IoT y Edge Computing: Historias de una relación necesaria

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https://github.com/pmanzoni/iotandendge

Schedule

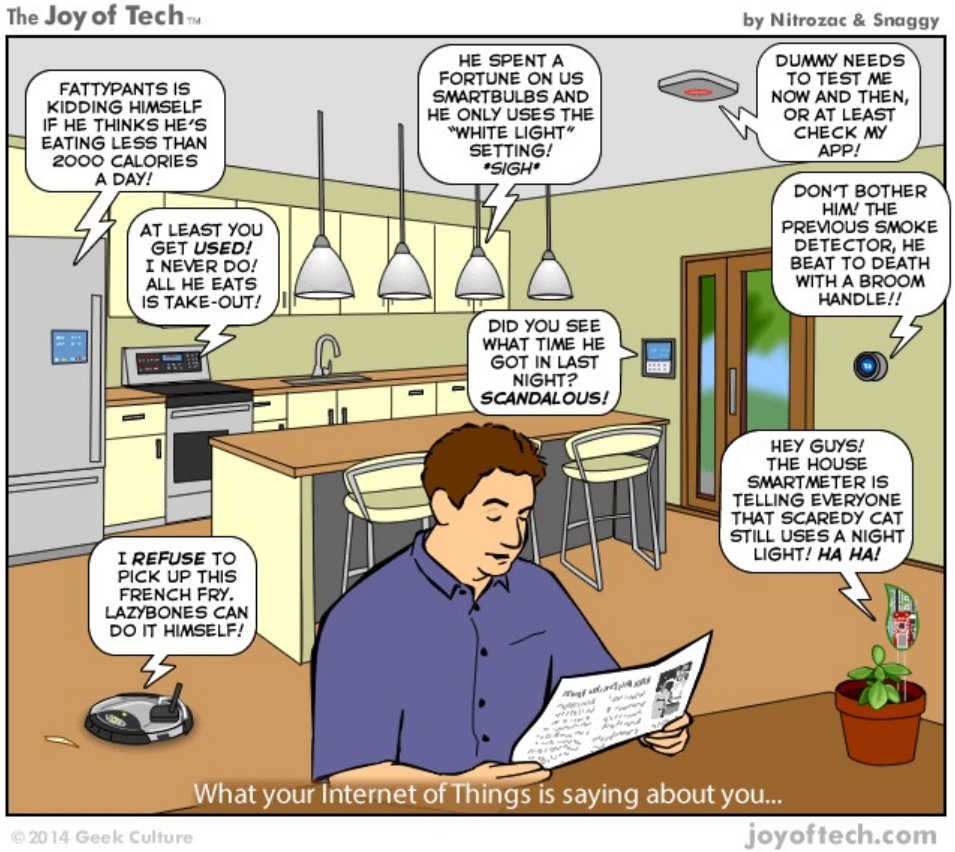
- **Jueves 7 de abril 2022**
- 10:00 – 11:30 Seminario técnico (Teoría)
  - "A brief introduction to IoT, LoRaWAN, and MQTT" (slides)
- 15:30 – 17:30 Seminario técnico (Laboratorio)
  - LoRaWAN and MQTT hands-on examples

- **Viernes 8 de abril 2022**
- 10:00 – 11:30 Seminario técnico (Teoría)
  - "A brief introduction to TinyML" (slides)
  - TinyML hands-on examples: TensorFlow Lite Micro
- 12:00 – 13:30 Seminario técnico (Laboratorio)
  - TinyML hands-on examples: Edge Impulse

A brief introduction to IoT

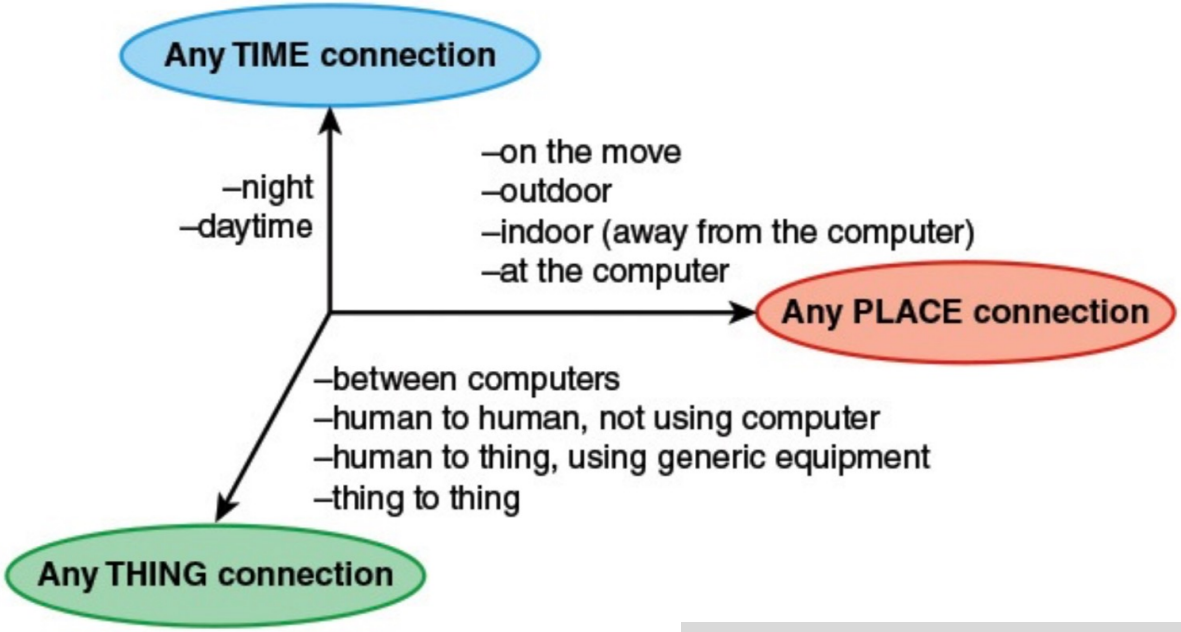
Internet of Things (IoT)

A quick and "physical" definition:
"A network of items—each embedded with sensors—which are connected to the Internet."



Overview of the IoT: a more formal definition

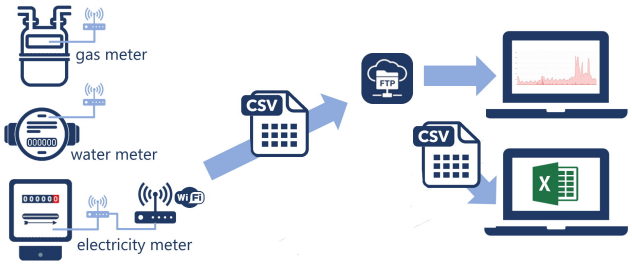
"The IoT can be viewed as a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies (ICT)."



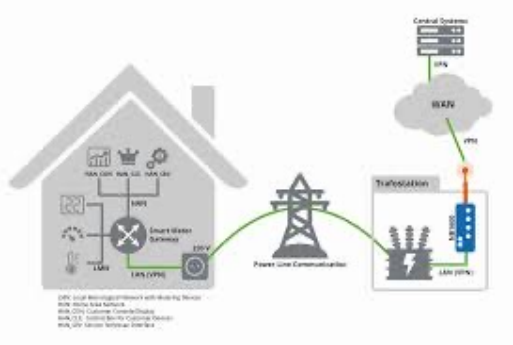
Source: Recommendation ITU-T Y.2060

Machine-to-Machine (M2M)

- The Machine-to-Machine Architecture model proposed by ETSI is considered a predecessor of IoT
- M2M was meant for automated interactions between devices



Smart metering

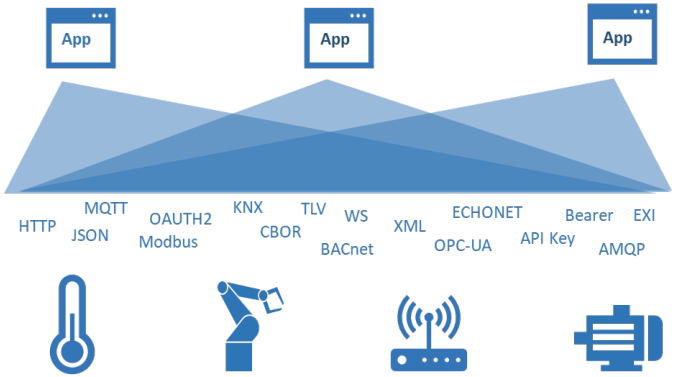


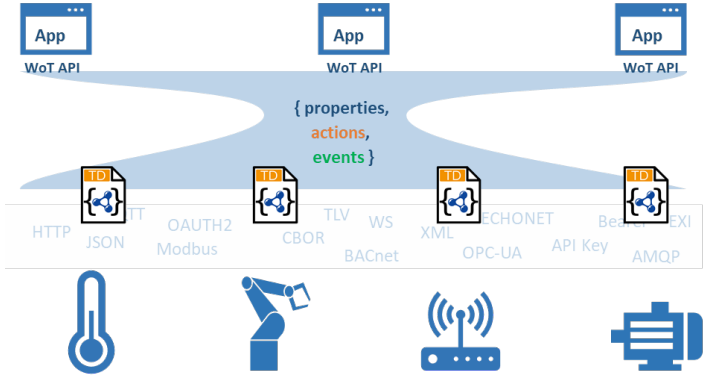
- Currently M2M and IoT are used interchangeably
  - https://www.etsi.org/technologies/internet-of-things
- Basic committees
  - https://www.etsi.org/committee/smartm2m
  - https://www.etsi.org/committee/onem2m

W3C Web of Things

https://www.w3.org/WoT/

- **"The Web of Things (WoT) is a term used to describe approaches, software architectural styles and programming patterns that allow real-world objects to be part of the World Wide Web."**
- The Web of Things (WoT) tries to avoid the fragmentation of the IoT simplifying integration across IoT platforms and application domains by using and extending existing, standardized Web technologies.
- From the developer's perspective, the WoT enables access and control over IoT resources and applications using mainstream web technologies (such as **HTML 5.0, JavaScript, Ajax, PHP, Ruby n Rails**, etc)
- The approach to building WoT is therefore based on RESTful principles and REST API s, which enable s both developers and deployers to benefit from the popularity and maturity of web technologies.





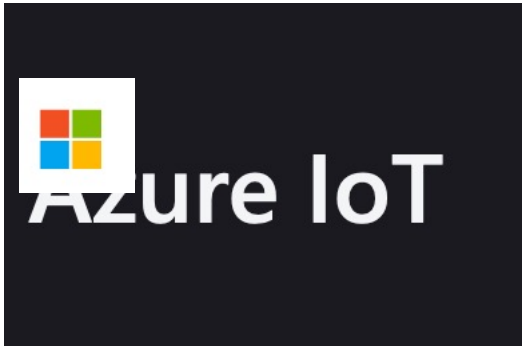
All big companies are active in this area

https://iot.telefonica.com/en/

https://www.cisco.com/c/en/us/solutions/internet-of-things/overview.html

https://cloud.google.com/solutions/iot/

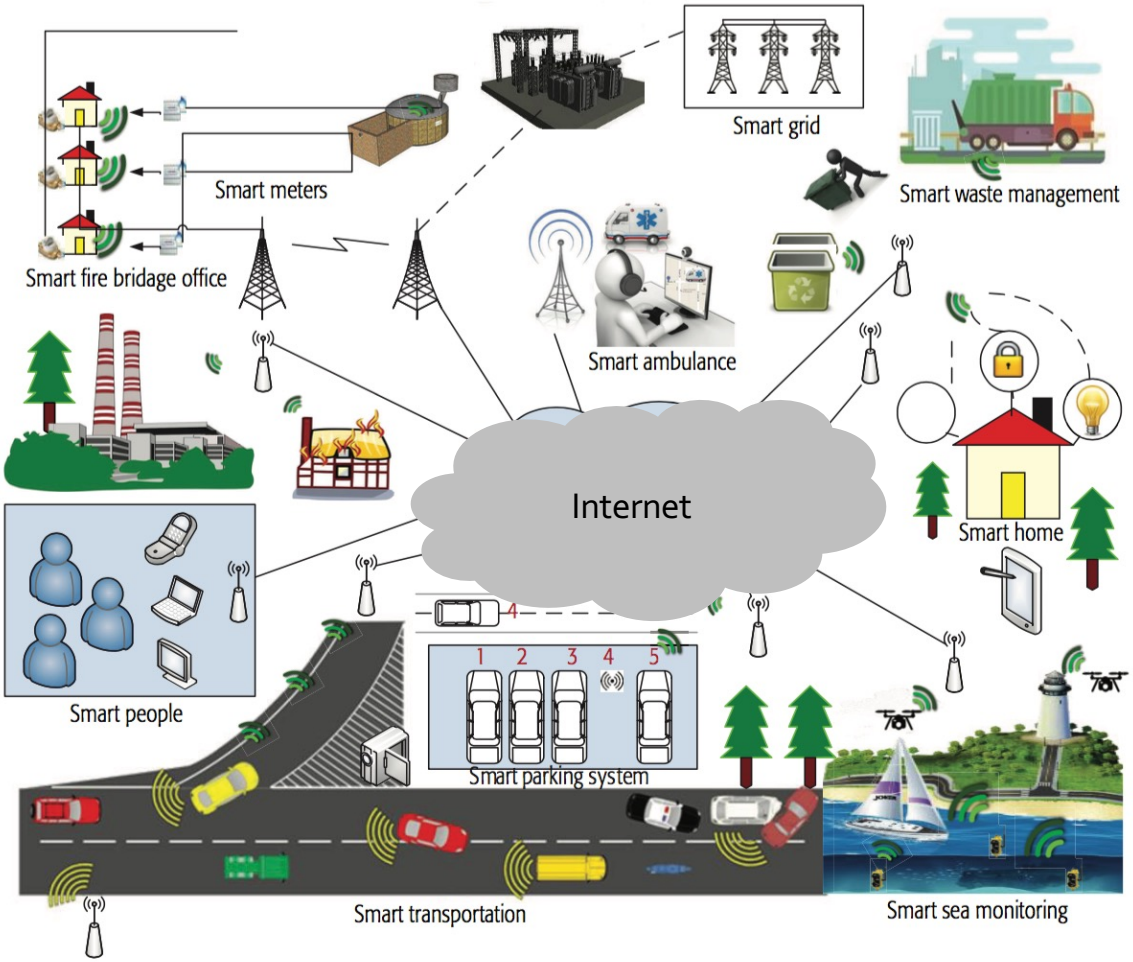
https://www.ibm.com/cloud/internet-of-things



https://azure.microsoft.com/es-es/overview/iot/#overview

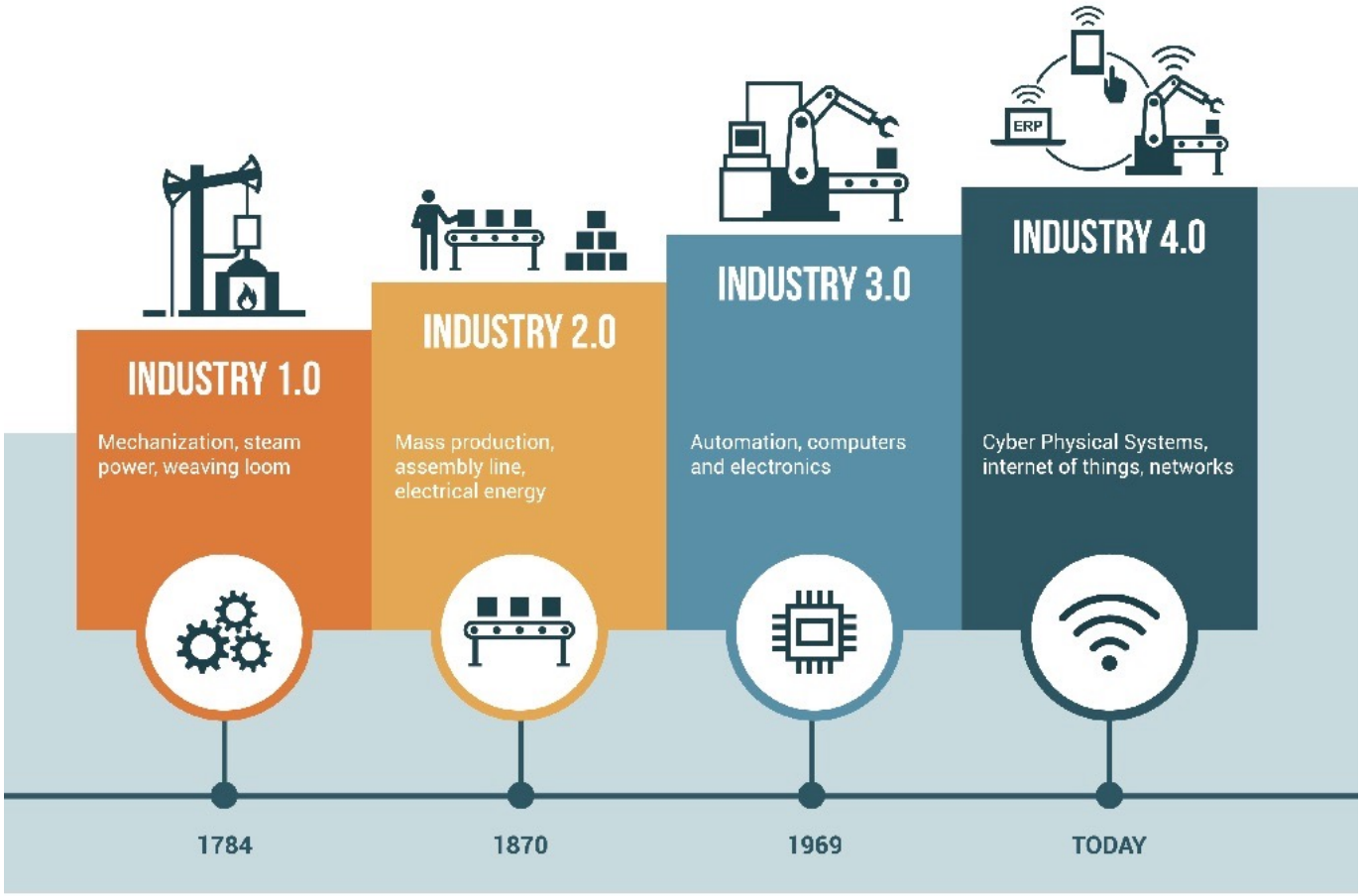
https://www.samsung.com/cl/smartthings/

Applications… smarter everything



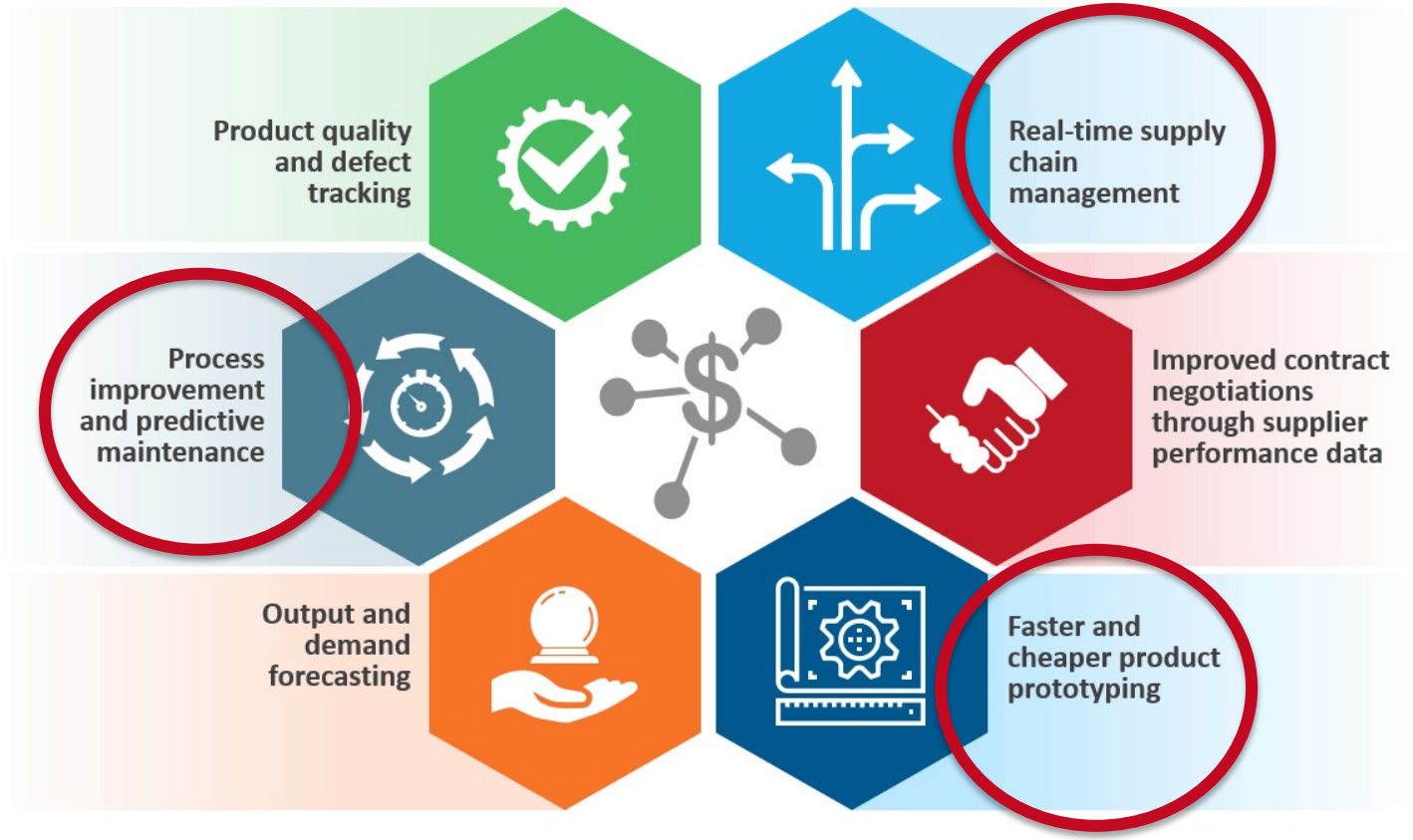
Enabling Communication Technologies for Smart Cities, IEEE Communications Magazine - January 2017

