IoT Security and Privacy

Lightweight IoT communication protocol:
Message Queuing Telemetry Transport (MQTT)

Learning Outcomes

Upon completion of this unit:

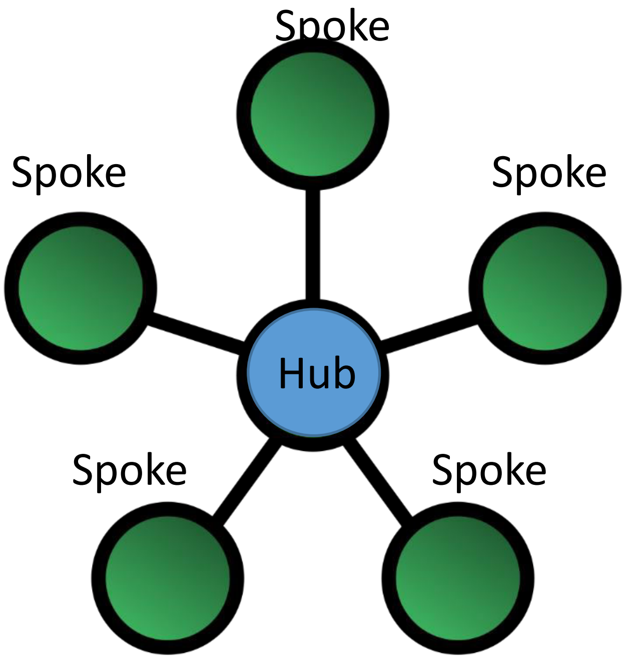
1. Students wills understand the IoT communication protocol Message Queuing Telemetry Transport (MQTT)
2. Students will be able to install, configure and use the MQTT implementation – Mosquitto
3. Students will be able to configure the use of SSL with Mosquitto to secure communication
4. Students will be able to configure the use of SSL with Mosquitto for authentication

Outline

- Message Queuing Telemetry Transport (MQTT)
- MQTT implementation: mosquitto
- MQTT Mosquitto transport security
- MQTT authentication

Messaging Broker System

- A messaging broker system uses a publish/subscribe protocol based on a “hub and spoke” model
  - Hub: server/broker
  - Spokes: clients
- Clients communicate with each other through the hub



Message Brokering Basic Terms

- **Broker**, called “servers” too
  - Accepts messages from clients
  - Delivers the messages to any interested clients
- **Client**
  - Publishes a message to a topic, or
  - Subscribes to a topic
  - or both.
- **Topic**: A *namespace* for messages on the broker
  - A forward slash / is used to separate the topic hierarchy
  - Clients do not need to initialize a topic before subscribing and publishing, and the broker will process the request automatically
  - e.g., myhome/groundfloor/familyroom/humidity

Message Brokering Basic Terms (Cont’d)

- **Publish**: a client sends a message to the broker, using a topic name.
- **Subscribe**: a client notifies the broker the topics of interest
  - The broker sends messages published to that topic to subscribers
  - A client can subscribe to multiple topics.
- **Unsubscribe**:
  - Tell the broker not to send the client the messages to a particular topic any more

MQTT Introduction

- MQTT is a messaging broker system
- Clients can publish (Pub) messages and subscribe (Sub) to topics.
  - Clients can both publish and subscribe.
- A broker communicates with clients.
- Topics can have subtopics.
  - Topics starting with $ are reserved for special topics
  - Refer to AWS IoT topics

Why not just use HTTP?

- HTTP is heavy
  - A lot of fields in the headers.
  - Needs multiple POST operations to distribute one message to multiple clients while a MQTT broker needs one publish
- A message brokering system is light
  - An MQTT packet can be only 2 bytes.

