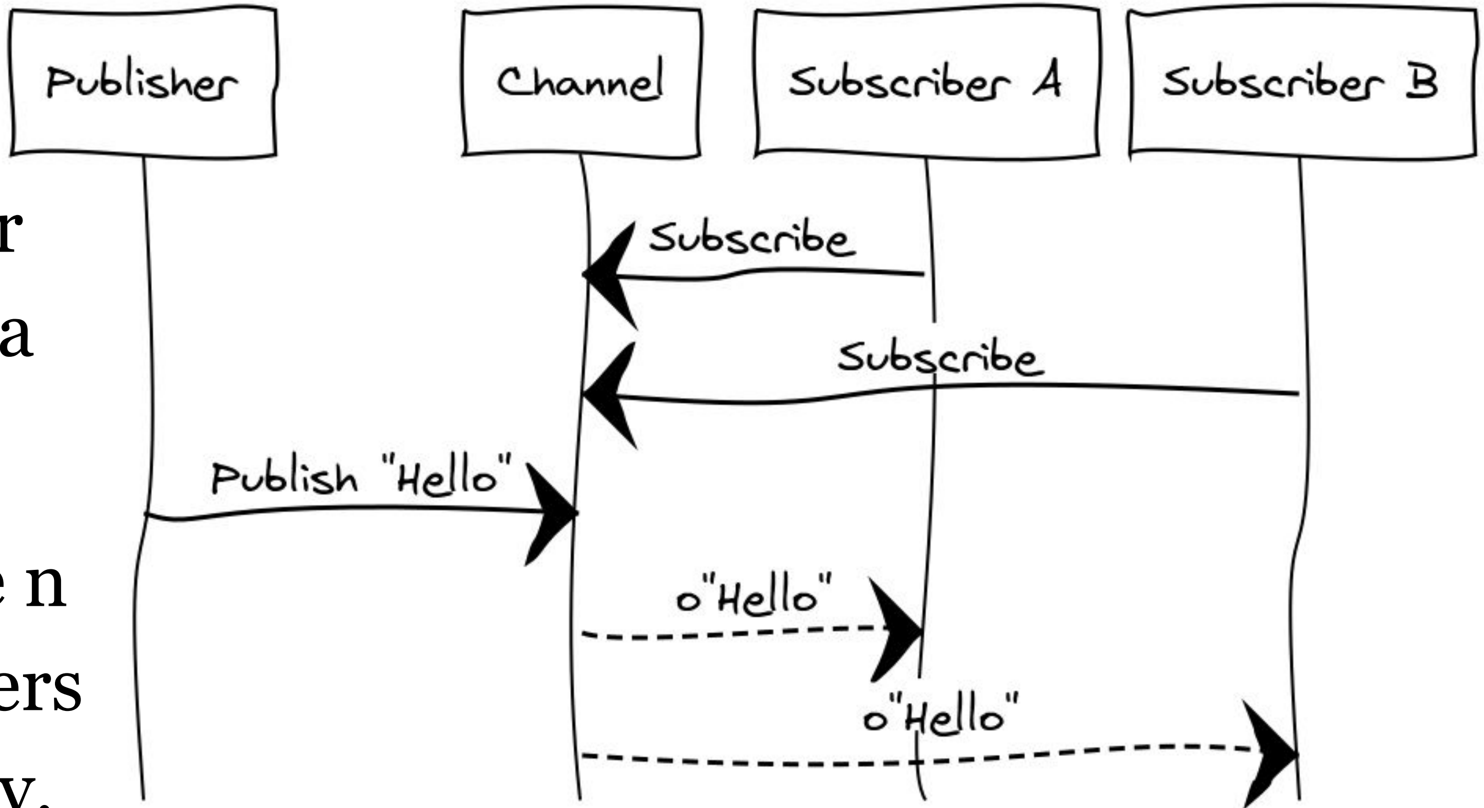
Subscriber gets the published message.



1:n

Publisher sends to a channel.