Industry 4.0 and Industrial IoT



How Industry 4.0 is Helping Manufacturers

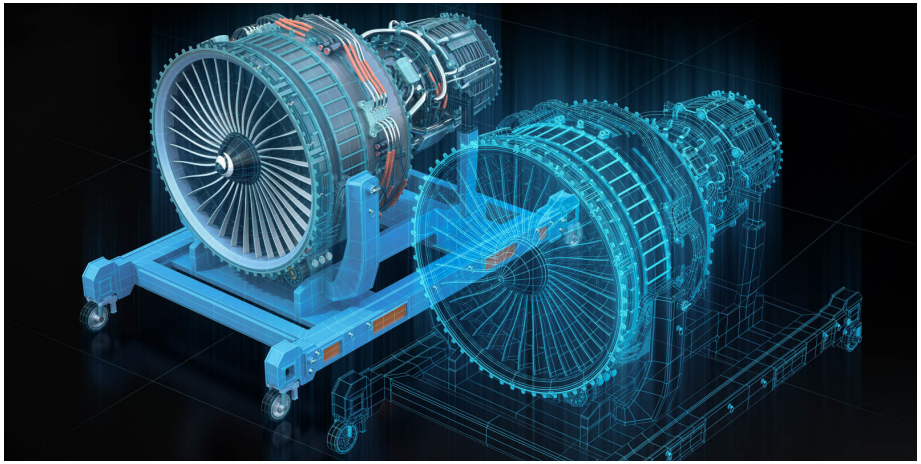
Industry 4.0 – automation and data exchange in manufacturing technologies – is helping manufacturers to achieve their goals of reducing cost and increasing profitability through improvements and optimization across the value chain



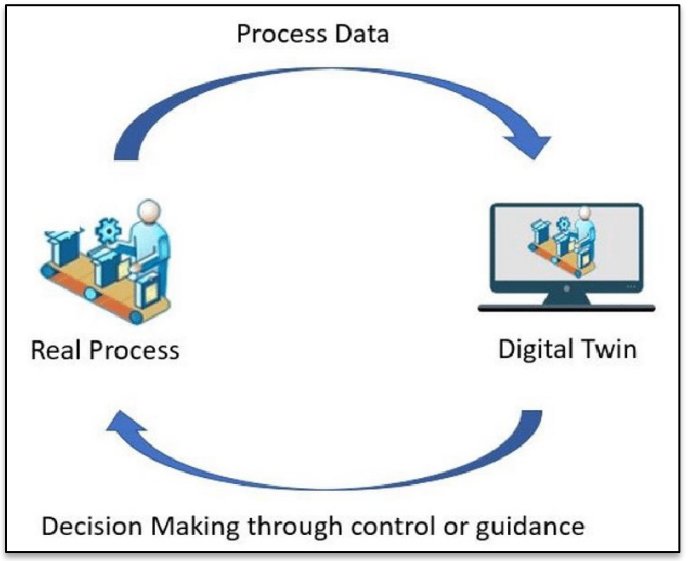
Everest Group® Enterprise Digital Adoption in Manufacturing | Pinnacle Model™ Assessment 2018

Industrial IoT example

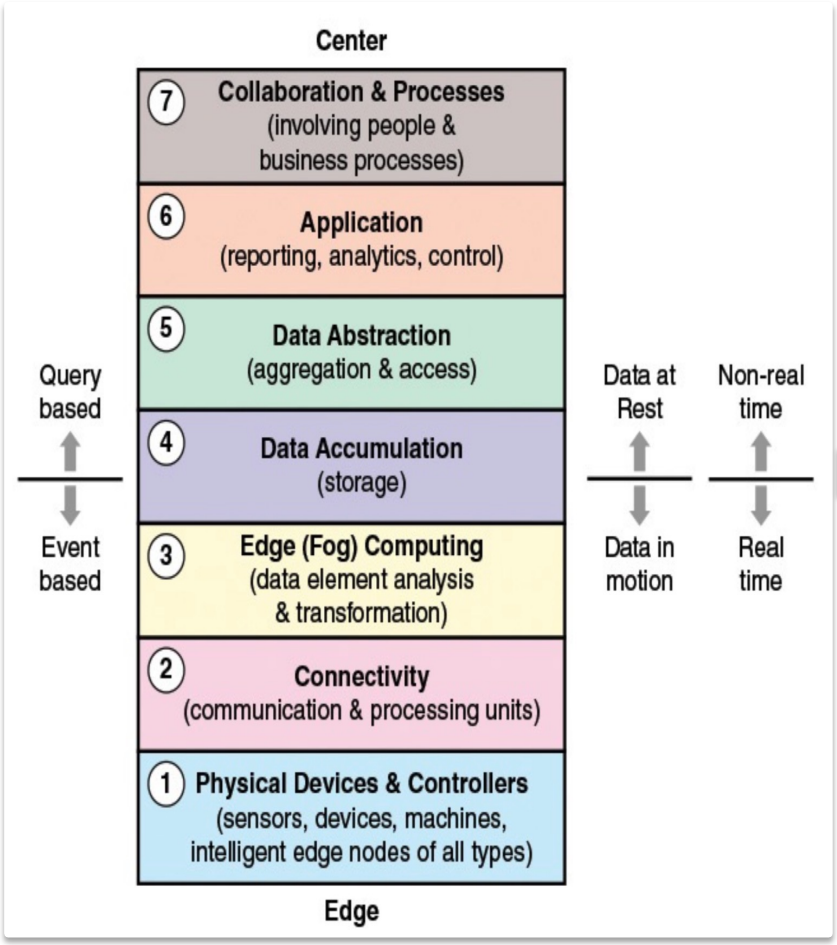
- **Rolls-Royce TotalCare**, "engine as a service".
  - Predictive maintenance (**know what will break**).
  - Anomaly detection (**find unknown issues**).
  - Live feedback (**from deployed engines**).

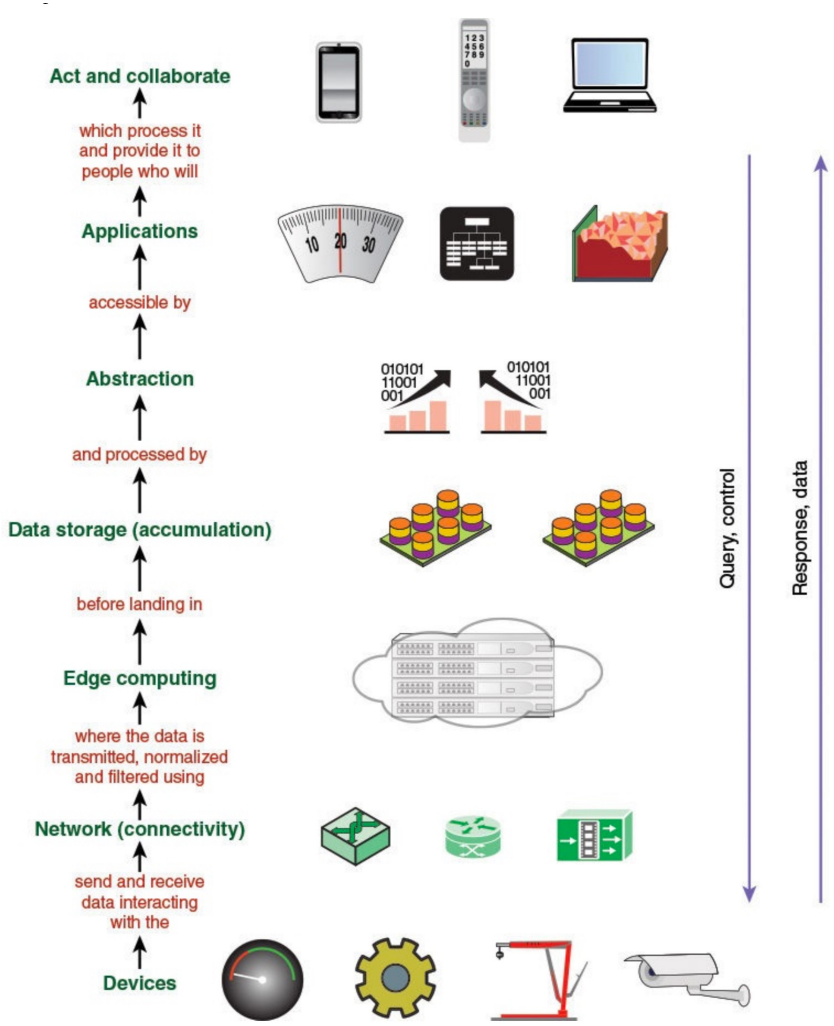


Digital Twins



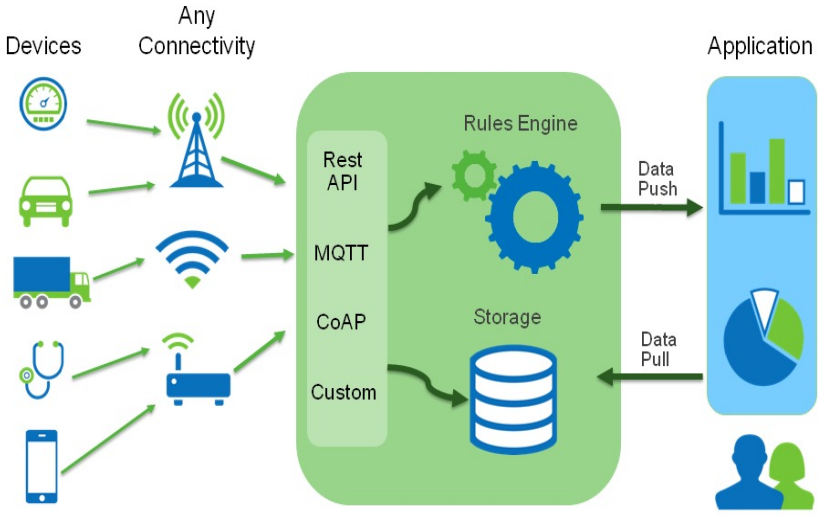
Reference Model





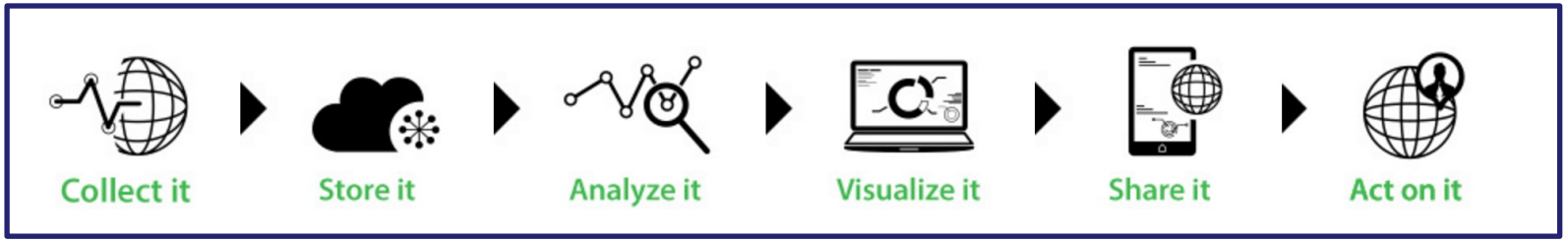
Simplified model

- Devices ("things")
  - These could be sensors, actuators, robots, cars, whatever can be connected.
  - A lot of inheritance from the world of "sensors networks"
- Connectivity
  - To connect things reliably to Internet.
  - Wireless connectivity is central to this task
- Platform
  - the collected data needs to be stored and processed somewhere. Typically cloud-based infrastructures

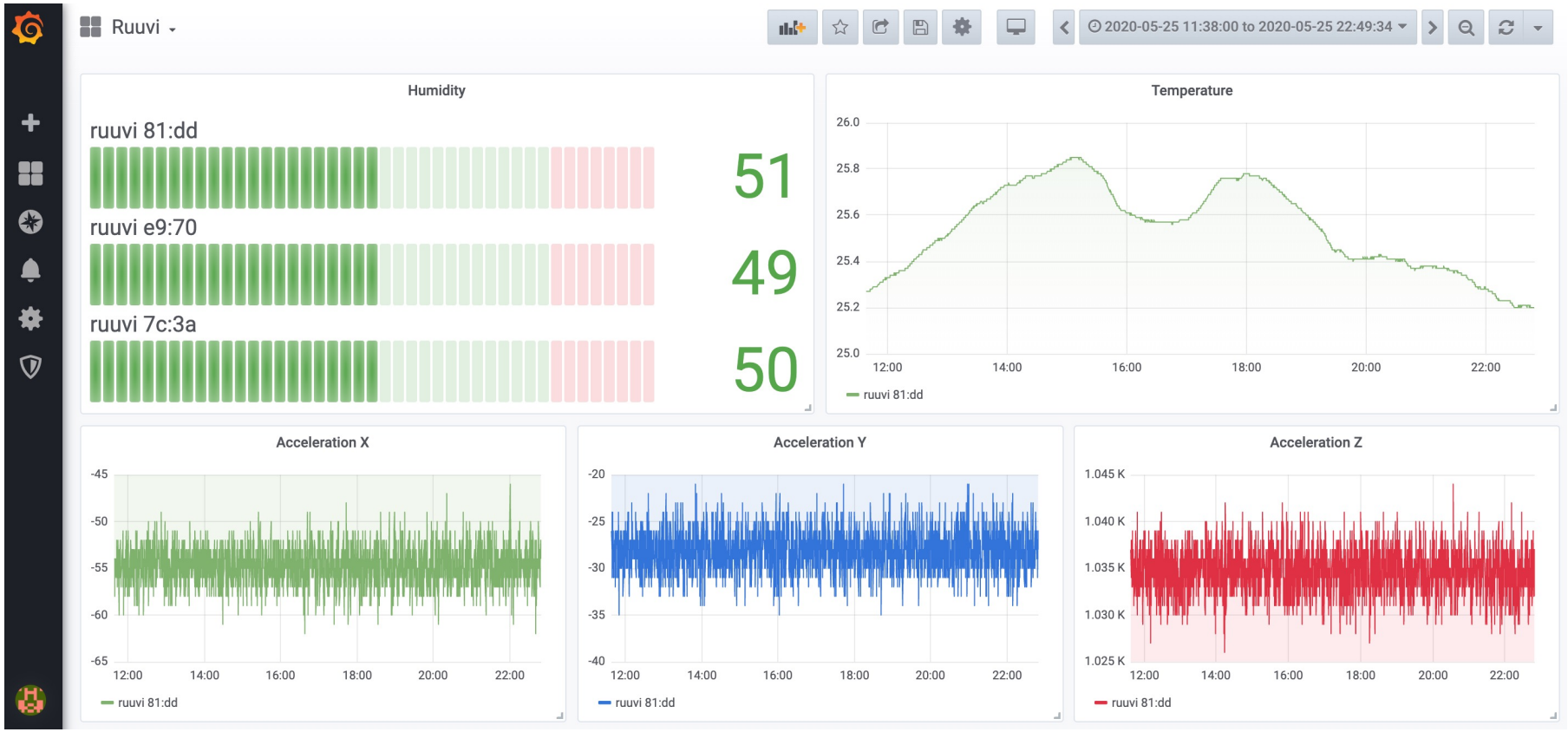


Platforms

- Amazon Web Services
- Google Cloud IoT
  - Firebase
- Microsoft Azure IoT Suite
- Salesforce IoT
- Oracle Internet of Things
- Cisco IoT Cloud Connect
- IBM Watson Internet of Things
- FIWARE
- Ubidots
- ThingSpeak
  - Based on MATLAB
- ThingsBoard
- GroveStreams
- SensorCloud
- …

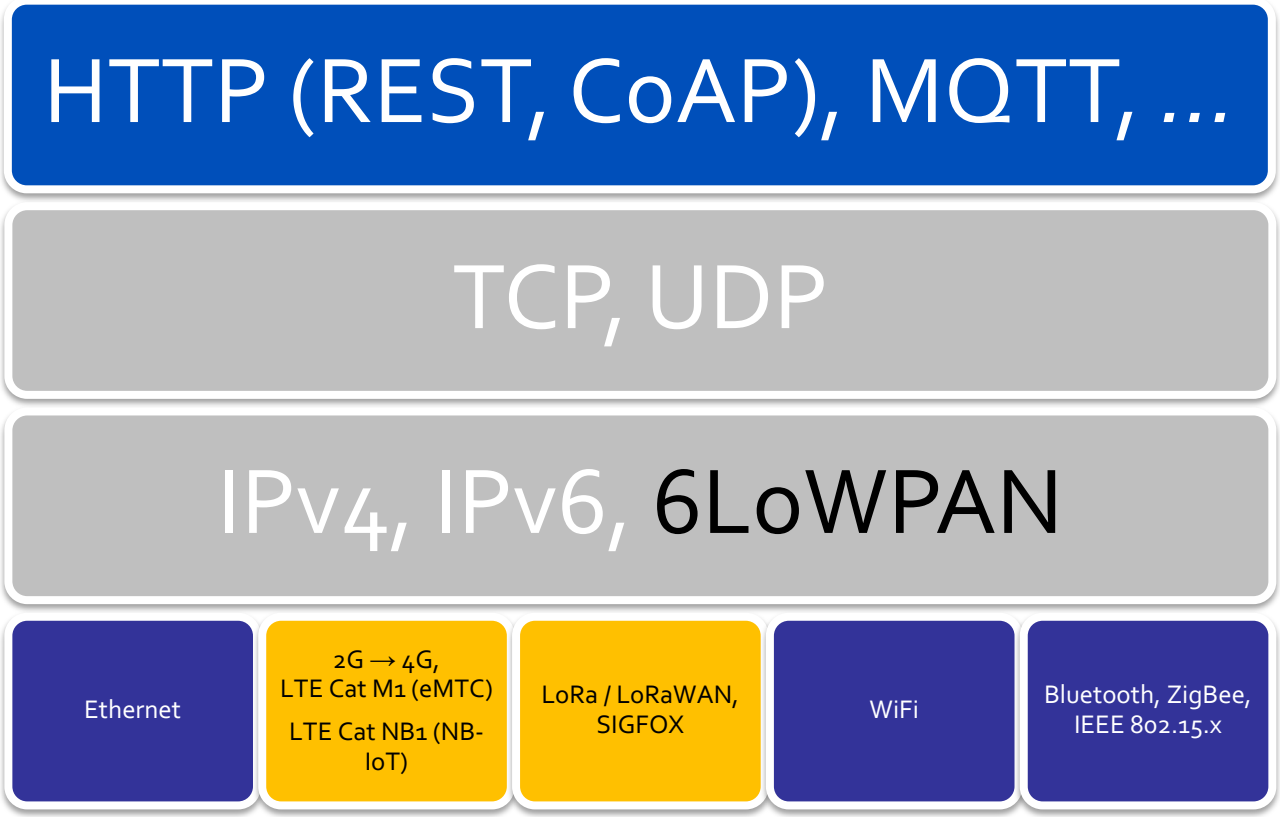


Data visualization & analytics: an example

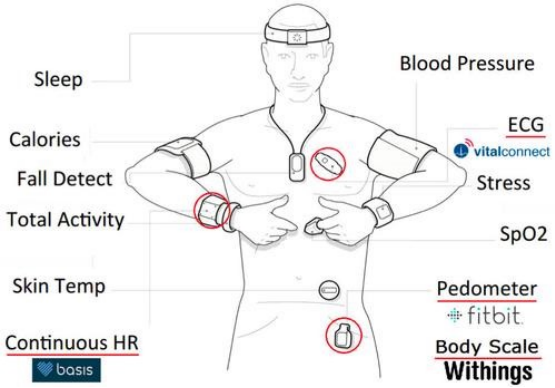


Data visualization & analytics: an example

Connectivity

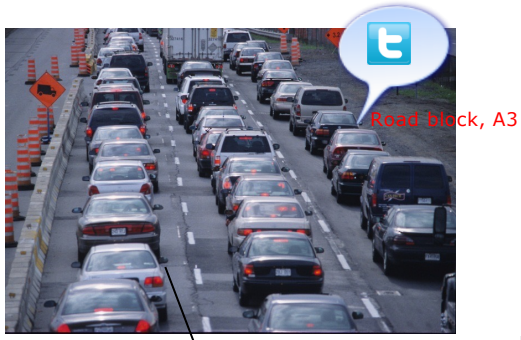


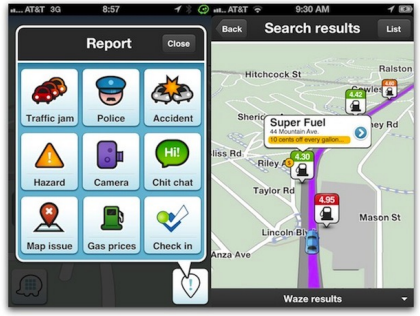
Examples of Things



Beyond conventional things/sensors

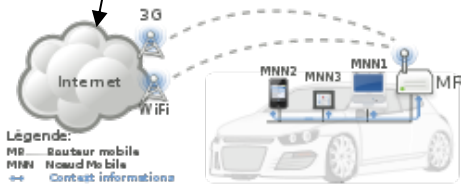
- Human as a sensor (citizen sensors)
  - e.g. tweeting real world data and/or events
- Virtual (software) sensors
  - e.g. Software agents/services generating/representing data





