

# IoT and Robotics Education with ARM mbed OS

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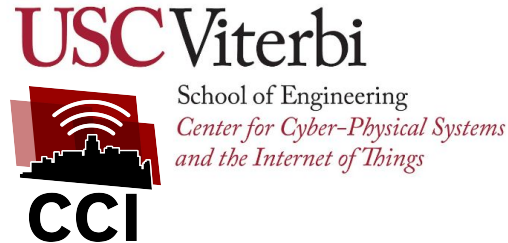
# Acknowledgement



This workshop is being offered with support from ARM



as well as the USC Viterbi Center for Cyber-Physical Systems and the Internet of Things



## Application Domains

**The USC Viterbi Center for CPS and IoT (CCI)** brings together more than 35 faculty across Viterbi and 8 faculty from other USC schools, with expertise spanning many key “horizontal” transformational technologies and “vertical” applications undergoing revolutionary changes. Visit us at <http://cci.usc.edu/>

## Technologies and Tools

	Transportation	Energy	Environment	Healthcare	Smart Buildings	Manufacturing	Smart Cities
Security and Privacy							
Software Engineering, Interfaces and Visualization							
Signal Processing, Data Analytics, Machine Learning, Control							
Network, Middleware, Storage and Cloud Computing							
Sensing, Energy-Harvesting and Computational Hardware							

# At a Glance



## Research Focus Areas:

- IoT protocols, platforms, and testbed
- Connected and autonomous vehicles
- Cyber-physical security and privacy
- Theoretical Foundations of CPS

## Educational Programs:

- New courses and programs at all levels: undergraduate, graduate, and professional
- IoT, CPS, connected vehicles

## Center Events:

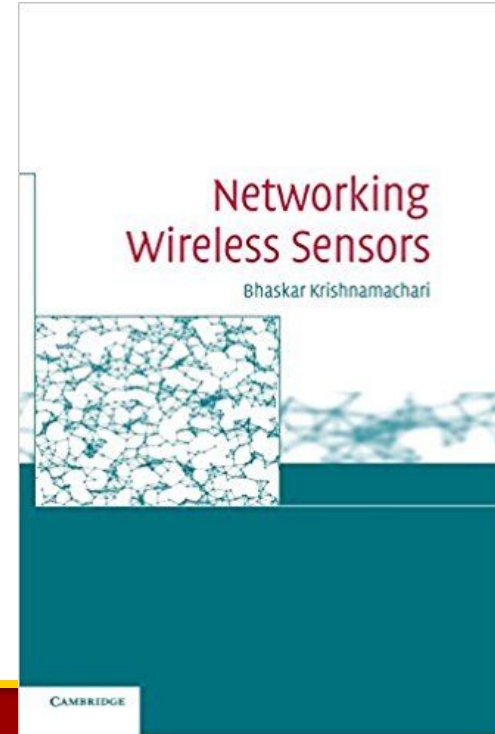
- Research seminars
- Thematic workshops
- Industry meetups



