Electronics for IoT

MQTT

Bernhard E. Boser
University of California, Berkeley
boser@eecs.berkeley.edu

So Far …

- INA219 to measure V, I, P
  - Photocell characterization
  - Many other applications

- I2C to send data from INA219 to ESP32
  - Great for local (short range) communication (ex: between chips on a board)
  - Will be used again for other sensors!

- Connect MCU to WiFi

Data Communication Options

- How do we send data to/from ESP32 to remote host computer?
- Need a protocol … i.e. established set of rules for communication
- HTTP protocol

  + ubiquitous

  - verbose
    - visual output difficult to parse
    - one way
    - needs webserver

- We will use MQTT over WiFi

MQTT

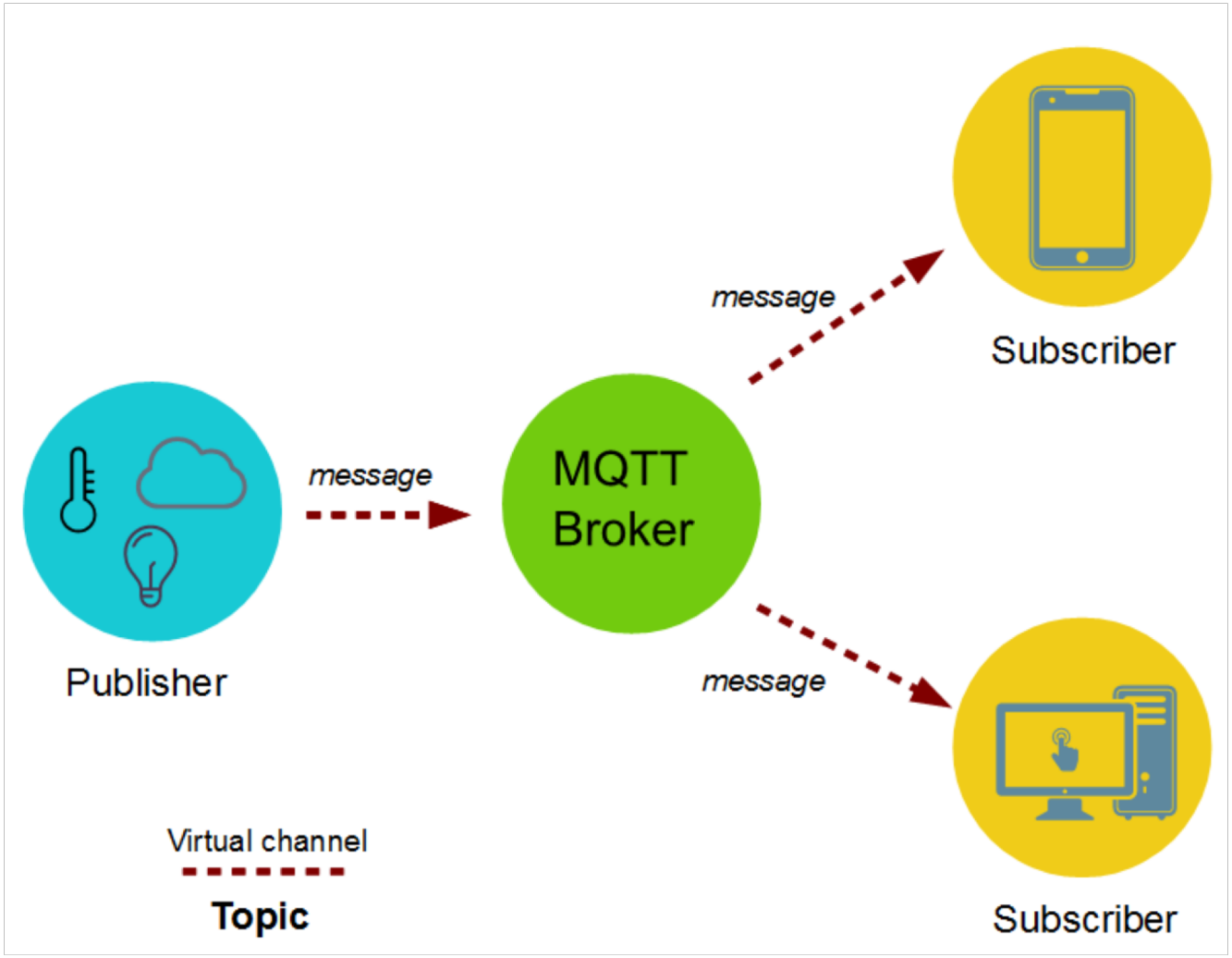
- Message Queuing Telemetry Transport
  - Misnomer: no queuing
  - Lightweight machine-machine messaging protocol
  - Lightweight →
    - low communication bandwidth,
    - suitable for implementation on resource-constrained devices
- Standard
  - ISO/IEC PRF 20922
  - Lot's of support available:
    - Implementations in many computer languages (e.g. Python)
    - Tutorials, documentation …
      - E.g. https://www.hivemq.com/blog/how-to-get-started-with-mqtt
      - Many others