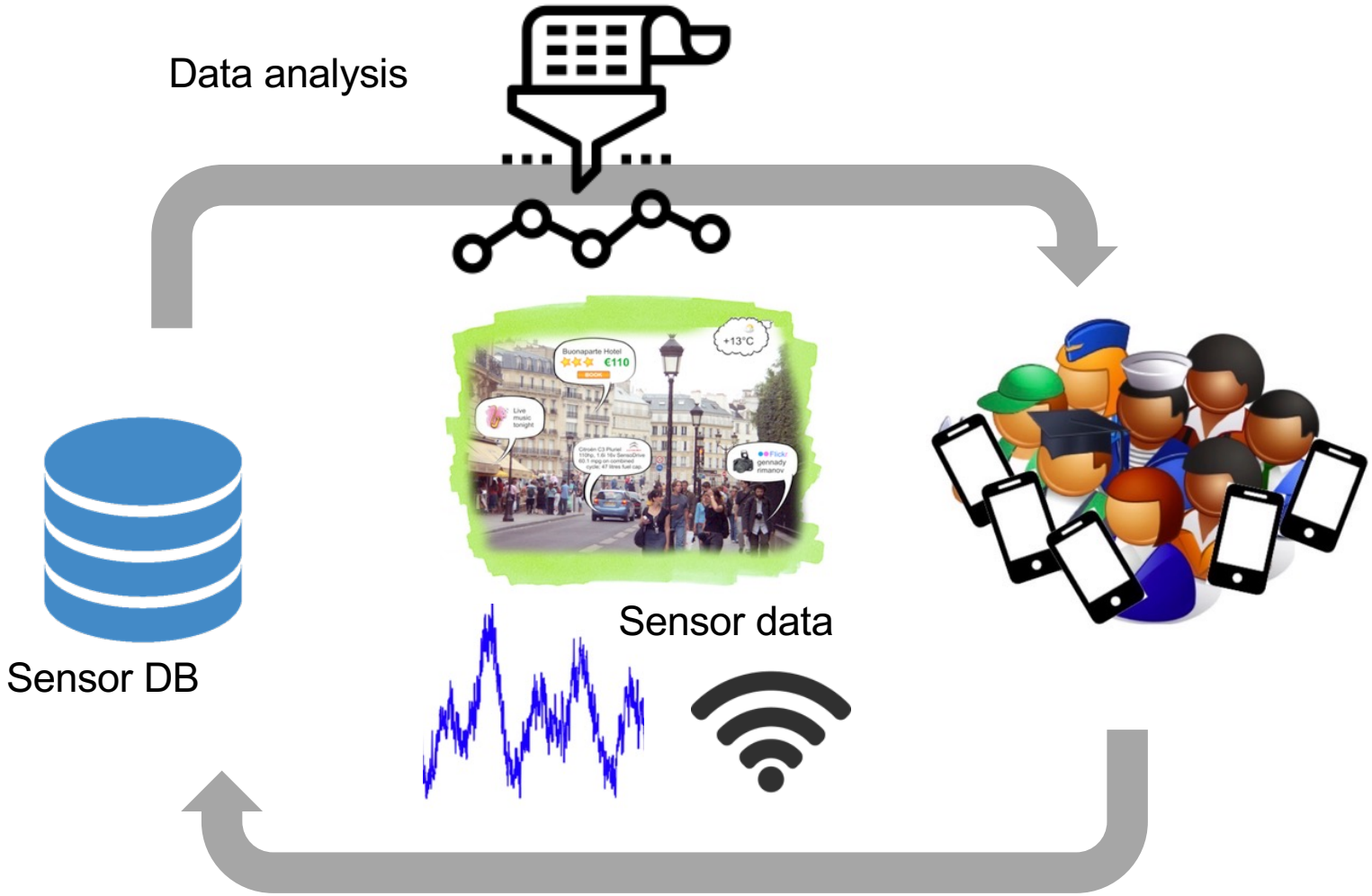
https://www.waze.com

Road block, A3

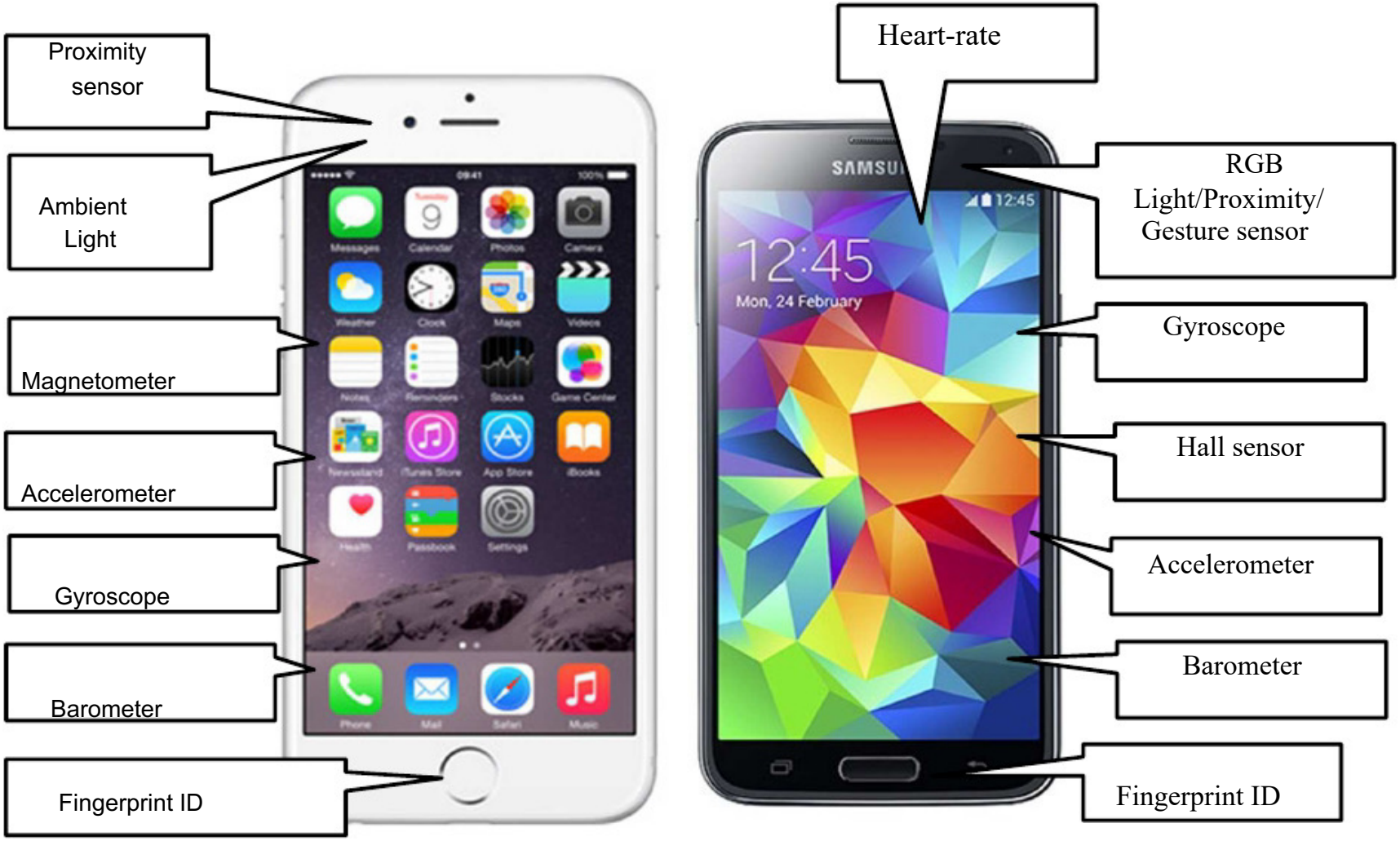


Suggest a different route

Crowdsensing

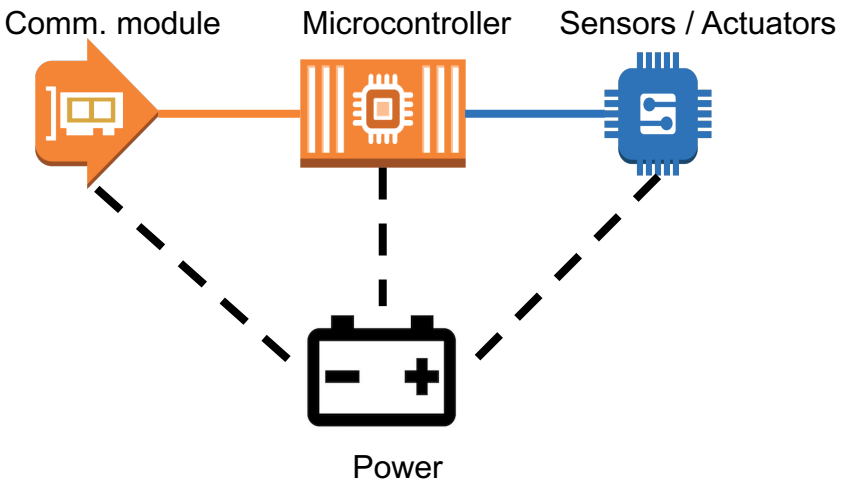


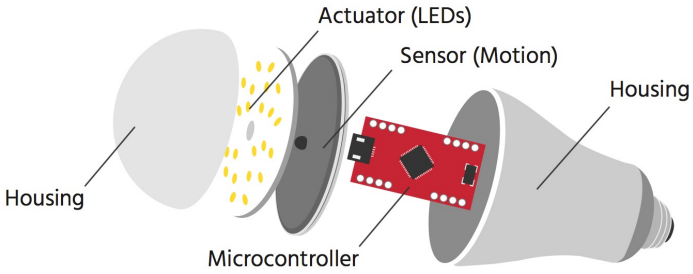
Sensors in Modern Smart Phones



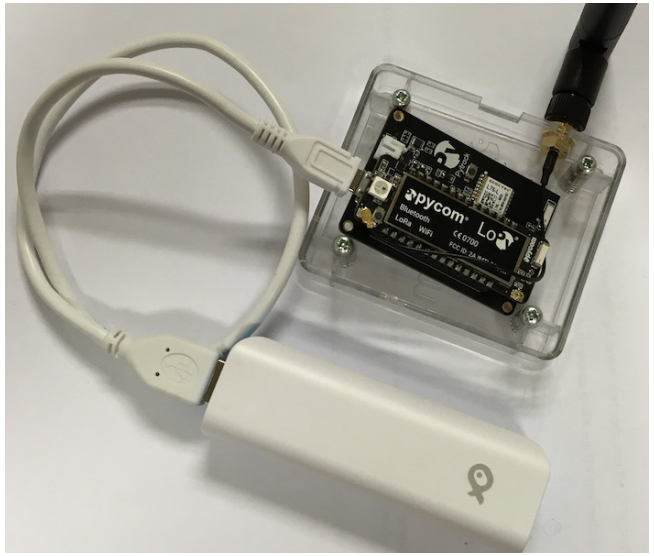
A basic model of a thing

- A "thing" generally consists of **four main parts:**
  - Sensors & actuators
  - Microcontroller
  - Communication unit
  - Power supply
- A "thing" has the **following properties**:
  - It's usually powered by battery. This implies limited source of energy.
  - It's generally small in size and low in cost. This limits their computing capability.





A Reference Guide to the Internet of Things Copyright © 2017 Bridgera LLC, RIoT



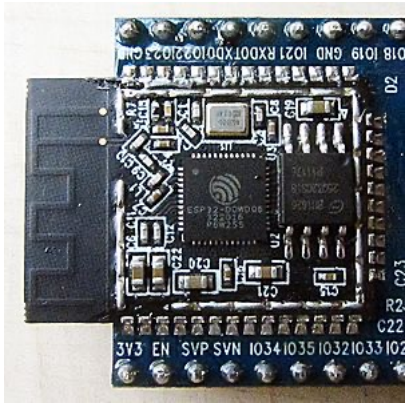
https://www.espressif.com/en/products/socs/esp32

Microcontroller: ESP32

- The ESP32 series employs a Tensilica Xtensa LX6 microprocessor in both dual-core and single-core variations. ESP32 is created and developed by Espressif System

http://esp32.net

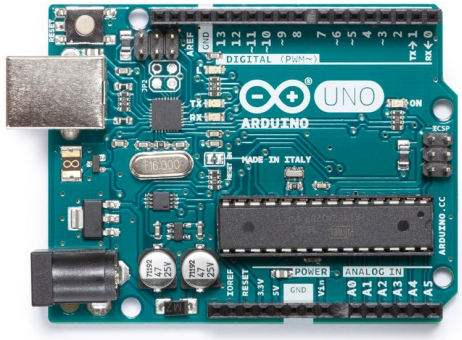
- CPU: Xtensa dual-core (or single-core) 32-bit LX6 microprocessor, operating at 160 or 240 MHz and performing at up to 600 DMIPS
- Memory: 520 KiB SRAM
- Wireless connectivity:
  - Wi-Fi: 802.11 b/g/n
  - Bluetooth: v4.2 BR/EDR and BLE
- Peripheral interfaces:
  - 12-bit SAR ADC up to 18 channels
  - 2 × 8-bit DACs
  - 10 × touch sensors (capacitive sensing GPIOs)
  - …

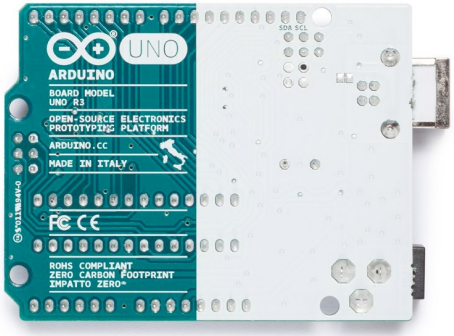


https://www.espressif.com/en/products/socs/esp32

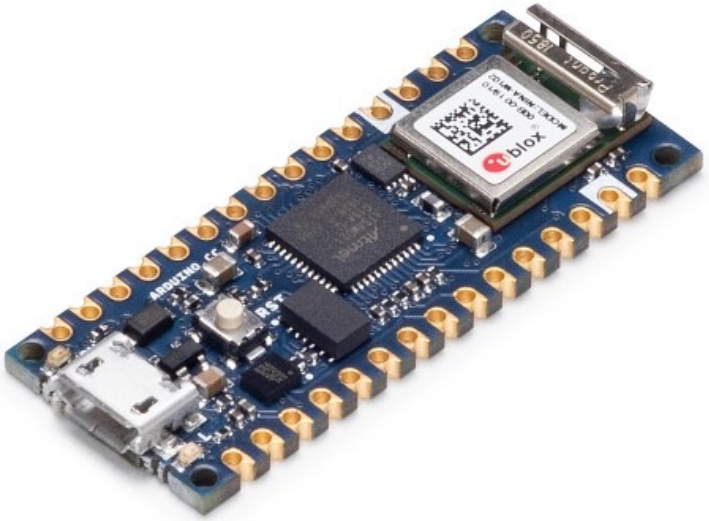
Arduino Uno

- The Arduino Uno model is widely used in Arduino development.
- It's built on top of a MCU ATmega328P microcontroller
- The board provides several digital and analog I/O pins, to which we can attach our sensor and actuator devices.
- SPI and I2C protocols are also provided by the Arduino Uno.
- More infos: https://store.arduino.cc/arduino-uno-rev3



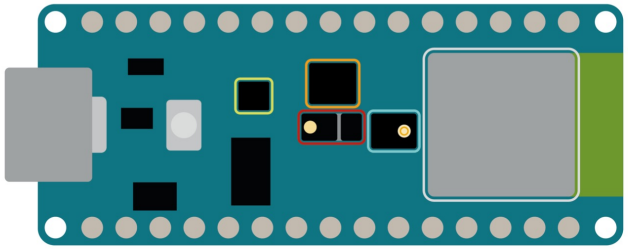


Arduino Nano



ARDUINO NANO 33 IOT

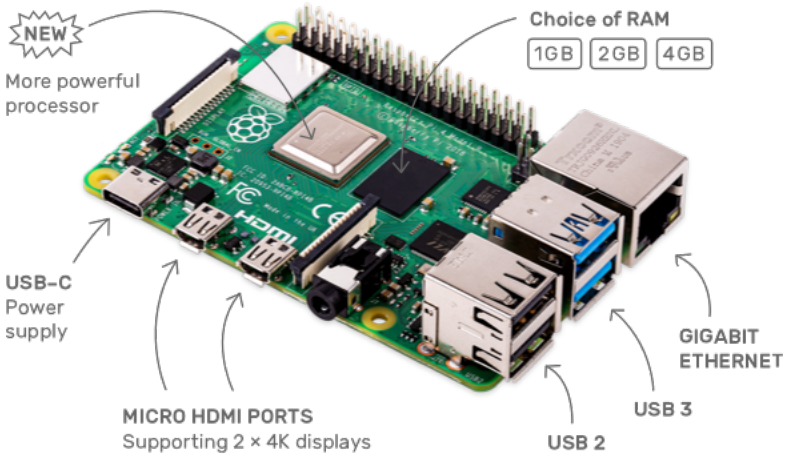
ARDUINO NANO 33 BLE SENSE



- Color, brightness, proximity and gesture sensor
- Digital microphone
- Motion, vibration and orientation sensor
- Temperature, humidity and pressure sensor
- Arm Cortex-M4 microcontroller and BLE module

Raspberry Pi 4

- Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz
- 1GB, 2GB, 4GB or 8GB LPDDR4-3200 SDRAM (depending on model)
- 2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE
- Gigabit Ethernet
- 2 USB 3.0 ports; 2 USB 2.0 ports.
- Power over Ethernet (PoE) enabled (requires separate PoE HAT)