Representational state transfer (REST) v.s. HTTP

- REST-compliant Web services define operations for clients to work on web resources
  - **Roy Fielding** defines REST in 2000 in his Ph.D dissertation
- Roy Fielding used REST to design HTTP 1.1 and Uniform Resource Identifiers (URI).
  - RESTful Web service operations through HTTP verbs GET, POST, PUT, DELETE
  - Note: HTTP was initiated by Tim Berners-Lee

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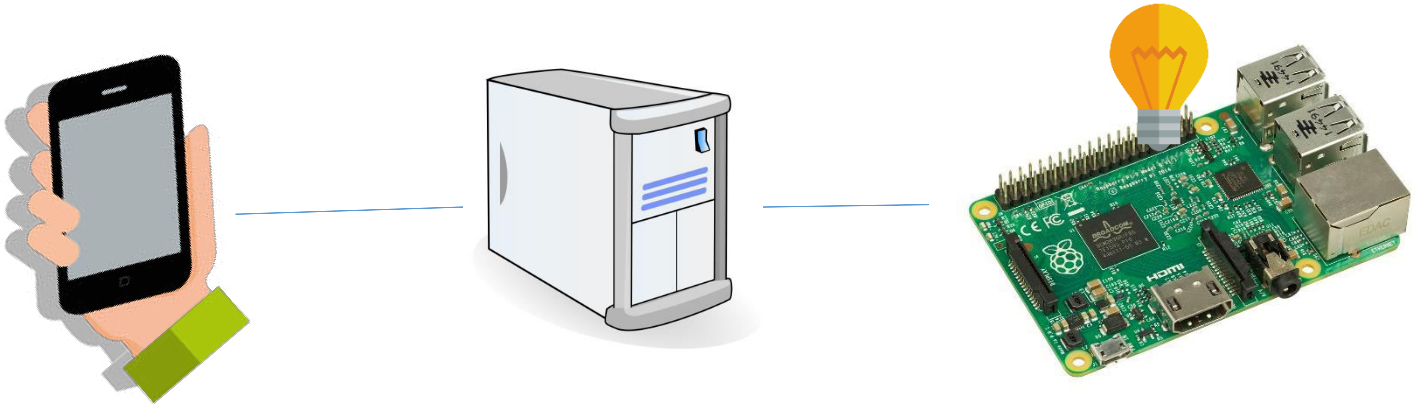
Example IoT system

- Example IoT system components
  - Smartphone – controller
  - MQTT server – broker
  - Client: IoT device



Client

Broker

Client

Mosquitto

- Open source MQTT Mosquitto is a broker server
  - Shipped with publishing and subscribing utilities - use *mosquitto_pub* and *mosquitto_sub*
- **Windows**: binary installers on mosquitto.org
- **Linux**: install “mosquitto” or “mosquitto-mqtt” with a package manager
- **Mac**: use homebrew to install mosquitto.
  - Add /usr/local/sbin to PATH by editing /etc/paths if necessary
- Running Mosquitto
  - Runs on port 1883 with no security by default

Testing Mosquitto

- On one computer, we can test the whole MQTT system
- 1nd console (terminal): the server
  - mosquitto -v # verbose mode
- 2rd console: subscribing to MQTT Topic with Mosquitto
  - mosquitto_sub -h 127.0.0.1 -i testSub -t debug
  - **Host flag (-h)** indicates the mosquitto server
  - **Identity flag (-i)** is client id. mosquitto_sub creates one if not provided.
  - **Topic flag (-t)** incidicates the topic to subscribe
- Notice: no topic is pre-created on the server
  - The topic is created when the subscriber or publish connect to the server.

Raspberry Pi as MQTT Client

- Choice one:
  - Install mosquitto and use mosquitto_pub and mosquitto_sub to communicate with a MQTT server.
- Choice two:
  - Write a client with an MQTT library for a preferred language like Python

Install MQTT for Python

- MQTT Python library: Paho Python Client
  - Open source
  - Supports the latest version of MQTT.

- Installation
  - Install “pip”
  - *pip install paho-mqtt*
  - Or *pip3 install paho-mqtt* for python v3

Example MQTT Python Code for Raspberry Pi

```python
import paho.mqtt.publish as publish
import time
print("Sending 0...")
publish.single("ledStatus", "0", hostname="macman")
time.sleep(1)
print("Sending 1...")
publish.single("ledStatus", "1", hostname="macman")
```

single - Publish a single message to a broker, then disconnect cleanly.

