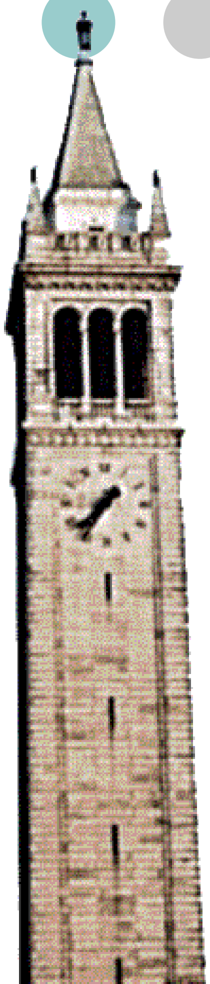
Introduction to Embedded Systems



Branden Ghena

UC Berkeley

EECS 149/249A

Fall 2017

Chapter X: Networking

Networking and Communications

Goal of lecture

- Want you to be aware of communication options and choices

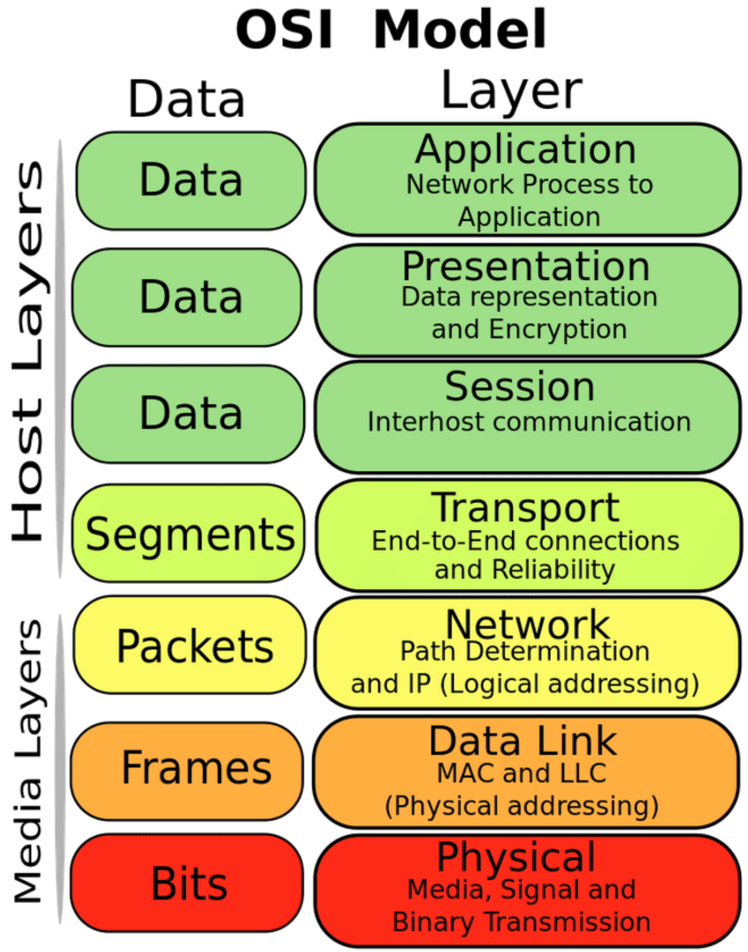
Outline

- Communications model
- Wired networks
- Wireless networks

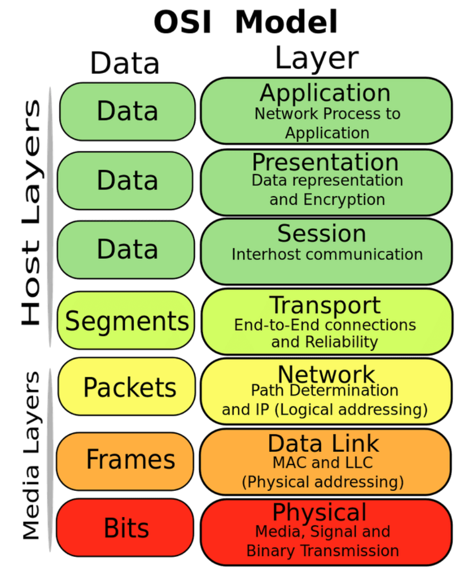
The Alphabet Soup

- 1588
- 6LoWPAN
- 802.15.4
- 802.1(AS)
- 802.11
- AVB
- BLE
- CAN
- CoAP
- CSMA/CA
- GSM
- HART
- HTTP
- IoT
- IPv6
- LTE
- MAC
- PAN
- PTP
- QoS
- REST
- TDMA
- TSMP
- TSN
- TTEthernet
- TTP
- WAN
- WLAN
- WPAN

Communications Layers



Physical Layer Technologies



Specifies electrical characteristics

- Voltages
- Frequencies

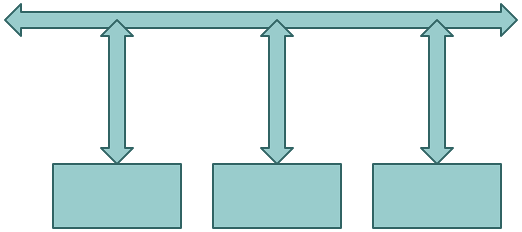
Specifies how to map signals to data

- Example low voltage = 0 and high voltage = 1
- Example oscillation at a high frequency = 0, low = 1

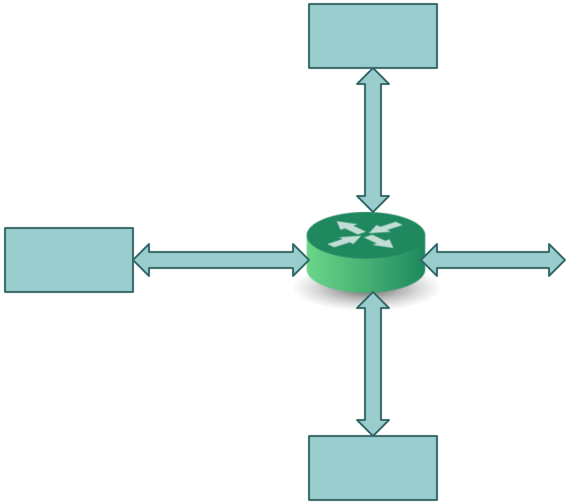
Specifies network topology as well

Network Topology

- Busses
  - Shared physical medium
  - MAC protocol dominates

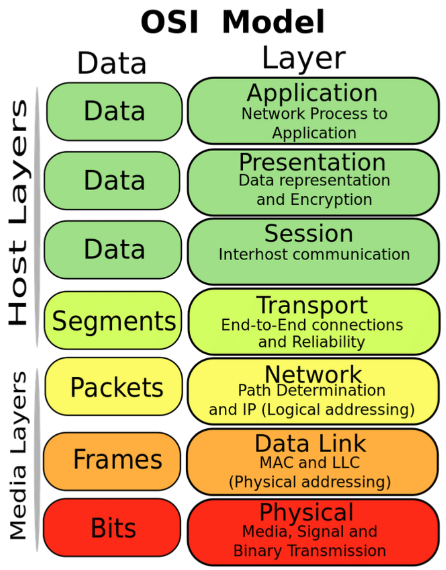


- Star networks
  - Private medium
  - MAC protocol is less important
  - Routing protocols become important
  - Buffers in routers



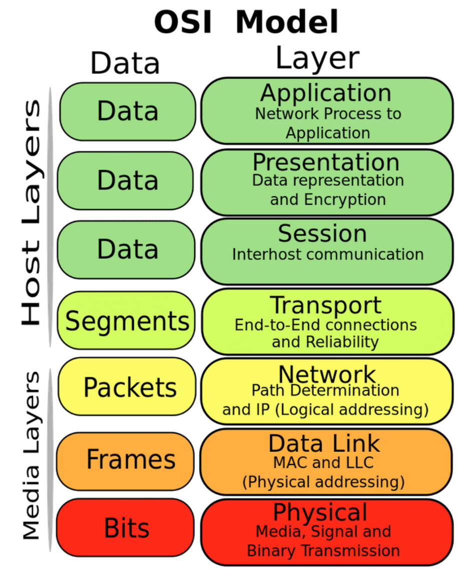
Is radio a bus or a star network?

Medium Access Controls



How do multiple devices share the same transmission technology?

Medium Access Controls



How do multiple devices share the same transmission technology?

- Don’t worry about it, let collisions happen
- Listen for others and don’t transmit if they are
- Coordinate with others and transmit at different times
- Transmit at different frequencies

MAC: Media Access Control
CSMA/CA vs. Time Slotted

Basis of Ethernet and WiFi

Carrier Sense Multiple Access / Collision Avoidance

- Listen for idle channel
- Send
- Wait for ack, retransmit if no ack after some timeout

Basis of TTA, TTEthernet, FlexRay/

Time Division Multiple Access (TDMA)

- Wait your turn
- Send when it's your turn
- Add various schemes to recover unused slots
- Maybe add slots for CSMA/CA

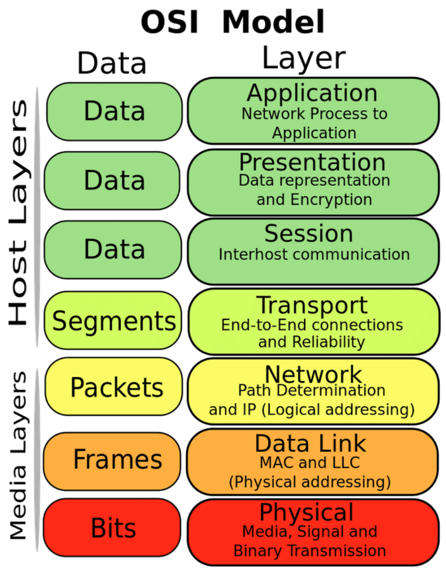
MAC: Media Access Control
FDMA

Frequency Division Multiple Access

- Protocol supports multiple “channels” each at a different frequency
- Send on a specific channel to not conflict with others

There are many other methods of sharing as well

Network Layer



How do I get a message to the correct device?

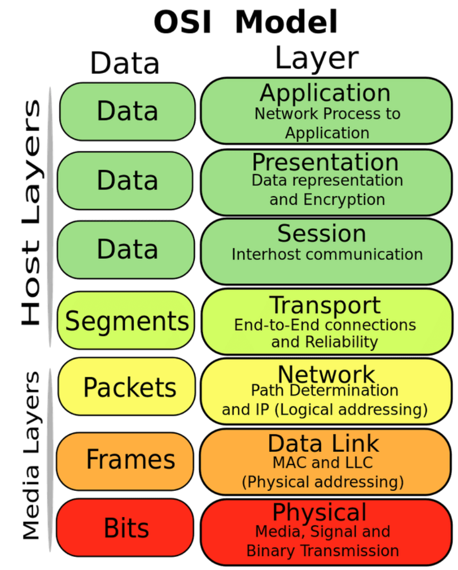
- How devices are named (addressed)?
- How are messages routed?

Example: IP

Issues with Routing

- Buffering — Reliability
  - Buffer overflow can cause packet drops.
- Routing tables — Security
  - To which port should the router send a packet?
- Priorities — QoS
  - Which packet queued for a port to send first?

Transport Layer Reliability

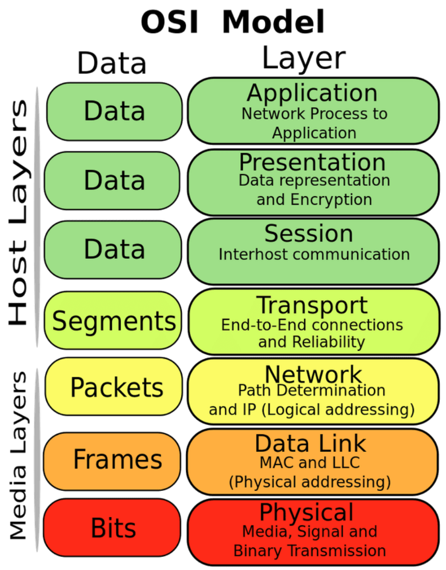


How do I reliably get messages between two devices?

- What if the message is too big for one packet?
- How do I know if the recipient got the message?

Example: TCP and UDP

Higher Layers



How do we handle data?

Includes:

- maintaining connections across computers
- deciding what messages to send
- data compression and encryption

WIRED NETWORKS

Wired Networks

- Ethernet
- CAN: Controller Area Network (Bosch, 1983)
- TTP: Time-Triggered Protocol (Vienna U. of Tech.)
- FlexRay (Automotive industry, deployed 2006…)
- TTEthernet (Time-triggered Ethernet)
- TSN (Time-sensitive networks)

Control over timing, guaranteed bandwidth, redundancy, and fault tolerance, are all issues that loom large in embedded systems.

Ethernet networks are acquiring high resolution clock synchronization, which can make them more suitable.

I²C, UART, and SPI

Why aren't these good enough for everything?

UART

I²C

SPI

I^2C, UART, and SPI

Why aren't these good enough for everything?

UART

- Slow. No shared bus.

I^2C

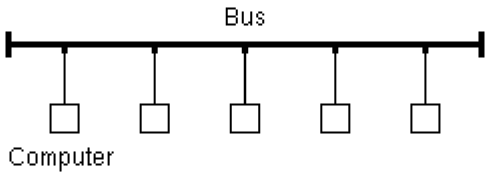
- Slow. Master-initiated communication. Short distance.

SPI

- Master-initiated communication. Lots of pins.