# IoT curriculum at USC



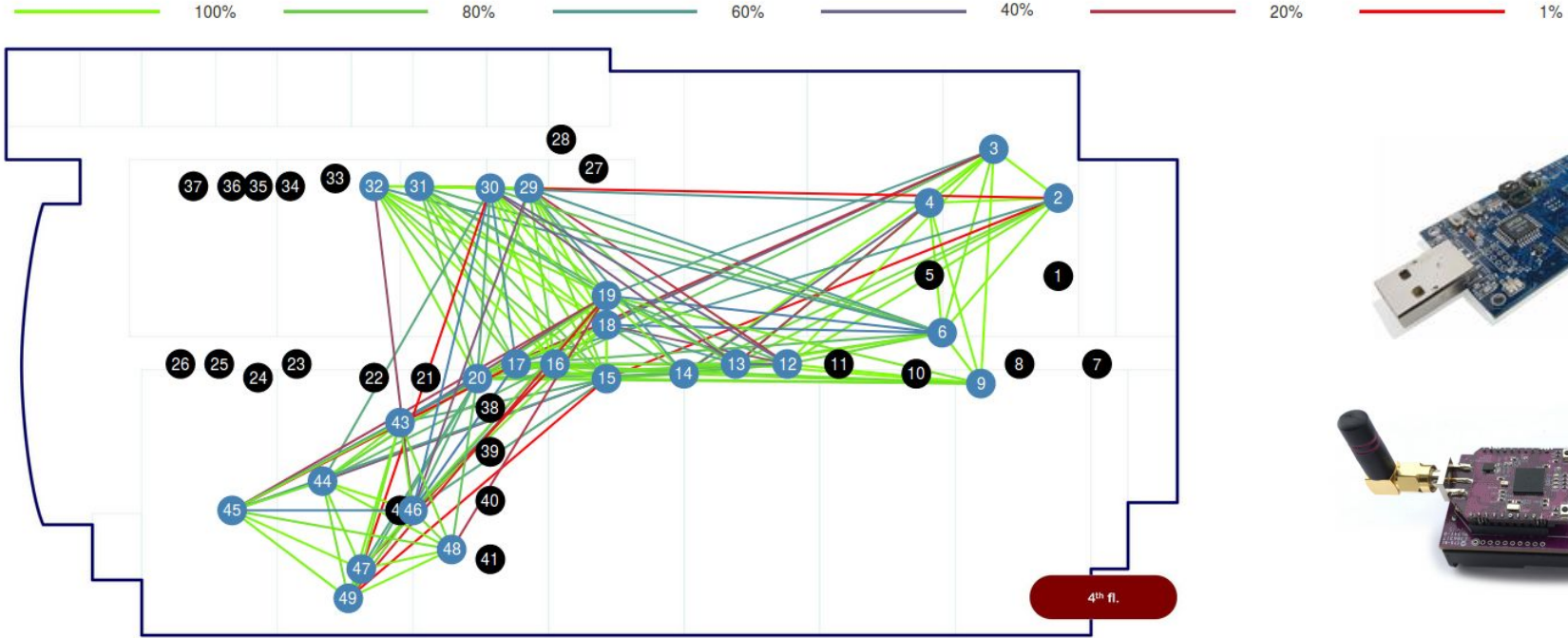
- Graduate course on Wireless Sensor Networks, now called Low-Power Wireless Networks, offered since 2002-2003.
  - Among the first of its kind
  - Covers networked embedded device programming (originally using TinyOS, ContikiOS)
  - Focus on network stack from MAC to transport layer protocols, multi-hop low power wireless networks
  - Book based on original version of course, published by Cambridge University Press





