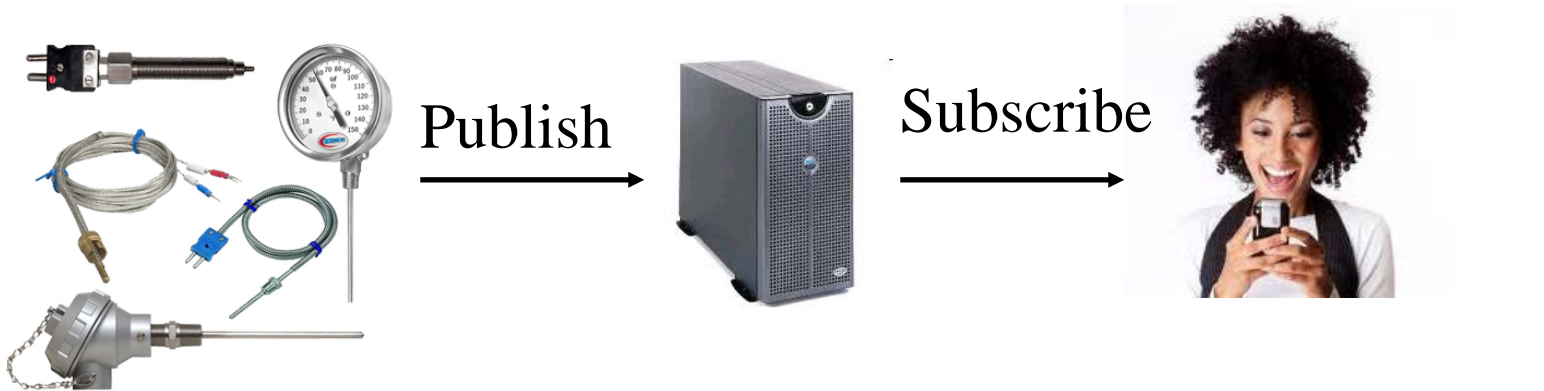# Messaging Protocols for Internet of Things: MQTT

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These slides and audio/video recordings of this class lecture are at:
http://www.cse.wustl.edu/~jain/cse570-21/

Student Questions

Overview

- MQ Telemetry Transport (MQTT)
  - MQTT Concepts
  - MQTT Application 2
  - MQTT vs. HTTP
- Hardware for IoT

- Note: This is 4th in a series of lectures on Internet of Things.
  Please see the URL on the first slide and every slide for other lectures of this series.

Student Questions

IoT Ecosystem

		Security	Management
Applications	Smart Health, Smart Home, Smart Grid Smart Transport, Smart Workspaces, …	TCG, Oath 2.0, SMACK, SASL, ISASecure, ace, CoAP, DTLS, Dice	IEEE 1905, IEEE 1451, …
Session	**MQTT**, CoRE, DDS, AMQP , …		
Routing	**6LowPAN**, **RPL**, 6Lo, 6tsch, Thread, 6-to-nonIP , …		
Datalink	WiFi, Bluetooth Smart, ZigBee Smart, Z-Wave, DECT/ULE, 3G/LTE, NFC, Weightless, **HomePlug GP**, 802.11ah, **802.15.4**, G.9959, WirelessHART, DASH7, ANT+ , LoRaWAN, …		
Software	Mbed, Homekit, AllSeen, IoTvity, ThingWorks, EVRYTHNG , …		
Operating Systems	Linux, Android, Contiki-OS, TinyOS, …		
Hardware	ARM, **Arduino**, Raspberry Pi, ARC-EM4, Mote, Smart Dust, Tmote Sky, …		

Student Questions

MQ Telemetry Transport (MQTT)

❏ Lightweight messaging protocol for M2M communication

❏ Telemetry = Tele-Metering = Remote measurements

❏ Invented and sponsored by IBM.
Now Open source. Open Source libraries available.

❏ MQ originated from "message queueing (MQ)" architecture used by IBM for service oriented networks. There is **no** queueing in MQTT.

