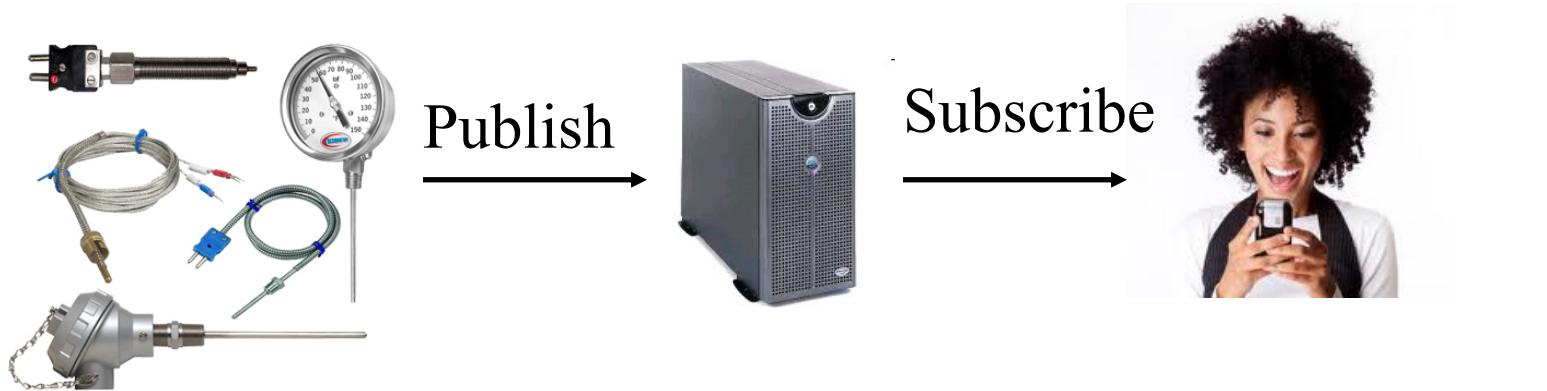


# Messaging Protocols for Internet of Things: MQTT



Raj Jain  
Washington University in Saint Louis  
Saint Louis, MO 63130  
Jain@cse.wustl.edu

These slides and audio/video recordings of this class lecture are at:  
<http://www.cse.wustl.edu/~jain/cse570-23/>

**Student Questions**



- ❑ MQ Telemetry Transport (MQTT)
  - MQTT Concepts
  - MQTT Application 2
  - MQTT vs. HTTP
- ❑ Hardware for IoT
  
- ❑ Note: This is 4<sup>th</sup> in a series of lectures on the Internet of Things.  
Please see the URL on the first slide and every slide for other lectures of this series.

## Student Questions

# IoT Ecosystem

<b>Applications</b>	Smart Health, Smart Home, Smart Grid Smart Transport, Smart Workspaces, ...	<b>Security</b>  TCG, Oath 2.0, SMACK, SASL, ISASecure, ace, CoAP, DTLS, Dice	<b>Management</b>  IEEE 1905, IEEE 1451, ...
<b>Session</b>	<b>MQTT</b> , CoRE, DDS, AMQP , ...		
<b>Routing</b>	<b>6LowPAN</b> , <b>RPL</b> , 6Lo, 6tsch, Thread, 6-to-nonIP , ...		
<b>Datalink</b>	WiFi, Bluetooth Smart, ZigBee Smart, Z-Wave, DECT/ULE, 3G/LTE, NFC, Weightless, <b>HomePlug GP</b> , 802.11ah, <b>802.15.4</b> , G.9959, WirelessHART, DASH7, ANT+ , LoRaWAN, ...		
<b>Software</b>	Mbed, Homekit, AllSeen, IoTvity, ThingWorks, EVERYTHING , ...		
<b>Operating Systems</b>	Linux, Android, Contiki-OS, TinyOS, ...		
<b>Hardware</b>	ARM, <b>Arduino</b> , 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 the “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 user (subscriber) can be offline. All brokers store messages, 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 a limited time. Users are mostly offline anyway. They come back once in a while and see important notifications.*
-