Ethernet

- Best-effort shared network between peers
- Open contention for network CSMA/CD
  - Detect collisions as they occur



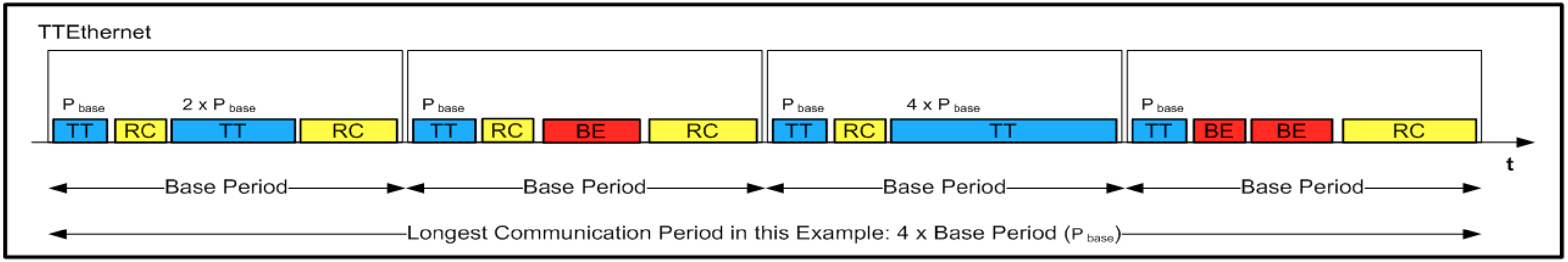
- Problem: collisions slow down the network

Note: this is all original Ethernet design

Time-Slotted Networks:
Example: TTEthernet (marketed by TTTech)

Combines three traffic types over Ethernet:

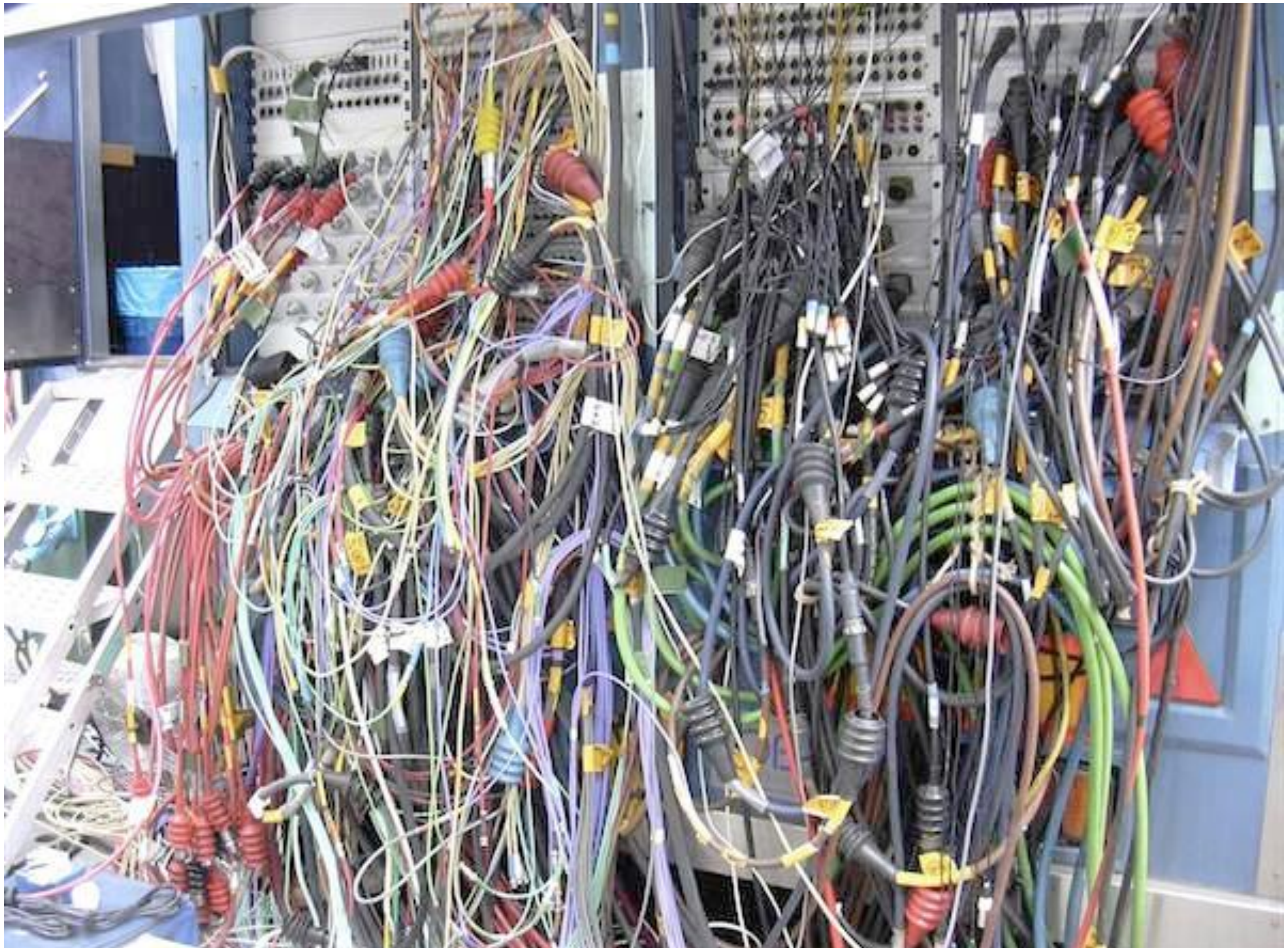
- TT: Time triggered
- RC: Rate constrained
- BE: Best effort



TSN: Time-Sensitive Networks

Before 2012, called AVB: Audio-Video Bridging.

Developed to solve this problem:



Broadcasting van. Photo by Gael Mace, licensed under creative commons attribution 3.0

TSN: Time-Sensitive Networks (aka AVB)
(Priority-based routing over Ethernet with reservations)

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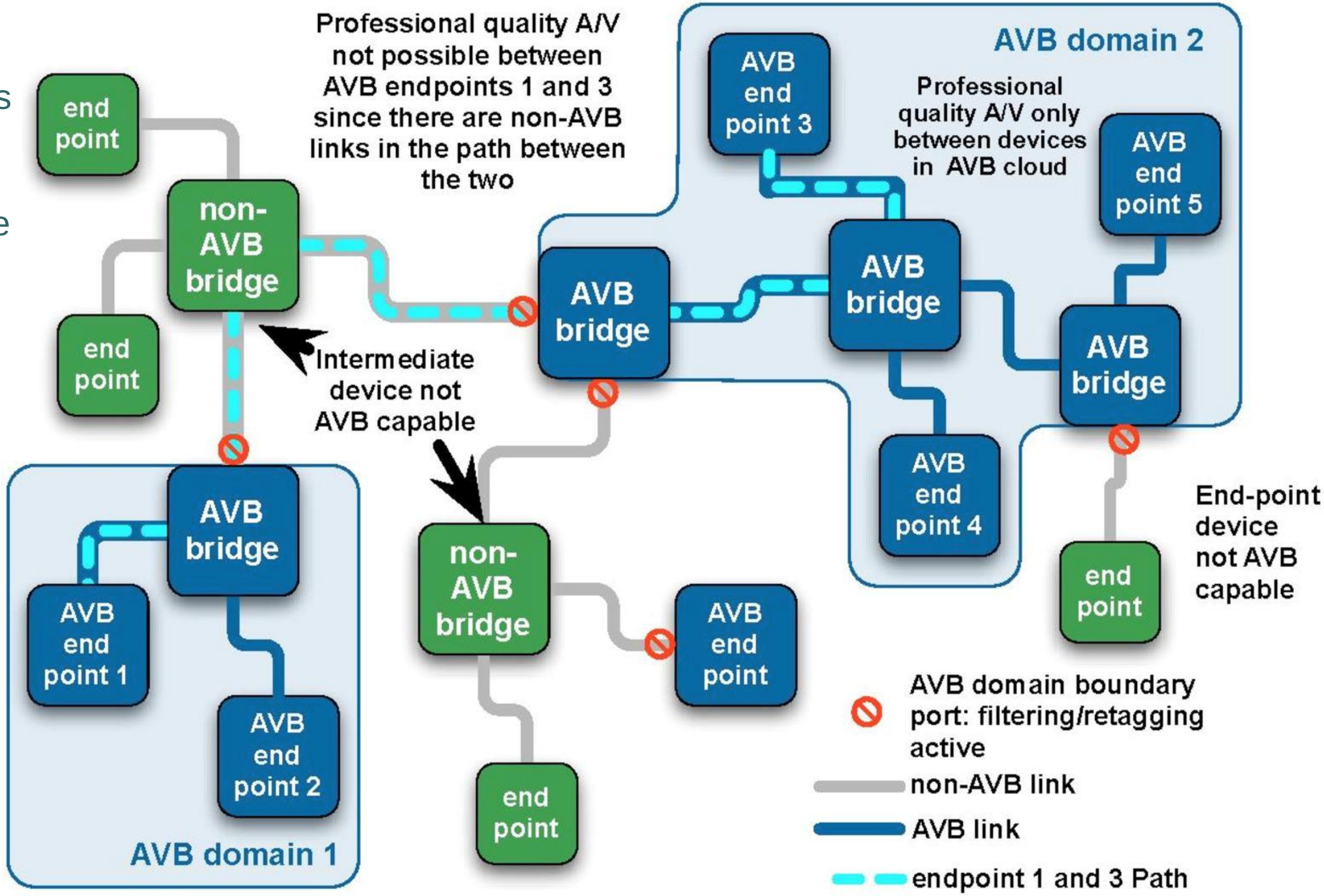

Part of IEEE 802.1 (Ethernet) family of standards.

Application of TSN

Meyer Sound CAL
(Column Array Loudspeaker),
based on research at CNMAT
(UC Berkeley), using IEEE
1588 over Ethernet

Enabler: Precision Time Protocols (PTP)
(IEEE 1588 and 802.1AS on Ethernet)

Press Release October 1, 2007

National Semiconductor
The Sight & Sound of Information

NEWS RELEASE

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Industry's First Ethernet Transceiver with IEEE 1588 PTP Hardware Support from National Semiconductor Delivers Outstanding Clock Accuracy

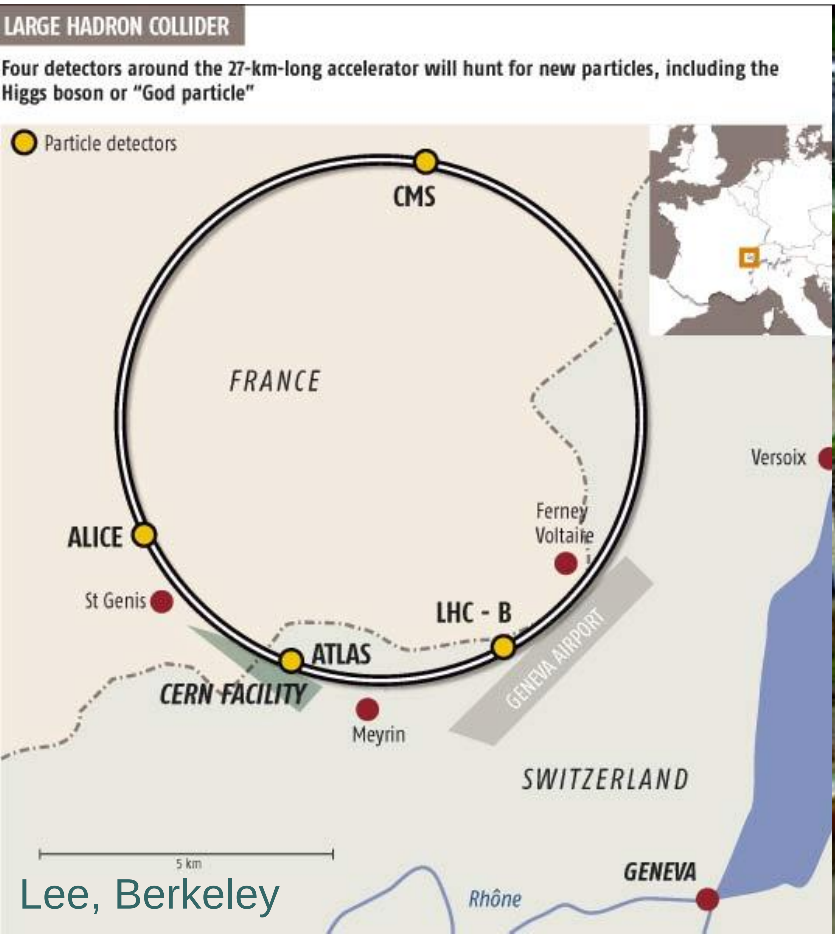
Using DP83640, Designers May Choose Any Microcontroller, FPGA or ASIC to Achieve 8- Nanosecond Precision with Maximum System Flexibility

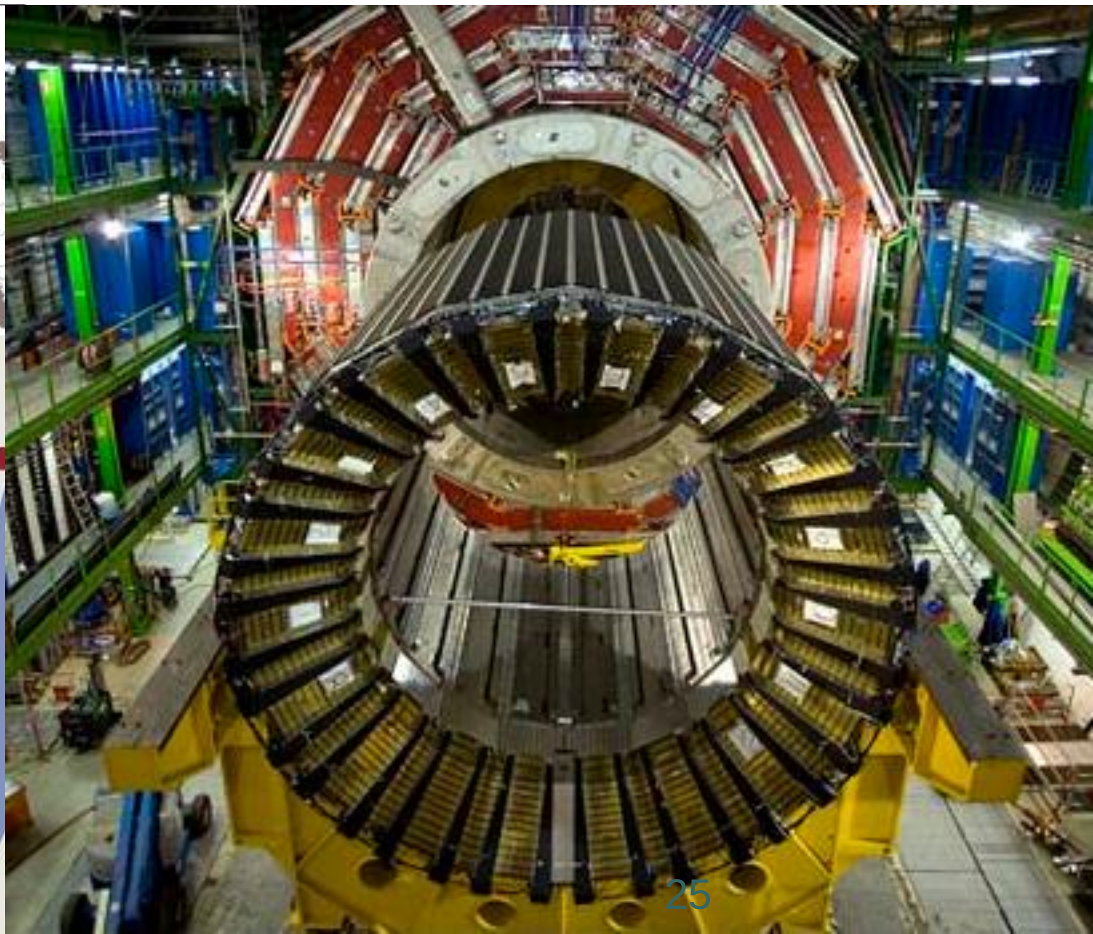
It is becoming routine for physical network interfaces (PHY) to provide hardware support for PTPs.

With this first generation PHY, clocks on a LAN agree on the current time of day to within 8ns, far more precise than GPS older techniques like NTP.

An Extreme Example: The Large Hadron Collider

The WhiteRabbit project at CERN is synchronizing the clocks of computers 10 km apart to within about 80 psec using a combination of GPS, IEEE 1588 PTP and synchronous ethernet.