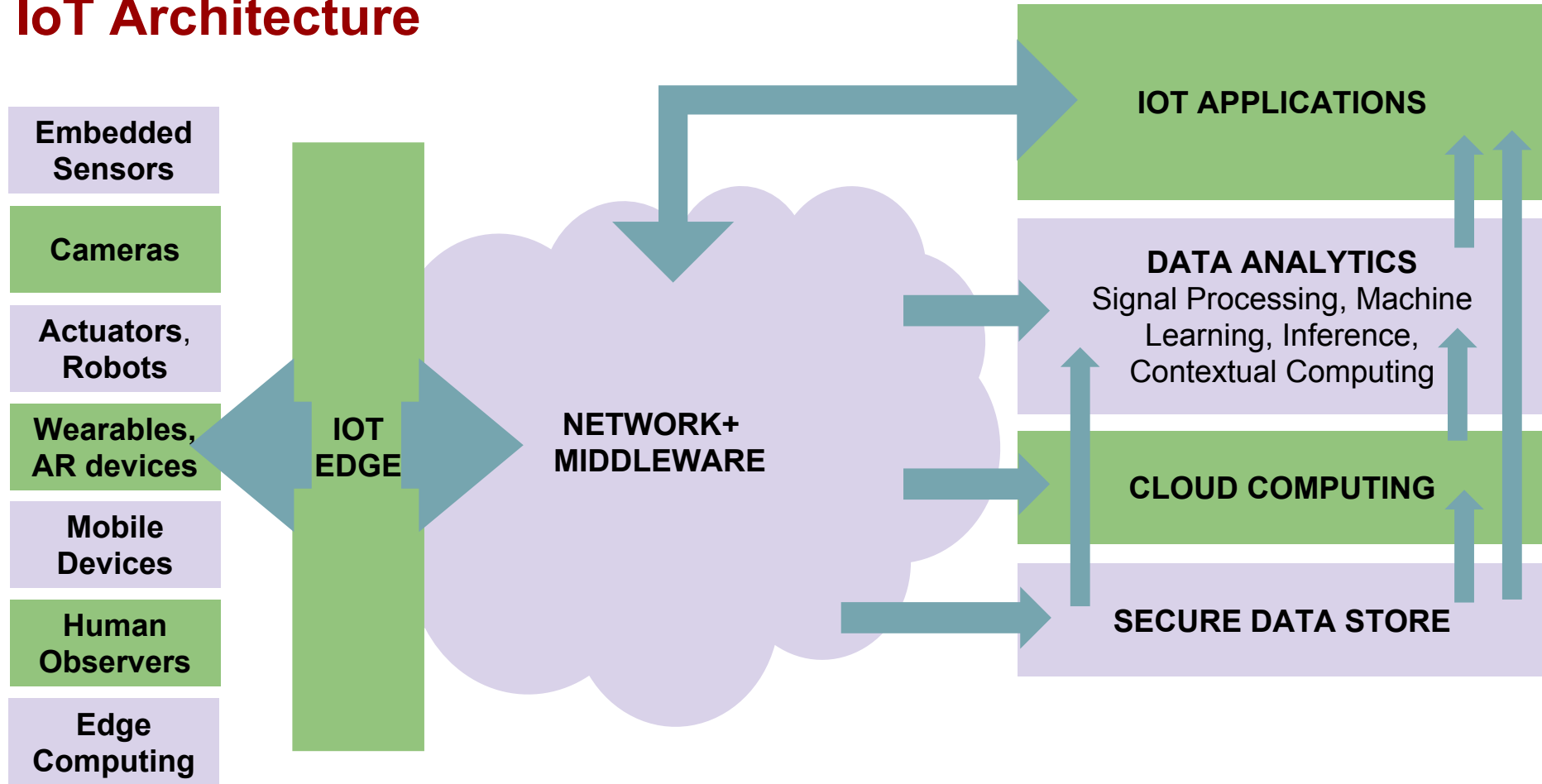
TutorNet Testbed

USC Viterbi  
School of Engineering





# IoT Architecture



# New Undergraduate IoT Course at USC



- EE 250L Distributed Systems for the Internet of Things
- Piloted spring 2017 as a special topics class, to be offered officially for the first time in spring 2018
- Topics covered:
  - Introduction to embedded processors, open motes (ARM Cortex M3) and raspberry pi
  - Programming embedded processors (mbedOS)
  - Sensing, ADC, PCB design
  - Sensor signal processing
  - Actuation, Feedback control, robotics
  - Wireless networking (IEEE 802.15.4 / 802.11)
  - Internet architecture, IP, UDP, TCP
  - Application layer. HTTP/CoAP, MQTT
  - Cloud computing, analytics, and storage
  - IoT security and privacy

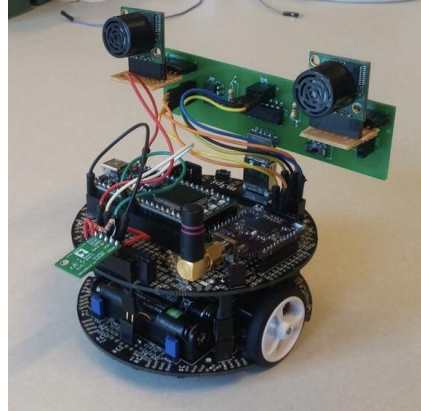
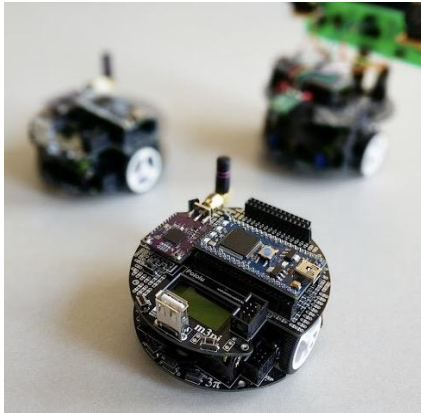