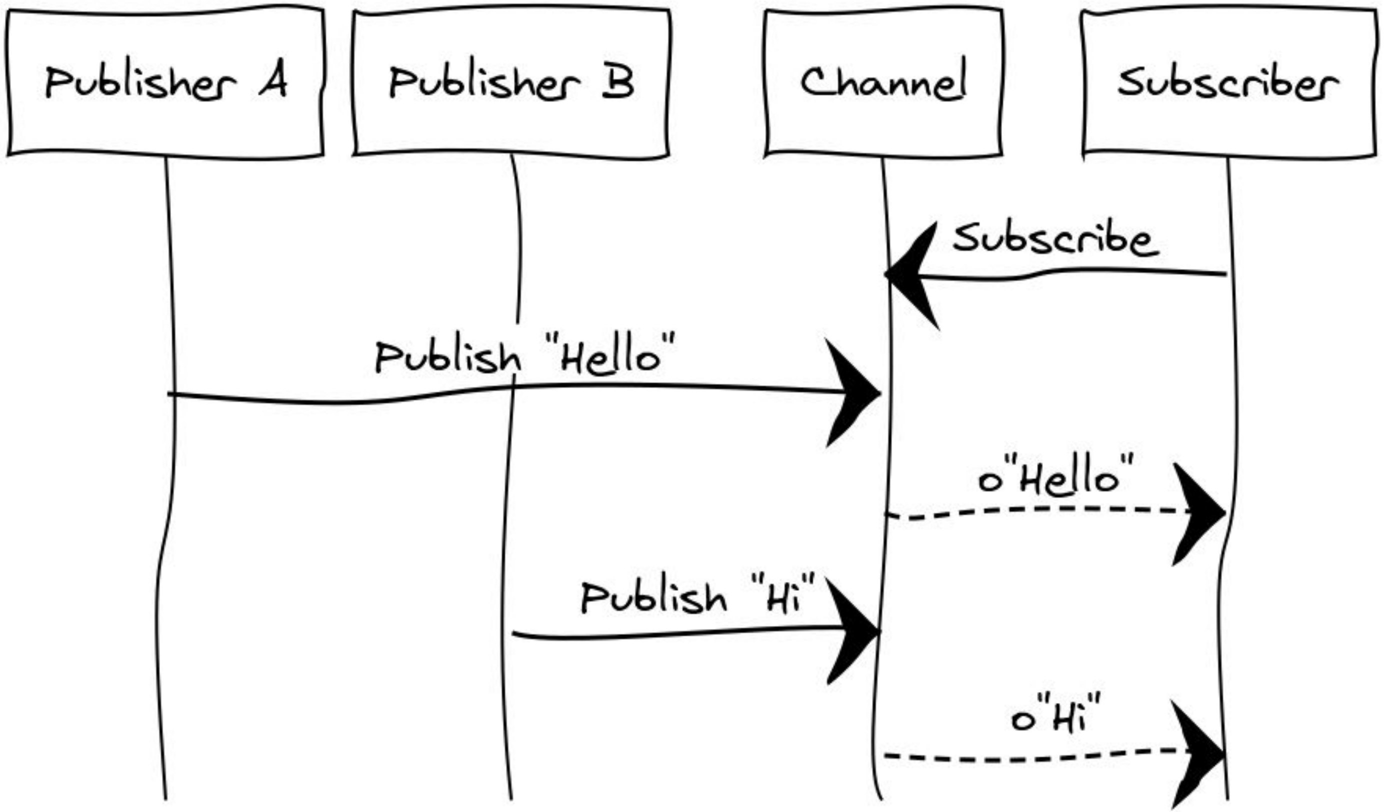
All of the n subscribers get a copy.



n:1

Publishers send to a channel.