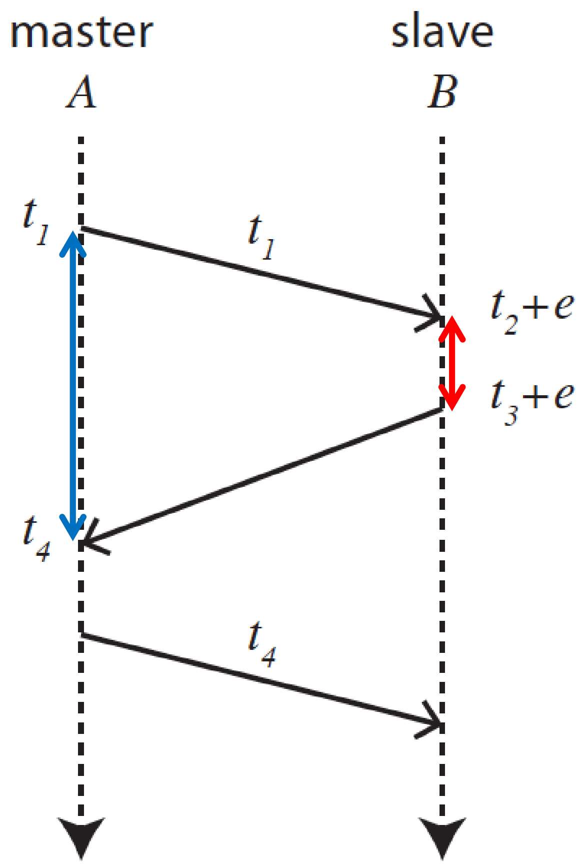


PTP Example

The slave synchronizes to the master

1. Measure round-trip delay
    1. Master sends a packet along with time that packet was sent (t_1)
    2. Slave receives packet at ($t_2 + e$)
    3. Slave sends response at ($t_3 + e$)
    4. Master receives packet at t_4
    5. Master sends t_4 to slave

RTT = (t_4 - t_1) – (($t_3 + e$) - ($t_2 + e$))



IEEE 1588,
IEEE 802.1AS

PTP Example

1. Assume symmetric delay

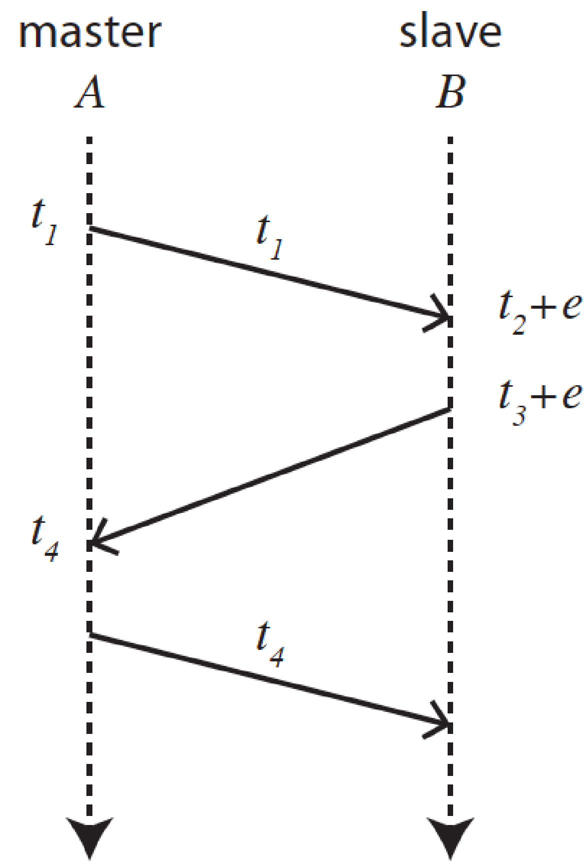
   One-way delay = $\frac{RTT}{2}$

2. Estimate error

   $$t_2 = t_1 + \frac{RTT}{2}$$

   $$\tilde{e} = (t_2 + e) - (t_1 + \frac{RTT}{2})$$

3. Adjust slave clock accordingly
4. Repeat periodically!



IEEE 1588,
IEEE 802.1AS

How PTP Synchronization works

Precision Time Protocols

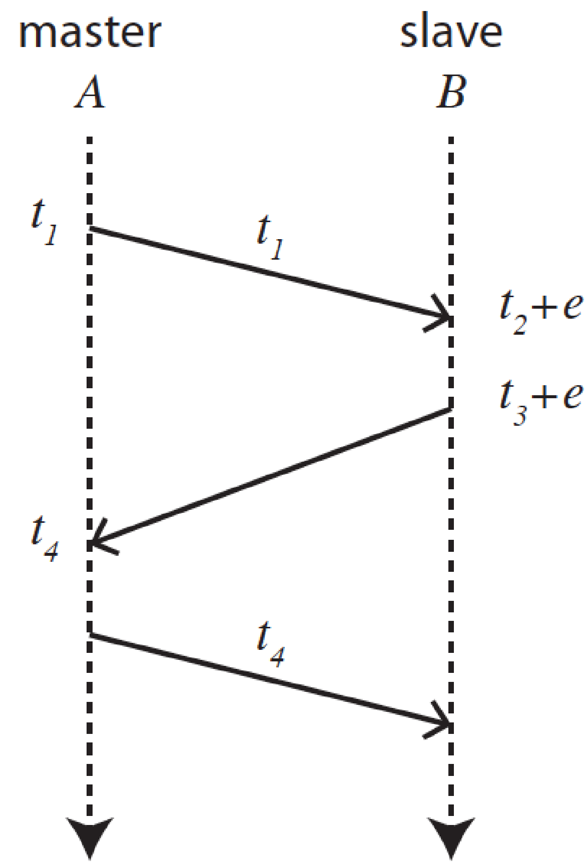
Round-trip delay:

$$r = (t_4 - t_1) - ((t_3 + e) - (t_2 + e)).$$

where e is the clock error in the slave. Estimate of the clock error is

$$\tilde{e} = (t_2 + e) - t_1 - r/2.$$

If communication latency is exactly symmetric, then $\tilde{e} = e$, the exact clock error. B calculates $\tilde{e}$ and adjusts its local clock.



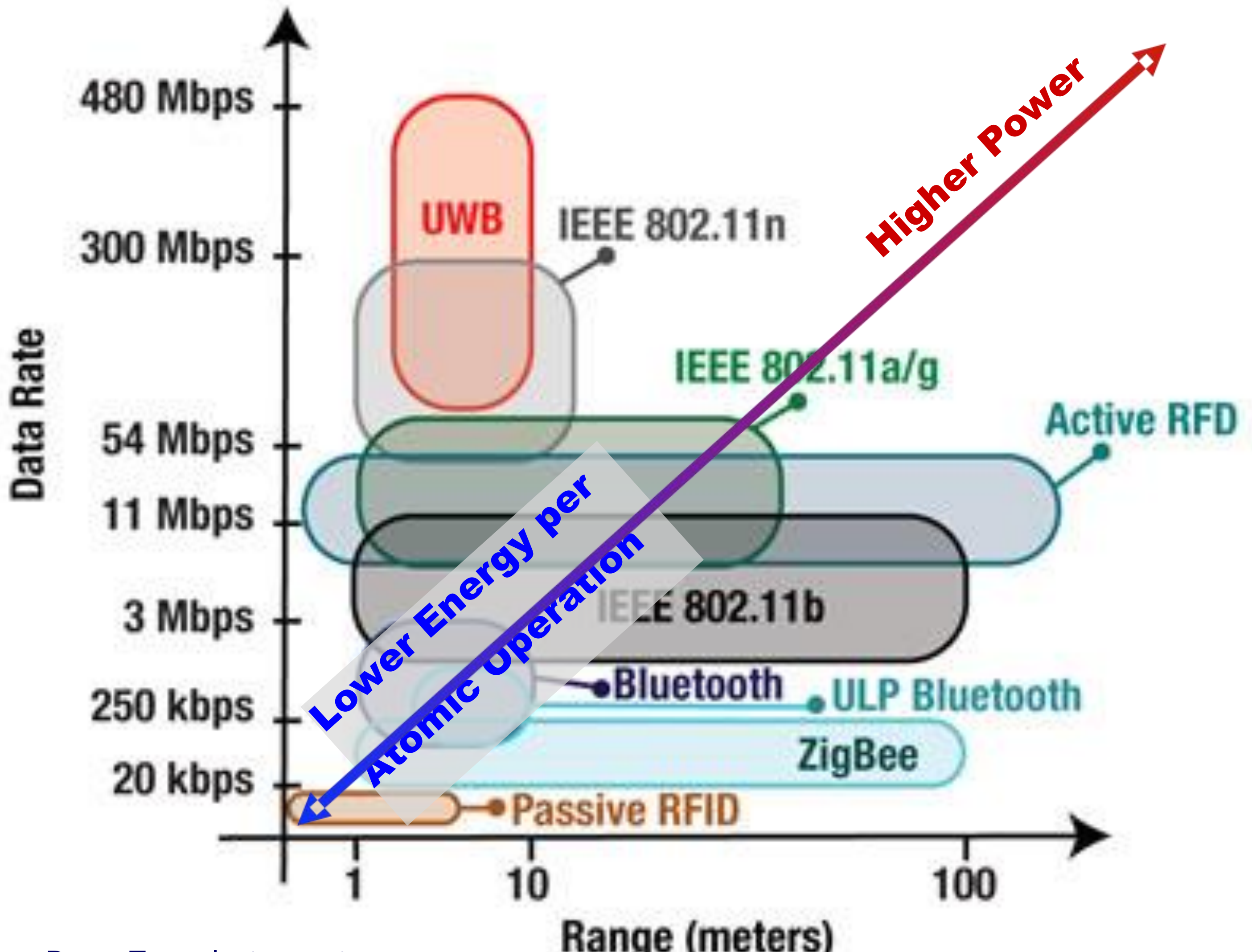
IEEE 1588,
IEEE 802.1AS

WIRELESS NETWORKS

Wireless

- Personal Area Networks (PANs)
  - Bluetooth, BLE
- Local Area Networks (LANs)
  - WiFi (IEEE 802.11*)
  - Zigbee, et al. (IEEE 802.15.4*)
- Wide Area Networks (WANs)
  - GSM (for voice, some data)
  - LTE and 5G (for audio, video)
  - Sigfox, Lora, LTE-M (for Machine-to-Machine, M2M, IoT)

Radio Technologies

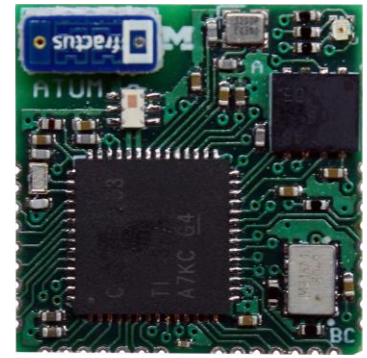


Source: Steve Dean, Texas Instruments
http://eecatalog.com/medical/2009/09/23/current-and-future-trends-in-medical-electronics/

Growing set of smart and connected devices

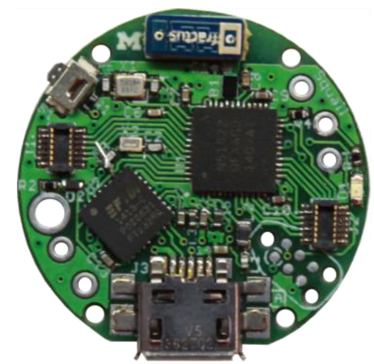
IEEE 802.15.4 (a.k.a. “ZigBee” stack)

- Workhorse radio technology for sensornets
- Widely adopted for low-power mesh protocols
- Middle (6LoWPAN, RPL) and upper (CoAP layers)
- Can last for years on a pair of AA batteries
- 850 million chipset sales in 2016 expected



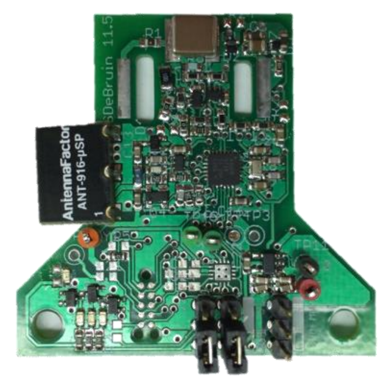
Bluetooth Low-Energy (BLE)

- Short-range RF technology
- On phones and peripherals
- Can beacon for years on coin cells
- 3 billion chipset sales in 2014



Near-Field Communications (NFC)

- Asymmetric backscatter technology
- Small (mobile) readers in smartphones
- Large (stationary) readers in infrastructure
- Ambient backscatter now emerging



Slide courtesy of Prabal Dutta

Personal Area Networks – Bluetooth Low Energy

WIRELESS NETWORKS

Bluetooth

Developed by Ericsson, Lund, Sweden, in 1994, to replace serial port wired connections over short distances.

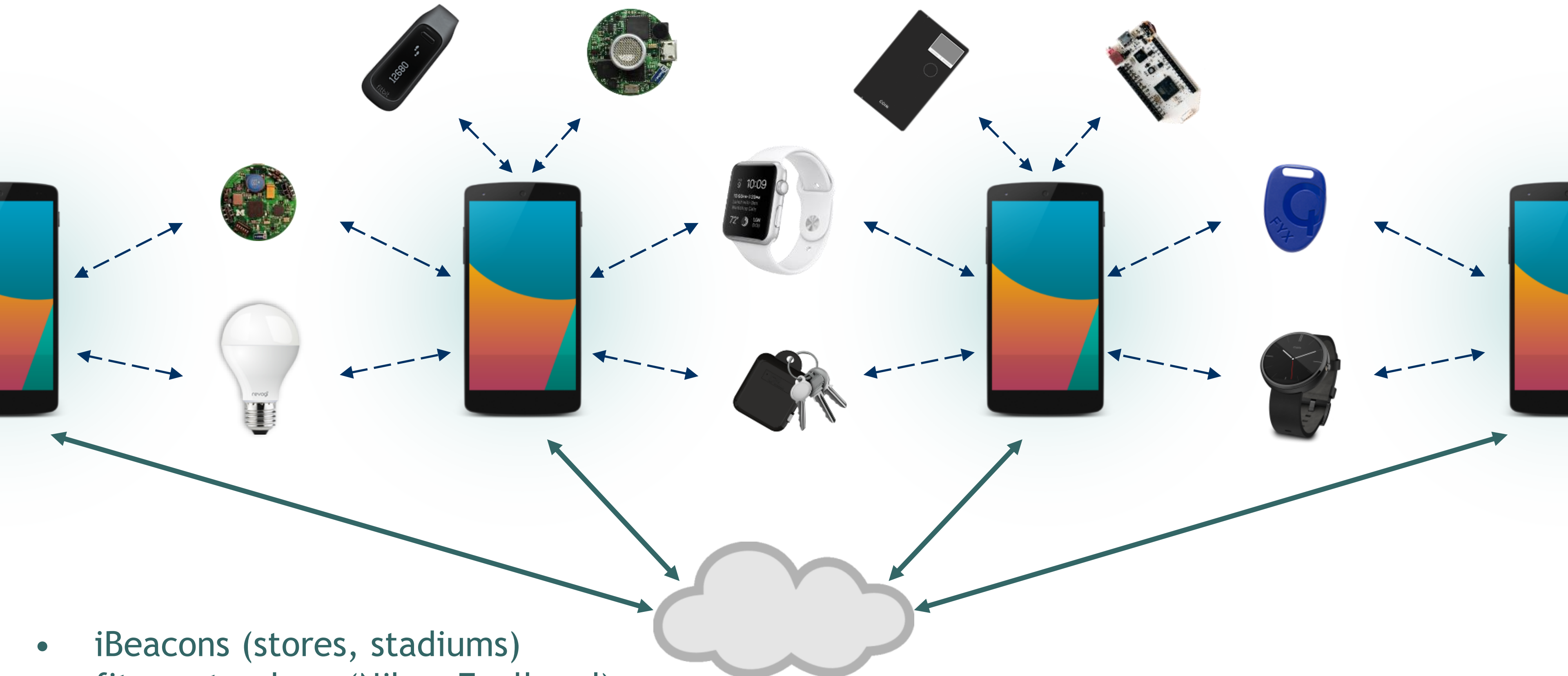
Standardized as IEEE 802.15.1

Operates in unlicensed industrial, scientific and medical (ISM) radio bands, 2.4 to 2.485 GHz, same as WiFi.

Bluetooth v4.0 includes Bluetooth Low Energy (BLE) (aka Bluetooth Smart, introduced by Nokia in 2006). Designed for low-cost, energy constrained devices.

One application of BLE is proximity sensing, as in Apple's iBeacon technology.