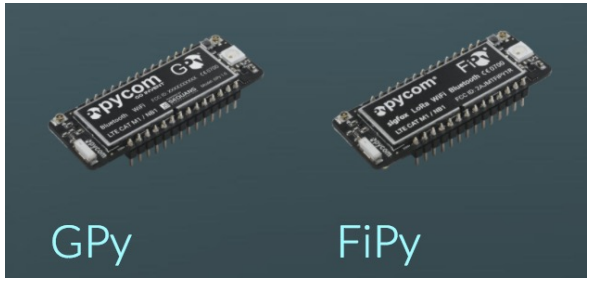


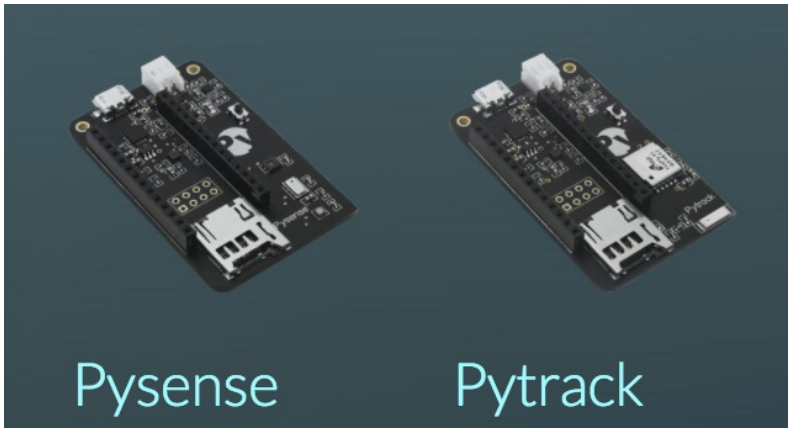
MicroPython

- MicroPython is a lean and efficient implementation of the Python 3 programming language optimised to run on microcontrollers and in constrained environments.
  - It is compact enough to fit and run within just 256k of code space and 16k of RAM.
  - It is packed full of advanced features such as an interactive prompt, arbitrary precision integers, closures, list comprehension, generators, exception handling and more.
  - **In addition to implementing a selection of core Python libraries, MicroPython includes modules such as "machine" for accessing low-level hardware.**
- You get an interactive prompt (the REPL) to execute commands immediately, along with the ability to run and import scripts from the built-in filesystem.
- MicroPython strives to be as compatible as possible with normal Python (known as CPython) so that if you know Python you already know MicroPython.
  - https://micropython.org/
  - Use MicroPython online: https://micropython.org/unicorn/

Nodes: HW alternatives for prototypes: Pycom

- Multi-network hardware.
  - Wifi, Bluetooth, Sigfox, LoRa and LTE-M
- Based on MicroPython
- The portfolio includes a comprehensive range of development boards, expansion boards, sensor shields and OEM hardware

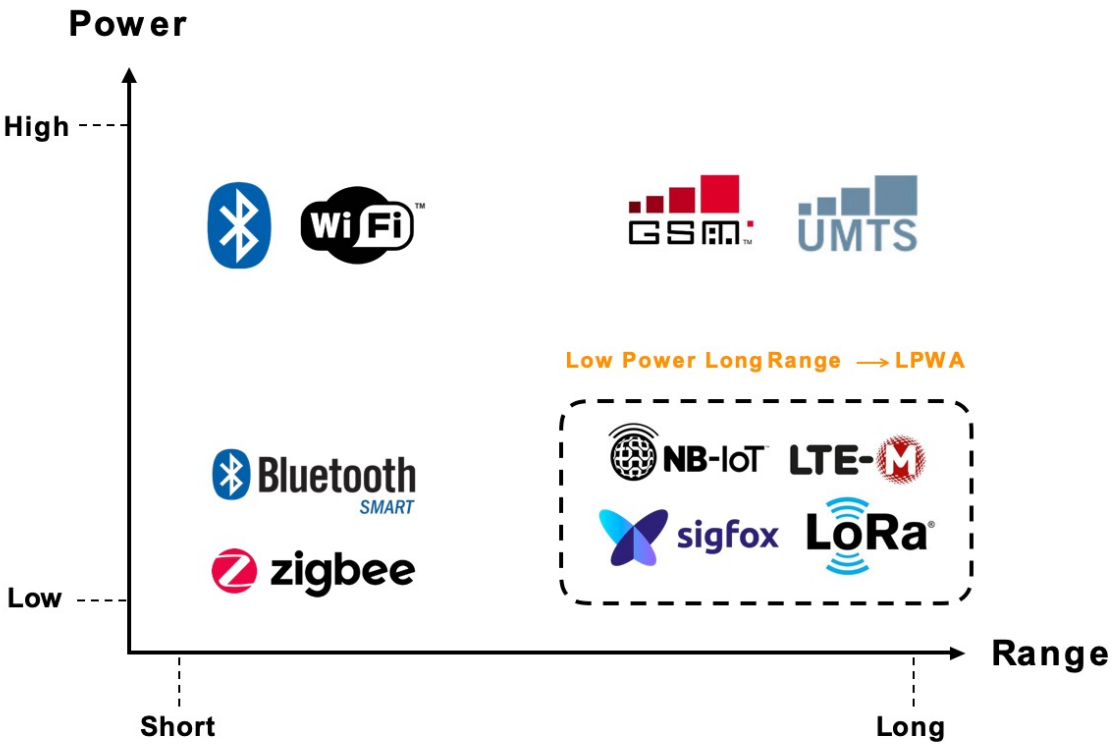




https://pycom.io/hardware/

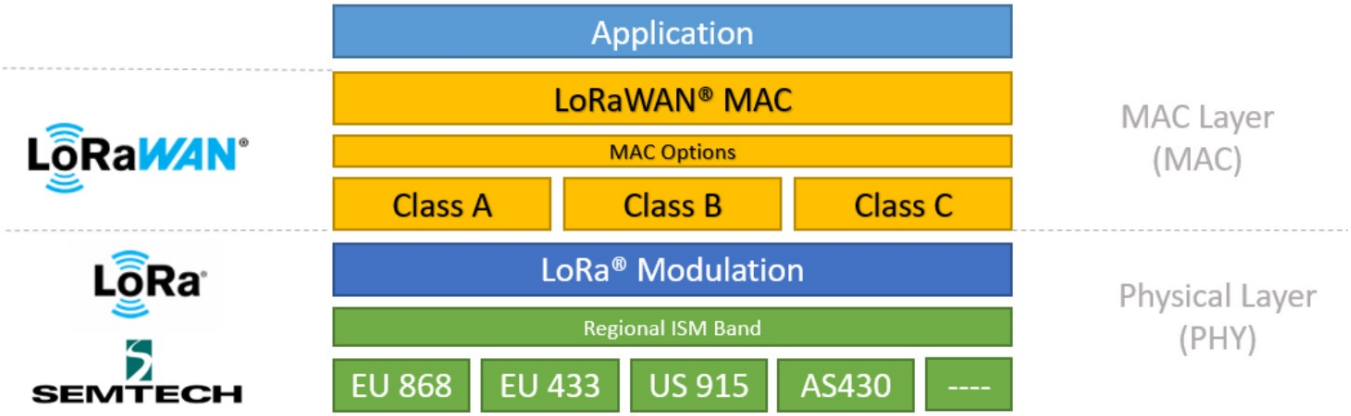
A brief introduction to LoRaWAN

LPWAN: range vs power



LoRaWAN: a sub-gigahertz wireless technology

- LoRaWAN™ is a Low Power Wide Area Network (LPWAN) specification intended for wireless battery-operated Things in a regional, national or global network
  - by Semtech Corporation (http://www.semtech.com/)
- LoRaWAN™ defines the communication protocol and system architecture for the network, while the LoRa physical layer enables the long-range communication link.



https://lora-developers.semtech.com/library/tech-papers-and-guides/lora-and-lorawan/ ©

https://lora-alliance.org/

LoRa® Alliance

- The LoRa® Alliance is an open, non-profit association of members whose mission is:
  - "..promote and drive the success of the LoRaWAN® protocol as the leading open global standard for secure, carrier-grade IoT LPWAN connectivity…"
  - "To develop and promote LoRaWAN® technology and its ecosystem to deliver massive IoT"
- Specification is free to download:
  - https://lora-alliance.org/resource-hub/lorawan-104-specification-package

LoRaWAN® L2 1.0.4 Specification (TS001-1.0.4)

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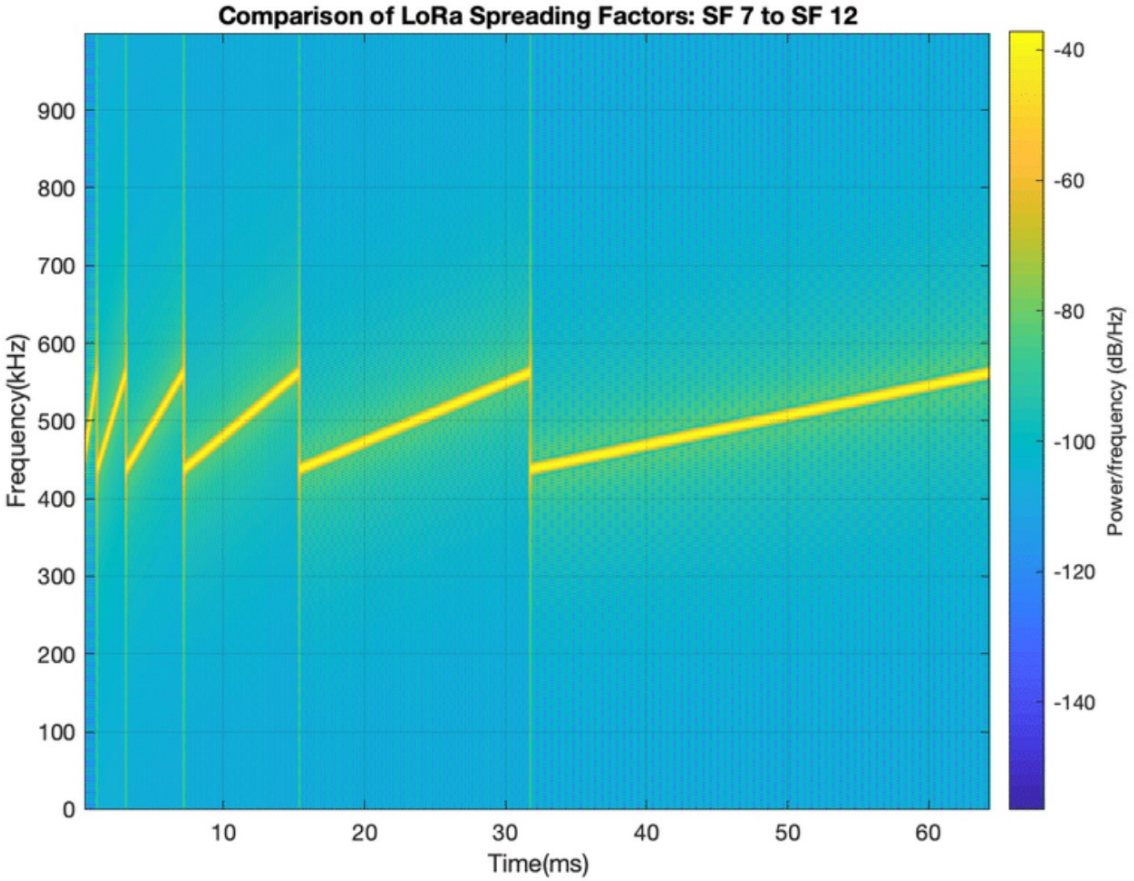
Version: 1.0.4
Date: October 2020
Status: Released

LoRaWAN specification depends on the region

	Europe	North America
Frequency band	867-869MHz	902-928MHz
Channels	10	64 + 8 +8
Channel BW Up	125/250kHz	125/500kHz
Channel BW Dn	125kHz	500kHz
TX Power Up	+14dBm	+20dBm typ (+30dBm allowed)
TX Power Dn	+14dBm	+27dBm
SF Up	7-12	7-10
Data rate	250bps- 50kbps	980bps-21.9kpbs
Link Budget Up	155dB	154dB
Link Budget Dn	155dB	157dB

https://lora-alliance.org/resource-hub/rp2-101-lorawanr-regional-parameters-0

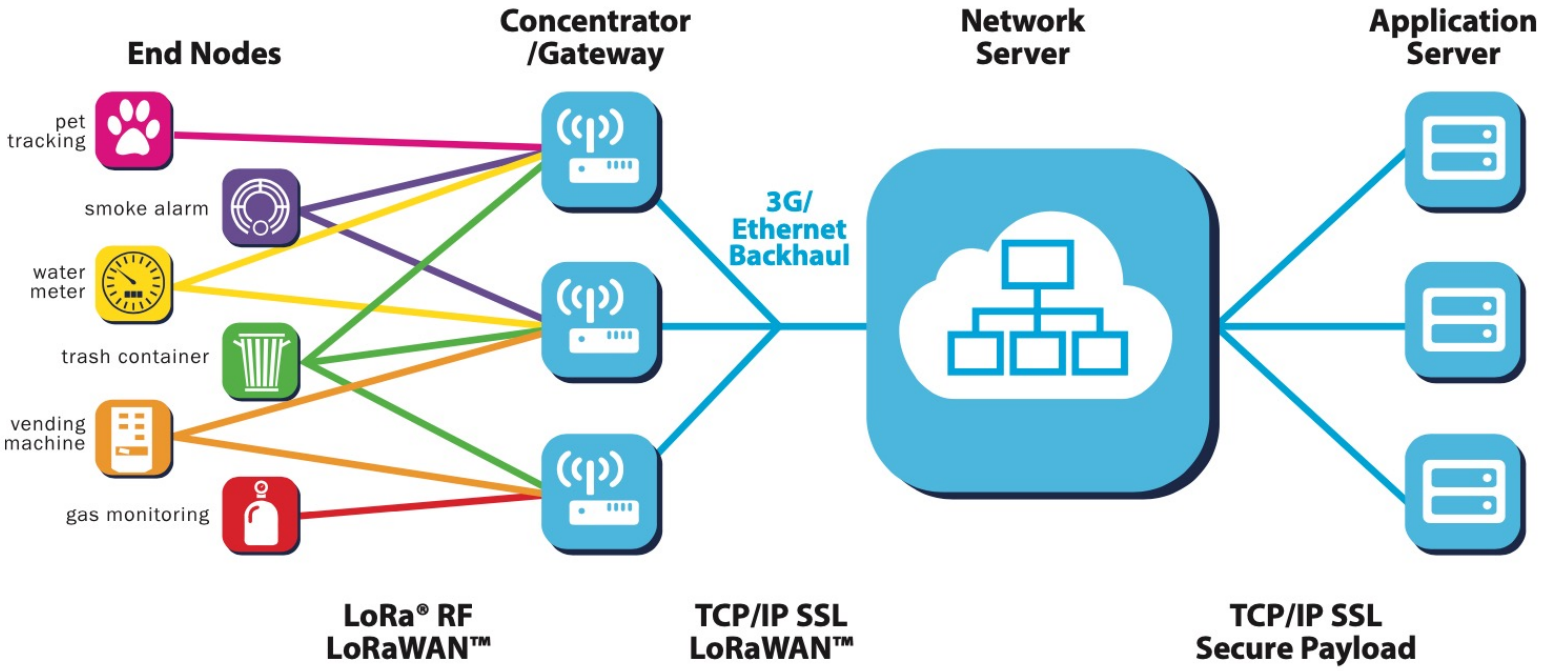
Chirp Modulation



https://www.youtube.com/watch?v=dxYY097QNs0

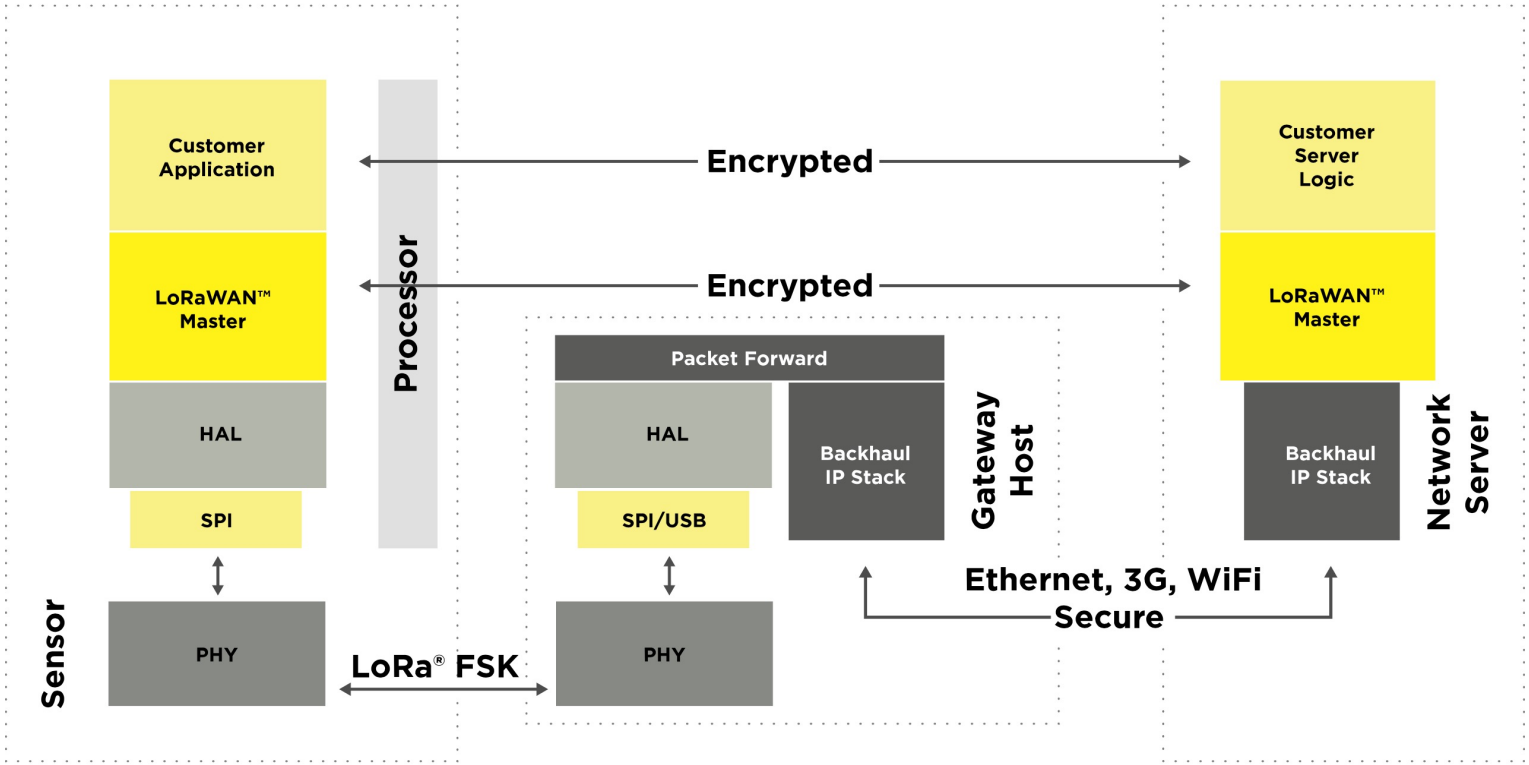
Kim, Dong-Hoon & Lee, Eun-Kyu & Kim, Jibum. (2019). Experiencing LoRa Network Establishment on a Smart Energy Campus Testbed. Sustainability. 11. 1917. 10.3390/su11071917.