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Mosquitto broker with SSL/TLS

- **Generating the server certificates**
  - wget https://github.com/owntracks/tools/raw/master/TLS/generate-CA.sh .
  - This script generates a self signed certificate to be used by Mosquito for providing TLS for the MQTT and WebSocket protocol.
  - openssl is needed.
- The following files are generated:
  - **ca.crt –** The CA (Certificate Authority, who published the host certificate) public certificate.
  - **hostname.crt –** The hostname, that will run the mosquitto broker, public certificate.
  - **hostname.key –** The hostname private key.

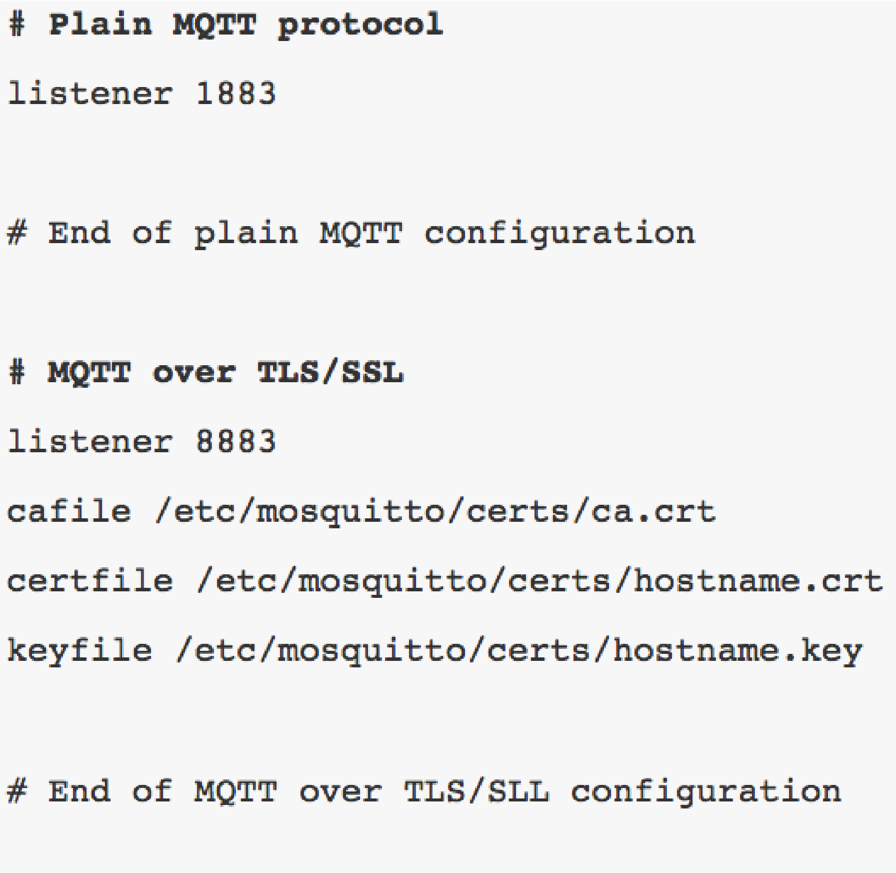
Create a folder for certificates and key files

- Copy the certificates and key files to a folder.
  - sudo -s
  - mkdir -p /etc/mosquitto/certs
  - cp ca.crt /etc/mosquitto/certs
  - cp hostname.* /etc/mosquitto/certs

mosquitto.conf

- **mosquitto.conf**
  - Configuration file for mosquitto.
  - Can be put anywhere.
  - By default, mosquitto does not need a configuration file and will use the default values.
  - Refer to the man page mosquitto(8) for information on how to load a configuration file.
- Format
  - Line with # as the very first character are comments.
  - Configuration lines: a variable name and its value separated by a single space.