❏ Telemetry data goes from devices to a server or broker.
Uses a publish/subscribe mechanism.

❏ Lightweight = Low network bandwidth and small code footprint

Student Questions

❏ Does MQTT support offline messages?

Offline can mean many things. The sensor (publisher), broker, network, or the user (subscriber) can be offline. All brokers store messages and so as long as they are up, messages will be available later for retrieval. Some sensors (e.g., video cameras) have local storage. If so, it can store data for some limited time. Users are mostly offline anyway. They come back once in a while and see important notifications.
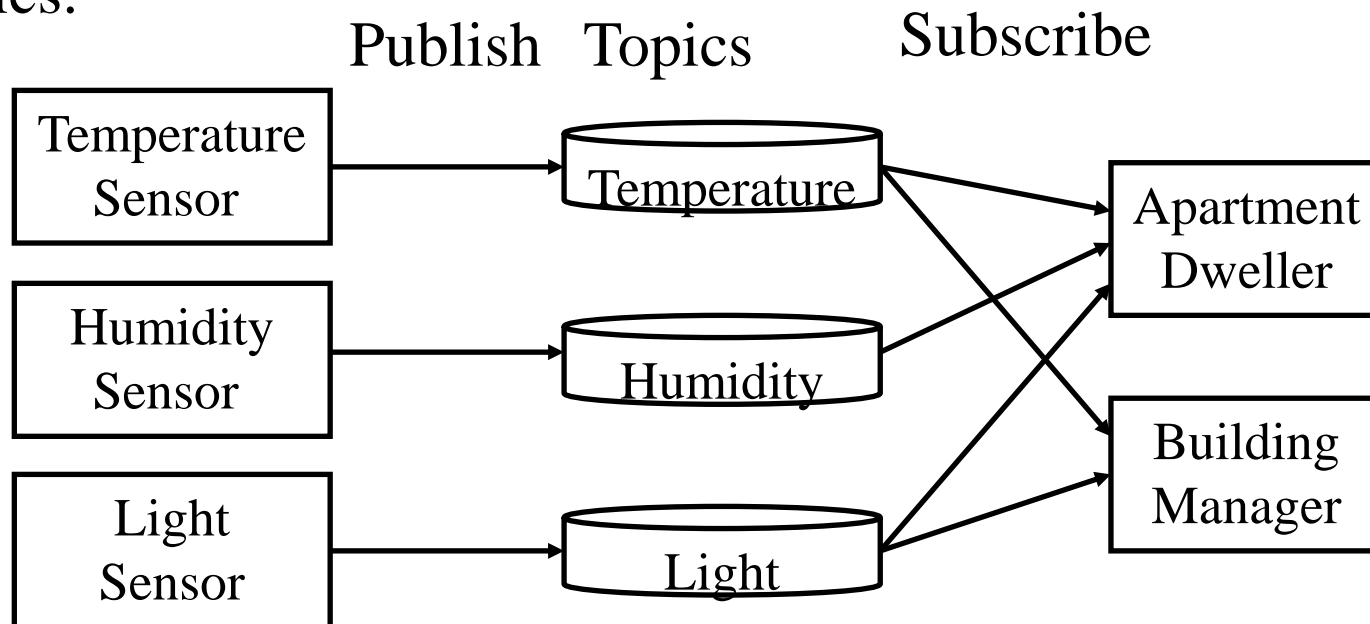
MQTT (Cont)

❑ Facebook messenger uses MQTT to minimize battery usage. Several other applications in medical, environmental applications

❑ Many open source implementations of clients and brokers are available

➢ Really small message broker (RSMB): C

➢ Mosquitto

➢ Micro broker: Java based for PDAs, notebooks

Student Questions

MQTT Concepts

❑ **Topics/Subscriptions**: Messages are published to topics. Clients can subscribe to a topic or a set of related topics

❑ **Publish/Subscribe**: Clients can subscribe to topics or publish to topics.