LoRaWAN network architecture



LoRa Alliance ©

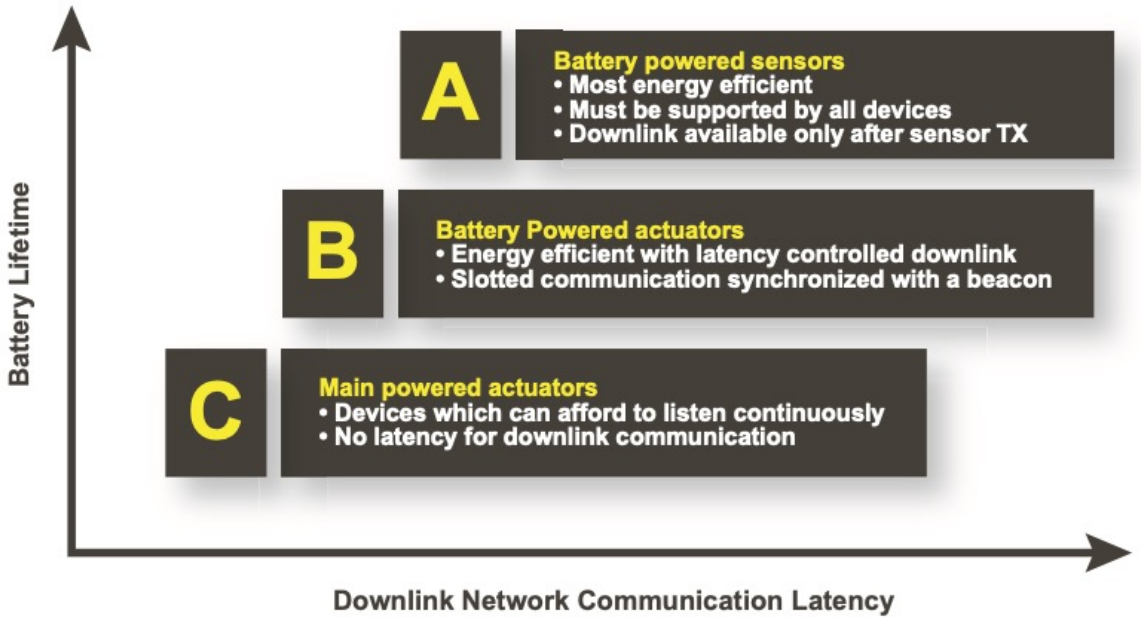
LoRaWAN data flow



HAL: Hardware Abstraction Layer

Three types of devices

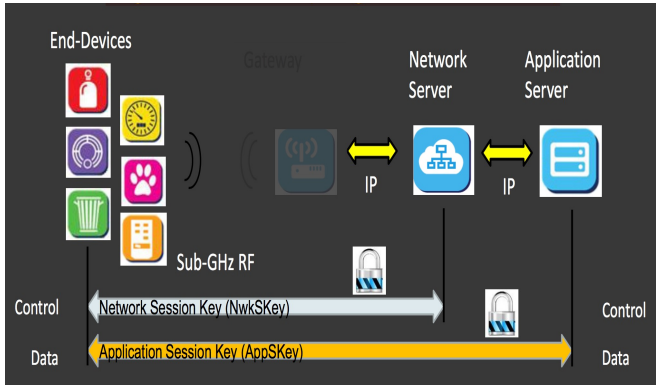
- LoRaWAN has three different classes of end-point devices to address the different needs reflected in the wide range of applications:



LoRa® Alliance Technical Marketing Workgroup

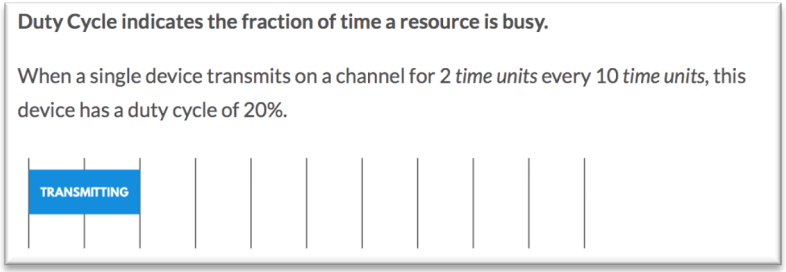
Devices activation

- LoRaWAN devices have a 64-bits unique identifier (`DevEUI`) that is assigned to the device by the chip manufacturer.
- However, all communication is done with a dynamic 32 bit device address (`DevAddr`) of which 7 bits are fixed (Network Server), leaving 25 bits that can be assigned to individual devices with a procedure called **Activation**.
- To exchange this information, two activation methods are available:
  - Over-the-Air Activation (OTAA)
    - Devices perform a join-procedure with the network, during which a dynamic DevAddr is assigned and security keys are negotiated with the device
  - Activation By Personalization (ABP)
    - Hardcode the DevAddr as well as the security keys in the device.



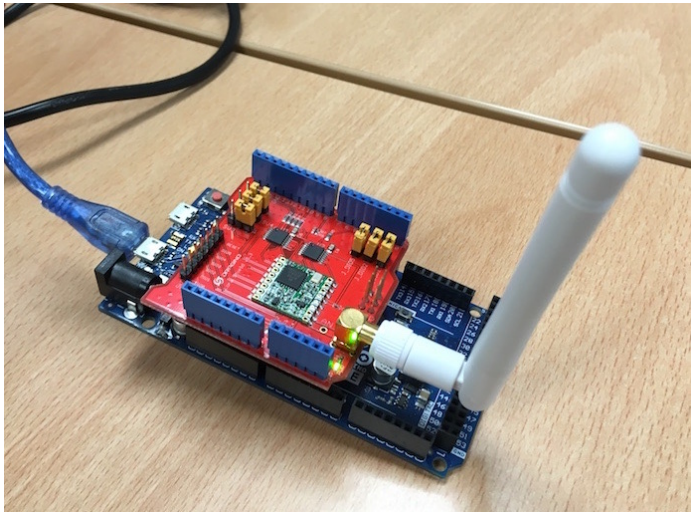
Maximum Duty Cycle

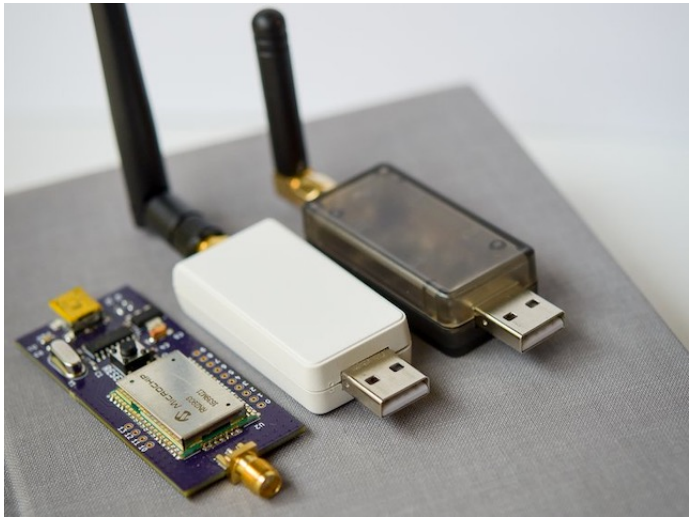
- The **duty cycle of radio devices is often regulated by government**.
  - In Europe, duty cycles are regulated by section 7.2.3 of the ETSI EN300.220 standard.



- Additionally, the **LoRaWAN specification dictates duty cycles for the join frequencies**, the frequencies devices of all LoRaWAN-compliant networks use for over-the-air activations (OTAA) of devices. In most regions this duty cycle is set to 1%.
- Finally, on "community network" like TTN there typically is a **Fair Access Policy** that limits the uplink airtime to 30 seconds per day (24 hours) per node and the downlink messages to 10 messages per day (24 hours) per node.

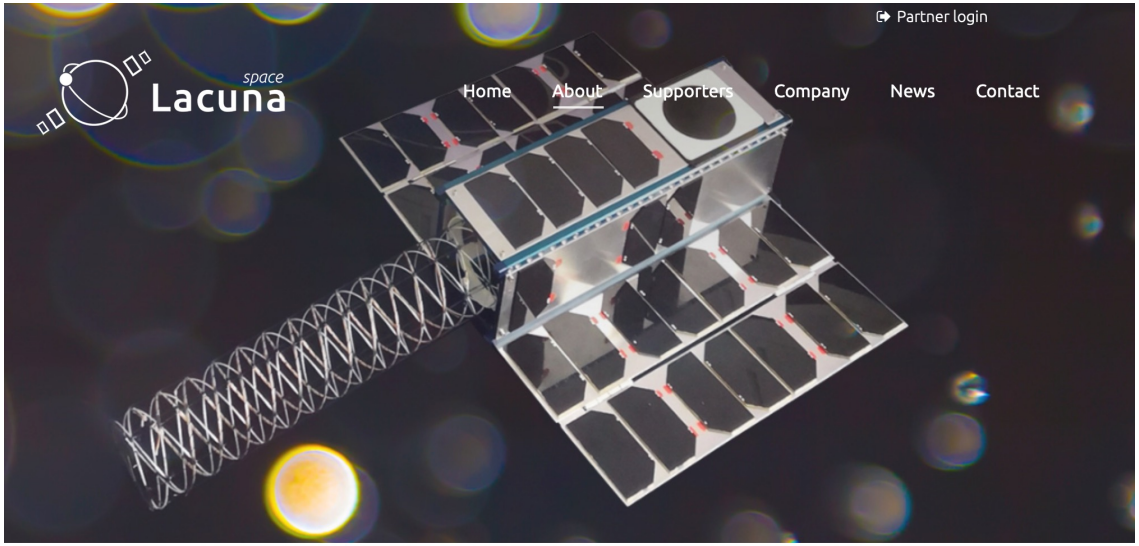
Some devices





https://lacuna.space

Nice project

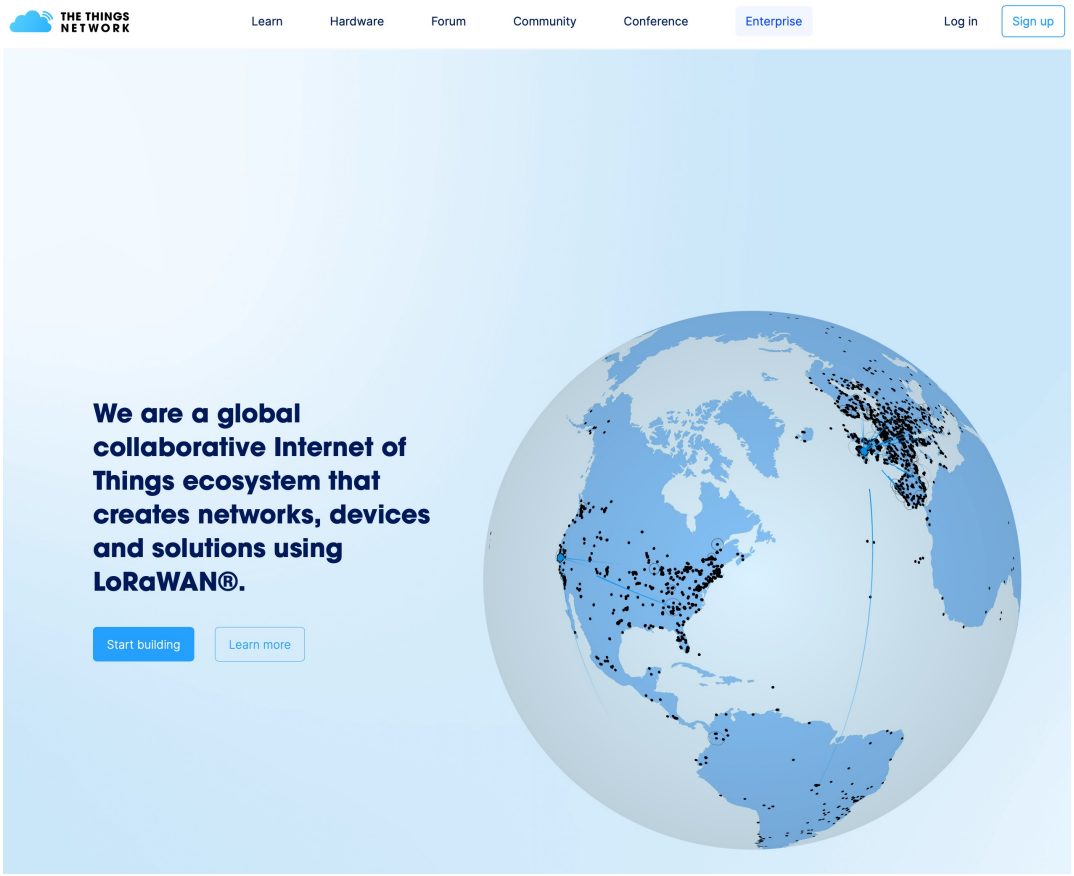


An ultra-low cost tracking and sensor detection service for small amounts of data

– think of it as 'things' rather than people tweeting short messages.

https://www.thethingsnetwork.org

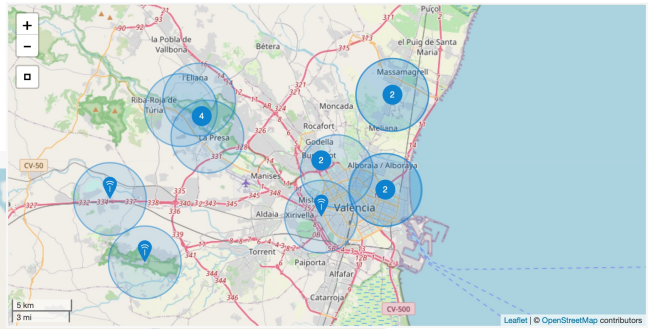
The Things Network (TTN)

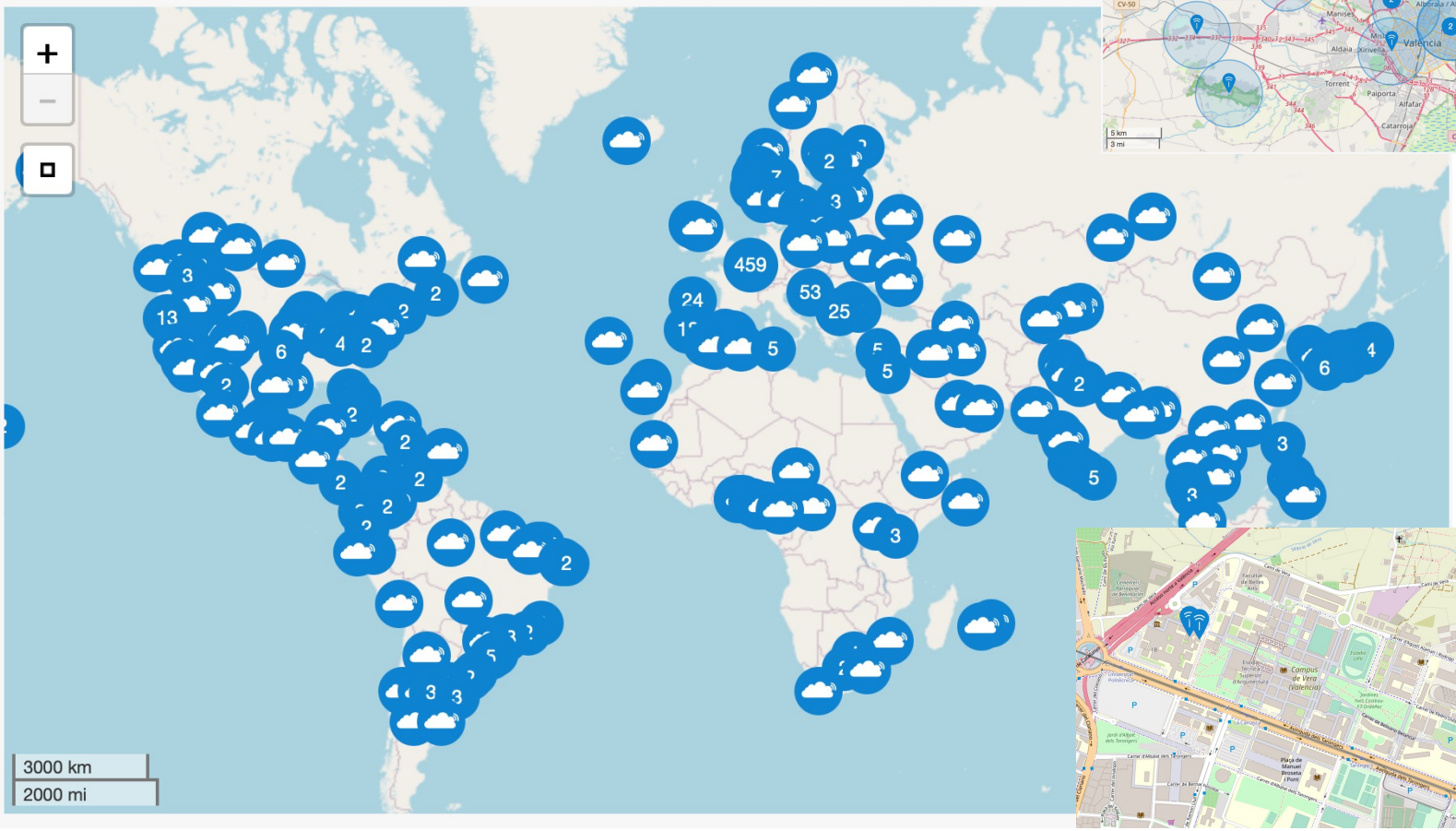


27.2M	151	970	154.6K	21.3K
Messages today	Countries	Certified developers	Members	Gateways

The Things Network (TTN)

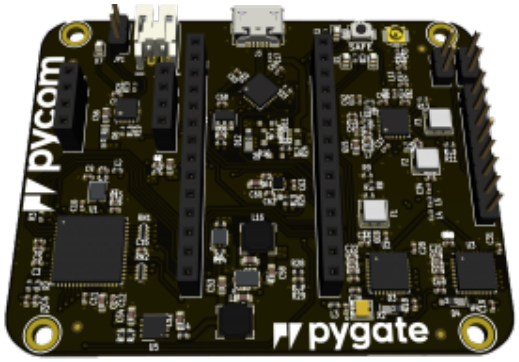
Currently (1oct2021) 21300 gateways active worldwide

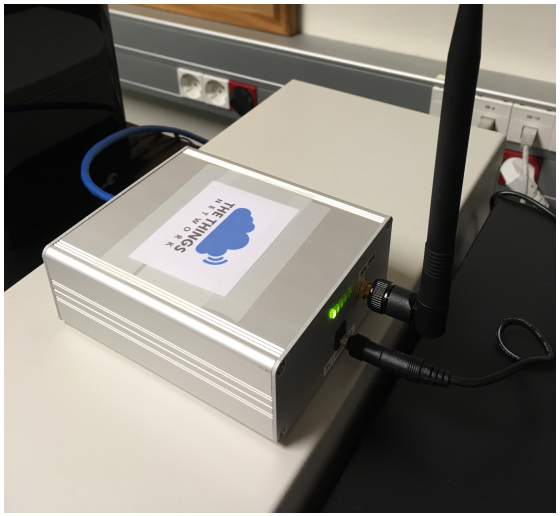


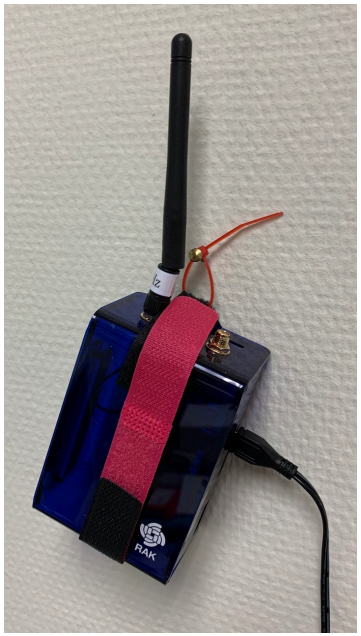


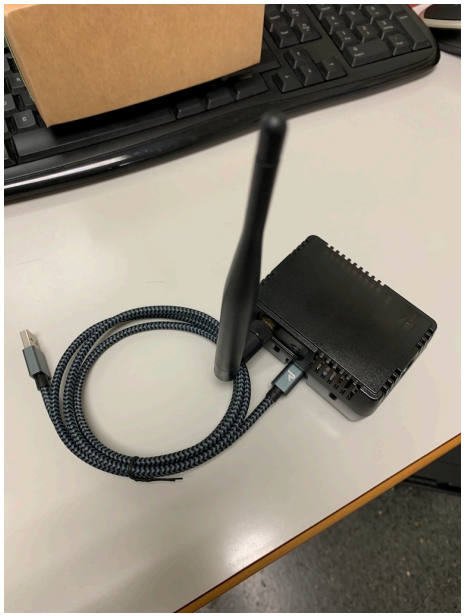
https://www.thethingsnetwork.org/community