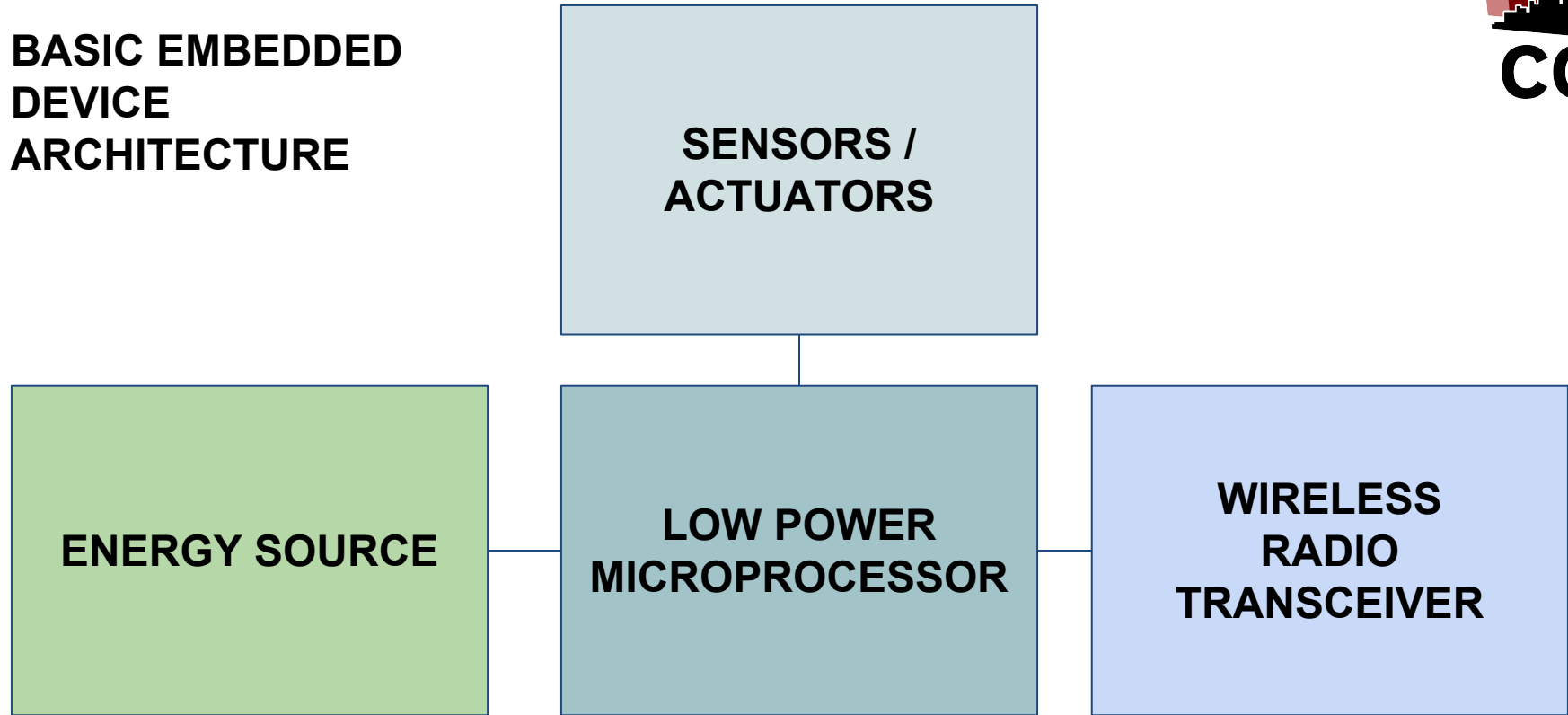
# Undergraduate + Graduate Research

## Wireless robotic networks

- Pololu 3pi robot
- Mbed + open mote
- Ultrasound+RF time difference of arrival based ranging and localization
- Aiming for distributed, swarm robotics with no cameras