Smartphones with BLE have kick-started consumer IoT



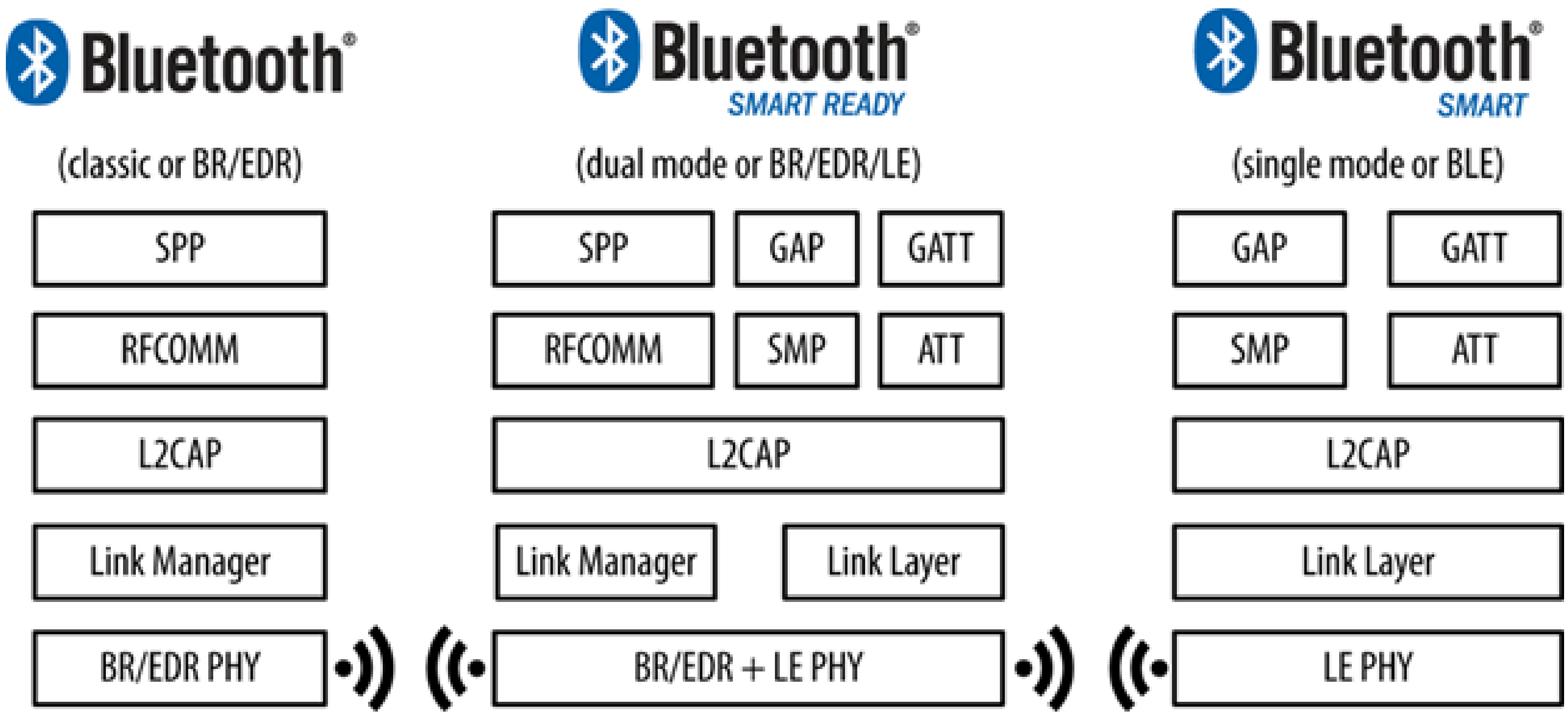
- iBeacons (stores, stadiums)
- fitness trackers (Nike+ Fuelband)
- medical devices (ConnectBlue)
- keys (Kwikset’s Kevo)

Slide adapted from Prabal Dutta

Introduction to BLE

Classic Bluetooth VS BLE

- Bluetooth was originally created for continuous streaming of data
- Classic Bluetooth is for larger amounts of data
- Not directly compatible with each other, only dual-mode devices can use both



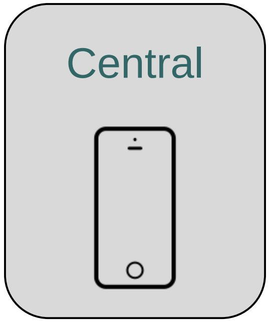
BLE High-level Architecture

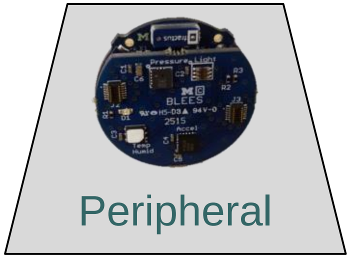
Centrals are high-power master devices

- Such as laptops or smartphones
- They listen for peripherals and choose to connect to them
- Sometimes termed Scanners outside of a connection

Peripherals are low-power slave devices

- They advertise their presence and can be connected to
- Sometimes termed Advertisers outside of a connection

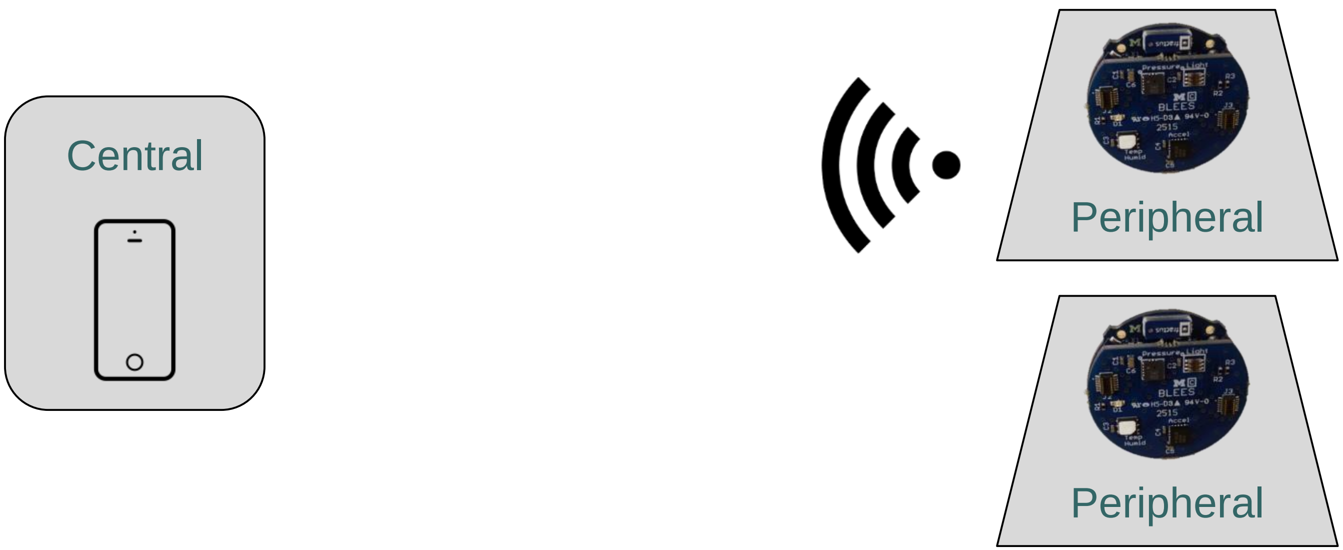




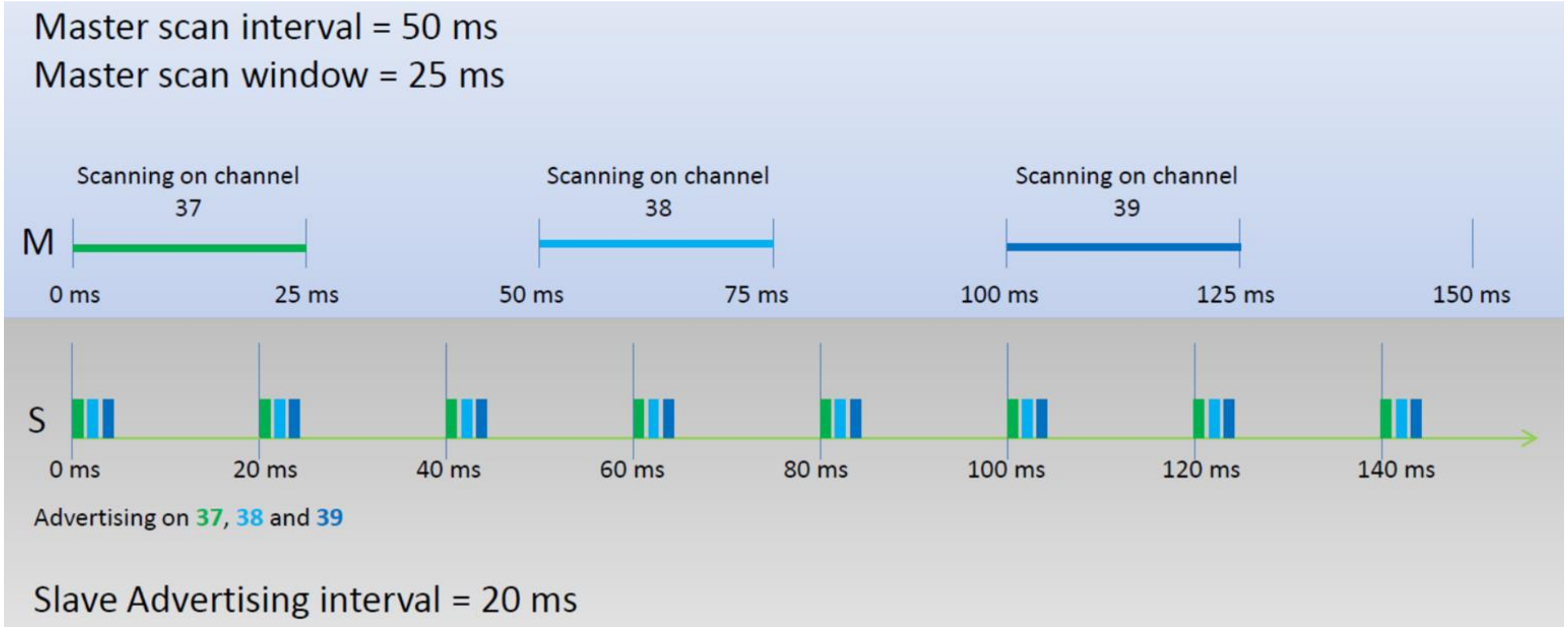
BLE Advertisements

Peripherals send out advertisement packets

- Periodic, broadcast transmission on three channels
- Enable device discovery
- Transmit up to 31 Bytes of data



BLE Advertisements



Advertising example from Nordic Semiconductor

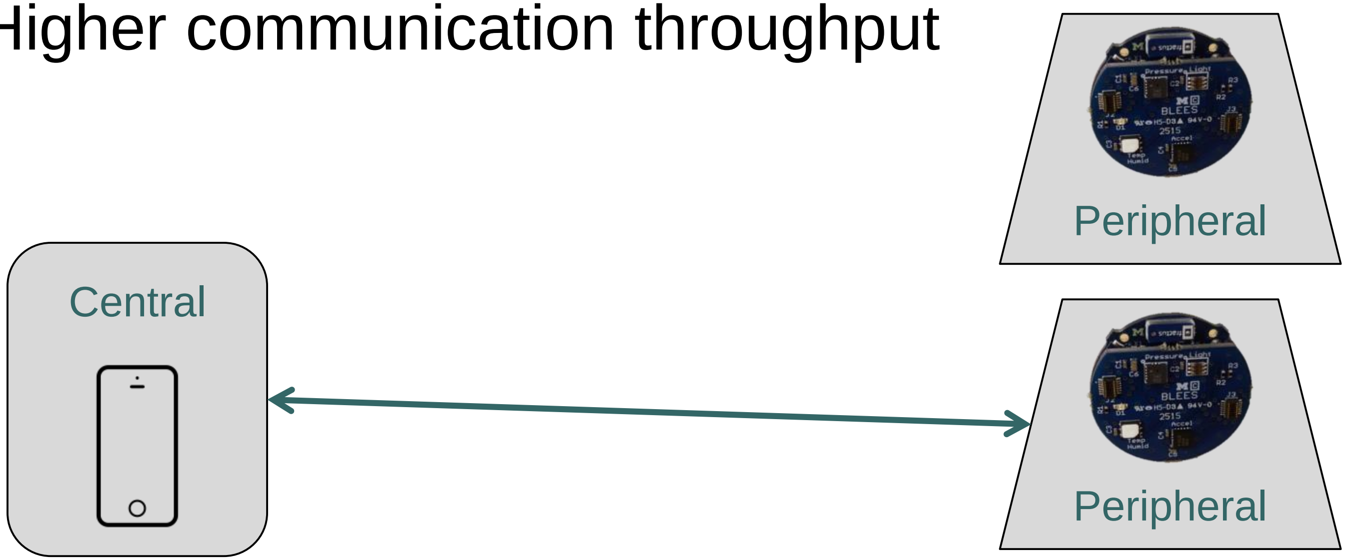
What are the advantages to end nodes of this transmission scheme?

What are the disadvantages?

BLE Connections

Centrals can connect to peripherals

- In response to an advertisement
- Forms private connection with end node
- Hops over 37 data channels
- Schedule receive and transmit windows
- Higher communication throughput



What makes it low energy?

Asymmetric relationship

- End nodes are slaves
- Master of connection burden is placed on phones

End devices rarely listen for data

- When not in a connection, listen only after transmit

Data rate is low

- 270 kbps when in a connection

BLE Security

A device can request a secure one-to-one connection using the Security Manager Protocol (SMP)

Two steps are needed to get a secure connection:

- Pair
- Bond

BLE Security: Pairing

Set up a secure connection using a Short Term Key (STK)

STK is relatively insecure, used only to protect the key exchange in the Bonding process

Three ways to pair devices and share a STK:

1. *Just Works*
   - Not secure, STK passed in plain text between devices
2. *Passkey Display*
   - User passes 6-digit passkey between devices, used to generate the STK
3. *Out Of Band*
   - Uses NFC or some other method to pass the STK

Slide courtesy of Prabal Dutta

BLE Security: Bonding

Devices then "Bond" by exchanging a stronger pair of keys, called "secret keys"

Secret key transmission is encrypted using the STK created in the pairing process

The secret keys are then stored in non-volatile memory, so the bonded devices can easily reconnect to each other later without having to pair or bond again

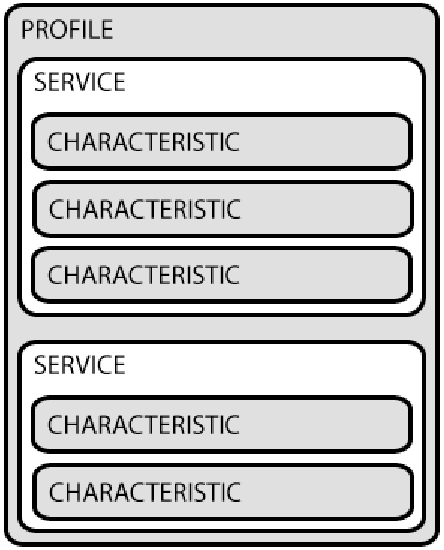
BLE Services

Services are used to exchange data in connections

- Both centrals and peripherals can have services
- Services can be thought of as a group of device data
- There are many standardized services
  - Environmental sensing, heart rate monitoring, etc.

Services have characteristics

  - Specific data which can be read or written
  - Up to 512 Bytes in length



BLE Service Example

As an example, the Environmental Sensing Service

- Characteristics
  - Temperature, Elevation, Humidity, Pollen Concentration, etc.
  - Read-only to get measurement value
- Descriptors
  - Measurement frequency, Measurement range
  - Often read-only to understand how the sensor works
  - Occasionally writable to change how the sensor works

BLE Standardization

What do we gain from all the standardization?

What do we lose?

BLE Standardization

What do we gain from all the standardization?

- Interoperability!