GRC Gateways

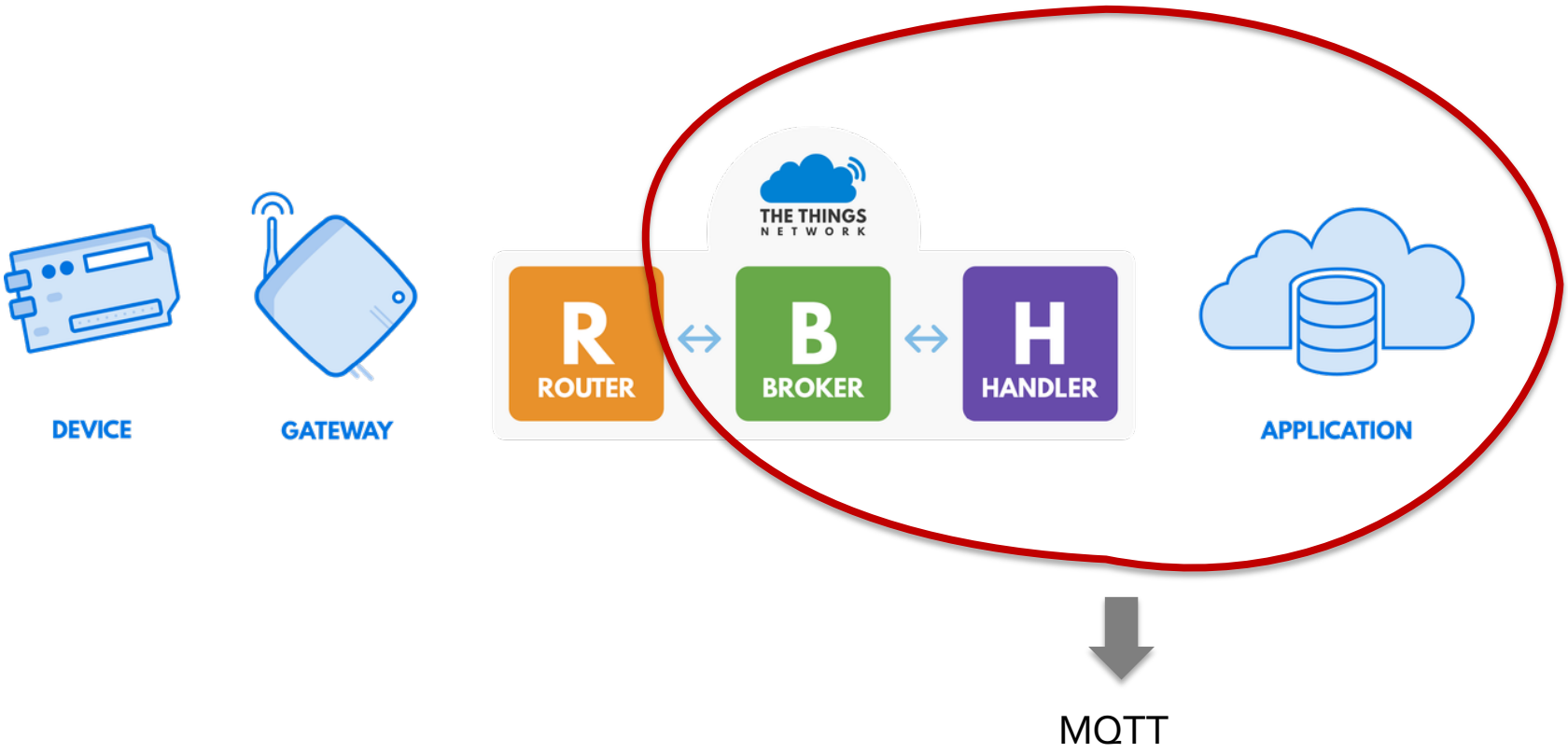








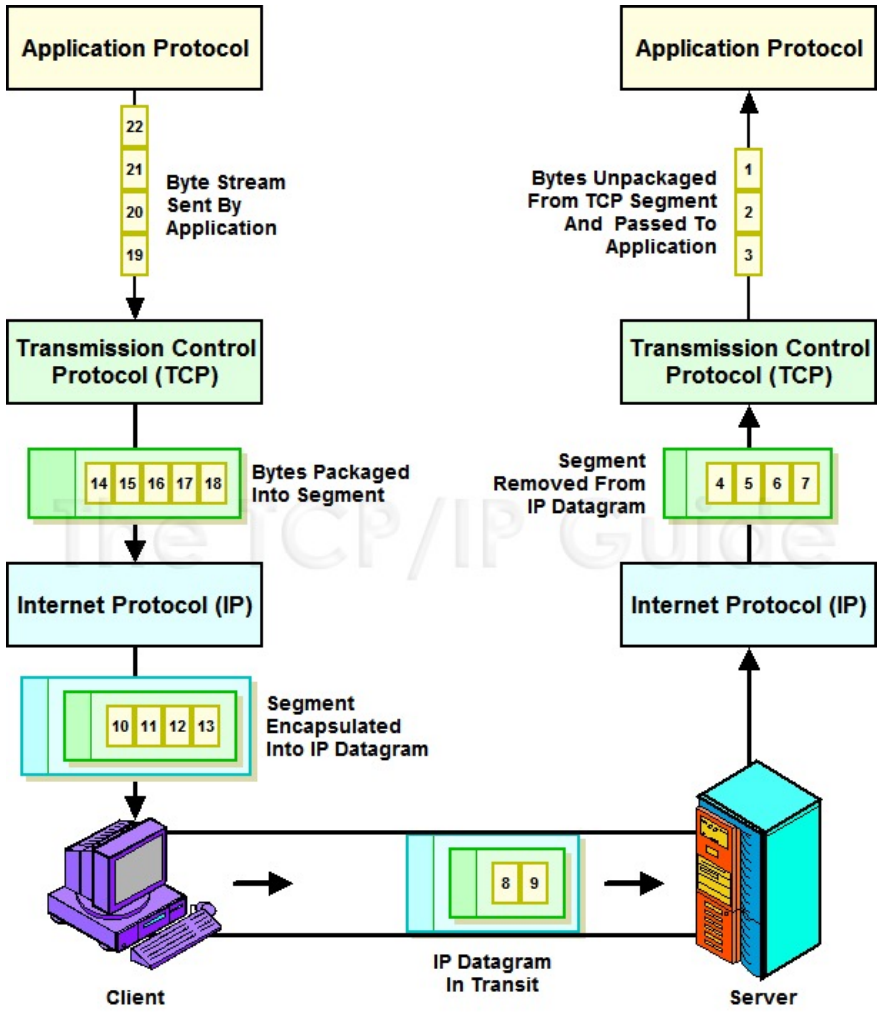
The Things Network (TTN)



A brief introduction to MQTT

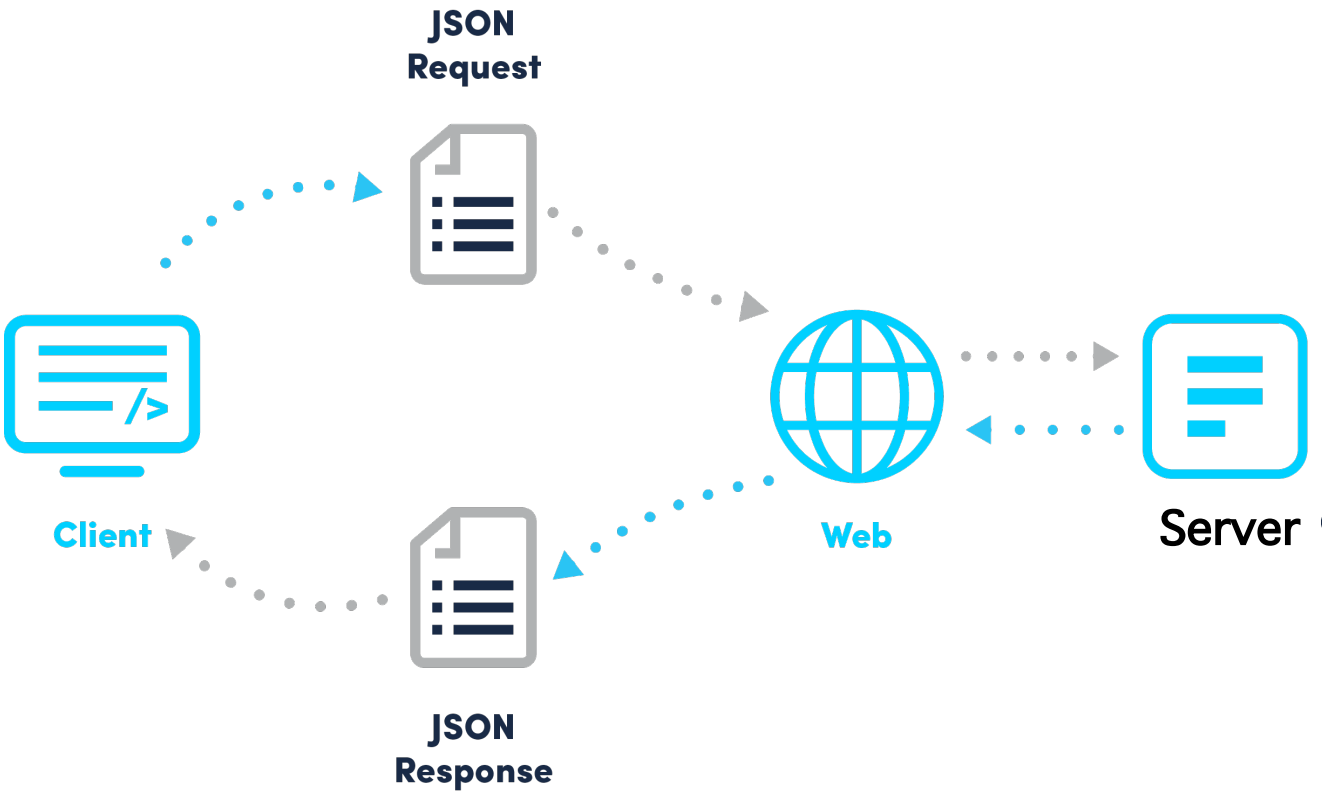
From "byte streams" to "messages"

- The "old" vision of data communication was based on **reliable byte streams**, i.e., TCP
- Nowadays **messages interchange** is becoming more common
  - E.g., Twitter, Whatsapp, Instagram, Snapchat, Facebook,…
- Actually is not that new…
  - emails: SMTP+MIME,
  - FTP,



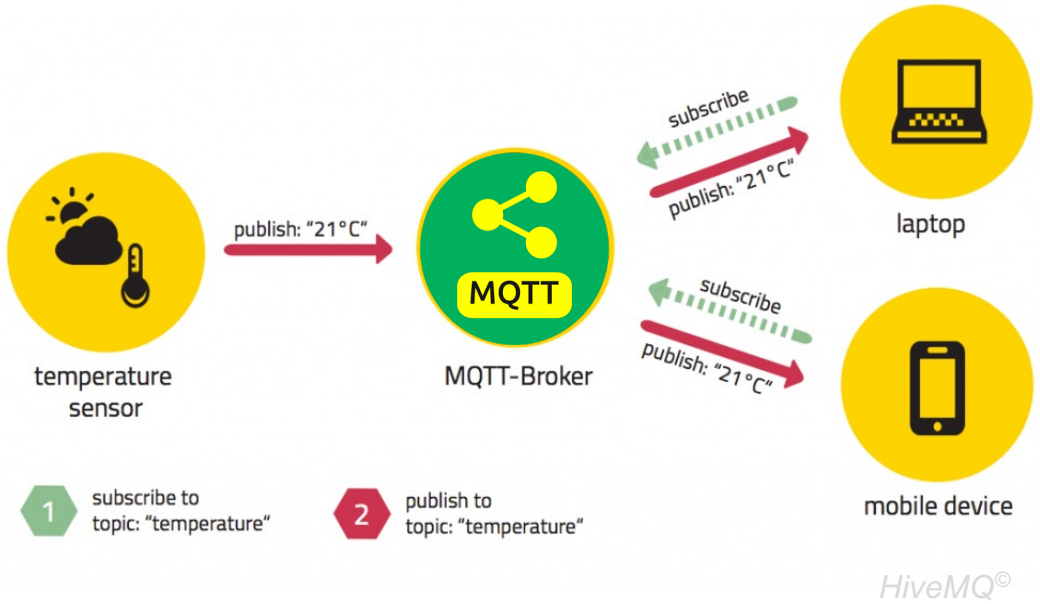
Request/response approach

- **REST**: Representational State Transfer
- Widely used; based on HTTP
- *Lighter version: **CoAP** (Constrained Application Protocol)*



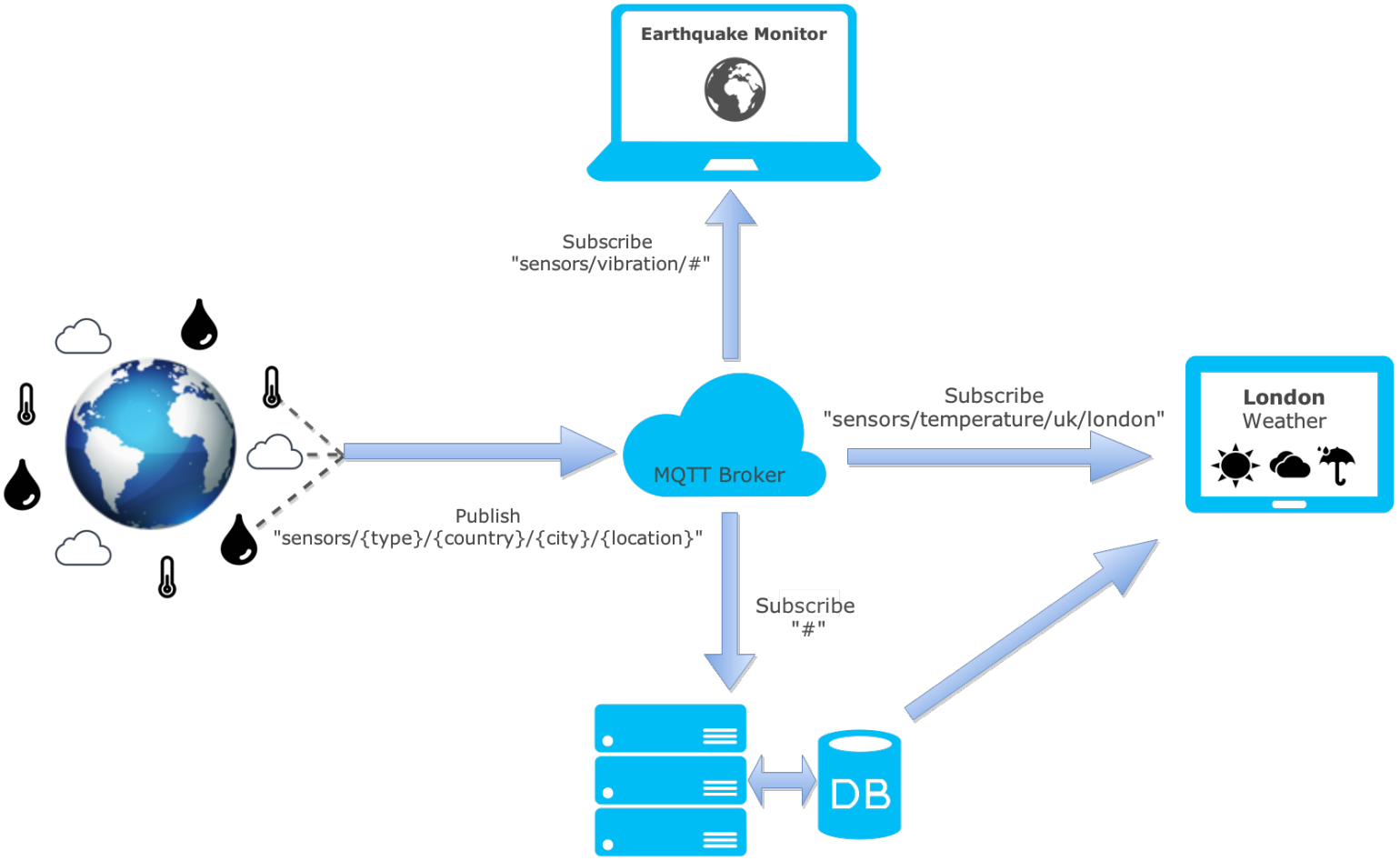
Pub/sub approach

- Pub/Sub separate a client, who is sending a message about a specific **topic**, called publisher, from another client (or more clients), who is receiving the message, called subscriber.
- There is a third component, called broker, which is known by both the publisher and subscriber, which filters all incoming messages and distributes them accordingly.



- Various protocols:
  MQTT, AMQP, XMPP (was Jabber)
- Growing technique
  E.g., https://cloud.google.com/iot/docs/how-tos/mqtt-bridge

An example



Source: https://zoetrope.io/tech-blog/brief-practical-introduction-mqtt-protocol-and-its-application-iot

Message Queuing Telemetry Transport

- A lightweight publish-subscribe protocol that can run on embedded devices and mobile platforms ➔ http://mqtt.org/
  - Low power usage.
  - Binary compressed headers
  - Maximum message size of 256MB
    - not really designed for sending large amounts of data
    - better at a high volume of low size messages.
- Documentation sources:
  - The MQTT community wiki:
    - `https://github.com/mqtt/mqtt.github.io/wiki`
  - A very good tutorial:
    - `http://www.hivemq.com/mqtt-essentials/`

Some details about versions

- **MQTT 3.1.1 is the current version of the protocol.**
  - Standard document here:
    - http://docs.oasis-open.org/mqtt/mqtt/v3.1.1/mqtt-v3.1.1.html
  - October 29th 2014: MQTT was officially approved as OASIS Standard.
    - https://www.oasis-open.org/committees/tc_home.php?wg_abbrev=mqtt

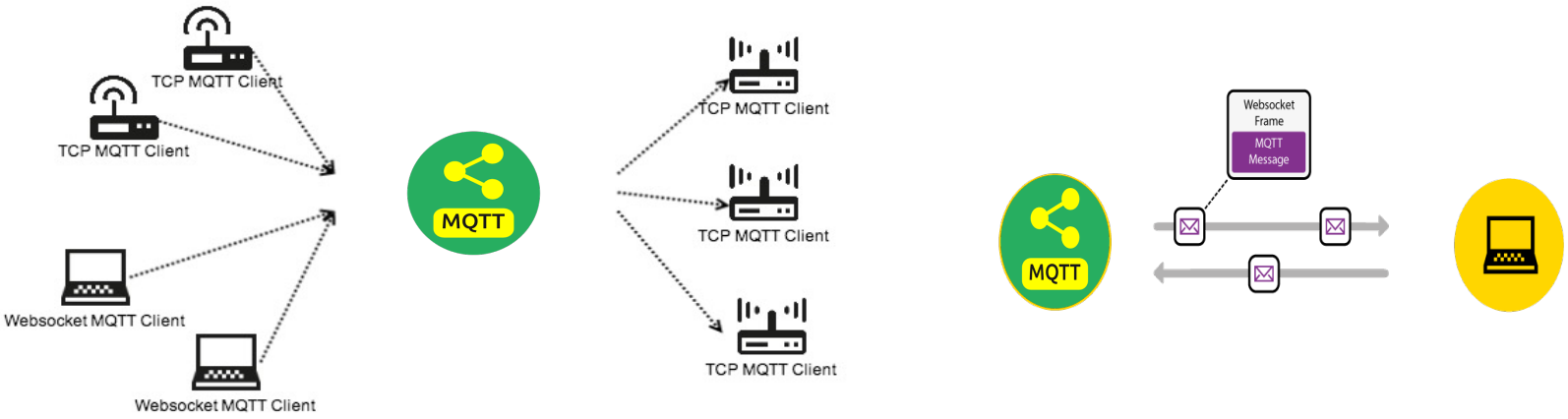
- MQTT v5.0 is the successor of MQTT 3.1.1
  - Current status: Committee Specification 02 (7 March 2019)
    - http://docs.oasis-open.org/mqtt/mqtt/v5.0/cs02/mqtt-v5.0-cs02.html
    - **Not backward compatible**; too many new things are introduced so existing implementations have to be revisited, for example:

1. More extensibility → user properties
2. Improved error reporting (Reason Code & Reason String)
3. Performance improvements and improved support for small clients
   - shared subscriptions
   - topic alias
4. Formalized common patterns → payload format description
5. Improved authentication

MQTT works on top of…

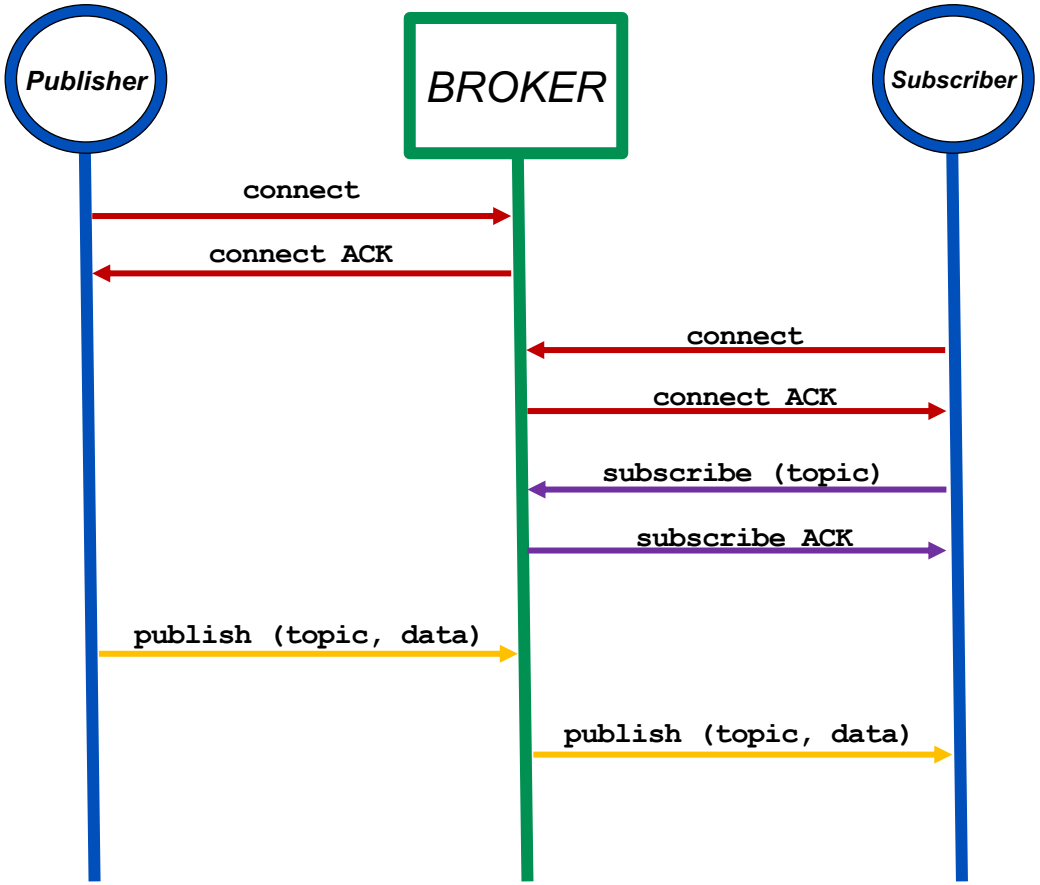
- mainly of TCP
  - There is also the closely related MQTT for Sensor Networks (MQTT-SN) where TCP is replaced by UDP → TCP stack is too complex for WSN

- websockets can be used, too!
  - Websockets allows you to receive MQTT data directly into a web browser.