# **BASIC EMBEDDED DEVICE ARCHITECTURE**

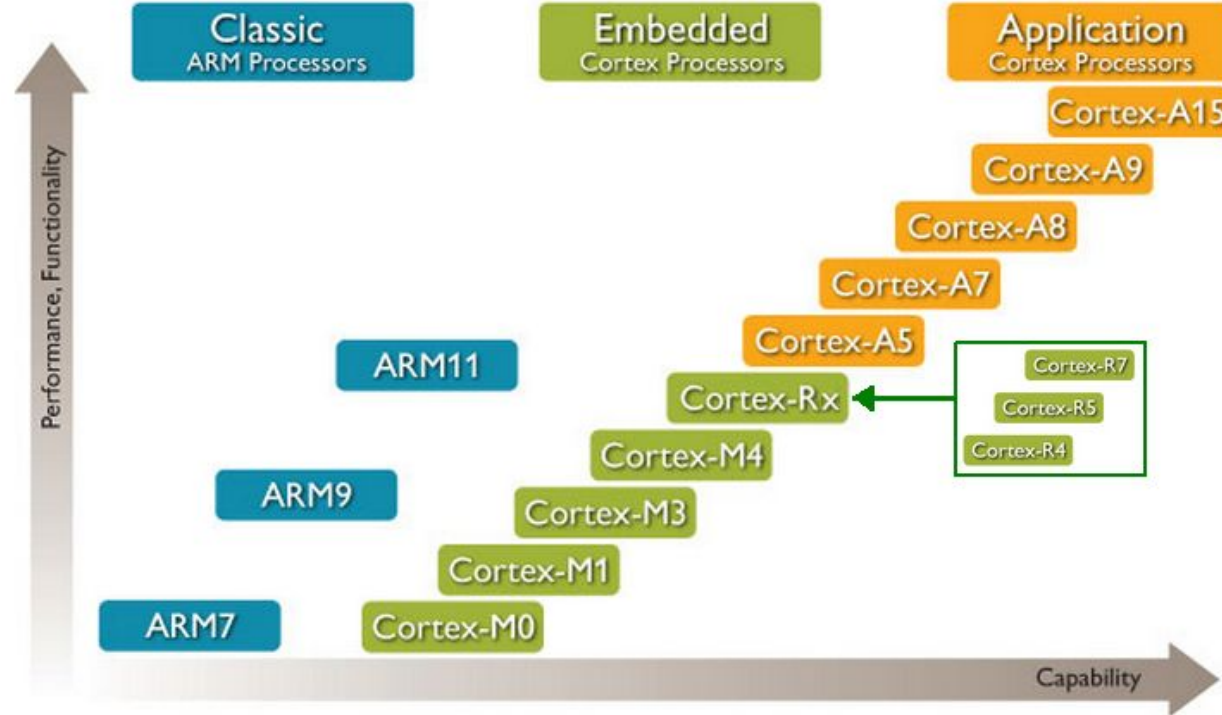


# ARM Processors

	Application processors	Real-Time processors	Microcontroller processors
<b>Design</b>	High clock frequency, Long pipeline, High performance, Multimedia support (NEON instruction set extension)	High clock frequency, Long to medium pipeline length, Deterministic (low interrupt latency)	Short pipeline, ultra low power, Deterministic (low interrupt latency)
<b>System features</b>	Memory Management Unit (MMU), cache memory, TrustZone® security extension	Memory Protection Unit (MPU), cache memory, Tightly Coupled Memory (TCM)	Memory Protection Unit (MPU), Nested Vectored Interrupt Controller (NVIC), Wakeup Interrupt Controller (WIC)
<b>Targeted markets</b>	Mobile computing, smart phones, energy efficient servers, high end microprocessors	Industrial microcontrollers, automobiles, Hard disk controllers, Baseband modem.	Microcontrollers, Deeply embedded systems (e.g. sensors, MEMS, mixed signal IC), Internet of Things (IoT)