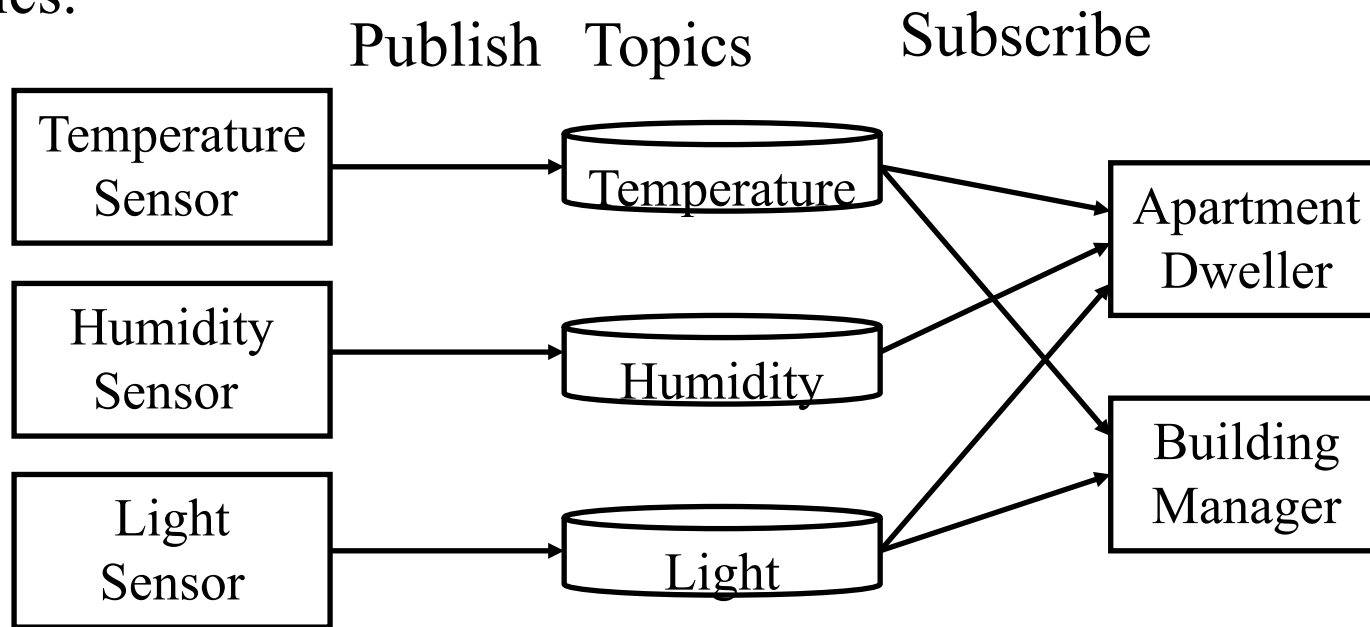
# MQTT (Cont)

- ❑ Facebook Messenger uses MQTT to minimize battery usage. Several other applications in medical and 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 or publish to topics.



## Student Questions

Ref: V. Lampkin, et al., "Building Smarter Planet Solutions with MQTT and IBM WebSphere MQ Telemetry,"

IBM Redbooks, SEP-2012, ISBN: 0738437085, 268 pp., (Safari Book), <http://www.redbooks.ibm.com/redbooks/pdfs/sg248054.pdf>

Washington University in St. Louis

<http://www.cse.wustl.edu/~jain/cse570-23/>

©2023 Raj Jain

# 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:** The server keeps messages even after sending them to all subscribers. New subscribers get the retained messages

## Student Questions

- ❑ For the retained msg, by the subscribers here, you mean “IoT devices,” not “users,” correct? This policy led to an attack on (azure and Google Cloud) details are in a paper called “Burglars’ IoT Paradise.”

*Subscribers = Users*

*Publishers = IoT devices*

*Brokers = IoT service providers, e.g., Amazon for Amazon cameras.*

- ❑ Is there any specific ruling on what and how long the messages should be kept? If the server keeps all messages indefinitely, that would not be economical for IoT.

