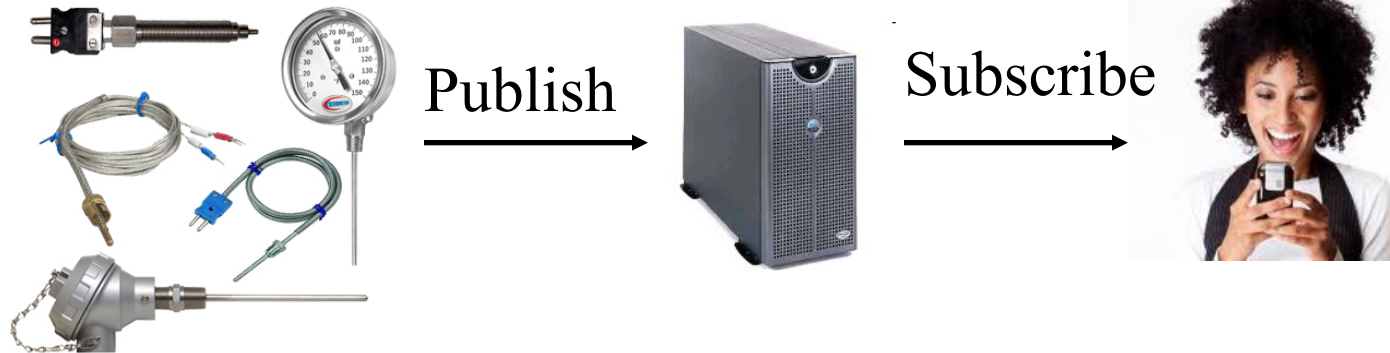


Messaging Protocols for Internet of Things: MQTT



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These slides and audio/video recordings of this class lecture are at:
<http://www.cse.wustl.edu/~jain/cse570-19/>



- ❑ 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.

IoT Ecosystem

Applications	Smart Health, Smart Home, Smart Grid Smart Transport, Smart Workspaces, ...	Security TCG, Oath 2.0, SMACK, SASL, ISASecure, ace, CoAP, DTLS, Dice	Management 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, EVRYTHING , ...		
Operating Systems	Linux, Android, Contiki-OS, TinyOS, ...		
Hardware	ARM, Arduino , Raspberry Pi, ARC-EM4, Mote, Smart Dust, Tmote Sky, ...		

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

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

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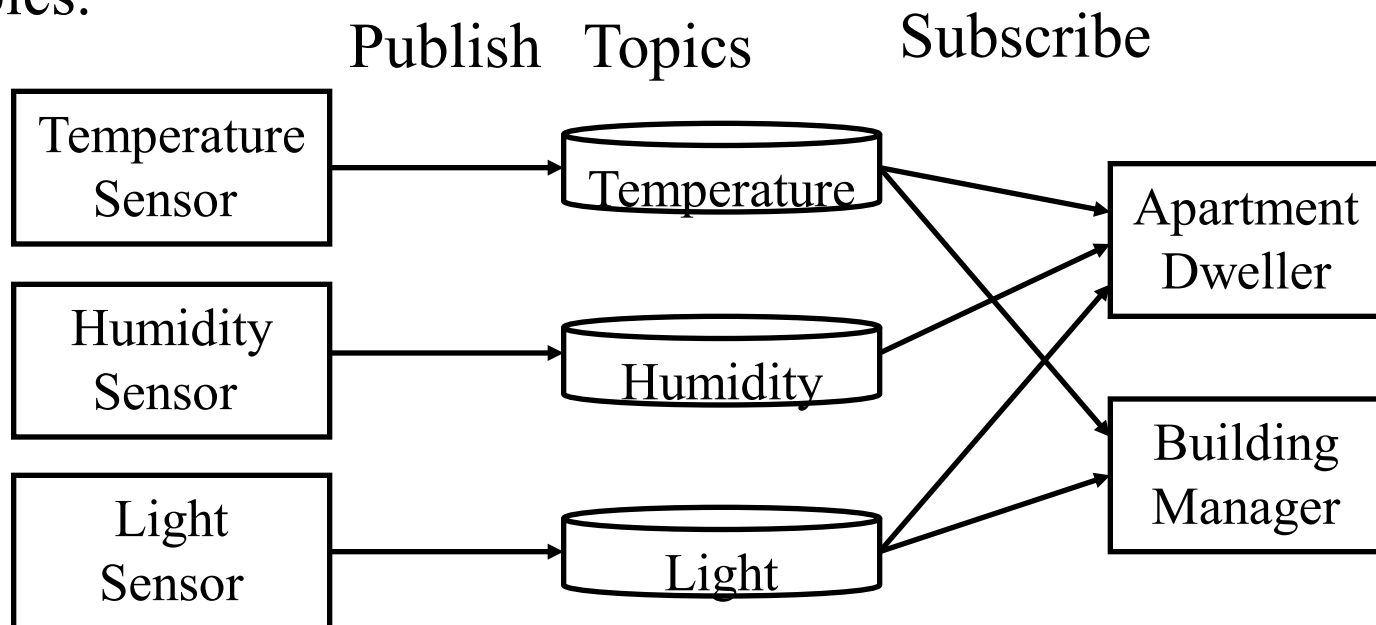
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MQTT (Cont)

- ❑ 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

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.