Facebook Messenger uses MQTT

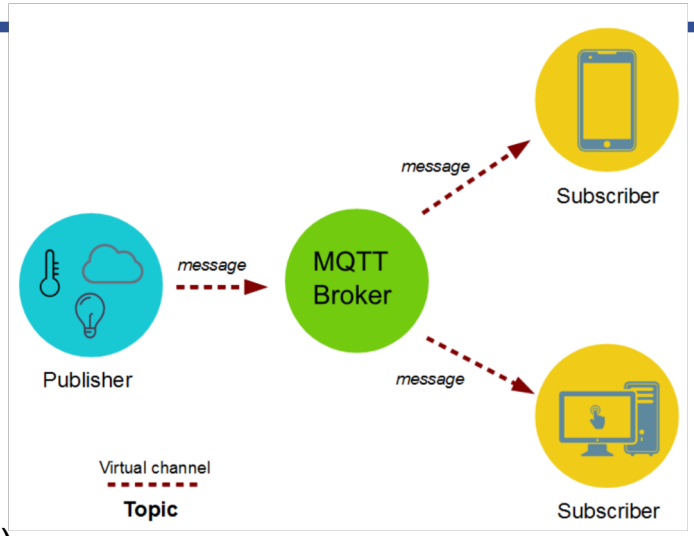
- https://www.hackerearth.com/blog/internet-of-things/mqtt-protocol/

- Why?
  - Low bandwidth use
  - Low power use
  - Supports many-2-many
  - Scalable: supports millions of u

MQTT Publish/Subscribe



A Cable TV Analogy



- Publisher: cable company
- Broker: internet provider
- Subscriber: household
- Topic: channel you can buy (ex: ESPN)
- Message: an episode (SportsCenter on 9/10/2018)

- Publisher sends out all messages on a topic
- All subscribers receive all messages on topics they subscribe to
- Routing of messages managed by broker
- Publisher doesn't need to know details of subscribers (ex: IP address)

MQTT Features

- Clients need only know broker, not each other
  - No “what’s your IP address”
  - Asynchronous:
    - No connection issues (“turn this on first, then …”)
- Text messages
  - Lightweight – good for low bandwidth situations
  - Easy parsing (you choose format)
- Topics
  - Organization
  - Hierarchical, separated by /, e.g.
    - solar/current, solar/voltage, kitchen/temperature, stocks/DJIA
    - alice/solar/current, fred/solar/current

MQTT Messages

- Topic
  - Hierarchical, separated by /
  - E.g.
    - Kitchen/temperature
    - IBM/stockprice
    - …
- Message
  - Arbitrary text

Putting it all together …

- Broker
- Client
  - Python library “MQTTClient”
  - Topics
  - Messages
  - QoS
- Security

MQTT Broker

- "Hub" of the service
- Many service offerings:
  - Amazon AWS, Microsoft Azure, IBM Watson, …
  - Free brokers for testing (no security)
    - iot.eclipse.org
    - iot49.eecs.berkeley.edu
  - Roll your own …
    - https://mosquitto.org

Sharing Brokers

- Typically, brokers are shared among many users
  - Thousands or millions on commercial servers, e.g. Amazon AWS
- That's great for sharing data and collaboration, e.g.
  - `boston/temperature`
  - `berkeley/temperature`
  - …
- But if several users send unrelated information to the same topic, e.g. everybody in EE49
  - `solar_panel_current`
- … the result is a mess!

Cooperatively sharing MQTT Brokers

- Prefix all topics with unique identifier, e.g.
  - `bernhardboser/current`
  - `aliceguyon/current`
- Commercial brokers enforce this
- Others, e.g.
  - `iot.eclipse.org`
  - `iot49.eecs.berkeley.edu`
- … rely on users following an agreed convention
- EE49:
  - Prefix all topics with your name
  - Beware of multiple participants with same name … (UID?)