*As long as the user pays. Brokers provide many different subscription plans.*

---

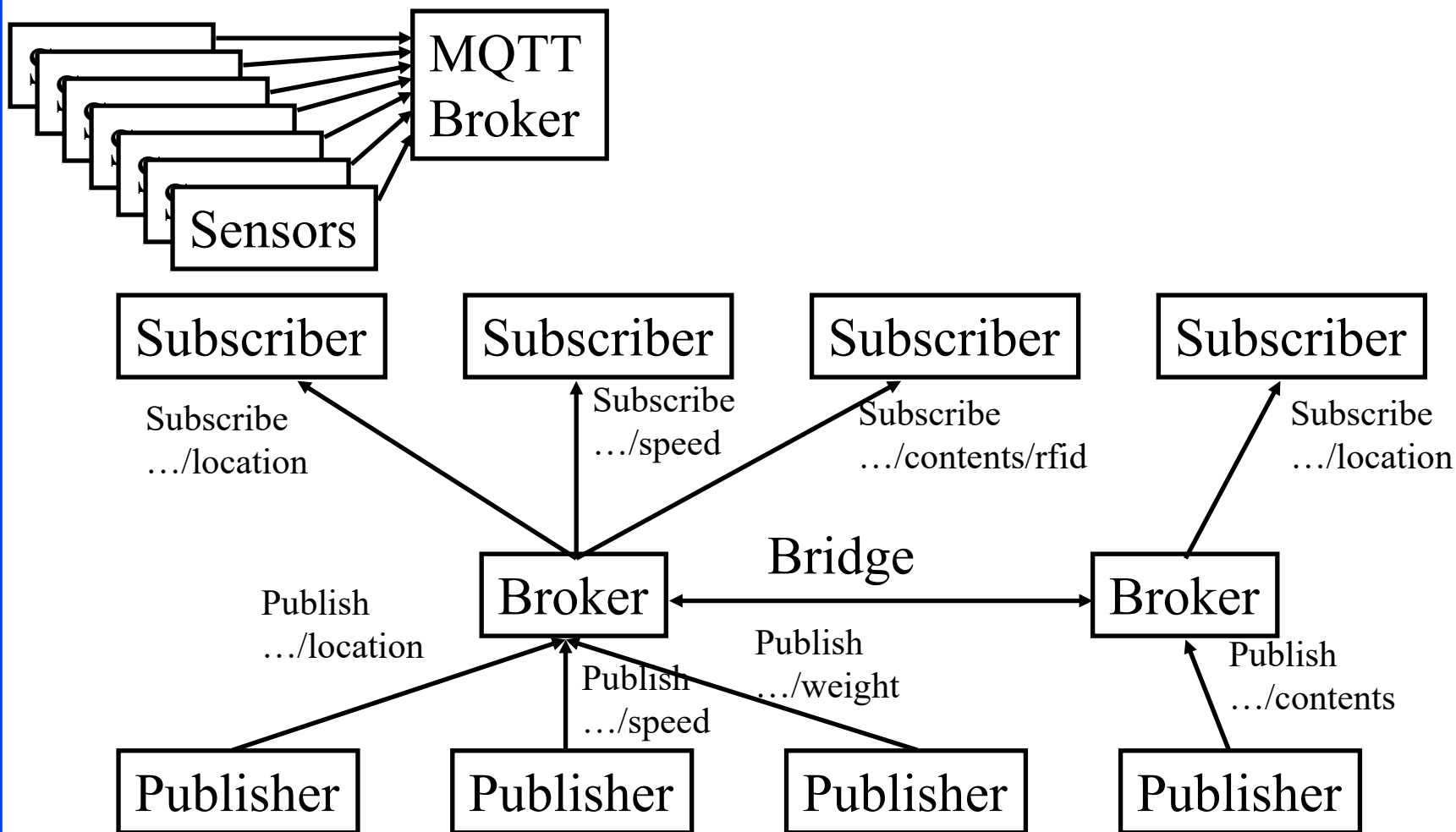
# MQTT Concepts (Cont)

- ❑ **Clean Sessions** and **Durable Connections**: At connection set up:  
Clean session flag  $\Rightarrow$  all subscriptions are removed on disconnect  
Otherwise, subscriptions remain in effect after disconnection  
 $\Rightarrow$  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  
 $\Rightarrow$  Alarm if the client loses connection
- ❑ Periodic **keep alive** messages  $\Rightarrow$  If a client is still alive
- ❑ **Topic Trees**: Topics are organized as trees using / character  
/# matches all sublevels  
/+ matches only one sublevel