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Student Questions

MQTT Concepts (Cont)

❑ **Quality of Service Levels**: Three levels:

0 = At most once (Best effort, No Ack),

1 = At least once (Acked, retransmitted if ack not received),

2 = Exactly once [Request to send (Publish), Clear-to-send (Pubrec), message (Pubrel), ack (Pubcomp)]

❑ **Retained Messages**: Server keeps messages even after sending it to all subscribers. New subscribers get the retained messages

MQTT Concepts (Cont)

❑ **Clean Sessions** and **Durable Connections**: At connection set up:
Clean session flag ⇒ all subscriptions are removed on disconnect
Otherwise subscriptions remain in effect after disconnection
⇒ Subsequent messages with high QoS are stored for delivery after reconnection

❑ **Wills**: At connection a client can inform that it has a will or a message that should be published if unexpected disconnection
⇒ Alarm if the client looses connection

❑ Periodic **keep alive** messages ⇒ If a client is still alive

❑ **Topic Trees**: Topics are organized as trees using / character
/# matches all sublevels
/+ matches only one sublevel

Student Questions

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MQTT Example
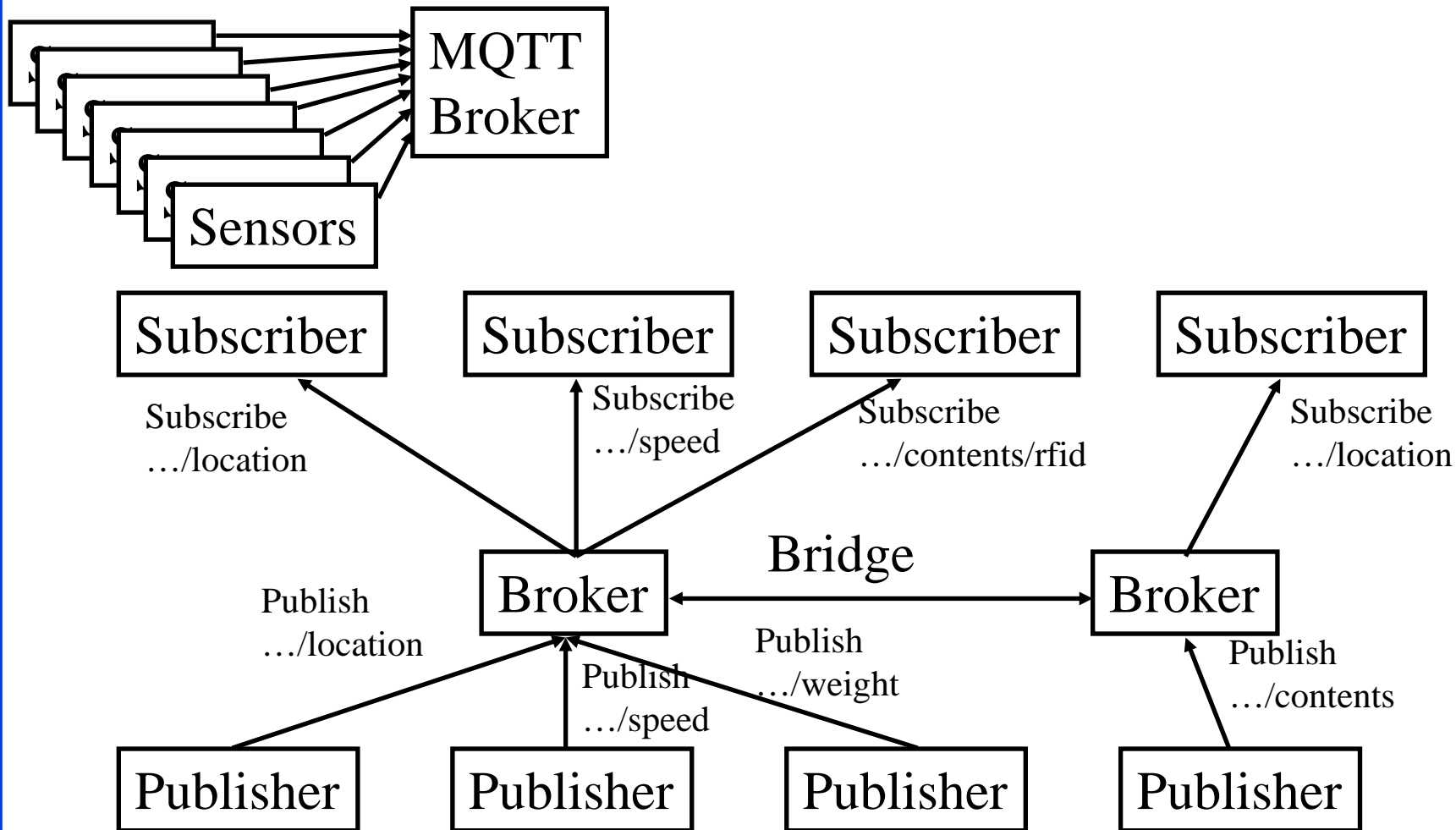
Student Questions