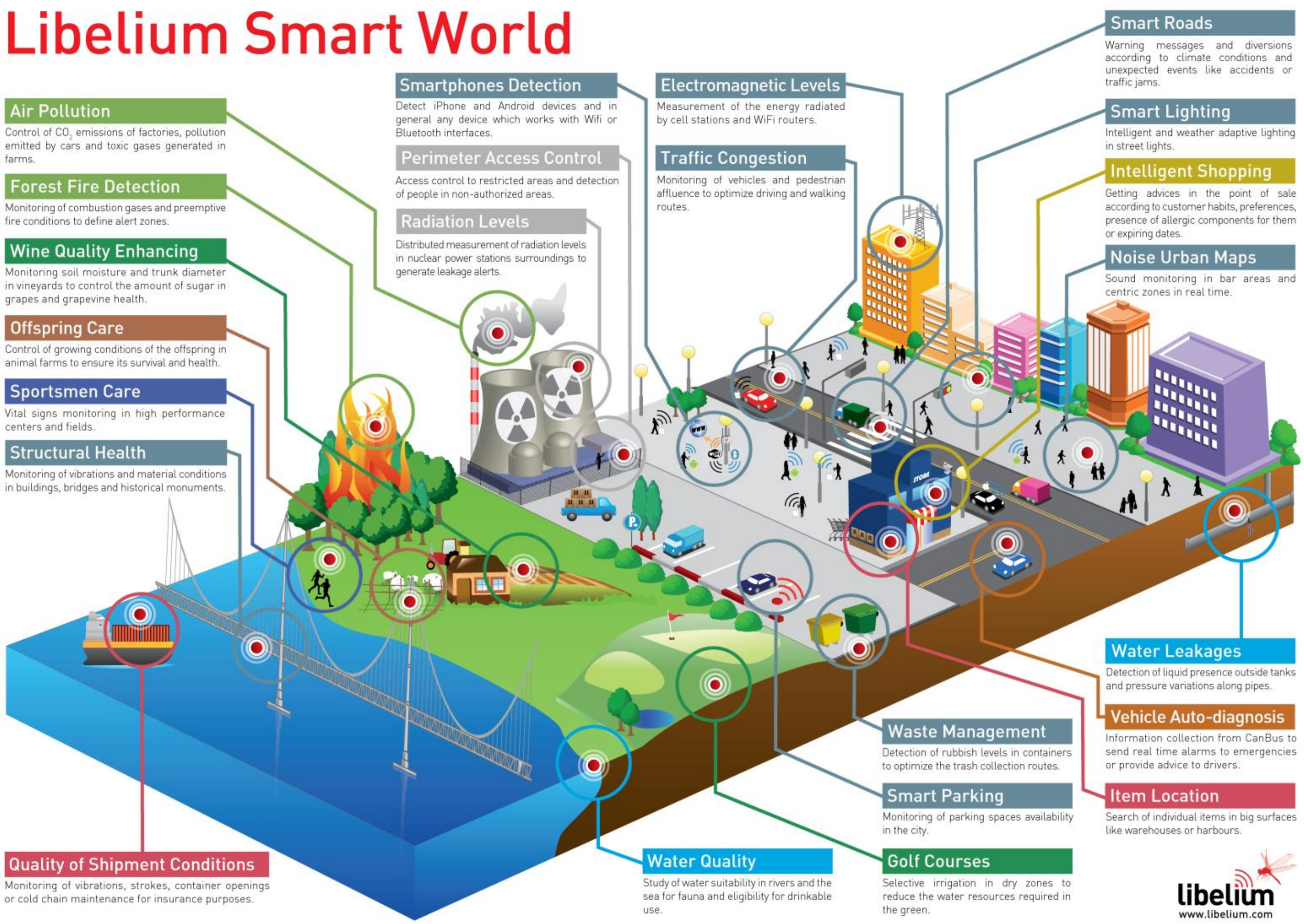
What do we lose?

- Complexity
- Flexibility

Wide Area Networks – LoRaWAN

WIRELESS NETWORKS

IoT is advancing towards city-scale applications

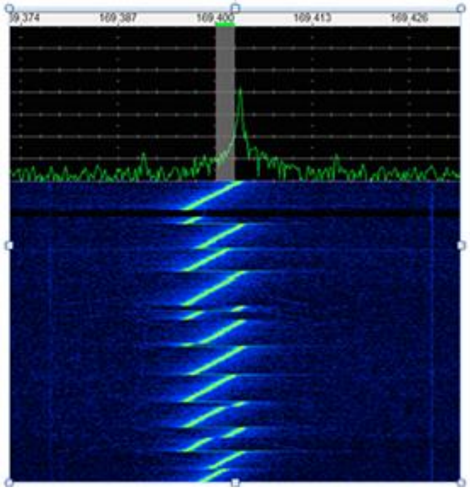


Example by Libelium

Systems are still resource-constrained

Need low-power, low-bandwidth,
but still long range

LoRaWAN



LoRa

- Physical layer protocol
- Chirp, spread-spectrum modulation
- 915 MHz in the United States (ISM band)

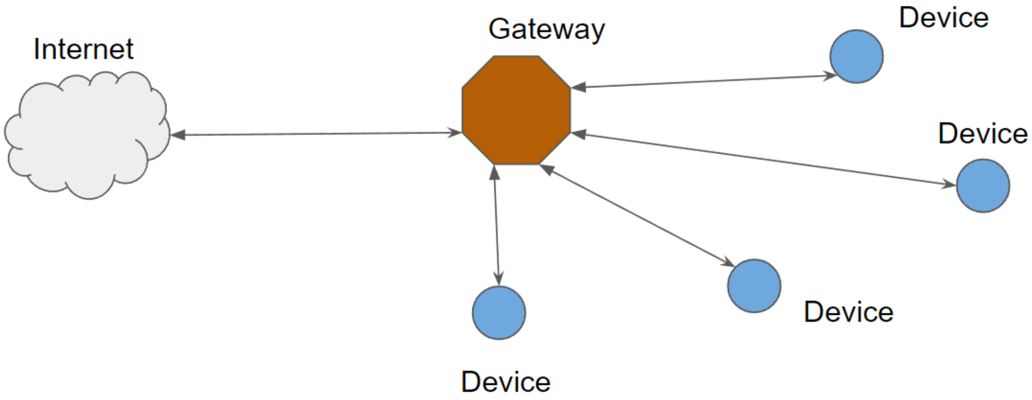
LoRaWAN

- Data-link layer protocol
- Specifies when to transmit and receive data over LoRa

LoRaWAN Network Architecture

All communication is two or from a gateway

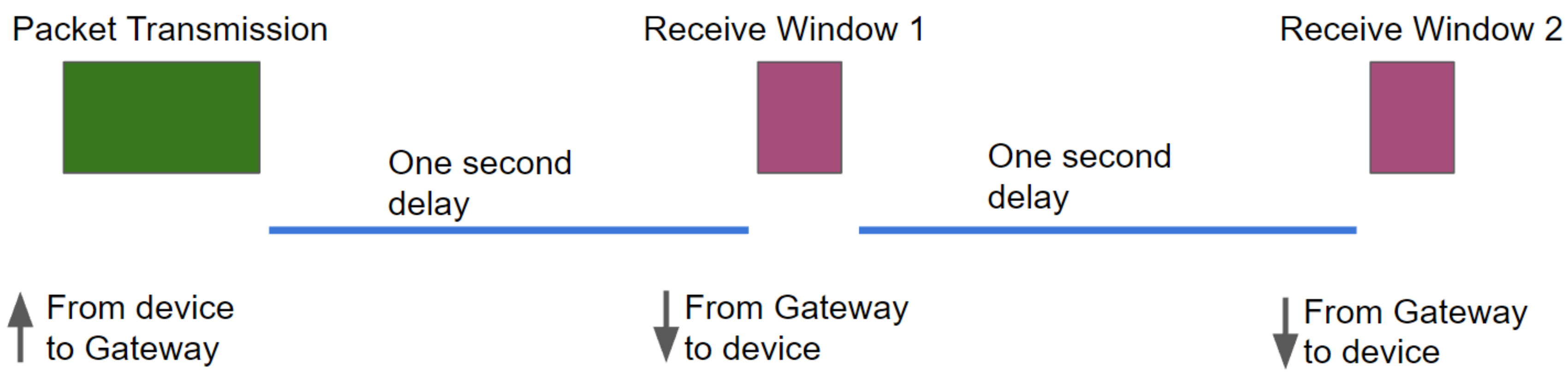
- Similar to master/slave relationship in BLE
- Devices do not directly communicate with each other



LoRaWAN Packet Transmission

The network expects mostly uplink transmissions

End nodes listen twice after each transmission

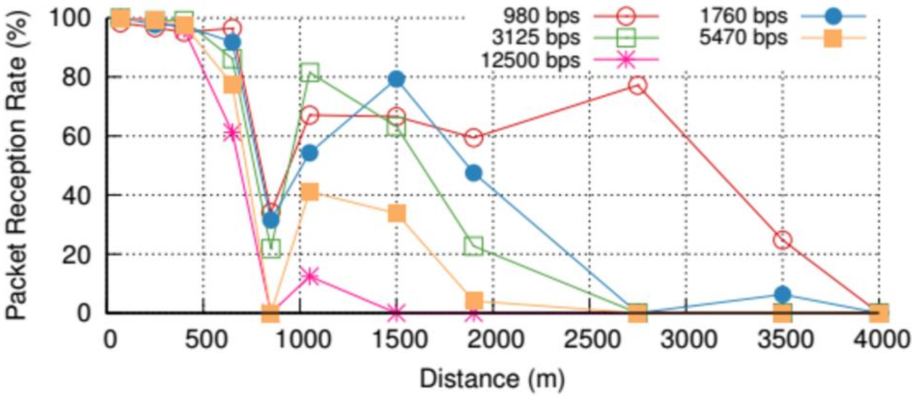


LoRaWAN Data Rate and Distance

LoRaWAN trades off distance and data rate

Name	Data Rate (bits/second)	Theoretical Range (kilometers)
Data Rate 0	980	25
Data Rate 1	1760	21
Data Rate 2	3125	13
Data Rate 3	5470	12
Data Rate 4	12500	9

Testing on campus and downtown



LECTURE PART 2

Attribution

Building off of the work of others is OK.

Failing to credit the others is not!!

A professional knows his or her sources!

Example: “We used the Arduino library for NeoPixel provided by AdaFruit, written by Phil Burgess, and distributed with an LGPL license.”

Example: “We used an Arduino Mega, made by the Italian company Smart Projects. The Mega is part of the Arduino family of open-source hardware and software that started in 2005 as a project for students at the Interaction Design Institute Ivrea in Ivrea, Italy. Arduino is named after a bar in Ivrea, which in turn is named after an Italian 11th century king.”

Example of Proper Attribution

Bluetooth stack for our credit card reader is authored by:

Serge C. C. Theef

And is available at the following website:

http://scam.foru.ru

It is free software, with the following copyright:

Copyright 2014 by Serge C. C. Theef, All rights reserved.

Permission is granted to use, reproduce, and distribute this software provided that all users of the software upload a valid credit card number to http://scam.foru.ru/ccupload .

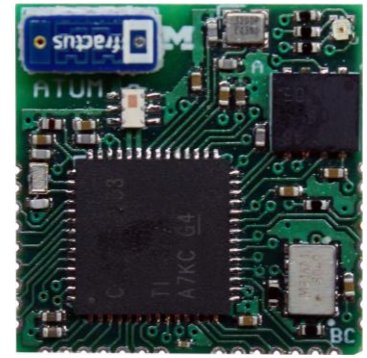
Local Area Networks – 802.15.4 and WiFi

WIRELESS NETWORKS

Growing set of smart and connected devices

IEEE 802.15.4 (a.k.a. “ZigBee” stack)

- Workhorse radio technology for sensornets
- Widely adopted for low-power mesh protocols
- Middle (6LoWPAN, RPL) and upper (CoAP layers)
- Can last for years on a pair of AA batteries
- 850 million chipset sales in 2016 expected



Bluetooth Low-Energy (BLE)

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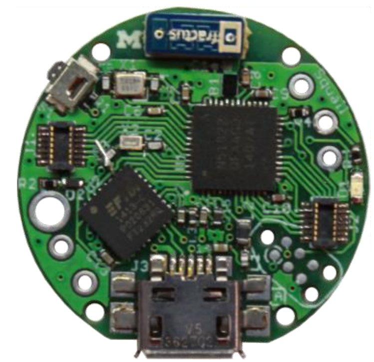
- On phones and peripherals
- Can beacon for years on coin cells
- 3 billion chipset sales in 2014



Near-Field Communications (NFC)

- Asymmetric backscatter technology
- Small (mobile) readers in smartphones
- Large (stationary) readers in infrastructure
- Ambient backscatter now emerging

Slide courtesy of Prabal Dutta

IEEE 802.15.4

Physical and MAC layer standard for low-rate wireless personal area networks (WPAN) for energy constrained devices. Provides the basis for:

- Zigbee: Adds mesh network and encryption
- WirelessHART: Highway Addressable Remote Transducer Protocol (HART)
  - Integrates TSMP, Time Synchronized Mesh Protocol, developed by Dust Networks.
- 6LoWPAN: IPv6 over low power WPAN

The New York Times

Thursday, November 3, 2016 | Today's Paper | Video

"The worm spreads by jumping directly from one lamp to its neighbors, using only their built-in ZigBee wireless connectivity and their physical proximity. The attack can start by plugging in a single infected bulb anywhere in the city, and then catastrophically spread everywhere within minutes, enabling the attacker to turn all the city lights on or off, permanently brick them, or exploit them in a massive DDOS attack."

FEATURED

Why Light Bulbs May Be the Next Hacker Target

By JOHN MARKOFF

Carlos Gonzalez for The New York Times

The Internet of Things, activated through apps, promises tremendous convenience to homeowners. But it may also prove irresistible to hackers.

Wireless "smart" devices may be the tech wave of the future, but researchers have found flaws that let hackers spread malicious code through them.