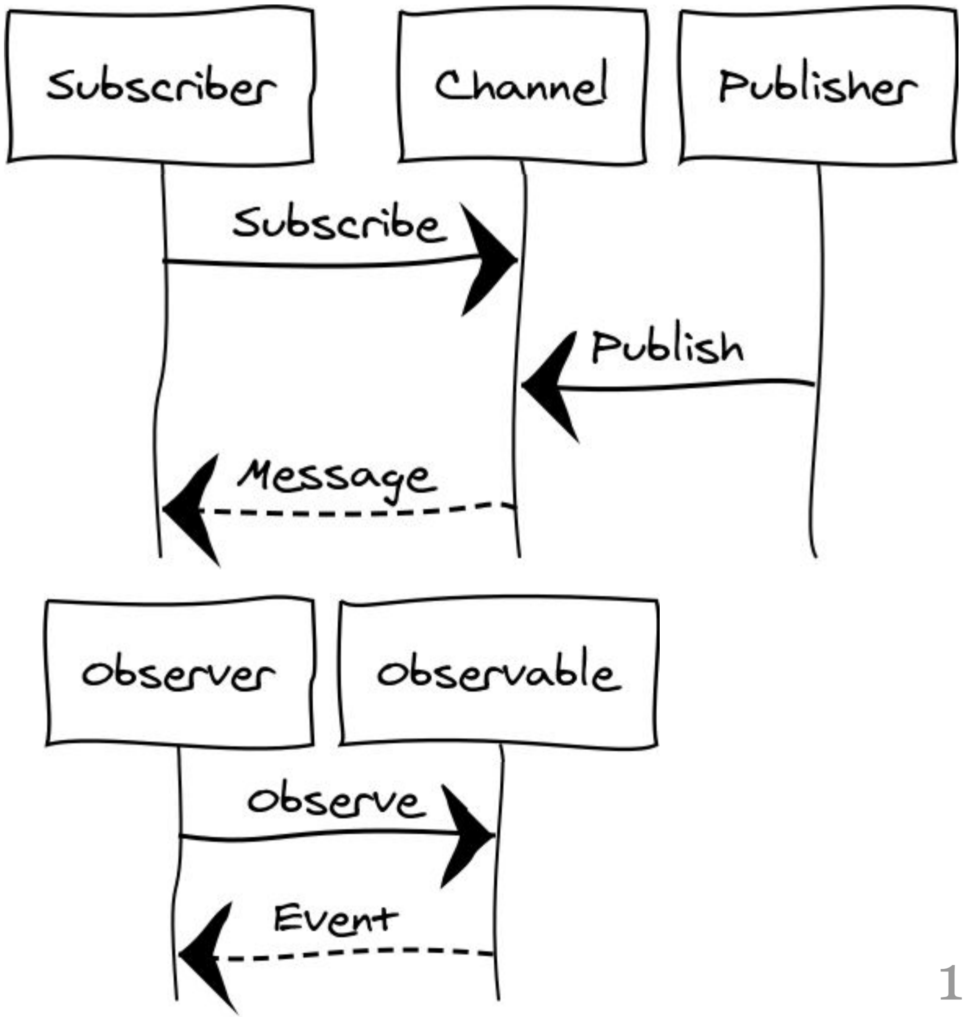
Subscriber gets each message.



Decoupling

With Pub/Sub the channel decouples the two parties.

