Introduction to Embedded Systems

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Chapter X: Networking

Wired Networks

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

Control over timing, guaranteed bandwidth, and 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 suitable.

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 TTEthernet, FlexRay/

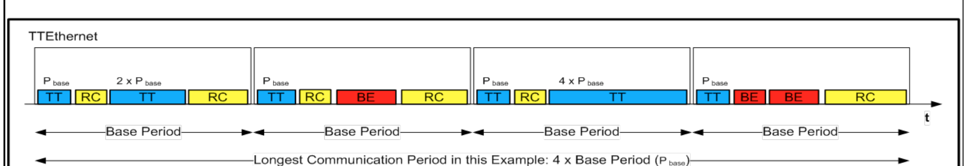
Time slotted

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

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

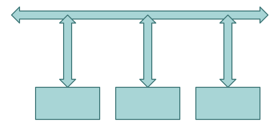
Combines three traffic types over ethernet:

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

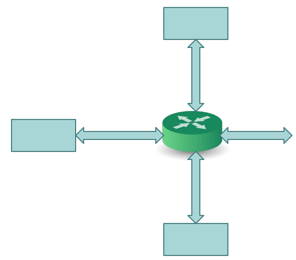


Routing

- Busses
  - Shared physical medium
  - MAC protocol dominates



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



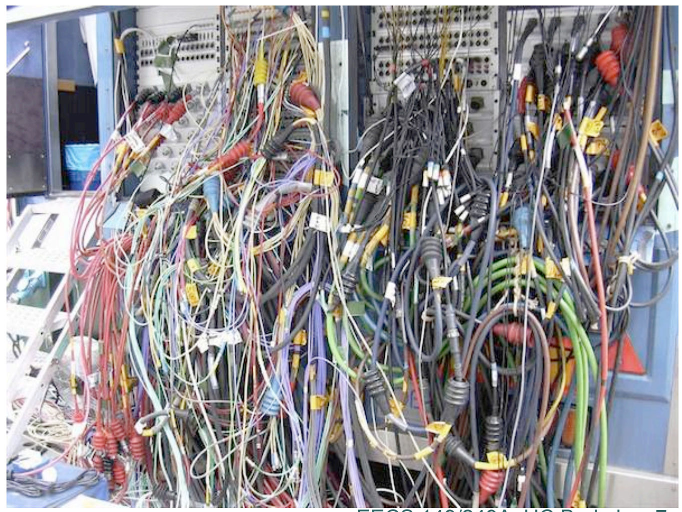
Is radio a bus?

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?

AVB: Audio-Video Bridging
(renamed in 2012 to TSN: Time-Sensitive Networking)

Developed to solve this problem:



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

AVB: Audio-Video Bridging
(Priority-based routing over Ethernet with reservations)

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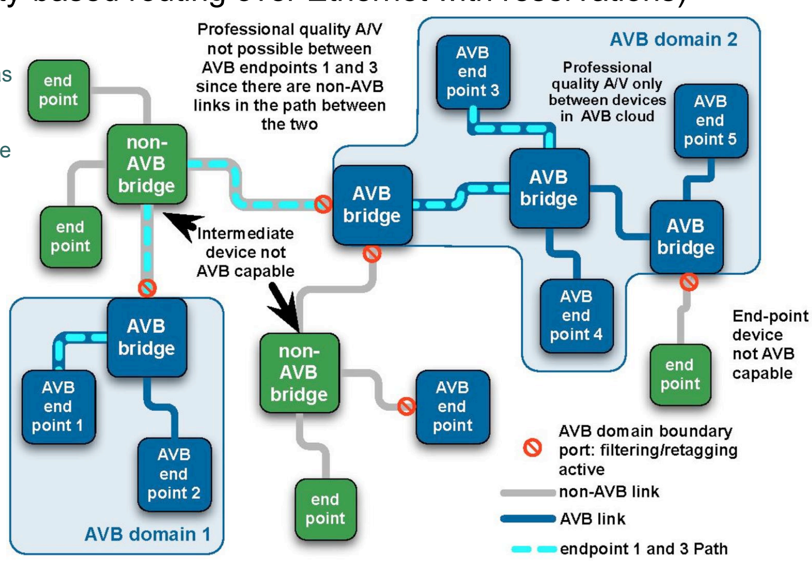

Part of IEEE 802.1 (ethernet) family of standards.