IoT Goes Nuclear: Creating a ZigBee Chain Reaction

Eyal Ronen(✉)*, Colin OFlynn†, Adi Shamir* and Achi-Or Weingarten*

PRELIMINARY DRAFT, VERSION 0.9

**Weizmann Institute of Science, Rehovot, Israel*

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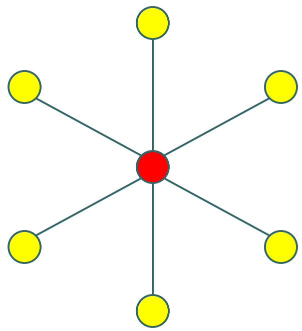
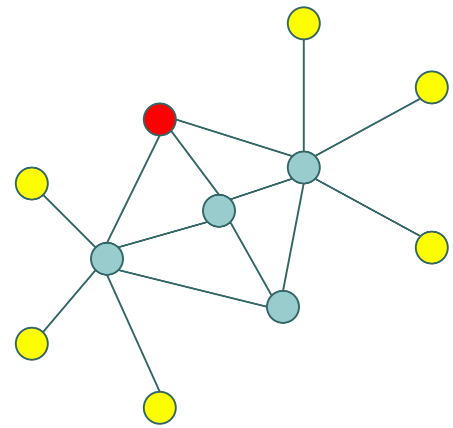
†Dalhousie University, Halifax, Canada

coflynn@dal.ca

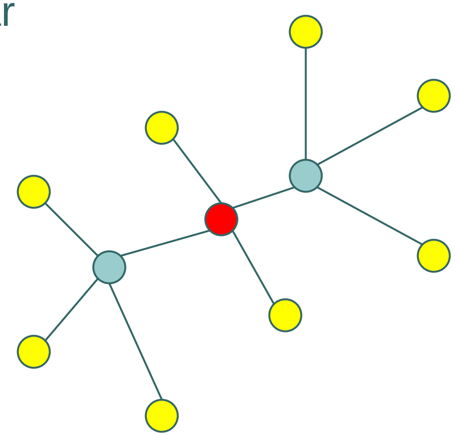
Network Topologies



Star



Mesh



Cluster Tree

- Coordinator
- End device
- Router / End device

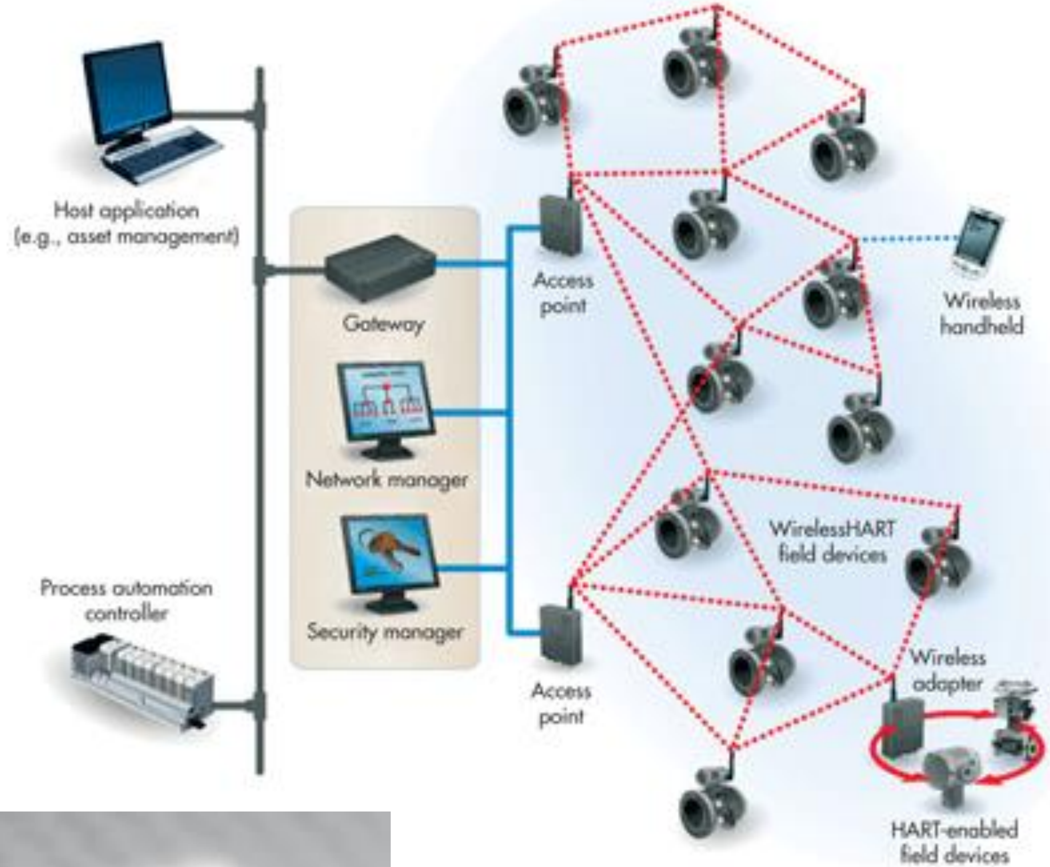
End devices capable of routing and/or coordinating are called peer-to-peer devices.

Unslotted vs. Slotted Modes

- Unslotted:
  - All nodes are always listening, or
  - Leaf nodes poll the coordinator for available data (coordinator and routers are always listening)
- Slotted: Typically has superframe with two periods:
  - Contention access period uses CSMA/CA
  - Contention-free period has assigned time slots
  - Requires clock synchronization or always-on radios

Energy Efficiency

Wireless HART uses Time Synchronized Mesh Protocol (TSMP) in a Mote-on-Chip (MoC), from Dust Networks Inc.

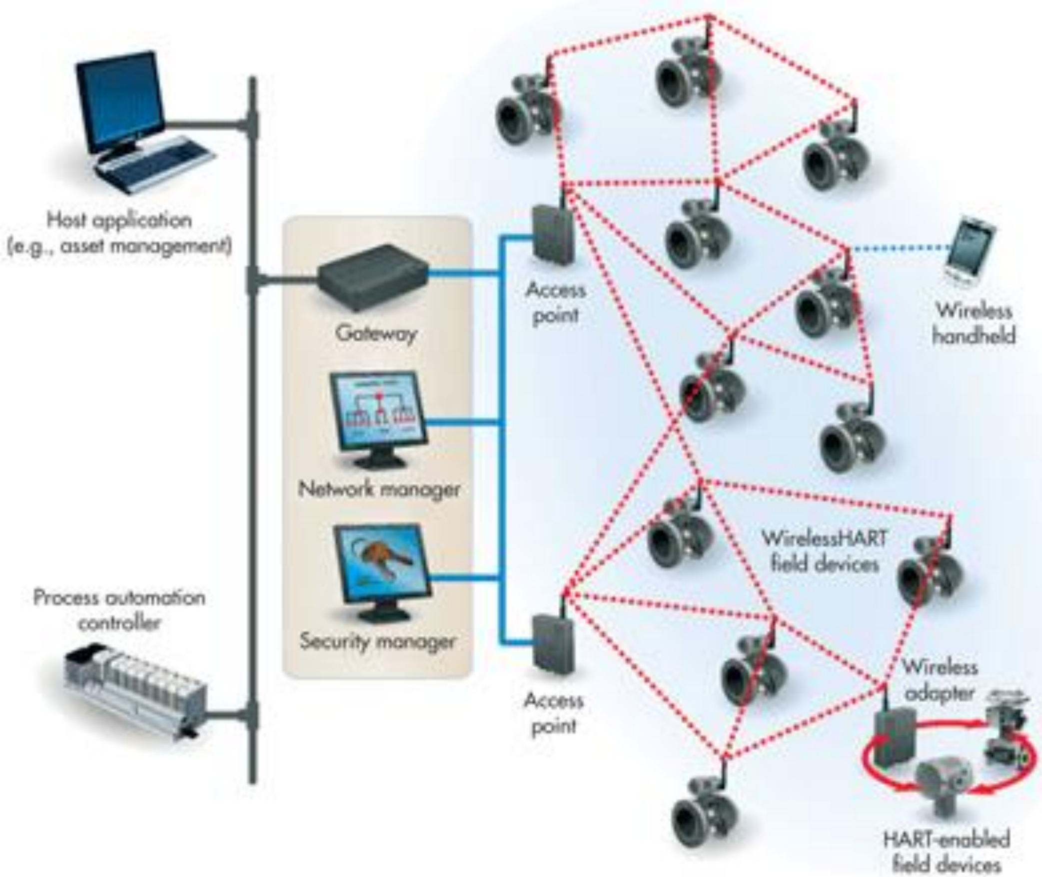


IEEE 802.15.4e

Routing to Energy-Constrained Devices CoAP: Constrained Application Protocol

Access to low-power, mesh networked devices via a gateway to give them an Internet presence (IPv6).

Gateway translates IPv6 128-bit (vs 32-bit in IPv4) addresses to 16-bit, locally unique addresses.

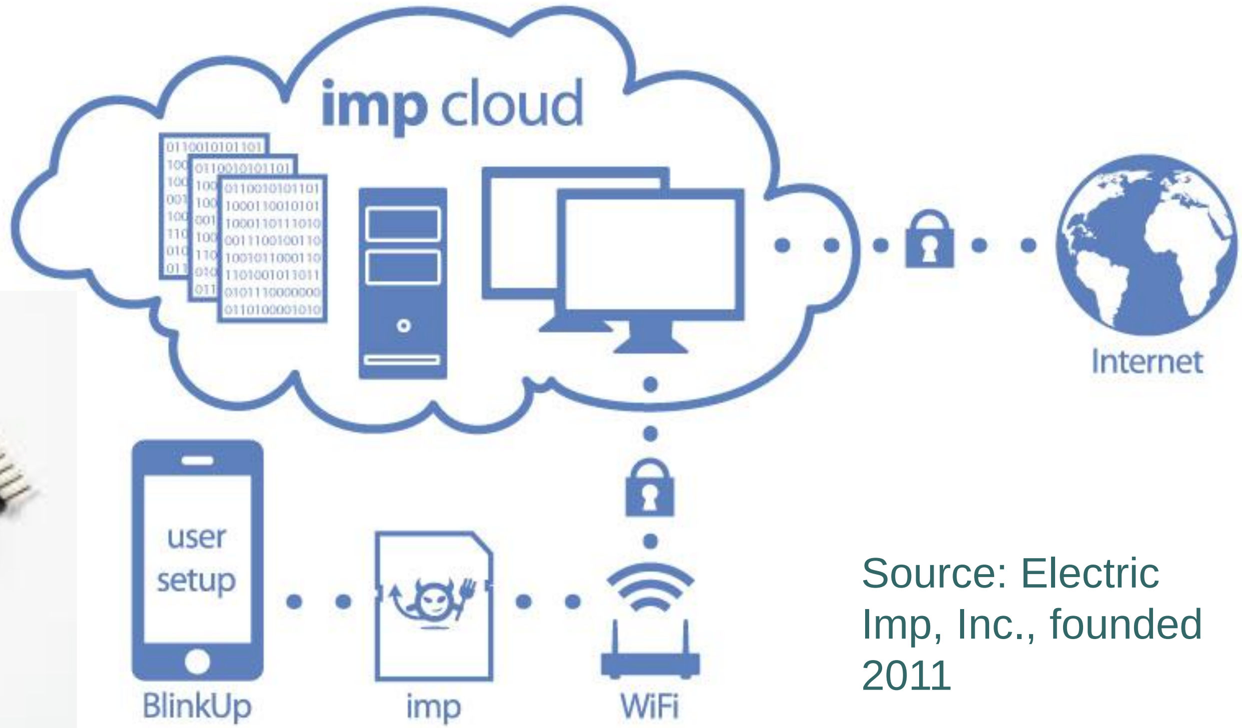


WiFi

- WLAN: Wireless Local Area Network (~20 meters)
- Developed in the 1990s (AT&T plus others)
- Access points provide gateways to wired networks
- Operates in 2.4 and 5 GHz unlicensed bands

- Requires larger antennas and more energy than Bluetooth or 802.15 networks.

Example IoT Technology using WiFi: Electric Imp



Source: Electric Imp, Inc., founded 2011

Publishes sensor data from built-in ADCs to the cloud, and then provides a RESTful interface to the data.

RESTful Interfaces

Representational State Transfer (REST) [1] uses web technology

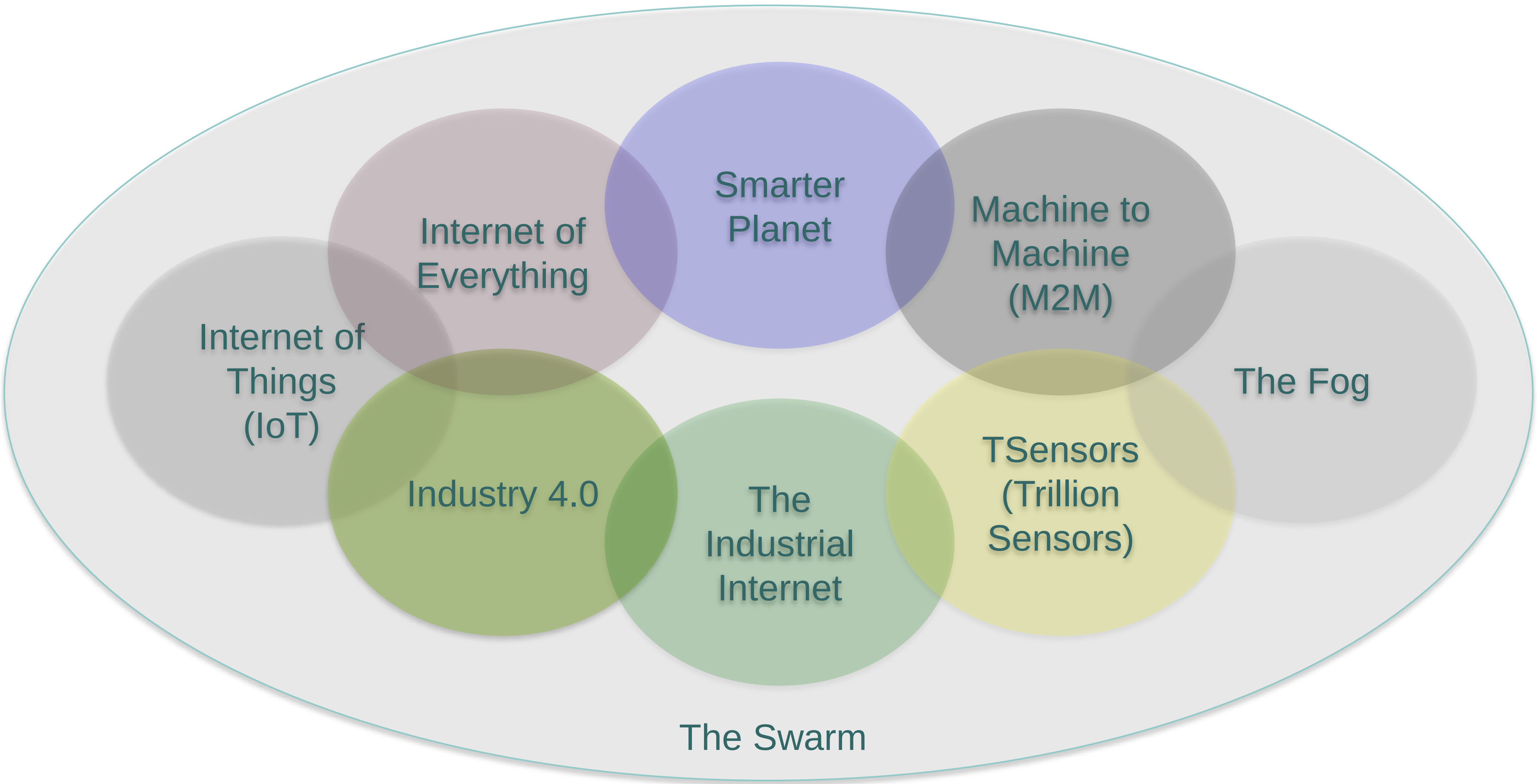
Example:

http://ptolemy.org:8077/sensor/get?id=A1243ADsA3209

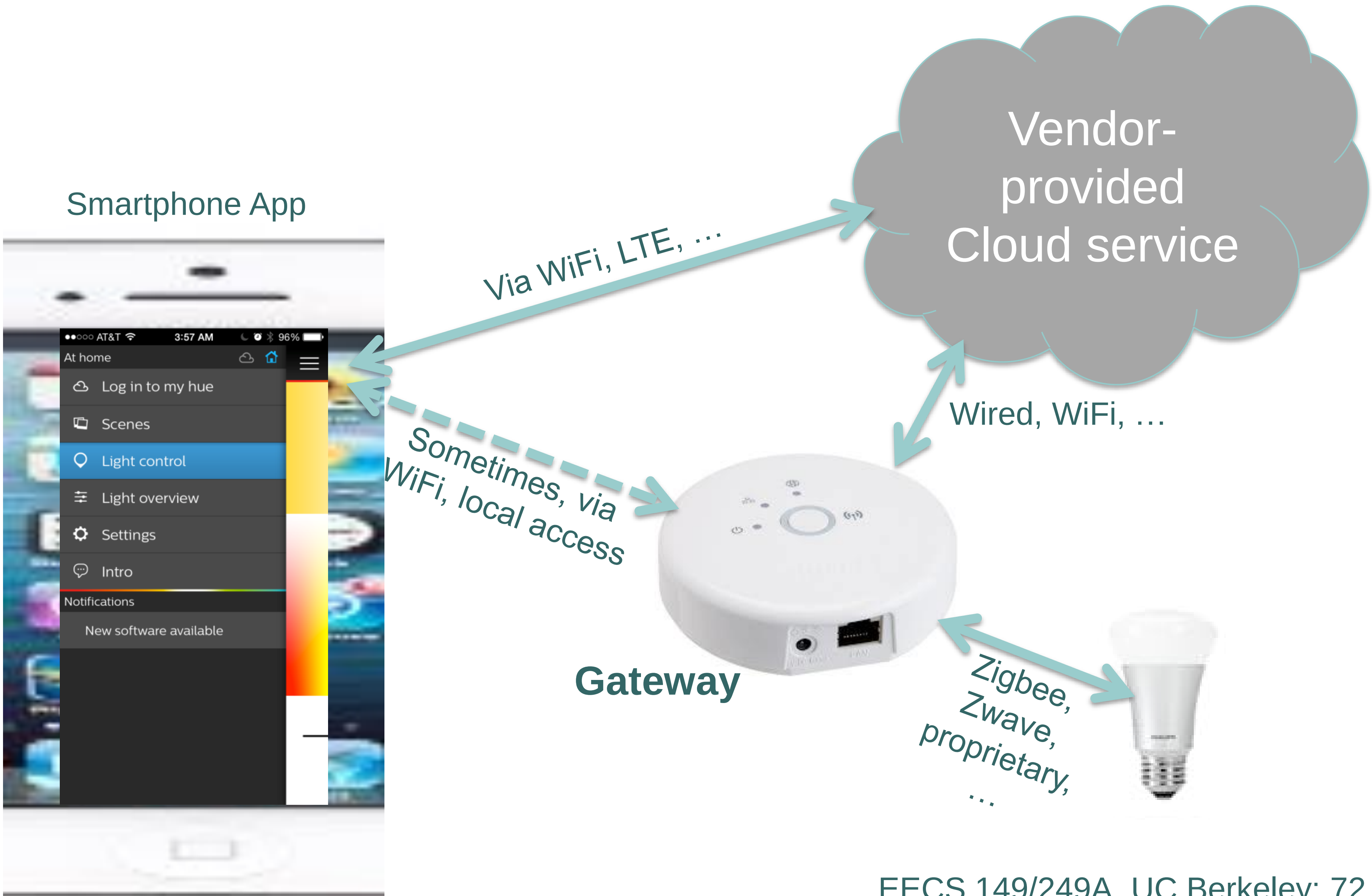
[1] Fielding, R. T. and R. N. Taylor (2002). "Principled Design of the Modern Web Architecture." ACM Transactions on Internet Technology (TOIT) **2**(2): 115-150.

COMMUNICATION AND THE INTERNET OF THINGS

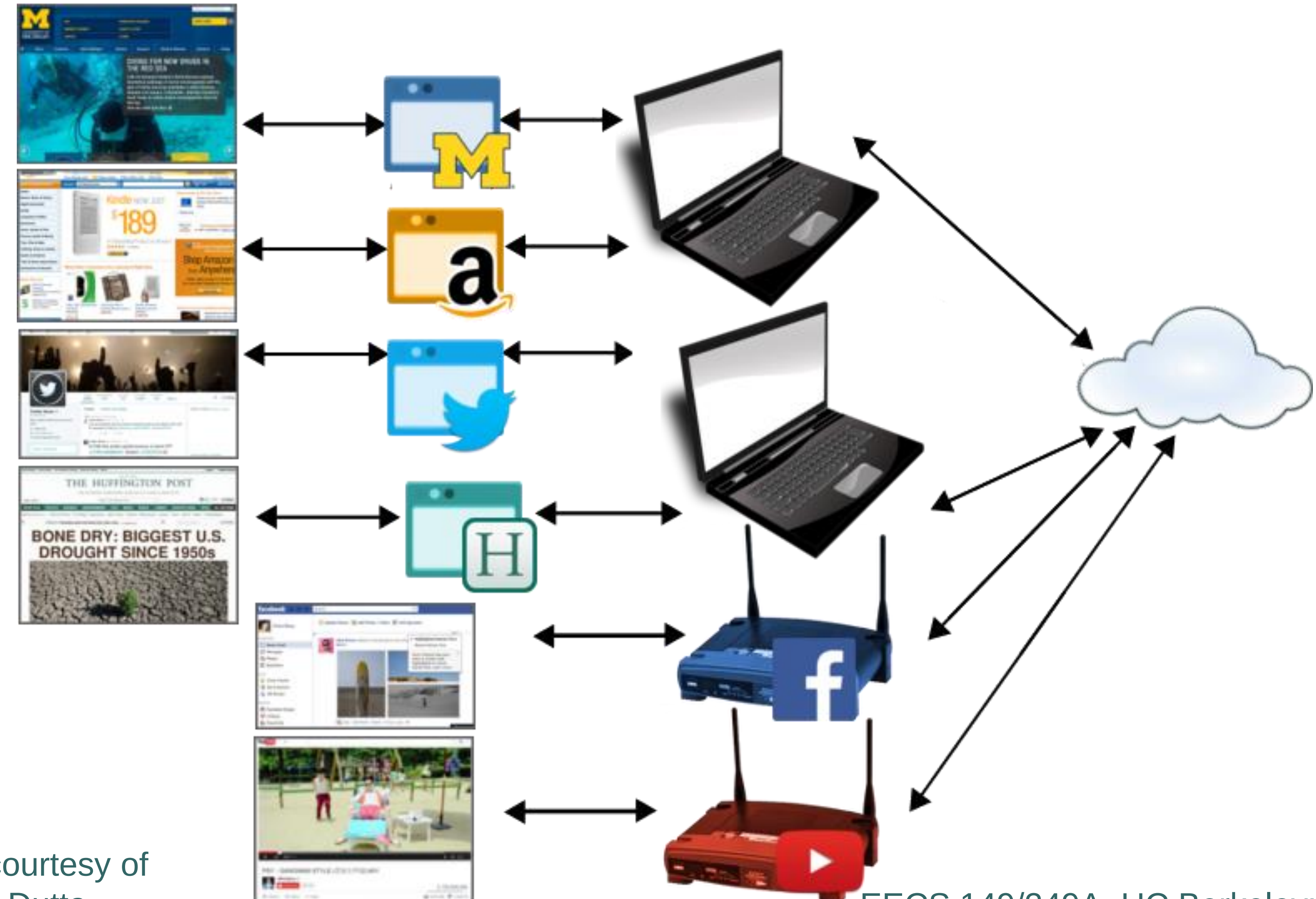
"Swarm" Technology
The Buzz around the Swarm



Typical IoT Architectures Today

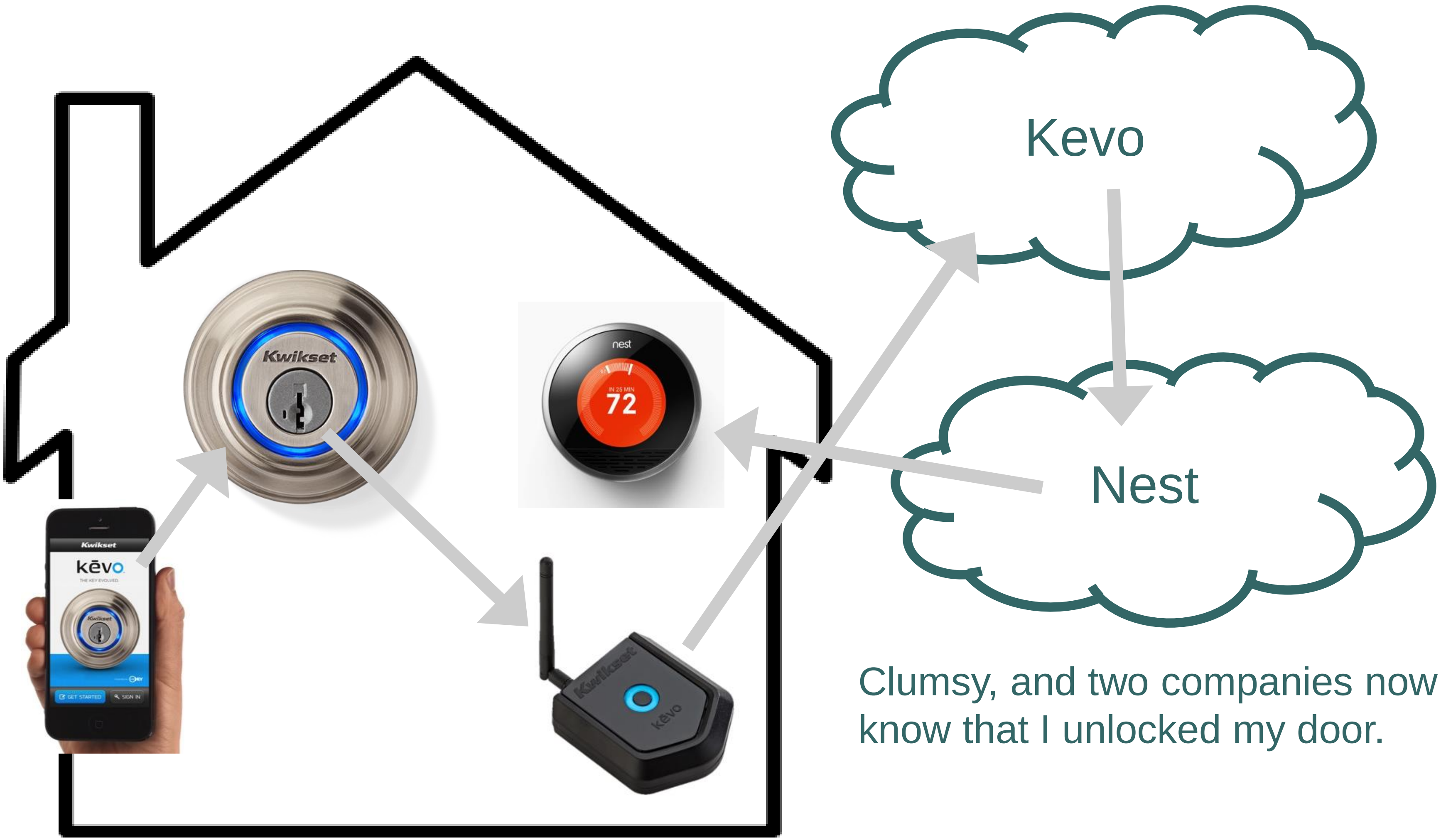


Imagine if every website required its own browser or router



Slide courtesy of Prabal Dutta

Orchestration: when I enter my house, turn on the AC

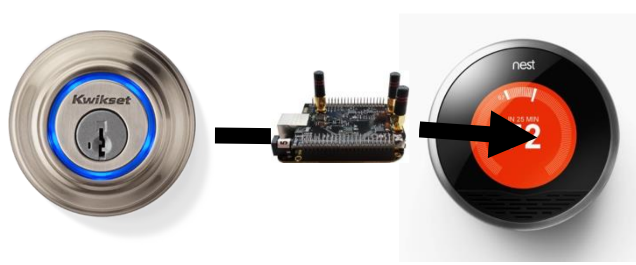


Clumsy, and two companies now know that I unlocked my door.

Slide courtesy of Prabal Dutta

Initial setup, configuration, and authorization may require complex interactions and cloud interaction

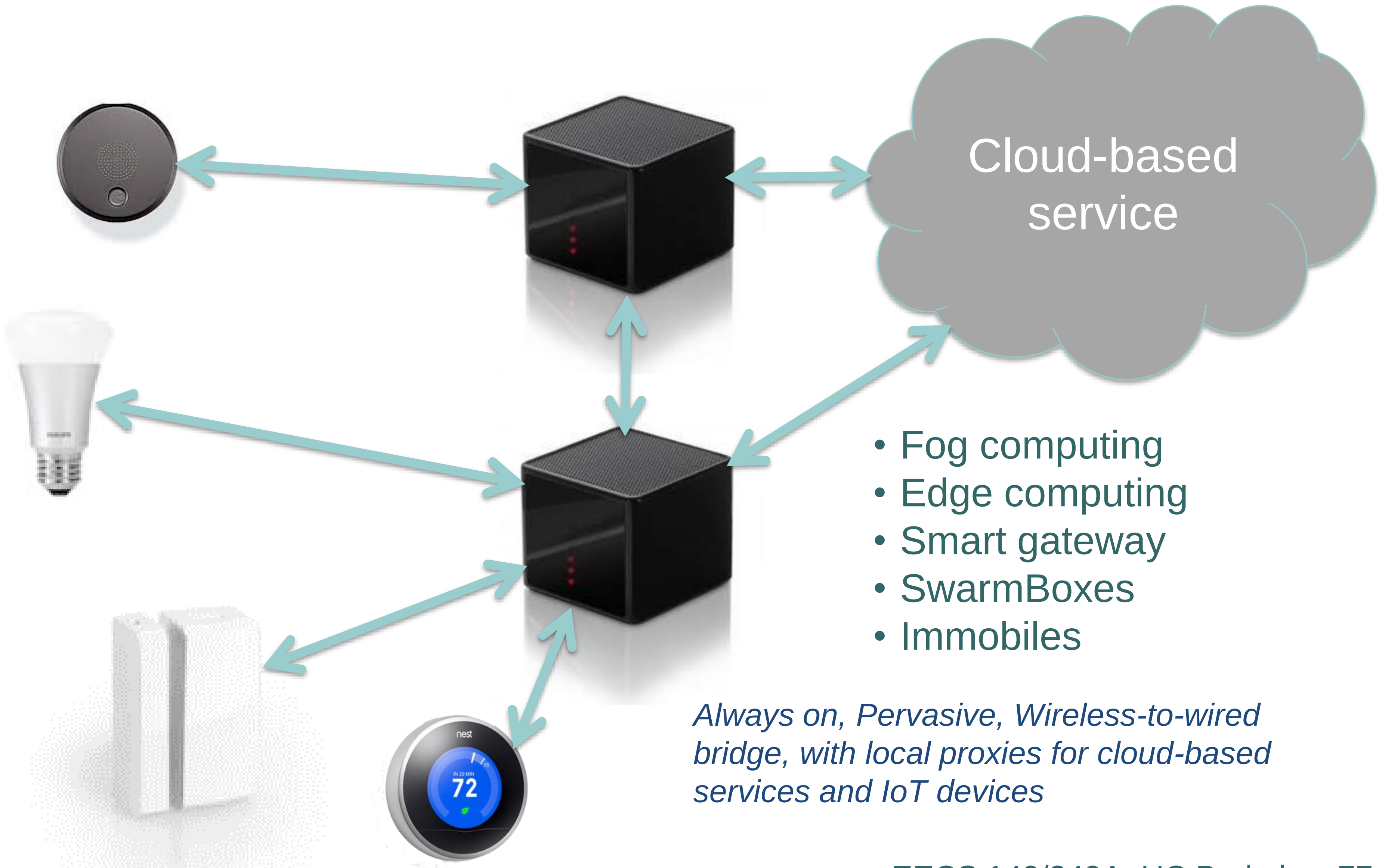
…but device interactions likely do not.



Challenges

- Smartphone apps proliferate, increasing user complexity.
- Vendor-specific gateways don’t scale well to many vendors.
- Latency of cloud-based services can be substantial.
- Composition of services can only be done in the cloud (e.g. using IFTTT), increasing latency.
- Many moving parts makes systems less reliable, and tracking the source of problems can be hard.