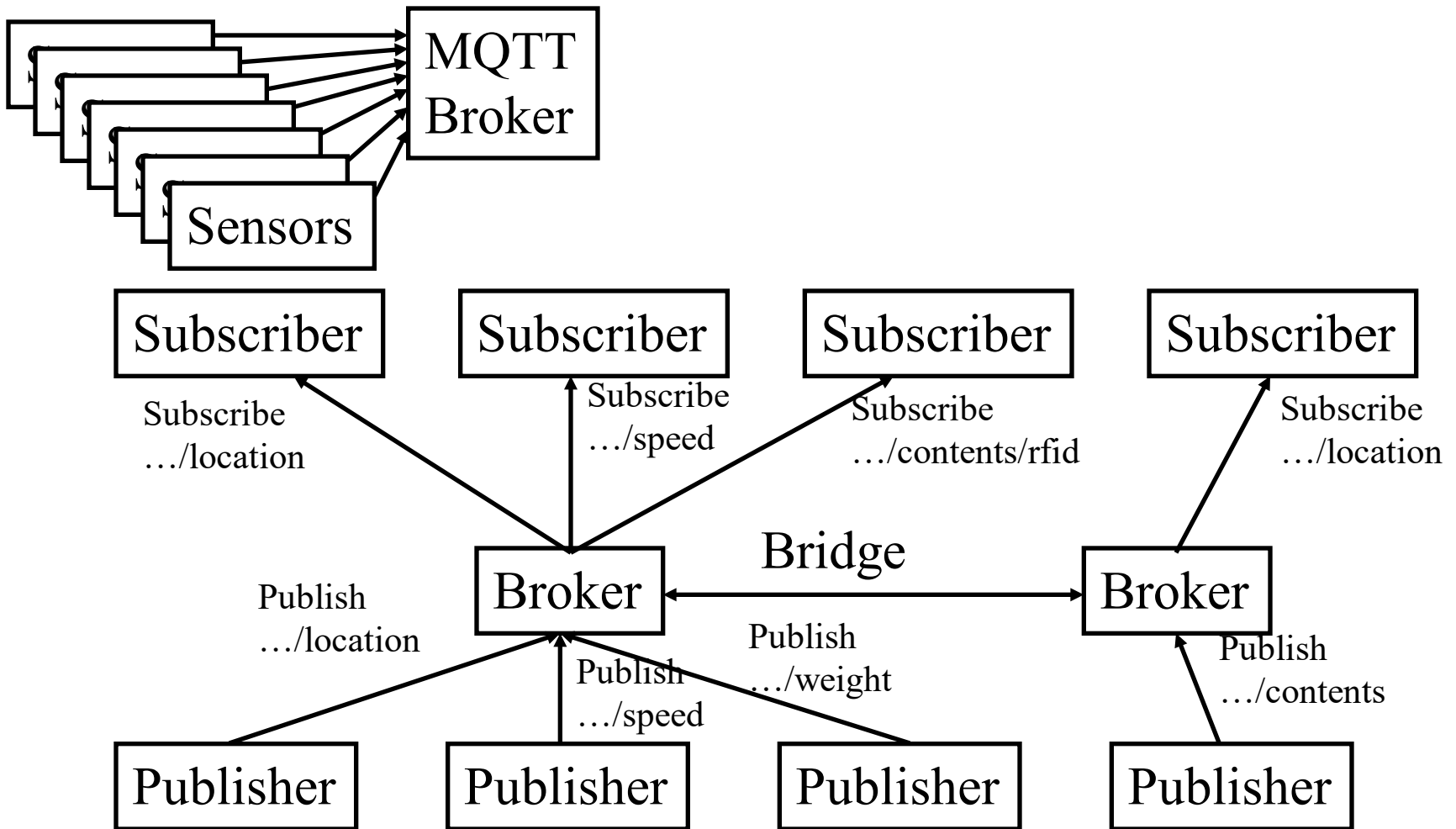
MQTT Concepts (Cont)

- ❑ **Quality of Service Levels:** Three levels:
 - 0 = At most once (Best effort, No Ack),
 - 1 = At least once (Aacked, 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)