Mosquitto configuration



```
# Plain MQTT protocol

listener 1883


# End of plain MQTT configuration


# MQTT over TLS/SSL

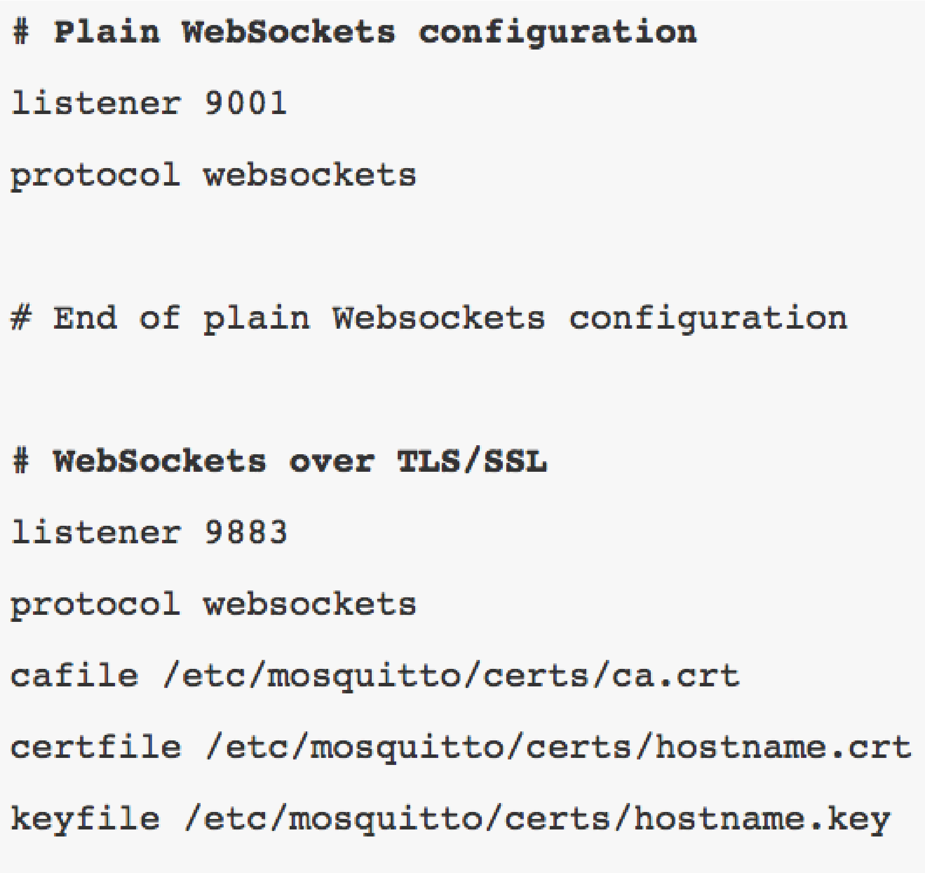
listener 8883

cafile /etc/mosquitto/certs/ca.crt

certfile /etc/mosquitto/certs/hostname.crt

keyfile /etc/mosquitto/certs/hostname.key


# End of MQTT over TLS/SLL configuration
```



```
# Plain WebSockets configuration

listener 9001

protocol websockets


# End of plain Websockets configuration


# WebSockets over TLS/SSL

listener 9883

protocol websockets

cafile /etc/mosquitto/certs/ca.crt

certfile /etc/mosquitto/certs/hostname.crt

keyfile /etc/mosquitto/certs/hostname.key
```

Testing MQTT TLS/SSL configuration

- mosquitto_pub --cafile /etc/mosquitto/certs/ca.crt -h localhost -t "test" -m "message" -p 8883

- mosquitto_sub -t \$SYS/broker/bytes/\# -v --cafile /etc/mosquitto/certs/ca.crt -p 8883

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Authentication

- By default, no authentication

- Unauthenticated encrypted support is provided through the use of the certificate based SSL/TLS based options cafile/capath, certfile and keyfile.
  - The broker needs to provide the client a certificate

username/password authentication

- Through *password_file*
  - Define usernames and passwords.

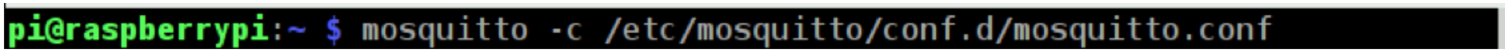
- If no encryption used, the username and password will be transmitted in plaintext
  - SSL/TLS should be used