- What does a broker do? I could not find its definition in the MQTT specification https://docs.oasis-open.org/mqtt/mqtt/v5.0/os/mqtt-v5.0-os.html Can it have a queue?

Brokers work on behalf of many publishers. They are more powerful than publishers. Yes, they can have a queue.

- Why are the two brokers connected? Is it for backup?

Load balancing, ownership, specialization, additional services. For example, many IoT providers work with Amazon Alexa and so Alexa is also a broker.

- If subscriber_1 subscribe topic "device/location", subscriber_2 to "device/speed", if a publisher wants to publish message to all those two subscribers at the same time, which topic should it publish to?

Your example has two topics. Publishers will publish both topics. In some cases, two publishers are required if each topic requires a different publisher.

- ❖ Could you explain the broker's function in the MQTT?

See Above.

MQTT Application Examples

❑ Home pacemaker monitoring solution
- ➢ Sensors on patient
- ➢ Collected by a monitoring equipment in home (broker) using MQTT
- ➢ Subscribed by a computer in the hospital
- ➢ Alerts the doctor if anything is out-of-order
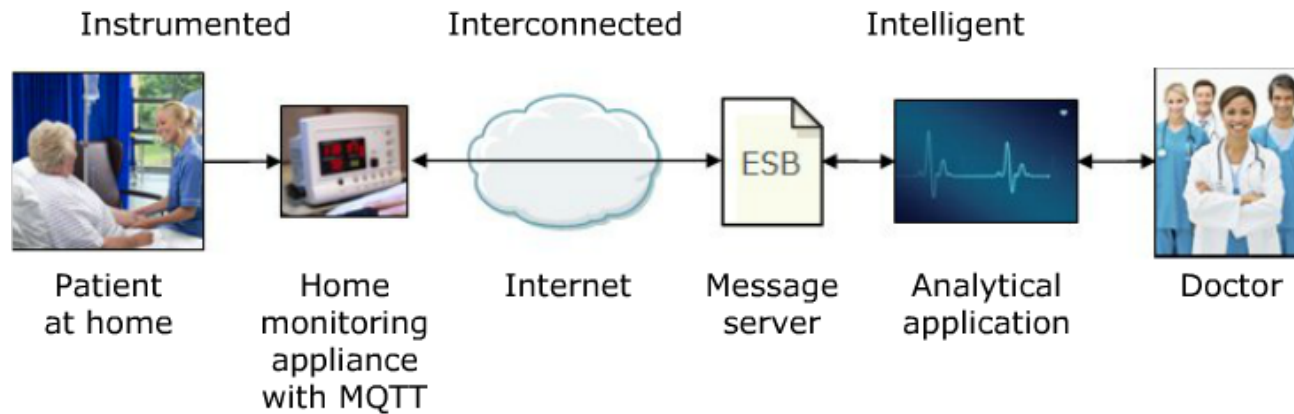
Source: Lampkin 2012

Student Questions

❑ What should be the Quality of Service Levels of this example?