Table 1: Summary of processor characteristics

# ARM Processors



From <http://www.emcu.it/CortexFamily/CortexFamily.html>

# Raspberry Pi 3 Model B

Dimensions  
85.6mm x 56mm x 21mm

element14



4 x USB 2 Ports

40 Pin  
Extended GPIO

10/100  
LAN Port

Broadcom  
BCM2837 64bit  
Quad Core CPU  
at 1.2GHz,  
1GB RAM

3.5mm 4-pole  
Composite Video  
and Audio  
Output Jack

CSI Camera Port

Full Size HDMI  
Video Output

Micro USB Power Input.  
Upgraded switched  
power source that can  
handle up to 2.5 Amps

DSI Display Port

MicroSD  
Card Slot

On Board  
Bluetooth 4.1  
Wi-Fi

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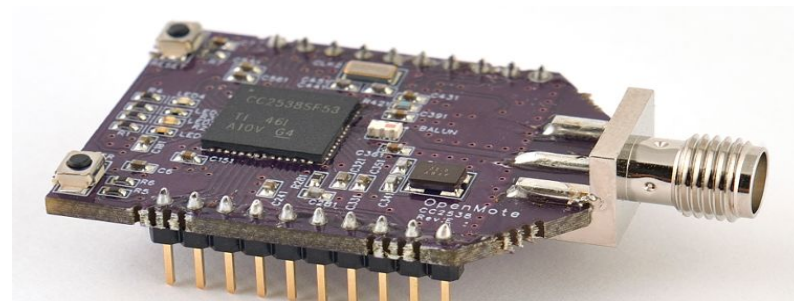
ARM  
Cortex  
A-53