Application of AVB

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

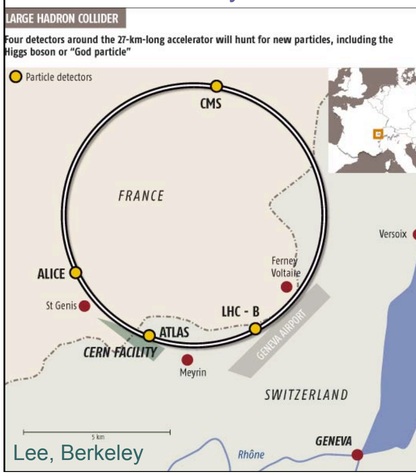
Using DP83640, Designers May Choose Any Microcontroller, FPGA or ASIC to Achieve 8- Nanosecond Precision with Maximum System Flexibility

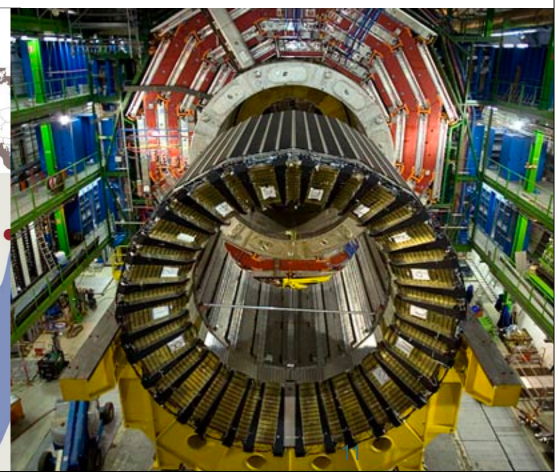
It is becoming routine for physical network interfaces (PHY) to provide hardware support for PTPs.

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.





How PTP Synchronization works

Precision Time Protocols

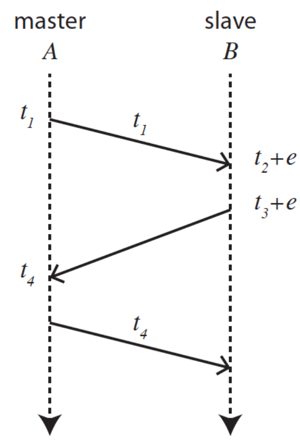
Round-trip delay:

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

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

- 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
  - LTE
  - Sigfox

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).

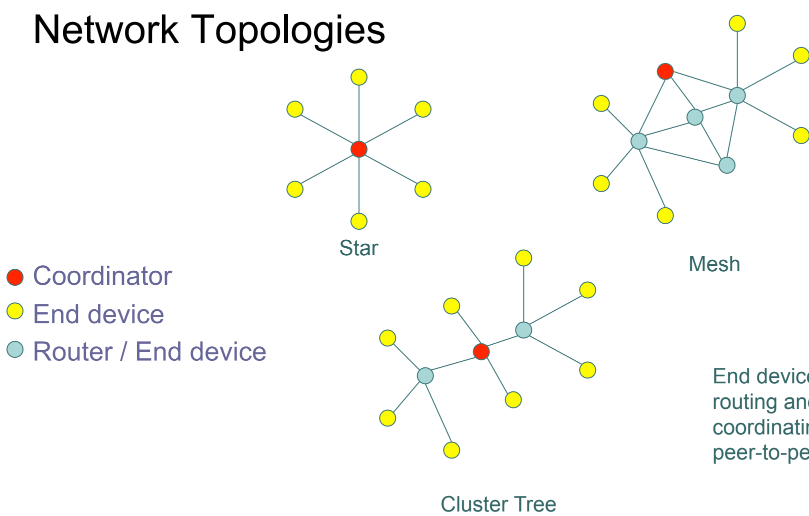
One application of BLE is proximity sensing, as in Apple's iBeacon technology.

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

Network Topologies



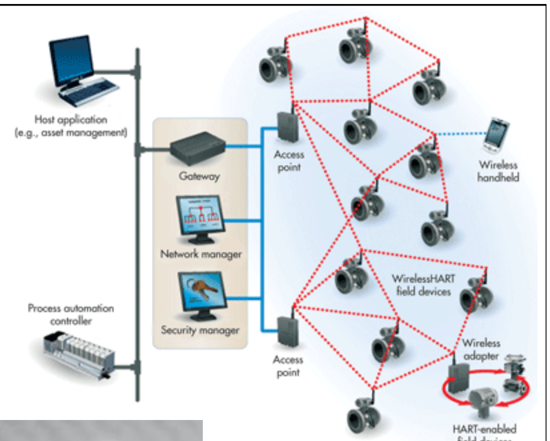
End devices capable of routing and/or coordinating are called peer-to-peer devices.

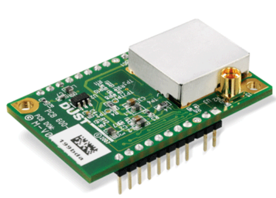
Unslotted vs. Slotted Modes

- 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.