## Student Questions



# 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 potent than publishers. Yes, they can have a queue.*

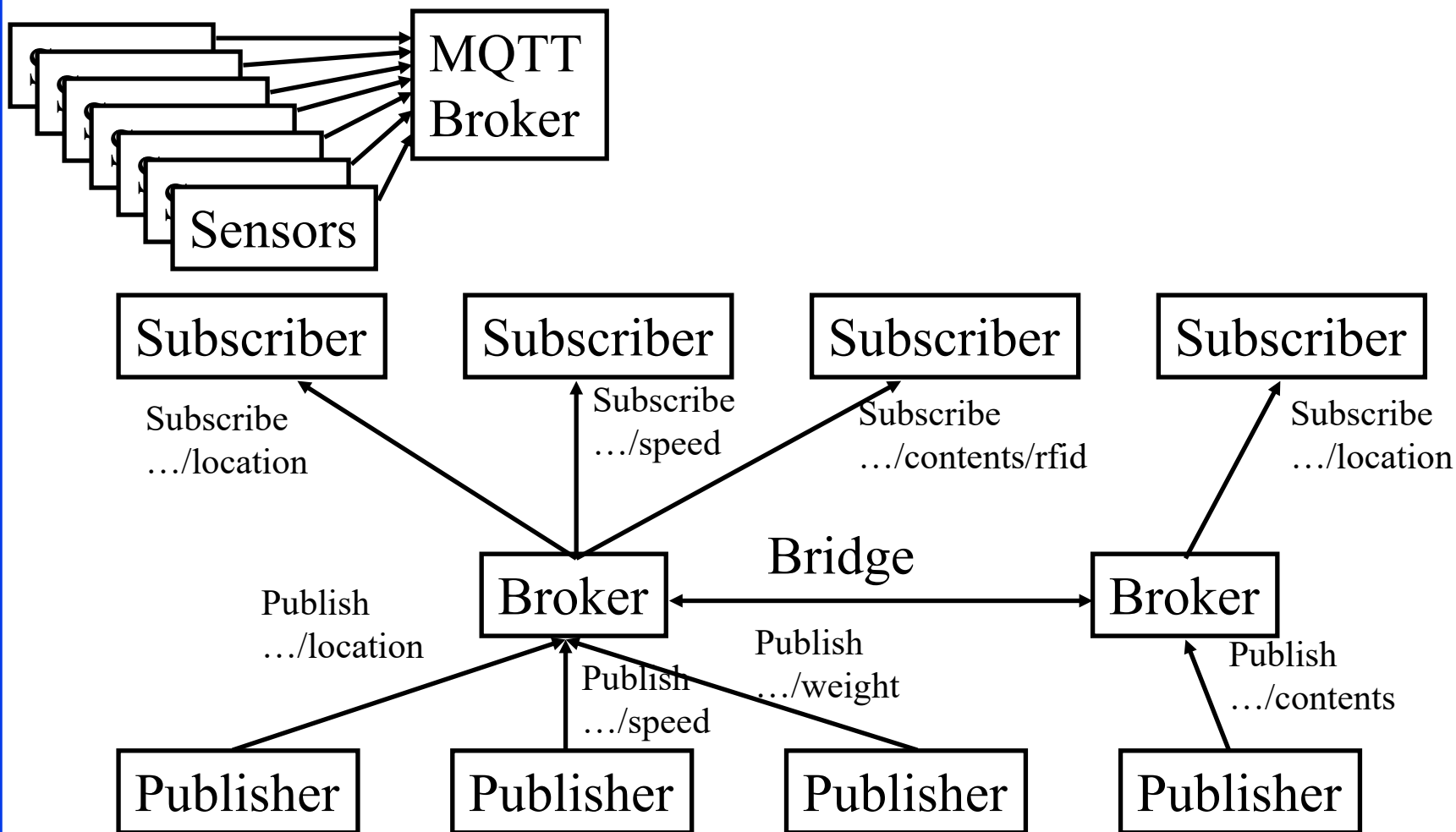
- ❑ Why are the two brokers connected? Is it for backup?

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

- ❑ If subscriber\_1 subscribes to the topic "device/location" and subscriber\_2 to "device/speed," if a publisher wants to publish messages to all those two subscribers simultaneously, which topic should it publish to?