openmote  
openhwarefortheinternetofthings



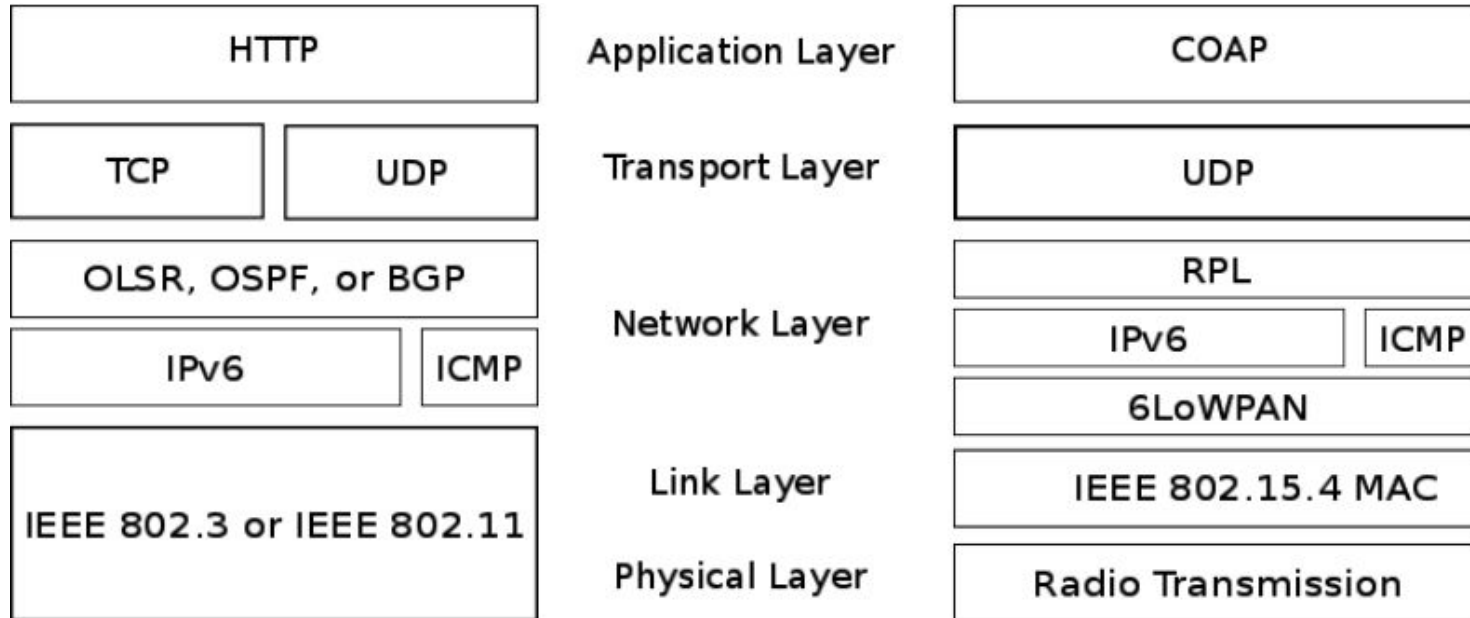
<http://www.openmote.com/>



based on TI's CC2538 SoC (System on Chip)  
ARM Cortex-M3 running at 16 MHz  
32 kbytes of RAM; 256 kbytes of FLASH  
Cryptoprocessor, public key accelerator



# Network Protocol Stack on Low Power Wireless Embedded Devices



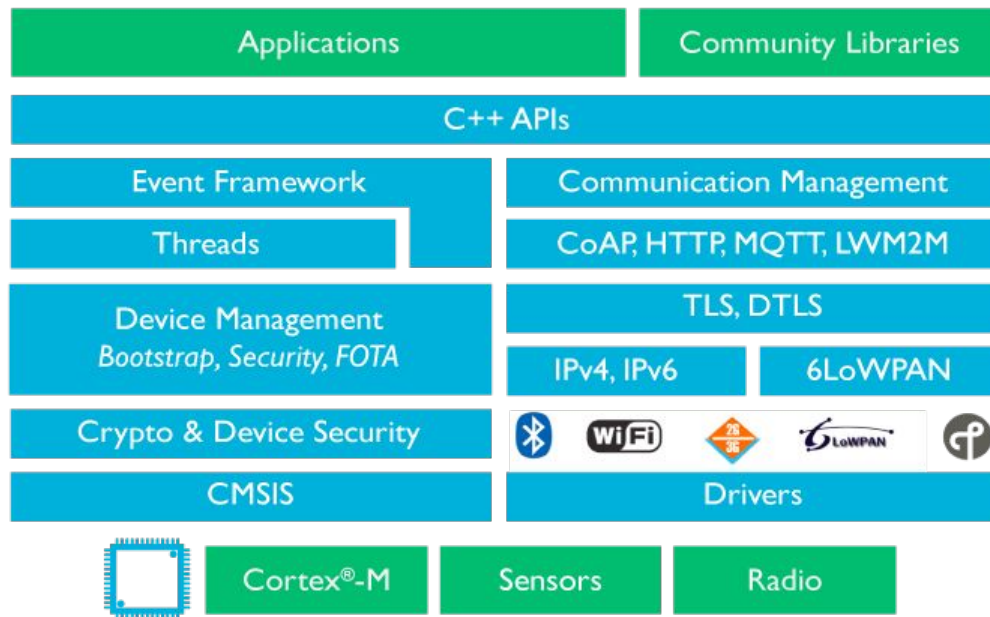
# mbed OS

ARM mbed OS is an open source embedded operating system designed specifically for the "things" in the Internet of Things.

It includes all the features you need to develop a connected product based on an ARM Cortex-M microcontroller, including security, connectivity, an RTOS, and drivers for sensors and I/O devices.