A New Infrastructure



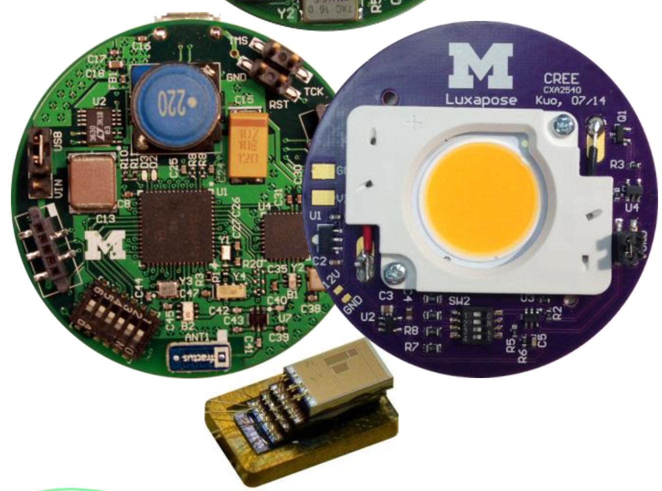
- Fog computing
- Edge computing
- Smart gateway
- SwarmBoxes
- Immobiles

Always on, Pervasive, Wireless-to-wired bridge, with local proxies for cloud-based services and IoT devices

Emerging set of proximal communication interfaces

Ultrasonic

- Small, low-power, short-range
- Supports very low-power wakeup
- Can support pairwise ranging of nodes

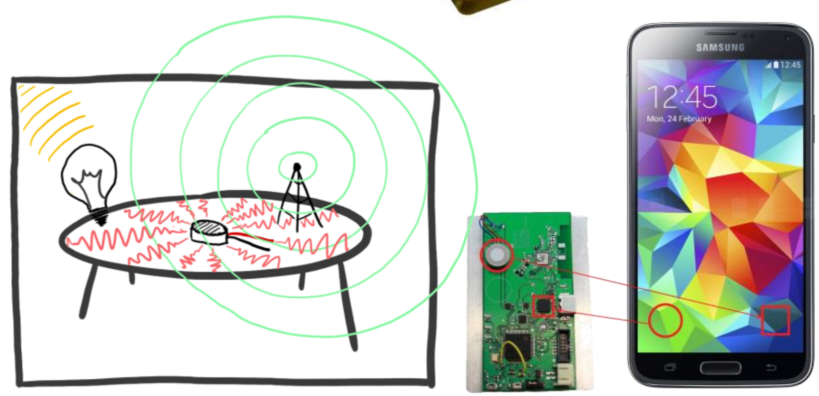


Visible Light

- Enabled by pervasive LEDs and cameras
- Supports indoor localization and comms
- Easy to modify existing LED lighting

Vibration

- Pervasive accelerometers
- Pervasive vibration motors
- Bootstrap desktop area context



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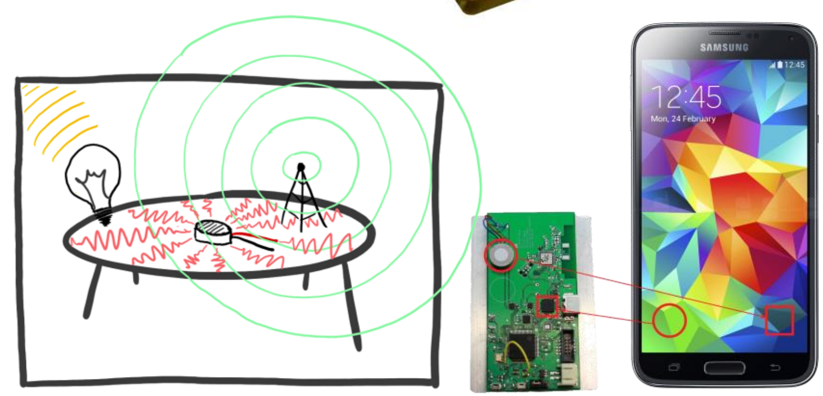


Emerging Retail Environment

Often have line-of-sight to lighting

- Groceries
- Drugstores
- Megastores
- Hardware stores
- Enterprise settings

Lots of overhead lighting in retail

Retailers deploying LED lighting

Customers using phones in stores

- Surf, Scan, Share

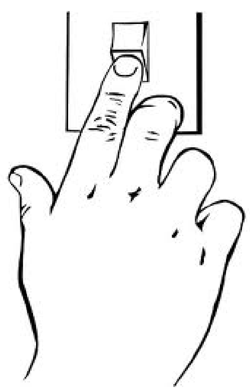
Customers installing retailer apps

- Maps, Barcodes, Deals, Shopping

Going from milli-Hz to mega-Hz switching

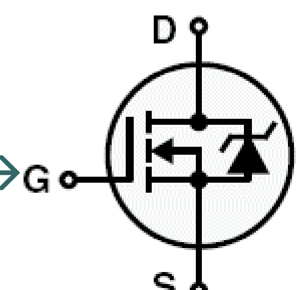
≠

$\sim 10^{-3}$ Hz



$\sim 10^{7}$ Hz

00010100 →



VLCP: visible light communications and positioning

LED luminaires

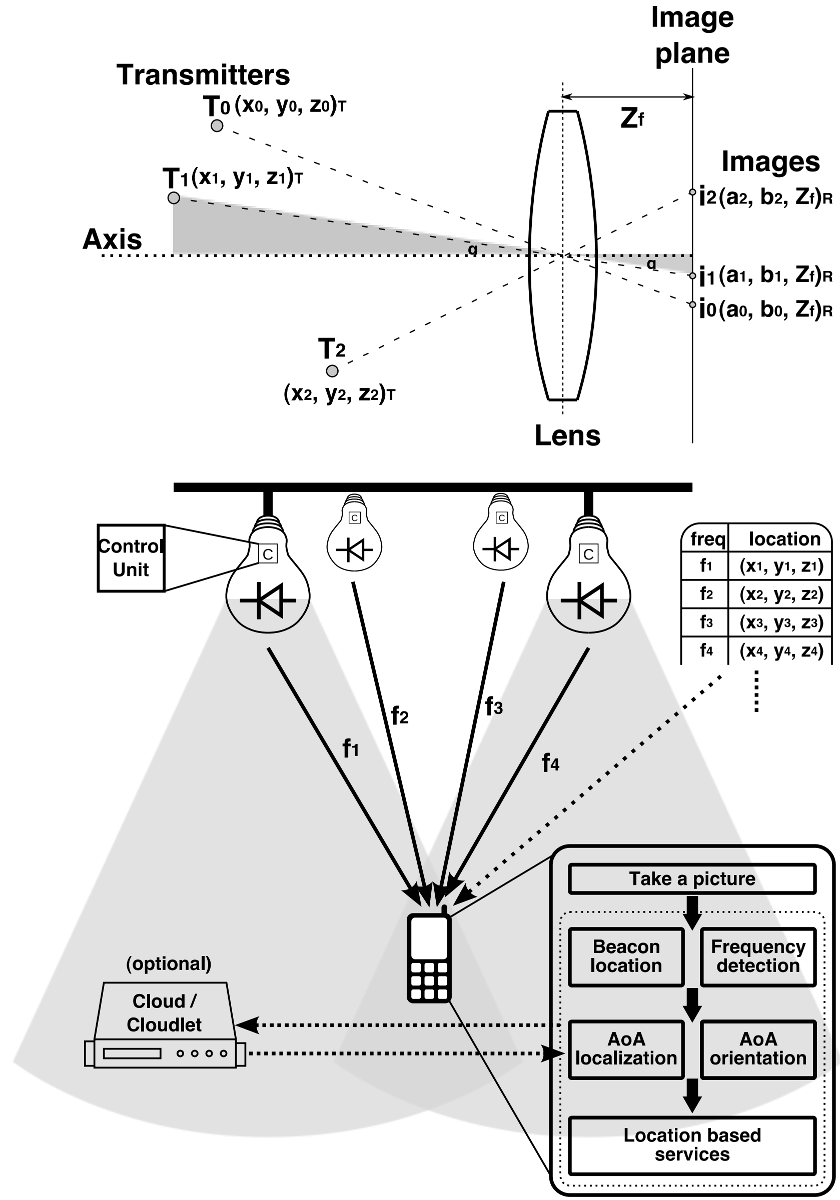
- Slightly-modified
- Transmit beacons
- Identities or coordinates

Smart phones

- Run background mobile app
- Take images periodically
- Perform local processing
- Offload to cloud/cloudlet

Cloud/cloudlet server

- Do photogrammetry
- Do AoA Localization
- Estimate location
- Estimate orientation
- Provide location-based services

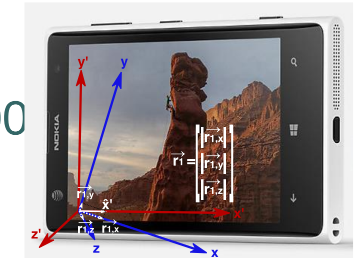


Ye-Sheng Kuo, Pat Pannuto, Ko-Jen Hsiao, and Prabal Dutta, "Luxapose: Indoor Positioning with Mobile Phones and Visible Light," In Proceedings of the 20th Annual International Conference on Mobile Computing and Networking (MobiCom'14), Maui, HI, Sep. 7-11, 2014.

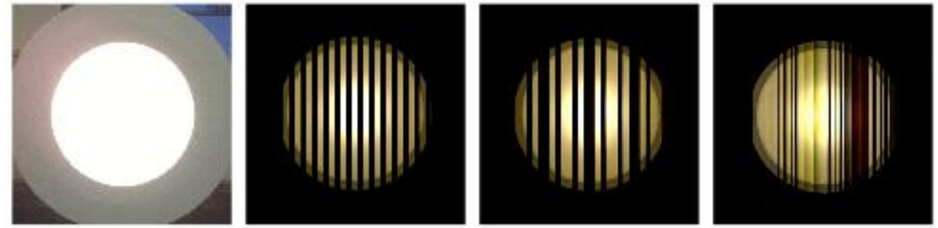
Indoor localization using VLCP

01100101000

LED Luminaire



Smart Phone



Illuminate | Idle | TX <66> | TX packet

Captured using a rolling shutter

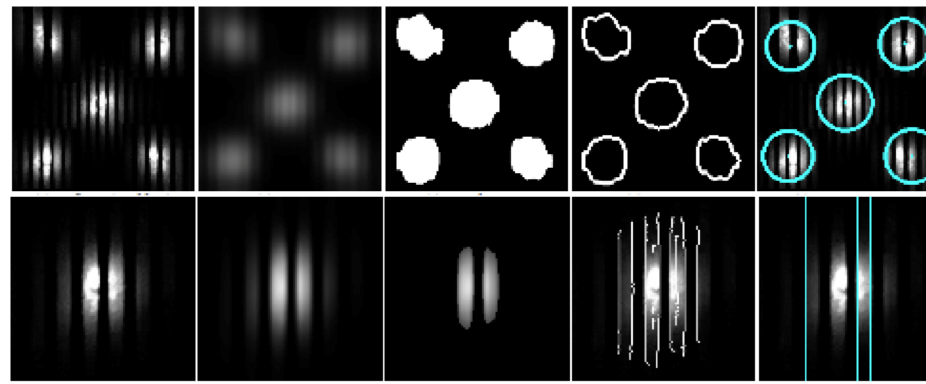
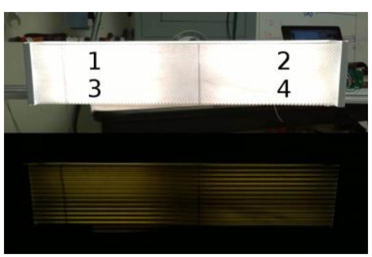
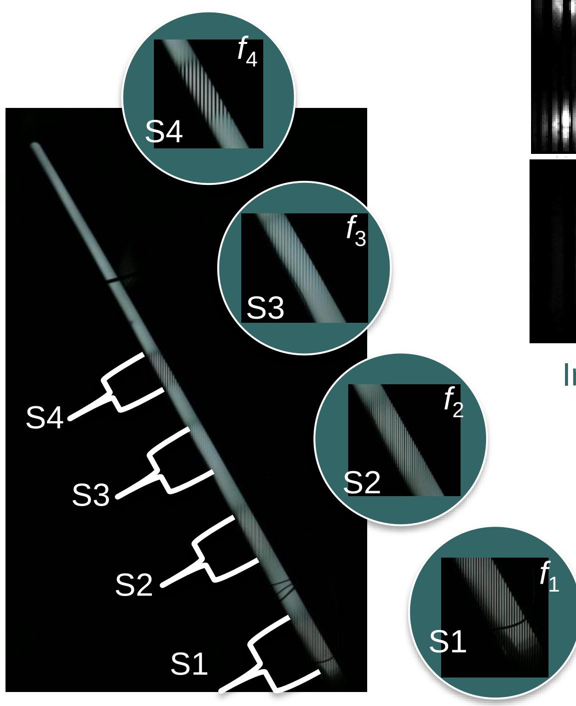


Image processing extracts beacon locations and frequencies





$$
\begin{aligned}
d_{0,1}^2 &= (u_0 - u_1)^2 + (v_0 - v_1)^2 + (w_0 - w_1)^2 \\
&= (K_0 a_0 - K_1 a_1)^2 + (K_0 b_0 - K_1 b_1)^2 + Z_f^2 (K_0 - K_1)^2 \\
&= K_0^2 \left|\overrightarrow{Oi_0}\right|^2 + K_1^2 \left|\overrightarrow{Oi_1}\right|^2 - 2K_0 K_1 (\overrightarrow{Oi_0} \cdot \overrightarrow{Oi_1}) \\
&= (x_0 - x_1)^2 + (y_0 - y_1)^2 + (z_0 - z_1)^2,
\end{aligned}
$$

Compute

$$
\sum_{m=1}^{N} \{(T_x - x_m)^2 + (T_y - y_m)^2 + (T_z - z_m)^2 - K_m^2 (a_m^2 + b_m^2 + Z_f^2)\}^2
$$

Minimize

Ye-Sheng Kuo, Pat Pannuto, Ko-Jen Hsiao, and Prabal Dutta, "Luxapose: Indoor Positioning with Mobile Phones and Visible Light," In Proceedings of the 20th Annual International Conference on Mobile Computing and Networking (MobiCom'14), Maui, HI, Sep. 7-11, 2014.

Bigger picture: Software-Defined Lighting

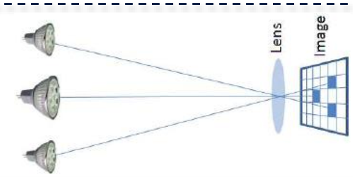
Illumination

Entertainment

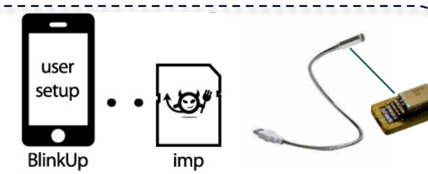
Communications

01100101000

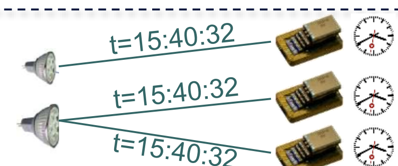
Indoor Positioning



Device Configuration



Clock Synchronization



The Alphabet Soup

- 1588
- 6LoWPAN
- 802.15.4
- 802.1(AS)
- 802.11
- AVB
- BLE
- CAN
- CoAP
- CSMA/CA
- GSM
- HART
- HTTP
- IoT
- IPv6
- LTE
- MAC
- PAN
- PTP
- QoS
- REST
- TDMA
- TSMP
- TSN
- TTEthernet
- TTP
- VLCP
- WAN
- WLAN
- WPAN

Conclusion

The hot trend today is towards “smart sensors and actuators” that are equipped with network interfaces (wired or wireless) and are accessed via web technologies (specifically HTTP) or wirelessly via bluetooth.

But quality of service (QoS) is hard to control, so these mechanisms are not always suitable.