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



Clients and brokers

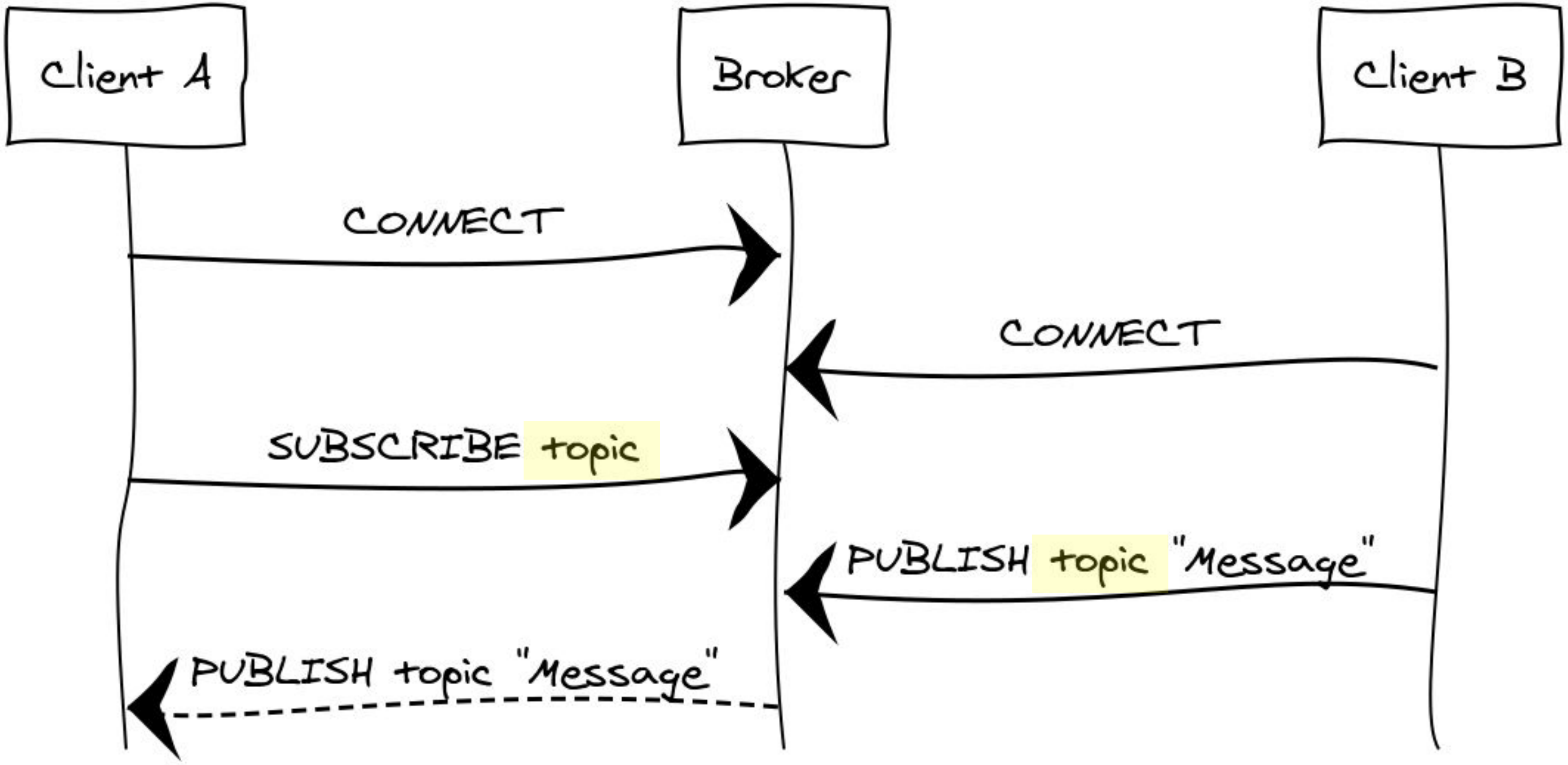
In MQTT, *clients* exchange messages via a *broker*.

Clients can be publishers, subscribers or both.