MQTT Step 1: Initialize

```
from mqttclient import MQTTClient
import network
import sys
import time

session = "insert unique session here”  # change this!
BROKER = "iot.eclipse.org"
```

MQTT Step 2: Check Wifi connection!!!

```
# check wifi connection!
wlan = network.WLAN(network.STA_IF)
wlan.active(True)
if not wlan.isconnected():
        print("no wifi connection")
        sys.exit()
else:
        print("connected to WiFi at IP", ip)
```

MQTT Step 3: Setup MQTT

```
# connect to MQTT broker
print("Connecting to MQTT broker", BROKER, "...", end="")
mqtt = MQTTClient(BROKER)
print("Connected!")

# Define function to execute when message is received on subscribed topic
def mqtt_callback(topic, msg):
    print("RECEIVE topic = {}, msg = {}".format(topic.decode('utf8'),  …
                                    msg.decode('utf-8')))

# Set callback function
mqtt.set_callback(mqtt_callback)

# Set subscribe topic
mqtt.subscribe(session + "/host/hello")
```

MQTT Step 4: Publish, Subscribe loop

```
for t in range(100):
        # Microcontroller sends hello statements
        topic = "{}/mcu/hello".format(session)
        data = "hello" + str(t)
        print("send topic='{}' data='{}'".format(topic, data))
        mqtt.publish(topic, data)
        # Check for any messages in subscribed topics
        for _ in range(10):
        mqtt.check_msg()
        time.sleep(0.5)

# free up resources
mqtt.disconnect()
```

Lab 3, part B: Skeleton of IoT App

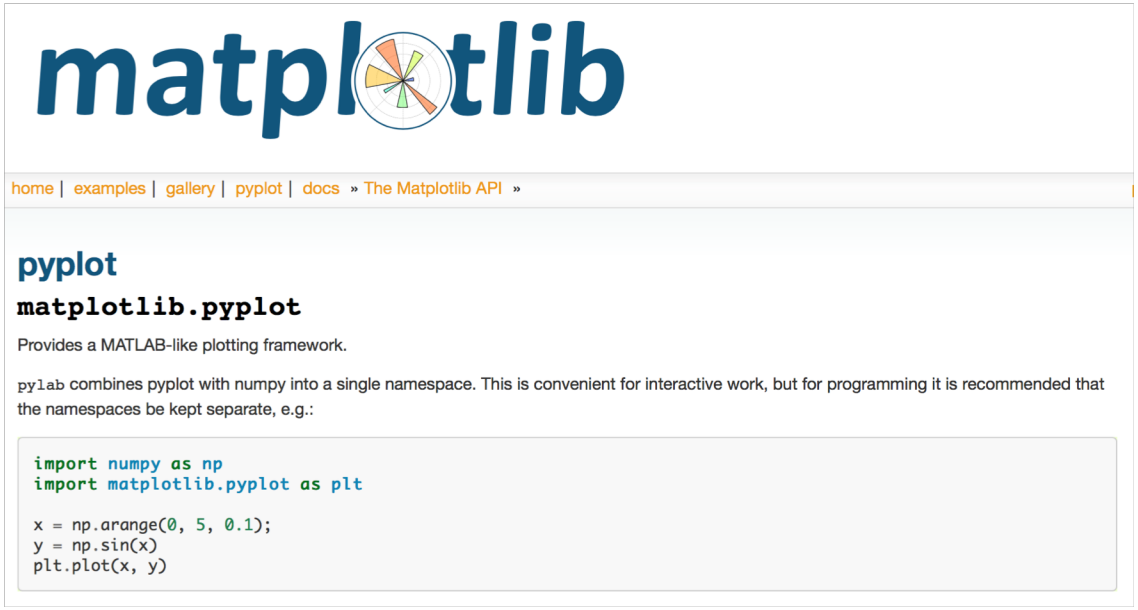
1. Establish Internet connection
   - E.g. `boot.py`
2. Initializations
   - MQTT client
   - I2C and INA219
3. On host:
   - Start MQTT client and subscribe …
4. Collect data
   - Measure solar cell I/V characteristic and send to cloud
5. Instruct host to create plot