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

# MQTT Example



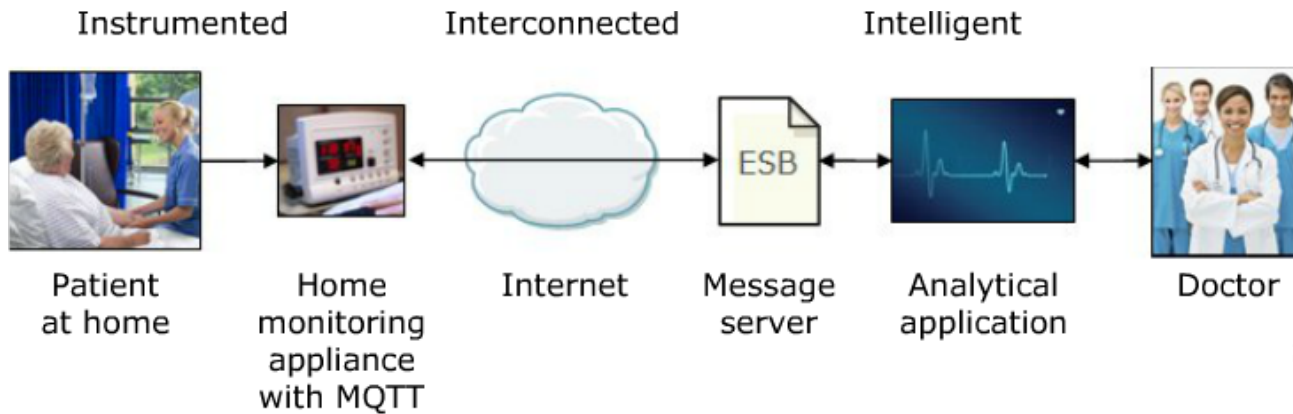
## Student Questions

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

*See the previous slide.*

# MQTT Application Examples

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



## Student Questions

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

*Doctors 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-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

Ref: V. Lampkin, et al., "Building Smarter Planet Solutions with MQTT and IBM WebSphere MQ Telemetry,"

IBM Redbooks, SEP-2012, ISBN: 0738437085, 268 pp., (Safari Book), <http://www.redbooks.ibm.com/redbooks/pdfs/sg248054.pdf>

Washington University in St. Louis

<http://www.cse.wustl.edu/~jain/cse570-23/>

©2023 Raj Jain

## 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 changes in the client who publishes. The client who subscribes 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

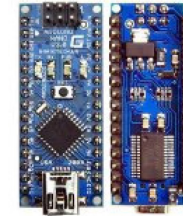
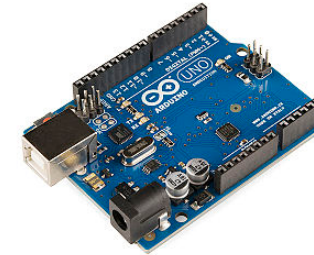
## Student Questions

# Single-Board Microcontrollers

## ❑ Arduino:

- Open-source hardware/software
- The 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 on Wikipedia



## Student Questions

- ❑ Can we treat Arduino as a computer?  
*Generally, Arduino is used as an I/O device.*
- ❑ Could you give some examples of something an Arduino can do but Raspberry Pi can't, and vice versa?

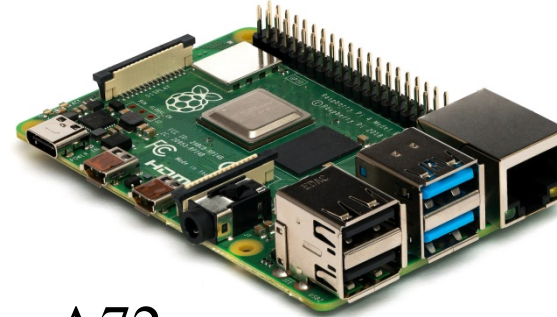
*Raspberry Pi is a computer. You can run several versions of Linux on Raspberry Pi and attach Ethernet, Monitor, mouse, and keyboard to it. Arduino is generally connected to a Raspberry Pi for these functions.*

# 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, Gigabit Ethernet, 802.11ac Wi-Fi, Bluetooth
- Low cost: Around \$35