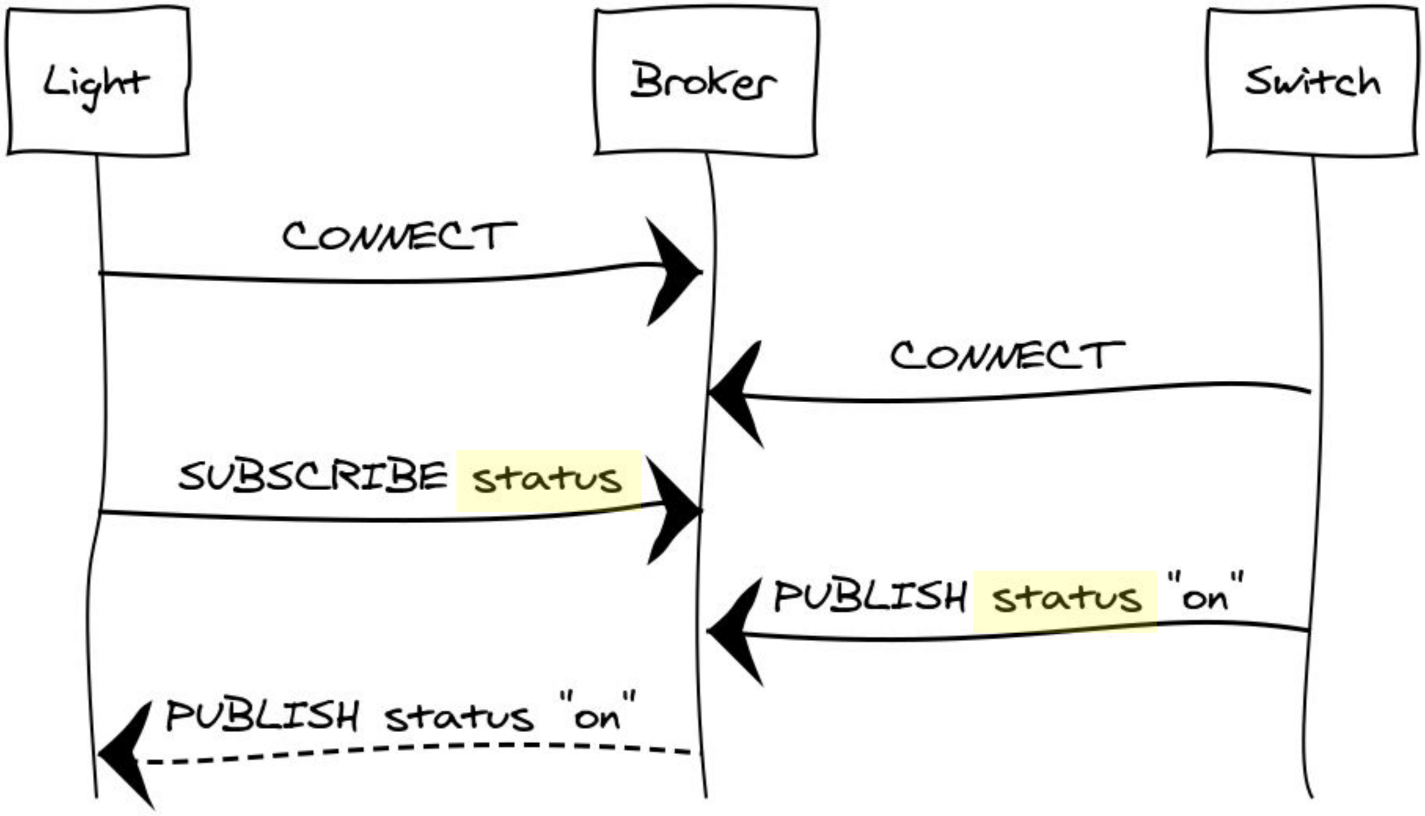
Brokers offer multiple channels, or *topics*.

Brokers can cache or store messages.

MQTT is session-based.



Connect to a broker, publish/subscribe to a topic.



Connected light with "broadcast" functionality.

MQTT in Node.js 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!'
```

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 `fhnw-idb/names`

Send* your name to the same topic.

*) Open a second terminal.

MQTT subscriber client in Node.js .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());
});
```

MQTT publisher client in Node.js .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);
});
```

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.

MQTT publisher client in CircuitPython

```
import … # see mqtt_pub_client.py

mqtt.set_socket(adafruit_esp32spi_socket, esp)
mqtt_client = mqtt.MQTT(
  broker="test.mosquitto.org", is_ssl=False)

mqtt_client.connect()
while True:
    mqtt_client.publish("hello", "Hello!")
```

MQTT subscriber client in CircuitPython

```
import … # see mqtt_sub_client.py
def handle_connect(client, …):
    mqtt_client.subscribe(topic="hello")
def handle_message(client, topic, message):
    print((topic, message))
mqtt_client.on_connect = handle_connect
mqtt_client.on_message = handle_message
mqtt_client.connect()
while True: mqtt_client.loop()
```

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.

Home

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

home/room/light/status   "off"
```

mqtt+json

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

`home/room/light`~~`/status`~~ `{"status":"off"}`

Broker

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

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 nRF52840 publisher/subscriber clients.