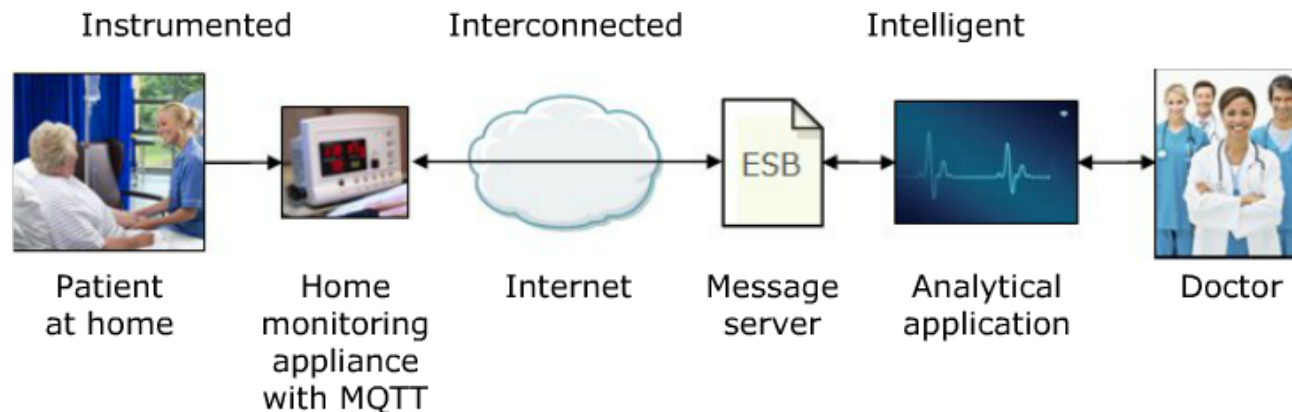
- ❑ **Clean Sessions** and **Durable Connections**: At connection set up:
Clean session flag \Rightarrow all subscriptions are removed on disconnect
Otherwise subscriptions remain in effect after disconnection
 \Rightarrow Subsequent messages with high QoS are stored for delivery after reconnection
-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

MQTT Example



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

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>

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IoT Hardware

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

Single-Board Microcontrollers

□ Arduino:

- Open-source hardware/software
- Name derived from Arduin of Ivrea (a King of Italy 1002-1041)
- 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



Ref: <https://en.wikipedia.org/wiki/Arduino> , https://en.wikipedia.org/wiki/Comparison_of_single-board_microcontrollers

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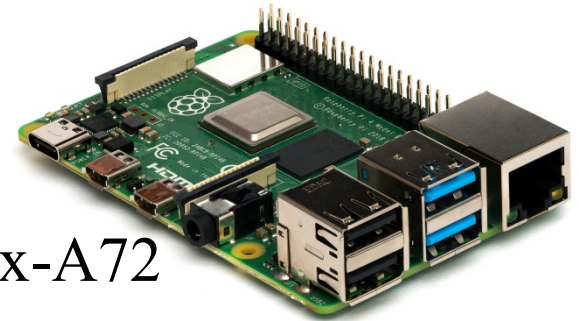
<http://www.cse.wustl.edu/~jain/cse570-19/>

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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



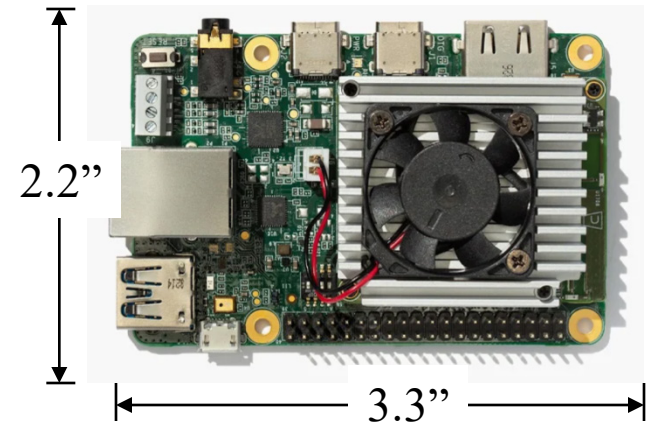
❑ See a list of 100+ other such computers in Wikipedia

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

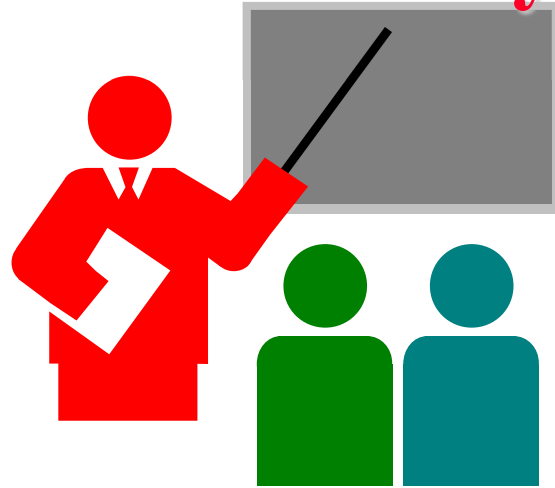
- Edge Tensor Processing Unit (TPU)
- Machine learning accelerator
- Cryptographic co-processor
- Gigabit Ethernet, Wi-Fi, Bluetooth
- USB, MicroSD
- HDMI, 3.5mm Audio
- Supports Mendel Linux, TensorFlow Lite, ...
- Low cost: Below \$150



❑ Similar offerings from Nvidia (Jetson nano) and others

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

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

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

References

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

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

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

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

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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=PLjGG94etKypJWOSPMh8Azcg5e_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>