Doctor and patients determine and specify the alert conditions. QoS also includes speed and resolution. It is determined by the cost of the system, e.g., high-cost cameras provide 4K video – high resolution video.

MQTT vs. HTTP

	MQTT	HTTP
Design	Data centric	Document centric
Pattern	Publish/Subscribe	Request /Response
Complexity	Simple	More Complex
Message Size	Small. Binary with 2B header	Large. ASCII
Service Levels	Three	One
Libraries	30kB C and 100 kB Java	Large
Data Distribution	1 to zero, one, or n	1 to 1 only

- ❑ Open source, http://www.eclipse.org/paho/
- ❑ Clients available in .NET, Perl, Python, REXX, Rube,
- ❑ Also for Arduino, Mbed, Nanode, Netduino

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Student Questions

- ❑ Can you explain the difference between 'data-centric' and 'document-centric'?

Data= computer-to-computer Documents = user-to-user or computer-to-user or user-to-computer. Documents are designed for humans.

- ❑ Does the fact that MQTT uses a broker provide any advantages or disadvantages compared to HTTP?

Sensors do not need multi-user server capability. This is an MQTT advantage.

- ❑ The publish/subscribe means the information change in the client who publish, the client who subscribe will immediately change at the same time. Is that correct?

No. Publish=Provide information Subscribe = Interested in information IoT devices publish and human users subscribe.

IoT Hardware

1. Single-Board Microcontrollers
2. Single-Board Computers
3. Single-Board AI Engines

Student Questions

Single-Board Microcontrollers

□ **Arduino**:
  ➢ Open-source hardware/software
  ➢ Name derived from Arduin of Ivrea (a King of Italy 1002-14)
  ➢ Can use a variety of microprocessors
    ❑ Many different products and form factors
  ➢ Standard digital and analog I/O pins
    ❑ Interface to many shields: Expansion boards for motors, Ethernet, GPS, Display, …
  ➢ Arduino IDE in Java w programming in C or C++
  ➢ Applications: Oscilloscope, Drone, Phone, …

□ 100+ microcontrollers listed in Wikipedia
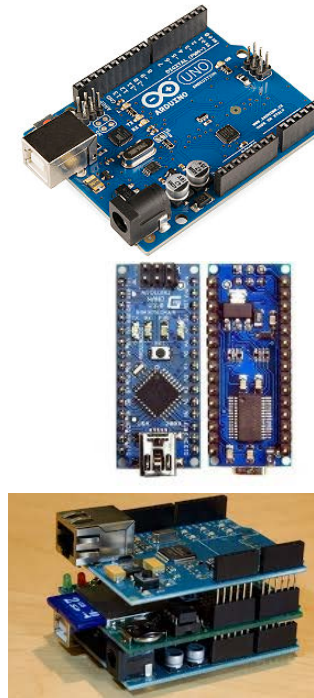
Student Questions

❑ Can we treat Arduino as a computer?
Generally, Arduino is used as an I/O device.
❑ Could you give some examples that something an Arduino can do, but Raspberry Pi can't, and vice versa?
Raspberry Pi is a computer. You may be able to run several versions of Linux on Raspberry Pi and attach Ethernet, Monitor, mouse, and keyboard to it. Arduino generally is connected to a Raspberry pi for these functions.

Ref: https://en.wikipedia.org/wiki/Arduino , https://en.wikipedia.org/wiki/Comparison_of_single-board_microcontrollers
http://www.cse.wustl.edu/~jain/cse570-21/
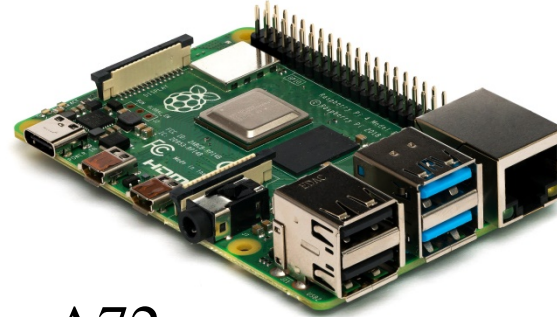
Single-Board Computers

❑ **Raspberry Pi**

  ➢ Currently V4 Model B

  ➢ Dual 4K displays

  ➢ 1.5 GHz 64-bit Quad-core ARM Cortex-A72

  ➢ Up to 4 GB RAM

  ➢ Supports Linux, Windows 10 (IoT Core), FreeBSD, etc.