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

Quality of Service

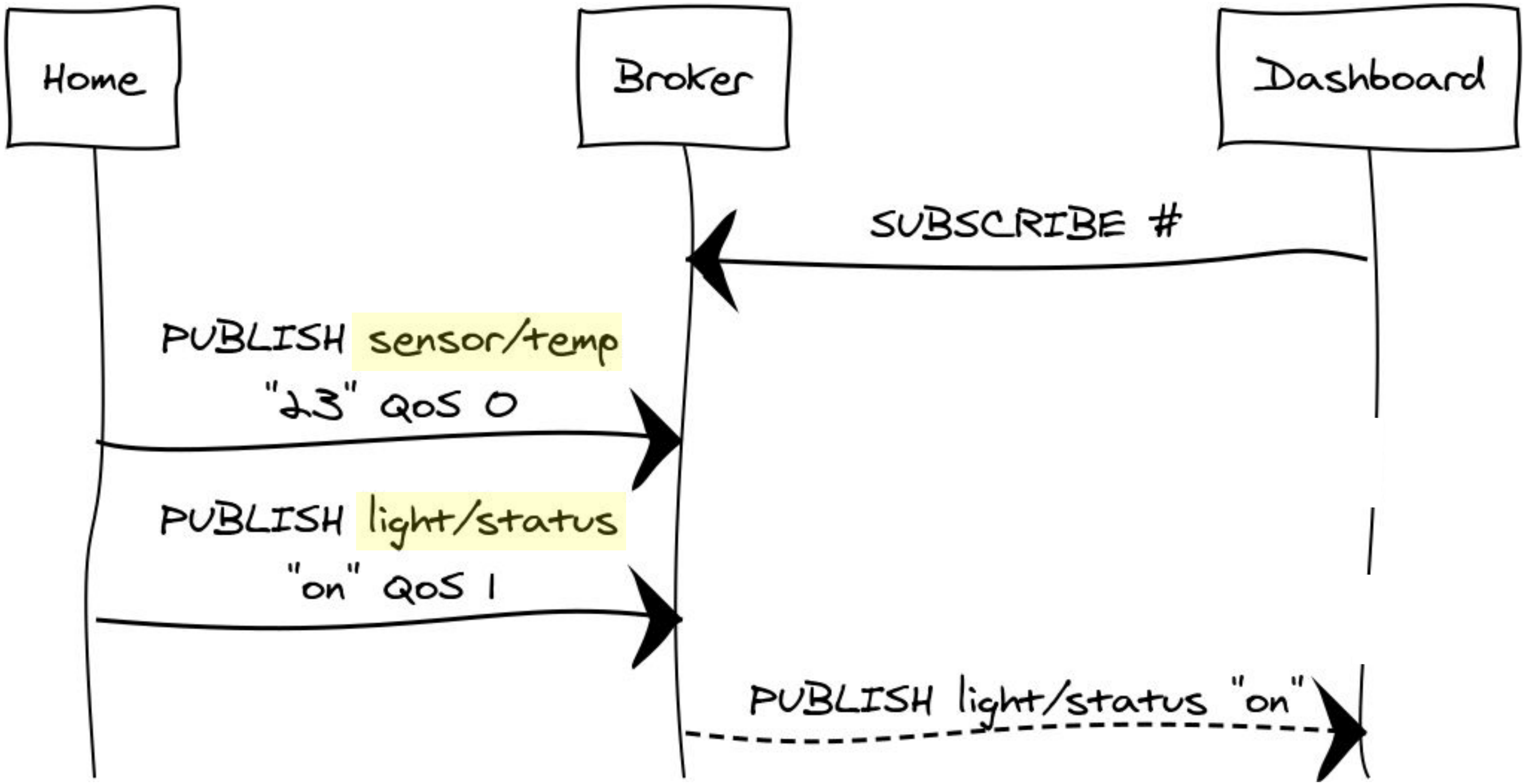
Clients indicate desired *QoS* when publishing.

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.