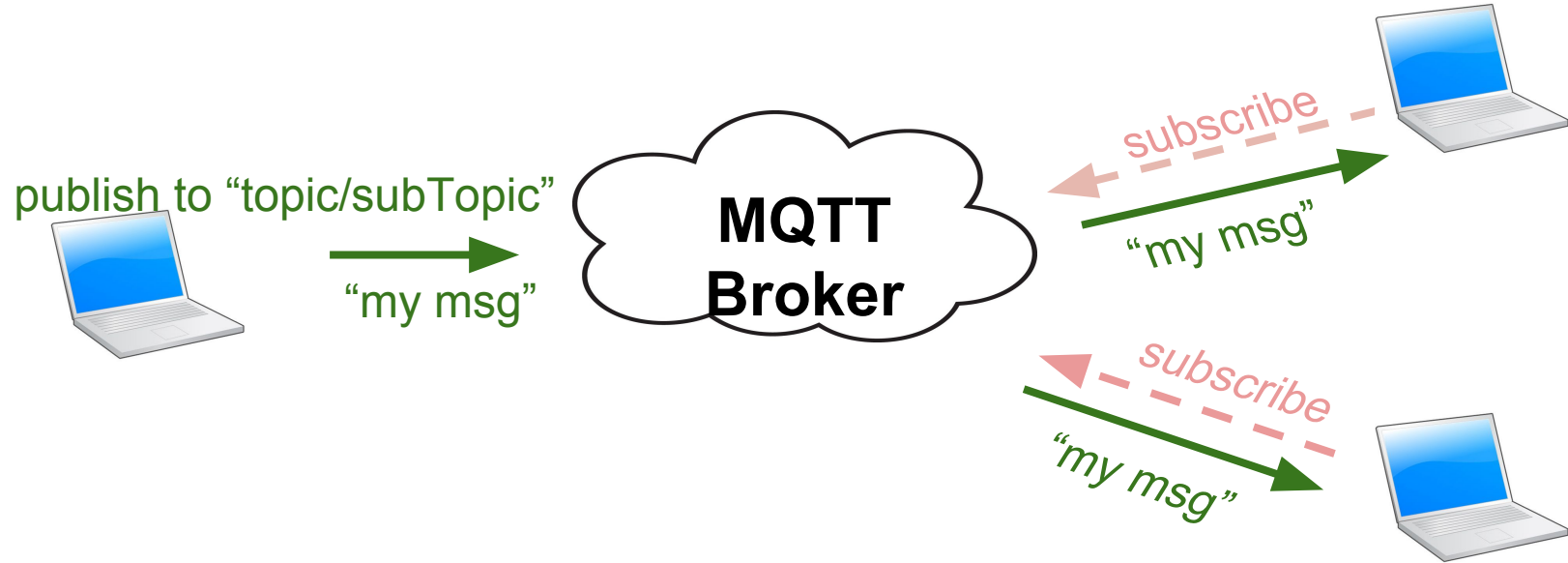
<https://www.mbed.com>

**arm** MBED



	BLE Beacon	WiFi Appliance	Thread Device	Sub-GHz Mesh	LoRa Sensor
<b>Key mbed OS Components</b>	RTOS, Drivers, BLE	RTOS, Drivers, TLS, Client	RTOS, Thread, TLS, Client	RTOS, 6LoWPAN Mesh, TLS, Client	RTOS Drivers, LoRa Library
<b>Hardware Components</b>	Cortex-M0 with BLE radio	Cortex-M3 with WiFi Network Co-processor	Cortex-M4 with 2.4 GHz 802.15.4 and Crypto	Cortex-M3 with 802.15.4 Transceiver	Cortex-M0 with LoRa Transceiver

# MQTT: Message Queue Telemetry Transport





## SERVERS



<https://mosquitto.org/>



<http://www.hivemq.com/>

## CLIENTS



<https://os.mbed.com/teams/mqtt/>



<https://eclipse.org/paho/>



MQTT  
C for Posix and Windows  
C++  
Embedded C/C++  
Java  
Android Service  
JavaScript  
Python  
Go  
C# .Net and WinRT

MQTT-SN  
C (Embedded)