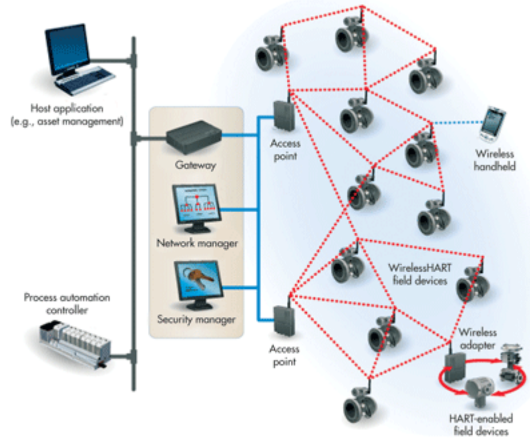


IEEE 802.15.4e

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.

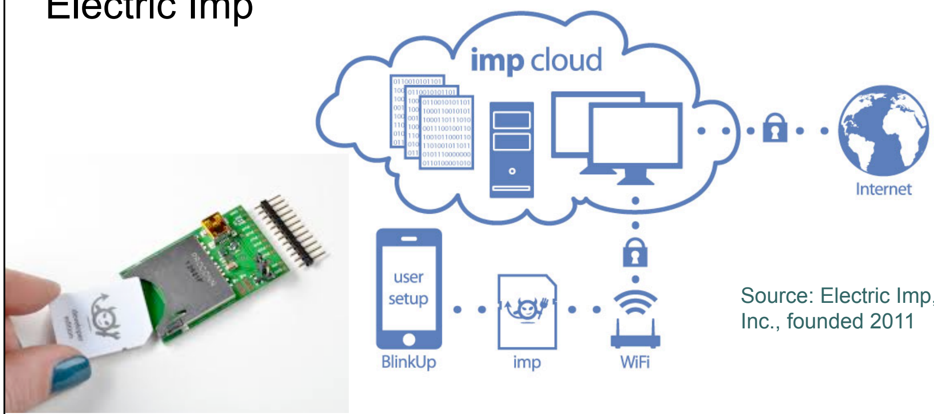


WiFi

- 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.

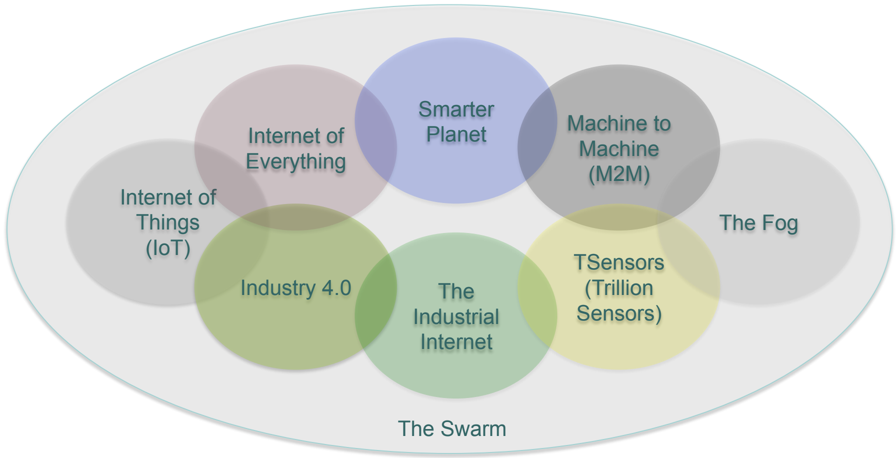
RESTful Interfaces

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

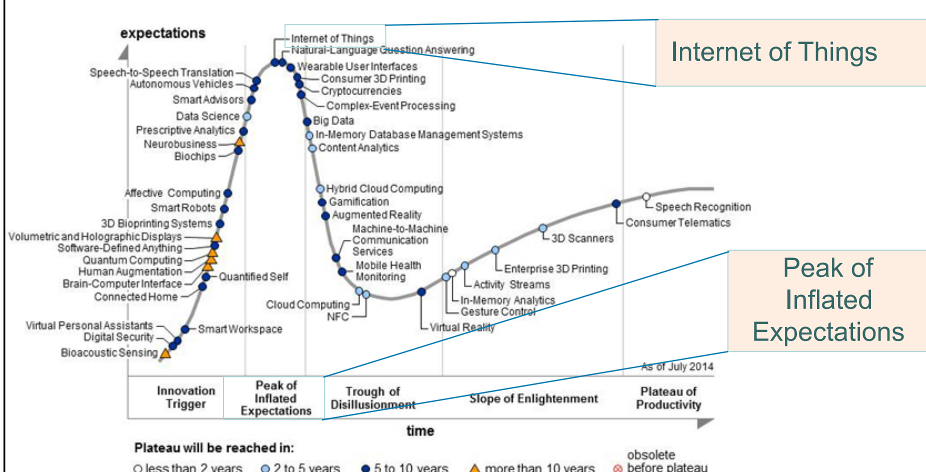
Example:
http://ptango.eecs.berkeley.edu:8077/keyvalue/get?id=A1243ADsA3209

[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.