- Both, TCP & websockets can work on top of "Transport Layer Security (TLS)" (and its predecessor, Secure Sockets Layer (SSL))

Publish/subscribe interactions sequence



Topics

- MQTT Topics are structured in a hierarchy similar to folders and files in a file system using the forward slash (/) as a delimiter.
- Allow to create a user friendly and self descriptive **naming structures**

- Topic names are:
  - Case sensitive
  - use UTF-8 strings.
  - Must consist of at least one character to be valid.
- Except for the $SYS topic **there is no default or standard topic structure.**

Special $SYS/ topics

- $SYS/broker/clients/connected
- $SYS/broker/clients/disconnected
- $SYS/broker/clients/total
- $SYS/broker/messages/sent
- $SYS/broker/uptime

Topics wildcards

- Topic subscriptions can have wildcards. These enable nodes to subscribe to groups of topics that don't exist yet, allowing greater flexibility in the network's messaging structure.
  - '+' matches anything at a given tree level
  - '#' matches a whole sub-tree
- Examples:
  - Subscribing to topic `house/#` covers:
    - house/room1/main-light
    - house/room1/alarm
    - house/garage/main-light
    - house/main-door
  - Subscribing to topic `house/+/main-light` covers:
    - house/room1/main-light
    - house/room2/main-light
    - house/garage/main-light
  - but doesn't cover
    - house/room1/side-light
    - house/room2/side-light

A few words on security

- MQTT has the option for Transport Layer Security (TLS) encryption.
- MQTT also provides username/password authentication with the broker.
  - Note that the password is transmitted in clear text. Thus, be sure to use TLS encryption if you are using authentication.

"It's not just you. We're all insecure in one way or another."

A few words on security

Smart homes can be easily hacked via unsecured MQTT servers

https://www.helpnetsecurity.com/2018/08/20/unsecured-mqtt-servers/

In fact, by using the Shodan IoT search engine, Avast researchers found over 49,000 MQTT servers exposed on the Internet and, of these, nearly 33,000 servers have no password protection, allowing attackers to access them and all the messages flowing through it.

TOTAL RESULTS

49,197

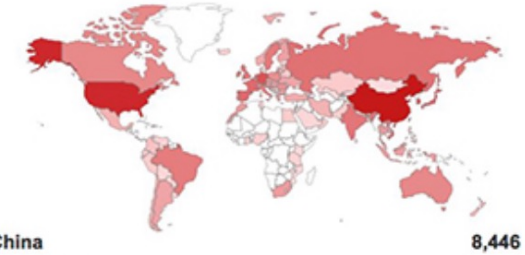
TOP COUNTRIES

China	12,151
United States	8,257
Germany	3,092
Korea, Republic of	2,003
Hong Kong	2,002

TOTAL RESULTS

32,888

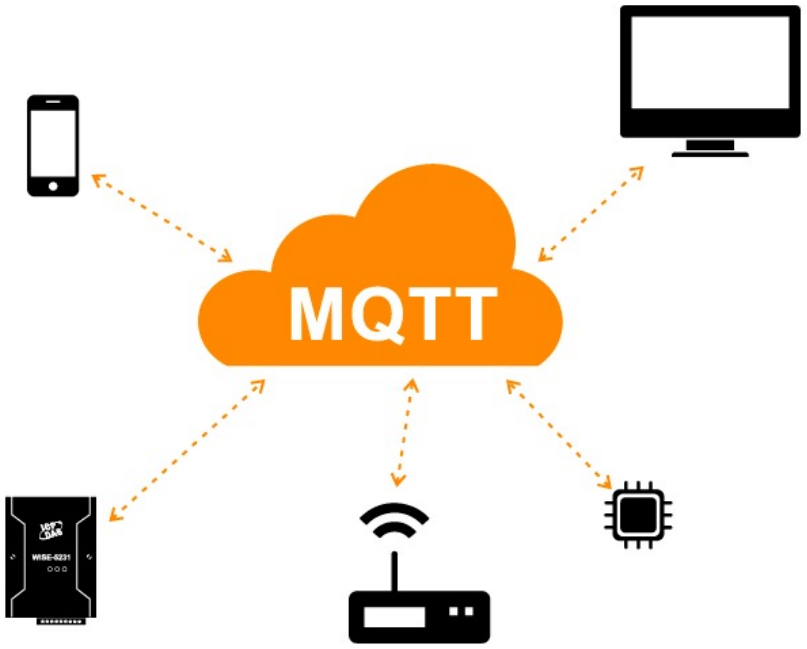
TOP COUNTRIES



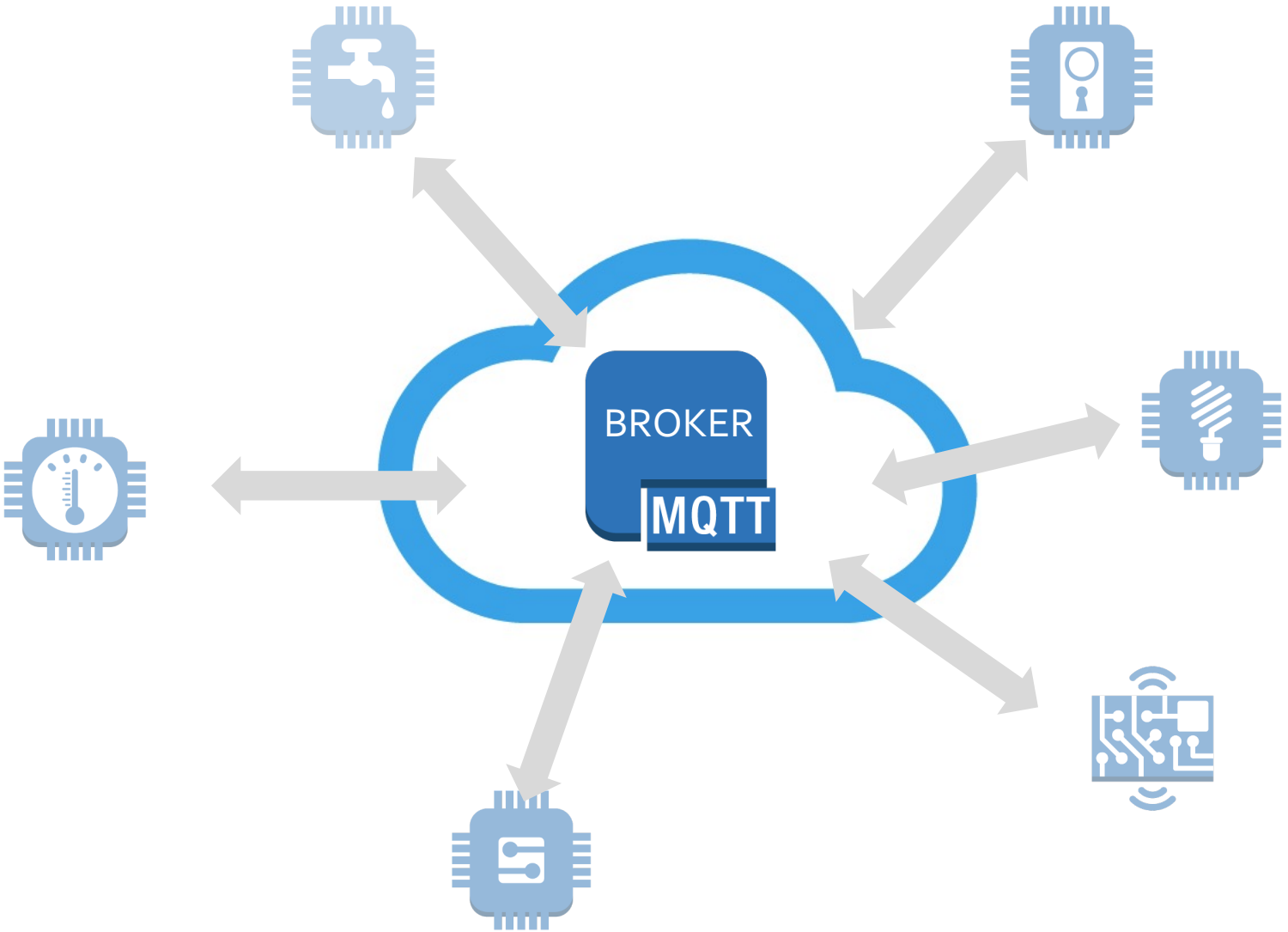
China	8,446
United States	4,733
Germany	1,719
Hong Kong	1,614
Taiwan	1,565

Intro to MQTT

- ✓ Brokers and clients



Creating a broker



Available MQTT brokers

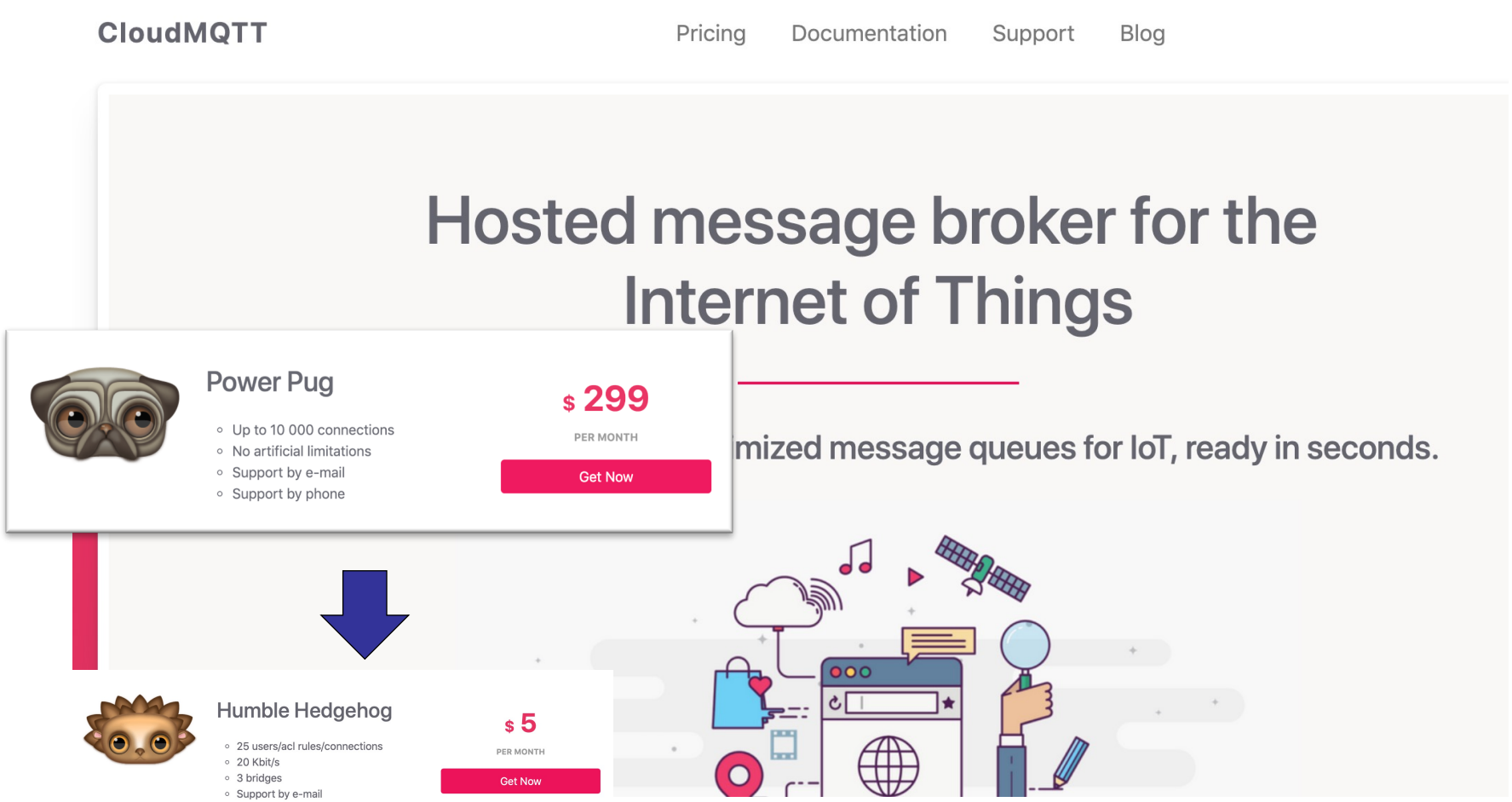
- The most widely used are:
  - http://mosquitto.org/
    - man page: https://mosquitto.org/man/mosquitto-8.html
  - http://www.hivemq.com/
    - The standard trial version only supports 25 connections.

- And also:
  - https://www.rabbitmq.com/mqtt.html
  - http://activemq.apache.org/mqtt.html

- A quite complete list can be found here:
  - https://github.com/mqtt/mqtt.github.io/wiki/servers