  ➢ MicroSDHC, USB3, Gigabti Ethernet, 802.11ac Wi-Fi, Bluetooth

  ➢ Low cost: Around $35
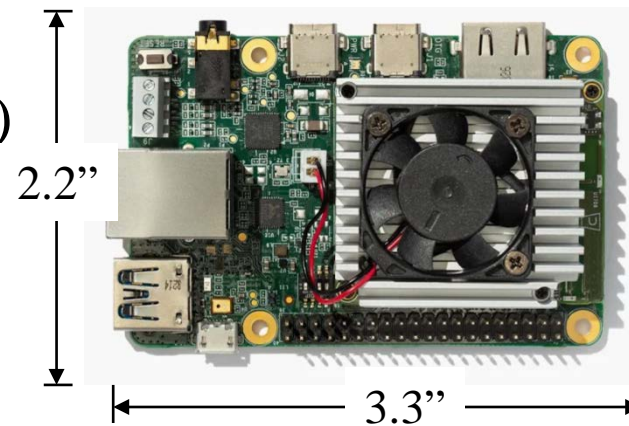
❑ See a list of 100+ other such computers in Wikipedia

Student Questions

Ref: https://en.wikipedia.org/wiki/Single-board_computer, https://en.wikipedia.org/wiki/Raspberry_Pi, https://www.raspberrypi.org/, https://en.wikipedia.org/wiki/Comparison_of_single-board_computers

Single-Board AI Engines

❑ **Google Coral Development Board**
  ➢ Edge Tensor Processing Unit (TPU)
  ➢ Machine learning accelerator
  ➢ Cryptographic co-processor
  ➢ Gigabit Ethernet, Wi-Fi, Bluetooth
  ➢ USB, MicroSD
  ➢ HDMI, 3.5mm Audio
  ➢ Supports Mendel Linux, TensorFlow Lite, …
  ➢ Low cost: Below $150
❑ Similar offerings from Nvidia (Jetson nano) and others

2.2"
3.3"

Ref: https://coral.withgoogle.com/docs/dev-board/datasheet/, https://en.wikipedia.org/wiki/Tensor_processing_unit

Student Questions
❑ Is TPU a combination of CPU and GPU? Or it has to be single one.
GPUs are designed for graphics, which require millions of pixels to be processed in parallel. This makes them good for AI where millions of data points have to be processed.
TPU is a CPU which has instructions and capacity for tensor processing and so it does not need a GPU for AI.

Summary
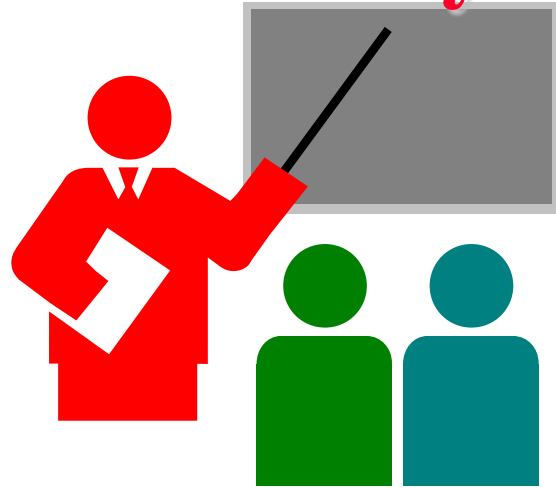
1. MQTT is a protocol used to publish and subscribe sensor information
2. Lightweight, low code size, open source
3. Hardware for IoT is moving from small controllers to intelligent Edge TPUs

Student Questions

❖ Are there any security implications of the protocol since it is lightweight?