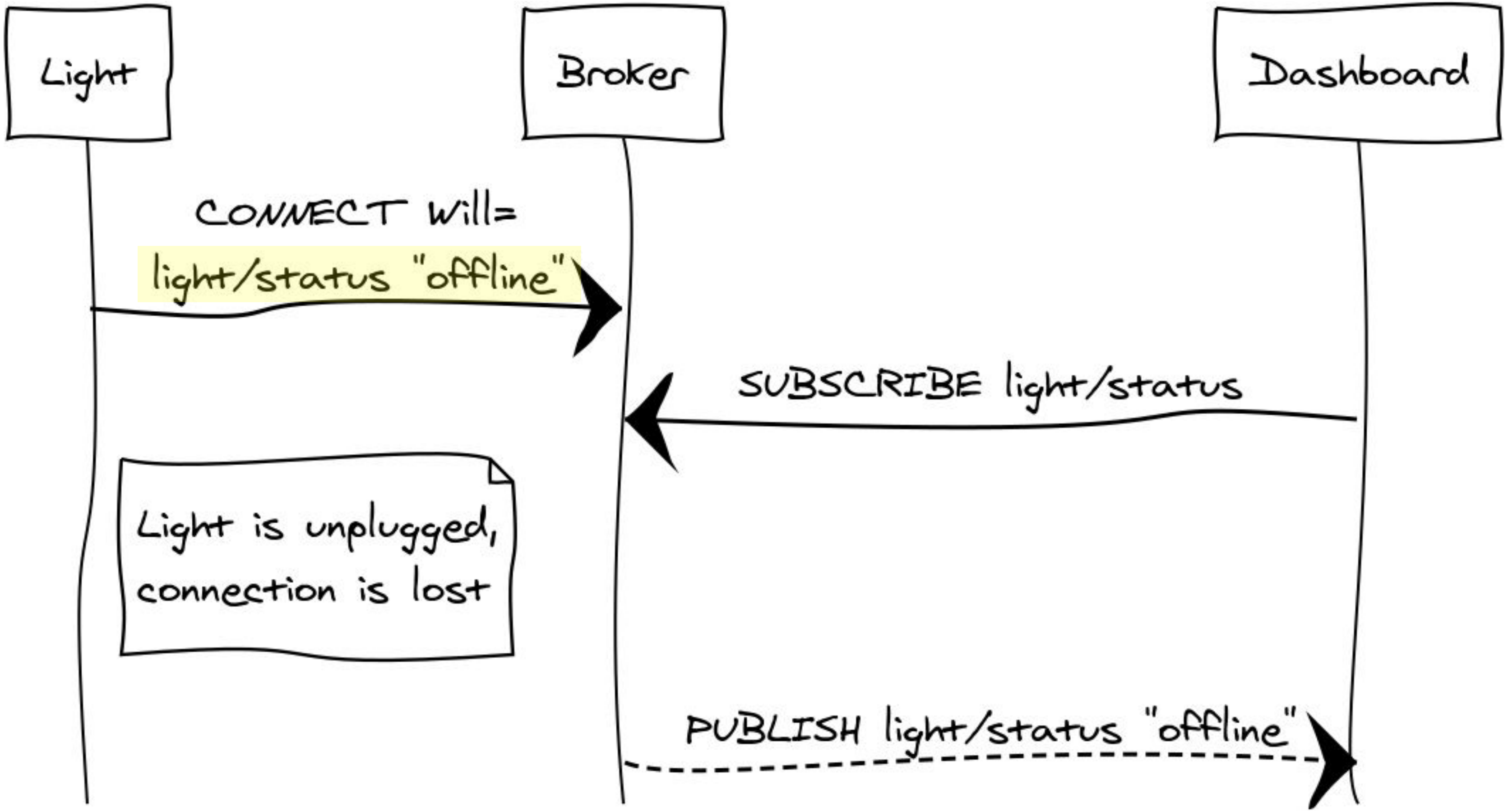

Home
Broker
Dashboard
SUBSCRIBE #
PUBLISH sensor/temp
"23" QoS 0
PUBLISH light/status
"on" QoS 1
PUBLISH light/status "on"

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.


Light
Broker
Dashboard
CONNECT will=
light/status "offline"
SUBSCRIBE light/status
Light is unplugged,
connection is lost
PUBLISH light/status "offline"

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 ist a dataflow-based, rule-based client.

HiveMQ is a MQTT client with Websocket support.

There are many other clients/libraries at mqtt.org.

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.

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 Teserakt*.

*) See also Is MQTT Secure?

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.

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.

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.

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.

JSON

JSON is a simple data format based on Unicode text:

```
{"temp": 23} // try 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 nRF52840, use the ujson CircuitPython library:

```
json = ujson.load("{\"temp\": 23}");
data = ujson.dump(json);
```

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.

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 in Node.js or CircuitPython.

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 content.

E.g. JSON, or the binary Protobuf format.

Next: Long Range Connectivity with LoRaWAN.

Feedback?

Find us on https://fhnw-idb.slack.com/

Or email thomas.amberg@fhnw.ch

and juerg.luthiger@fhnw.ch