Plotting

- Transfer data from ESP32 to host computer (ex: laptop)
- Then plotting is easy
  - Matlab, Excel, Python, …
- Within python, you can use matplotlib

Python Plotting Library

- https://matplotlib.org
- Similar to matlab

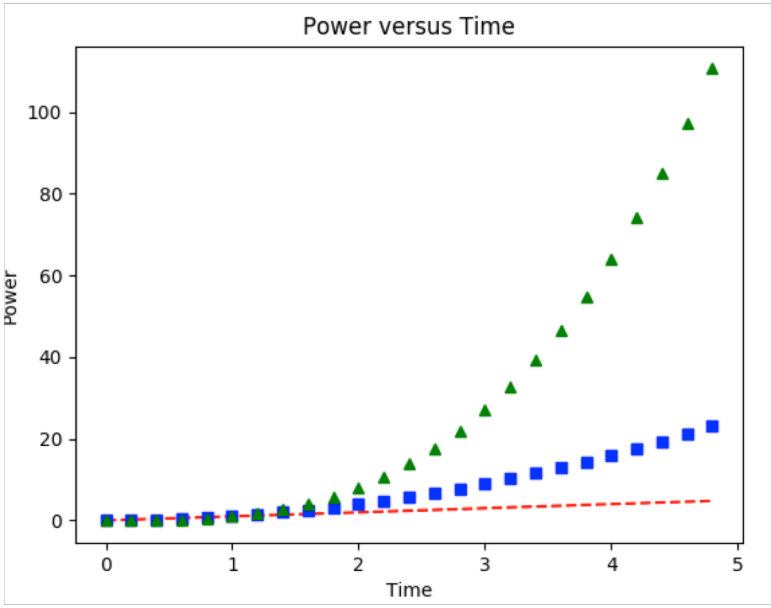


Pyplot Example (matlab style)

```
import numpy as np
import matplotlib.pyplot as plt

# evenly sampled time at 200ms intervals
t = np.arange(0., 5., 0.2)

# red dashes, blue squares and green triangles
plt.plot(t, t, 'r--', t, t**2, 'bs', t, t**3, 'g^')
plt.xlabel('Time')
plt.ylabel('Power')
plt.title('Power versus Time')
plt.show()
```



subscribe

```
def mqtt_callback(topic, msg):
    print("RECEIVE topic = {}, msg = {}".format(topic, msg))

mqtt.set_callback(mqtt_callback)
mqtt.subscribe("iot49/a")
mqtt.subscribe("iot49/b")

while True:
    mqtt.check_msg()
```

What's wrong with these topics?

publish

```
topic = "iot49/esp32"
message = "hi there!"
mqtt.publish(topic, message)
```

publish – subscribe loop

```
for i in range(1000):
    topic = "iot49/esp32"
    message = "hello " + str(i)
    print("PUBLISH topic = {} message = {}".format(topic, message))
    mqtt.publish(topic, message)
    for _ in range(10):
        mqtt.check_msg()
        sleep(0.5)
```

Python strings / byte arrays

- byte:
  - 8-Bits of data
  - Can hold $2^8 = 256$ values
- char:
  - ~ 127 (ASCII) latin, decimals, and punctuation
  - Thousands with other alphabets (Greek, …)
- Python 3 treats bytes and chars different
  - Python 2 “blurs the lines”
  - Code that works in Python 2 won’t necessarily in Python 3
- Literals:
  - String: `'this is a string literal'`
  - Byte array: `b'this is a byte array literal'`

string / byte array conversions

```
>>> b'byte array'.decode('utf-8')
'byte array'
>>> 'some string'.encode('utf-8')
b'some string'
```

- Encoding:
  - E.g. utf-8 (many others)
  - For only latin characters, this rarely matters
  - For others, get funny symbols if incorrect …
- MQTT library uses byte arrays (not strings) …

Putting it all together …

- Broker
- Client
  - Python library “MQTTClient”
  - Topics
  - Messages
  - QoS
- Security

MQTT QoS

- QoS
  - 1: deliver at most one time
  - 2: deliver at least one time
  - 3: deliver exactly one time
- Optional arguments to publish and subscribe:
  - mqtt.publish(topic, message, qos=0)
  - mqtt.subscribe(topic, qos=0)
- Not all brokers and clients support all QoS levels
- MQTT has a few other features
  - E.g. last will
  - Check the online documentation