Yes. IoT security is a topic of research. MQTT is one component in the IoT protocol chain that can be broken.

Reading List

❑ V. Lampkin, et al., "Building Smarter Planet Solutions with MQTT and IBM WebSphere MQ Telemetry," IBM Redbooks, SEP-2012, ISBN: 0738437085, 268 pp.,
http://www.redbooks.ibm.com/redbooks/pdfs/sg248054.pdf

Wikipedia Links

❑ https://en.wikipedia.org/wiki/MQ_Telemetry_Transport

❑ https://en.wikipedia.org/wiki/Arduino

❑ https://en.wikipedia.org/wiki/Comparison_of_single-board_computers

❑ https://en.wikipedia.org/wiki/Comparison_of_single-board_microcontrollers

❑ https://en.wikipedia.org/wiki/Raspberry_Pi

❑ https://en.wikipedia.org/wiki/Single-board_computer

❑ https://en.wikipedia.org/wiki/Tensor_processing_unit

Student Questions

References

- <http://www.eclipse.org/paho/>
- <https://coral.withgoogle.com/docs/dev-board/datasheet/>
- <https://www.raspberrypi.org/>

Student Questions

Acronyms

- .NET   Microsoft's software framework
- 3G   Third Generation
- AMQP   Advanced Queueing Message Protocol
- ARC-EM4   Name of a Product
- ARM   Acorn RISC Machine
- ASCII   American Standard Code for Information Exchange
- AVR   Name of Atmel 8-bit RISC processor
- CoAP   Constrained Application Protocol
- DDS   Data Distribution Service
- DECT   Digital Enhanced Cordless Telecommunication
- DTLS   Datagram Transport Level Security
- GP   Green Physical Layer
- GPS   Global Positioning System
- HTTP   Hypertext Transfer Protocol
- IDE   Integrated Development Environment
- IEEE   Institution of Electrical and Electronics Engineers

Student Questions

Acronyms (Cont)

- IoT   Internet of Things
- IP   Internet Protocol
- ISASecure   Security Certification by ISCI
- ISCI   ISA Security Compliance Institute
- kB   Kilo Byte
- LoRaWAN   Long-Range Wide Area Network
- LTE   Long-Term Evolution
- MQ   Message Queueing
- MQTT   MQ Telemetry Transport
- NFC   Near Field Communication
- PDA   Personal Digital Assistant
- QoS   Quality of Service
- REXX   REstructed eXtended eXecutor (an interpreted programming language)
- RPL   Routing over Low-Power and Lossy
- RSMB   Really small message broker

Student Questions

Acronyms (Cont)

- SASL   Simple Authentication and Security Layer
- SDHC   Secure Digital High-Capacity
- SMACK   Simplified Mandatory Access Control Kernel
- TCG   Trusted Control Group
- TPU   Tensor Processing Unit
- TinyOS   Tiny Operating System
- ULE   Ultra-Low Energy
- URL   Uniform Resource Locator
- WiFi   Wireless Fidelity
- WirelessHART Wireless Highway Addressable Remote Transducer Protocol

Student Questions

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http://rajjain.com

http://www.cse.wustl.edu/~jain/cse570-21/m_13mqt.htm

http://www.cse.wustl.edu/~jain/cse570-21/

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Related Modules

CSE567M: Computer Systems Analysis (Spring 2013),

https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof

CSE473S: Introduction to Computer Networks (Fall 2011),

https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcgy5e_10TiDw

Wireless and Mobile Networking (Spring 2016),

https://www.youtube.com/playlist?list=PLjGG94etKypKeb0nzyN9tSs_HCd5c4wXF

CSE571S: Network Security (Fall 2011),

https://www.youtube.com/playlist?list=PLjGG94etKypKvzfVtutHcPFJXumyyg93u

Video Podcasts of Prof. Raj Jain's Lectures,

https://www.youtube.com/channel/UCN4-5wzNP9-ruOzQMs-8NUw

Student Questions