❑ See a list of 100+ other such computers on Wikipedia



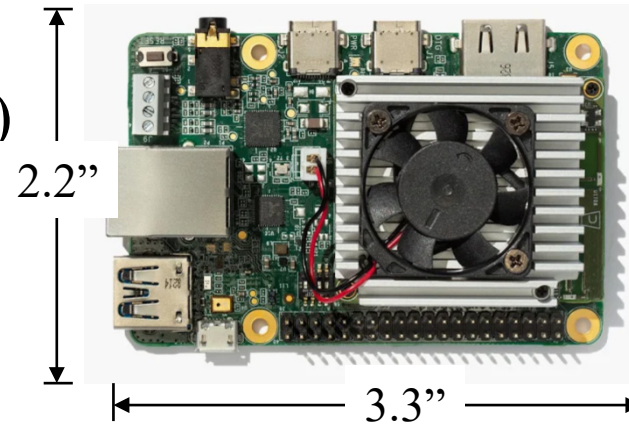
## Student Questions

Ref: [https://en.wikipedia.org/wiki/Single-board\\_computer](https://en.wikipedia.org/wiki/Single-board_computer), [https://en.wikipedia.org/wiki/Raspberry\\_Pi](https://en.wikipedia.org/wiki/Raspberry_Pi), <https://www.raspberrypi.org/>, [https://en.wikipedia.org/wiki/Comparison\\_of\\_single-board\\_computers](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

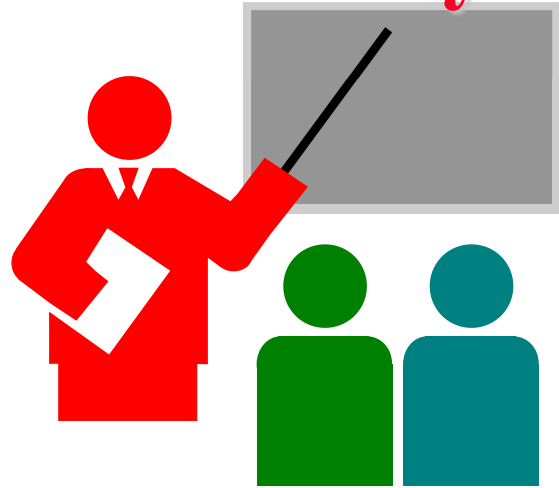
Ref: <https://coral.withgoogle.com/docs/dev-board/datasheet/>, [https://en.wikipedia.org/wiki/Tensor\\_processing\\_unit](https://en.wikipedia.org/wiki/Tensor_processing_unit)

## Student Questions

- ❑ Is TPU a combination of CPU and GPU?  
Or does it have to be a single one?  
*GPUs are designed for graphics, which require millions of pixels to be processed in parallel. This makes them suitable for AI, where millions of data points must be processed.*  
*TPU is a CPU with instructions and capacity for tensor processing, 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/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_computers)
- ❑ [https://en.wikipedia.org/wiki/Comparison\\_of\\_single-board\\_microcontrollers](https://en.wikipedia.org/wiki/Comparison_of_single-board_microcontrollers)
- ❑ [https://en.wikipedia.org/wiki/Raspberry\\_Pi](https://en.wikipedia.org/wiki/Raspberry_Pi)
- ❑ [https://en.wikipedia.org/wiki/Single-board\\_computer](https://en.wikipedia.org/wiki/Single-board_computer)
- ❑ [https://en.wikipedia.org/wiki/Tensor\\_processing\\_unit](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 REstructured 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

**Scan This to Download These Slides**



Raj Jain

<http://rajjain.com>

**Student Questions**

[http://www.cse.wustl.edu/~jain/cse570-23/m\\_13mqt.htm](http://www.cse.wustl.edu/~jain/cse570-23/m_13mqt.htm)

**Scan This to Download These Slides**



Raj Jain

<http://rajjain.com>

[http://www.cse.wustl.edu/~jain/cse570-23/m\\_13mqt.htm](http://www.cse.wustl.edu/~jain/cse570-23/m_13mqt.htm)

**Student Questions**



# Related Modules



CSE567M: Computer Systems Analysis (Spring 2013),

[https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n\\_1X0bWWNyZcof](https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof)

CSE473S: Introduction to Computer Networks (Fall 2011),

[https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8AzcgY5e\\_10TiDw](https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8AzcgY5e_10TiDw)



 Wireless and Mobile Networking (Spring 2016),

[https://www.youtube.com/playlist?list=PLjGG94etKypKeb0nzyN9tSs\\_HCd5c4wXF](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