“Swarm” Technology
The Buzz around the Swarm

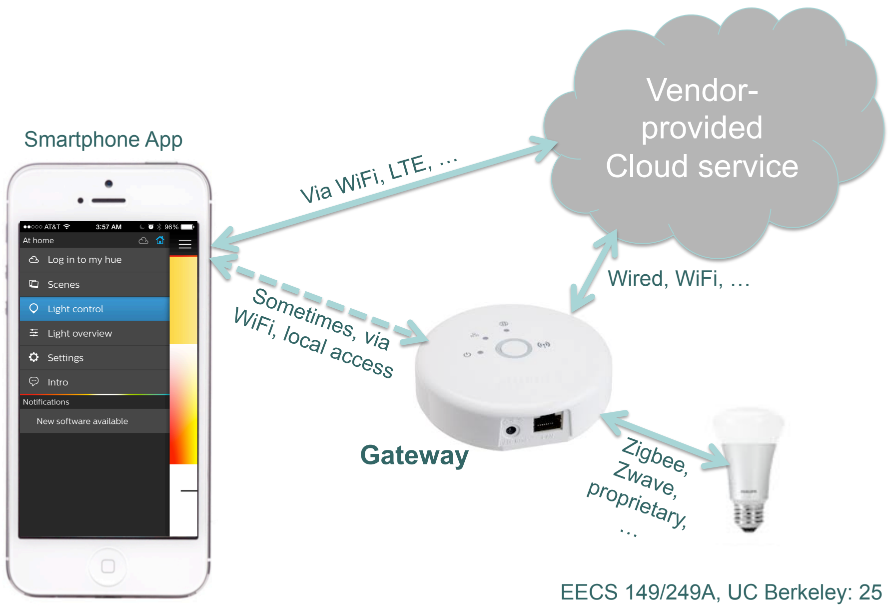


Gartner Hype Cycle 2014



http://www.gartner.com/technology/research/hype-cycles/

Typical IoT Architectures Today

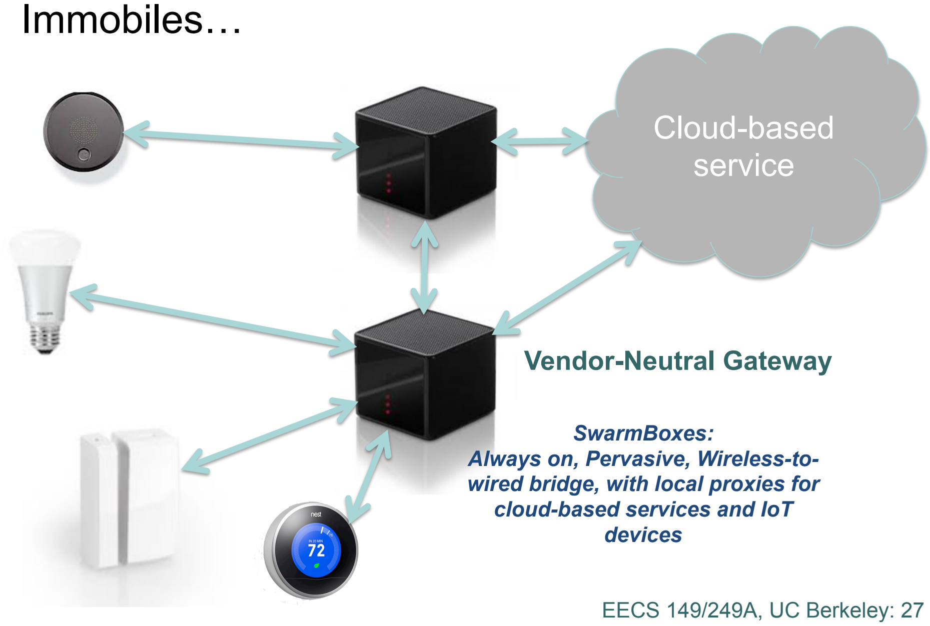


Challenges

- 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 Immobiles…

Designing these boxes and their services is one of the major goals of the TerraSwarm Research Center



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
- TSMP
- TSN
- TTP
- 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.