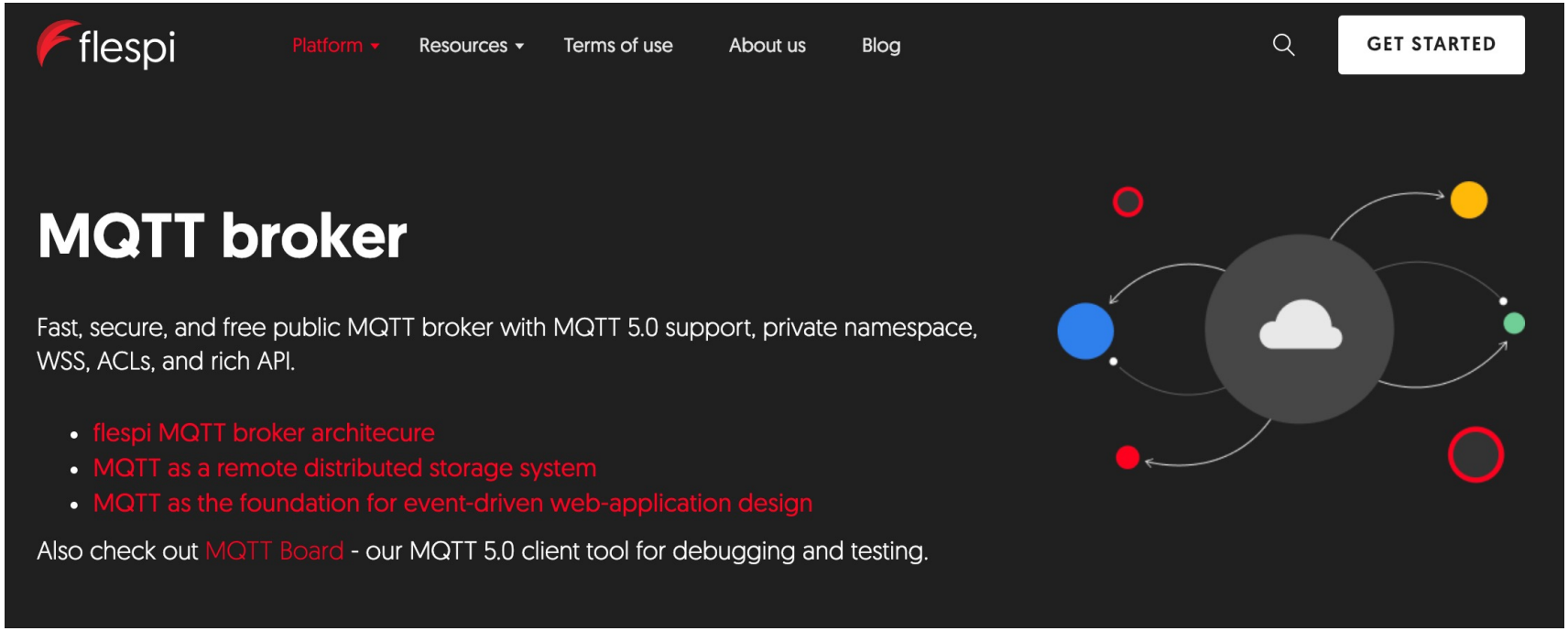
Cloud based MQTT brokers: CloudMQTT

https://www.cloudmqtt.com/ ➔ based on Mosquitto



Cloud based brokers: flespi

https://flespi.com/mqtt-broker



Cloud based brokers: flespi

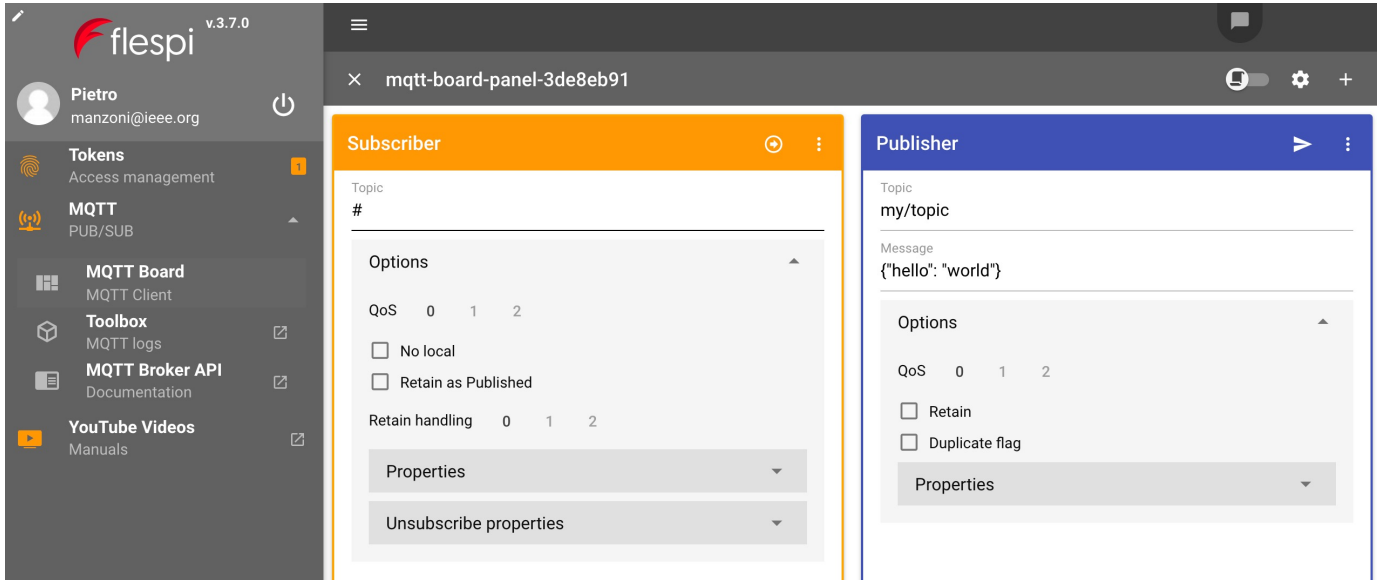
Terms of use

Free $0/mo

MQTT

100 active MQTT sessions

https://flespi.io/#/panel/mqttboard



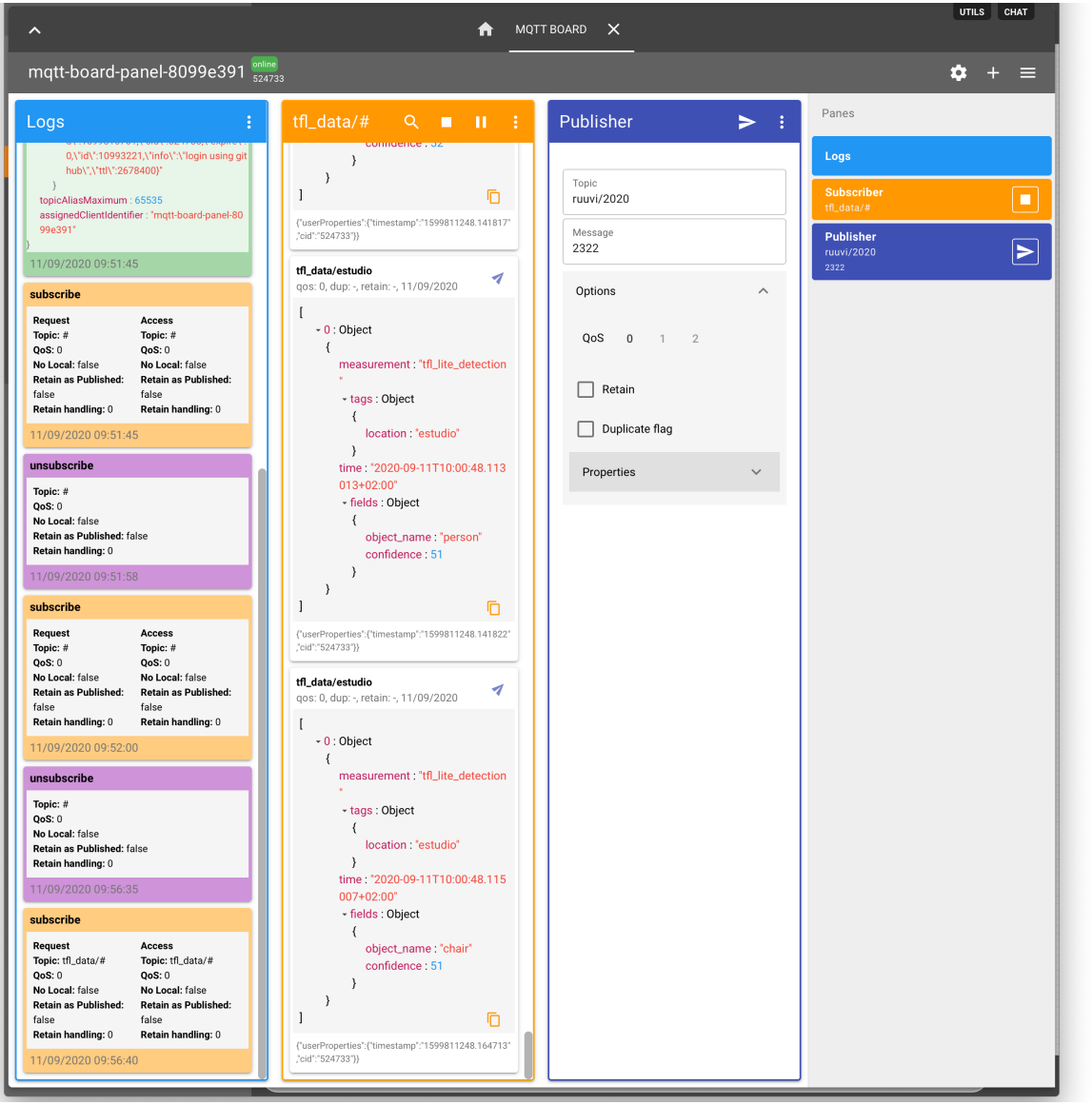
https://flespi.com/mqtt-api

flespi MQTT broker connection details

- **Host** — **mqtt.flespi.io**.
  Port — **8883 (SSL)** or **1883 (non-SSL)**; for MQTT over WebSockets: **443 (SSL)** or **80 (non-SSL)**.
- **Authorization** — use a flespi platform token as MQTT session username; no password.
- **Client ID** — use any unique identifier within your flespi user session.
- **Topic** — you can publish messages to any topic except **flespi/**.
- **ACL** — both **flespi/** and **MQTT pub/sub** restrictions determined by the token.

```
I1RKMMIUJpplQoSgAQ8MvDUJWNNJ9R2HIJgijO1S1gt5rajaeIOaiaKWwlHt2z1z
```

Flespi dashboard



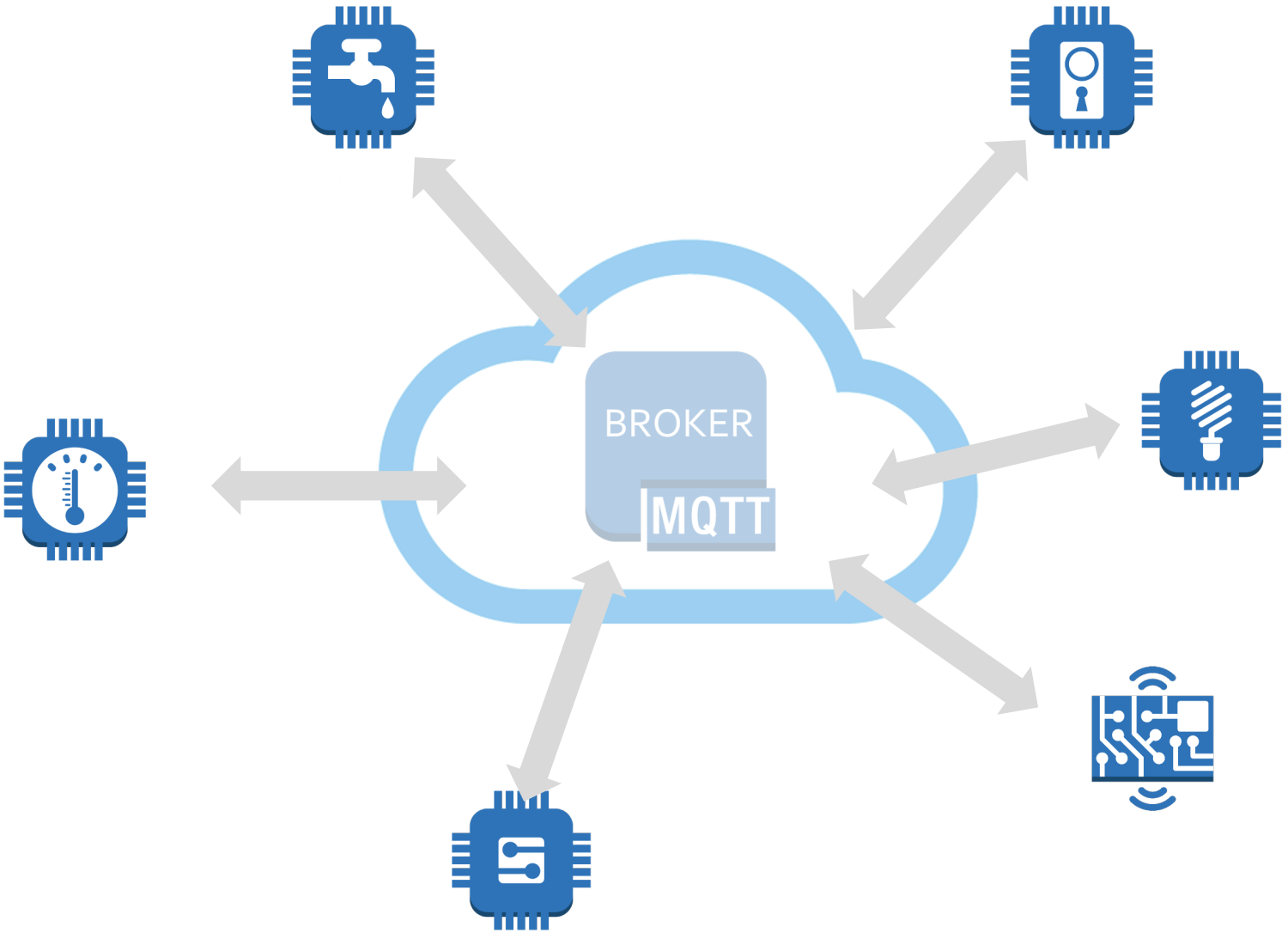
Open brokers ("Sandboxes")

- TCP based:
  - https://iot.eclipse.org/getting-started/#sandboxes
    - Hostname: **iot.eclipse.org**
  - http://test.mosquitto.org/
    - Hostname: **test.mosquitto.org**
  - https://www.hivemq.com/mqtt-demo/
    - Hostname: **broker.hivemq.com**
    - http://www.mqtt-dashboard.com/
  - Ports:
    - standard: 1883
    - encrypted: 8883 *(TLS v1.2, v1.1 or v1.0 with x509 certificates)*

- Websockets based:
  - broker.mqttdashboard.com port: 8000
  - test.mosquitto.org port: 8080
  - broker.hivemq.com port: 8000

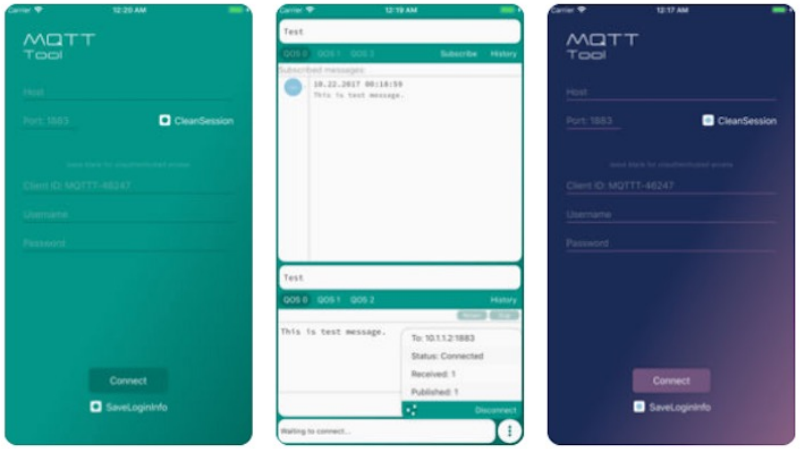
- https://github.com/mqtt/mqtt.github.io/wiki/public_brokers

Creating clients

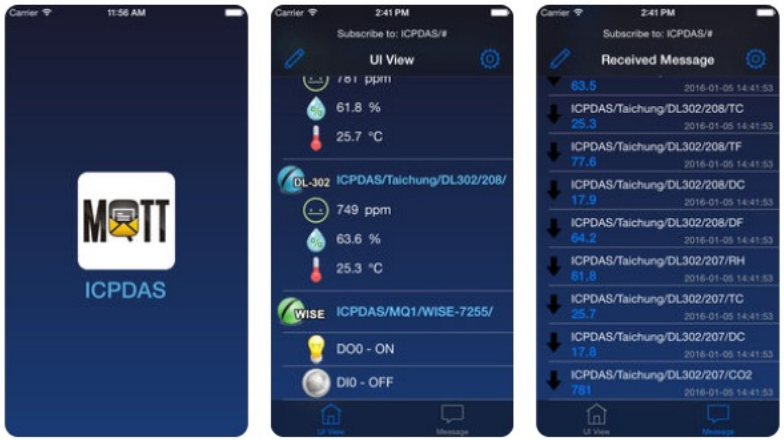


MQTT clients: iOS

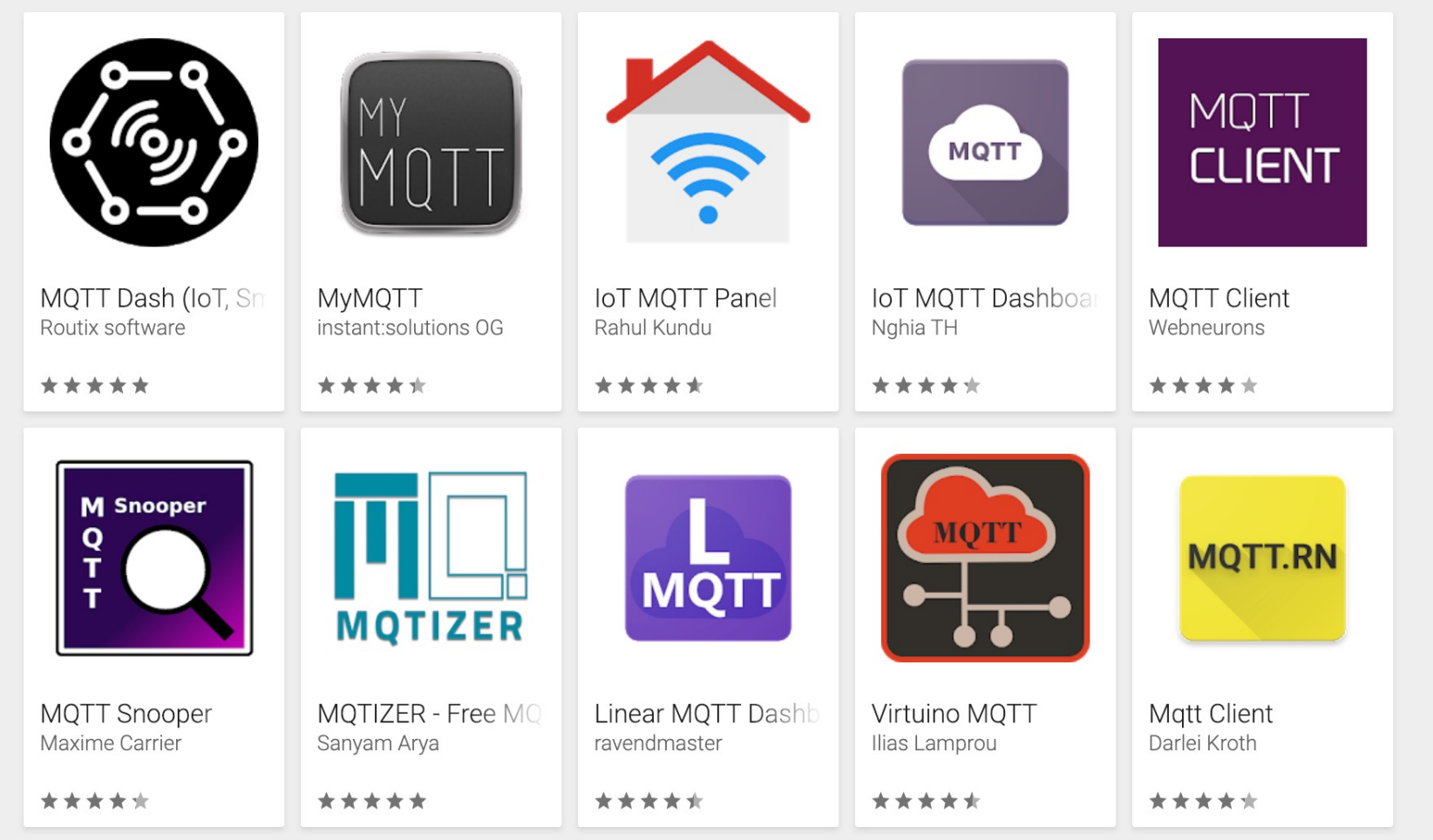
Mqttt
Utilidades



ICPDAS MQ...
Utilidades

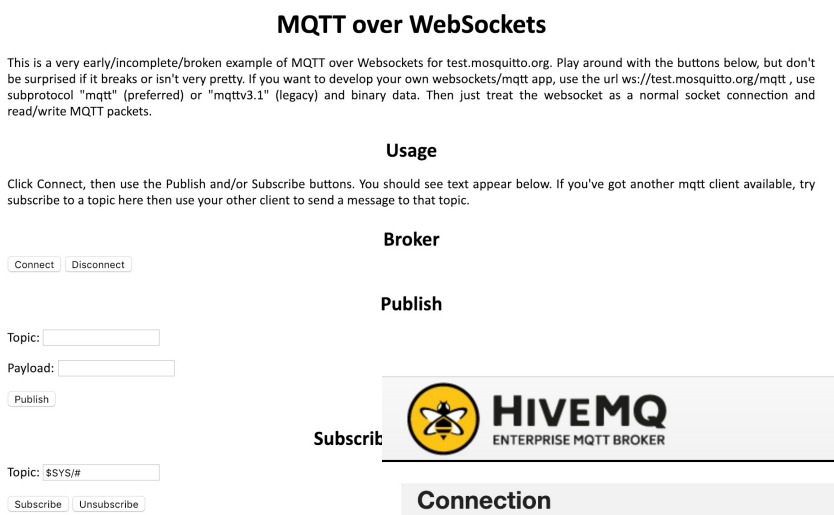


MQTT clients: Android

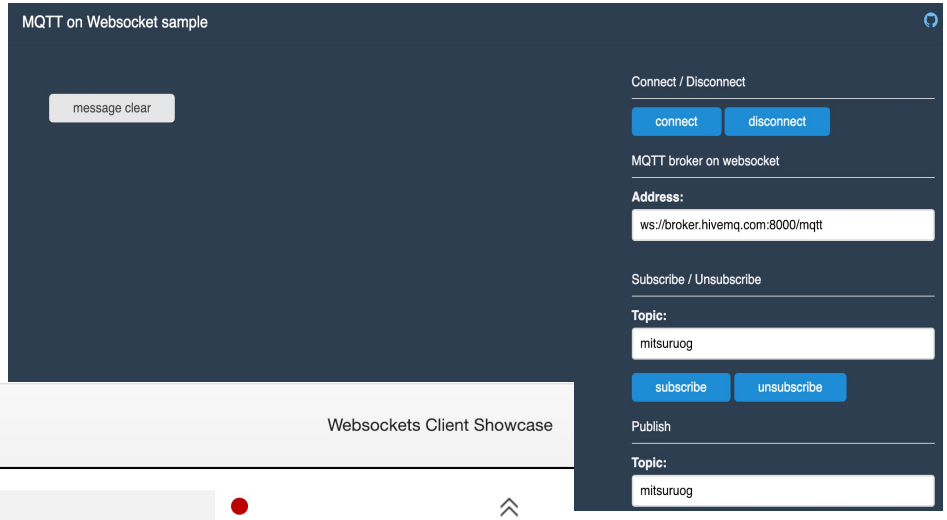


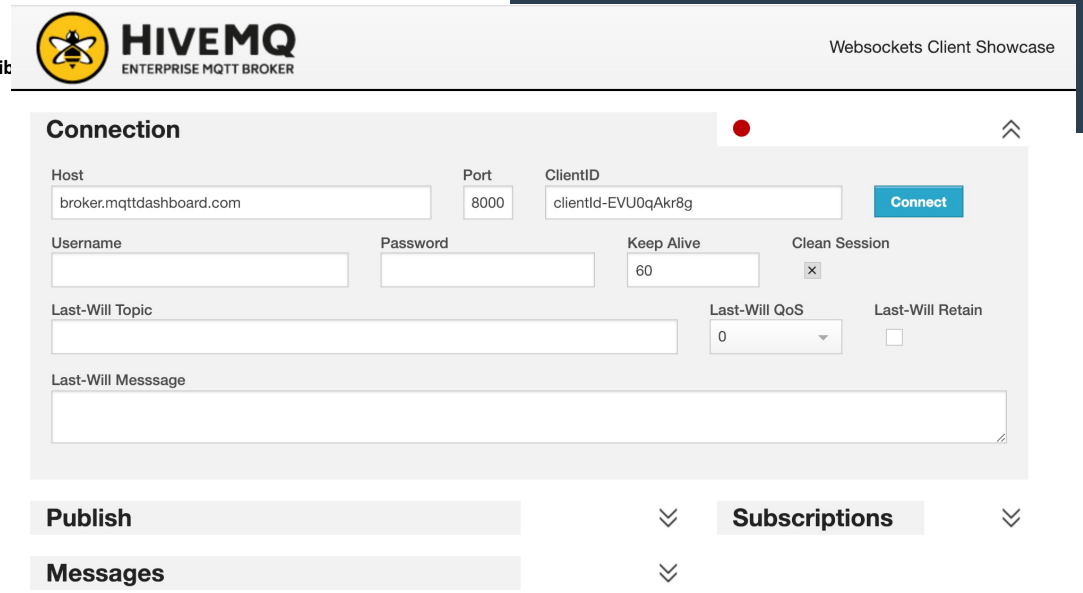
MQTT websocket clients

http://test.mosquitto.org/ws.html



http://mitsuruog.github.io/what-mqtt/





http://www.hivemq.com/demos/websocket-client/

http://mqtt-explorer.com