Authentication via certificate based encryption

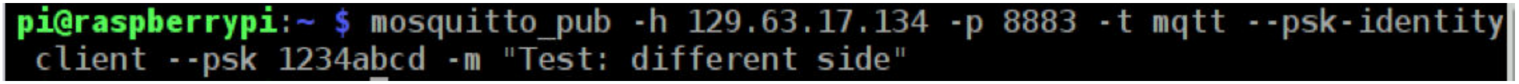
- Through *require_certificate,* which can be *true or false*
- If *require_certificate false*, no certificate based authentication for clients
  - Clients can verify server’s certificate
  - Authentication of clients will have to rely on username/password if needed
- If *require_certificate true*, the client must provide a valid certificate to the server before further communication
  - use*_identity_as_username* can affect the authentication.
    - If true, the Common Name (CN) from the client certificate is used as the identity
    - “If false, the client **must** (?) authenticate as normal (if required by password_file) through the MQTT options.”

pre-shared-key based encryption

- pre-shared-key based encryption through the *psk_hint* and *psk_file* options in the configuration file,
  - the client must provide a valid identity and key to connect to the broker



```
pi@raspberrypi:~ $ mosquitto -c /etc/mosquitto/conf.d/mosquitto.conf
```

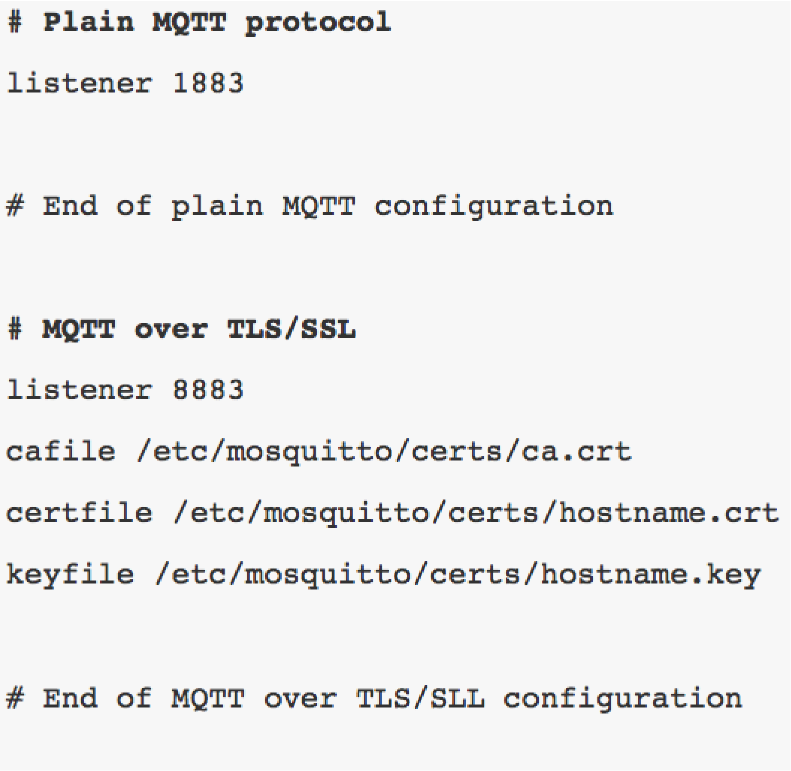


```
pi@raspberrypi:~ $ mosquitto_pub -h 129.63.17.134 -p 8883 -t mqtt --psk-identity
 client --psk 1234abcd -m "Test: different side"
```

- If use_identity_as_username is true
  - The PSK identity is used for access control purposes.
- If use_identity_as_username is false
  - The client may still authenticate via username/password so that different users have different passwords?
- Note: for programming paho does not support psk yet and c language libmosquitto supports it

Notes

- Certificate and PSK based encryption are configured for each listener.
- Authentication plugins can be created to replace the password authentication (*password_file)* and psk authentication *psk_file*
  - For example, database lookups.
- Multiple authentication schemes can be simultaneously supported



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certfile /etc/mosquitto/certs/hostname.crt
keyfile /etc/mosquitto/certs/hostname.key

# End of MQTT over TLS/SLL configuration
```

Reference

[1] James Lewis, MQTT Introduction and Tutorial Part One - Message Brokers and why your IoT device should use them, February 17, 2016.

[2] James Lewis, MQTT Tutorial for Raspberry Pi, Arduino, and ESP8266 - Send MQTT messages between 3 different platforms, February 24, 2016

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[6] J. Dunmire, SSL/TLS Client Certs to Secure MQTT, 2016

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