Electronics for IoT

Hardware for IoT

Bernhard E. Boser
University of California, Berkeley
boser@eecs.berkeley.edu

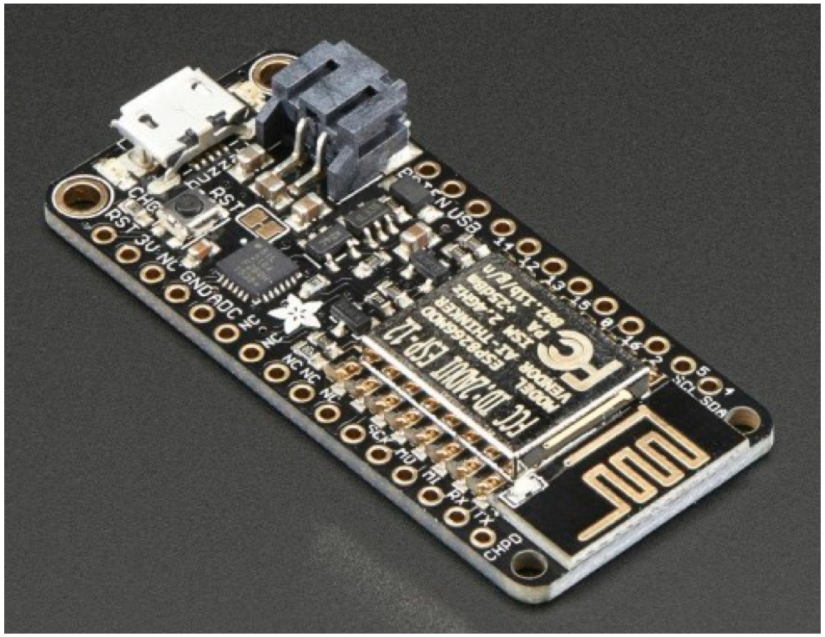
IoT Nodes

- Cloud
- Processors
- Wireless connectivity

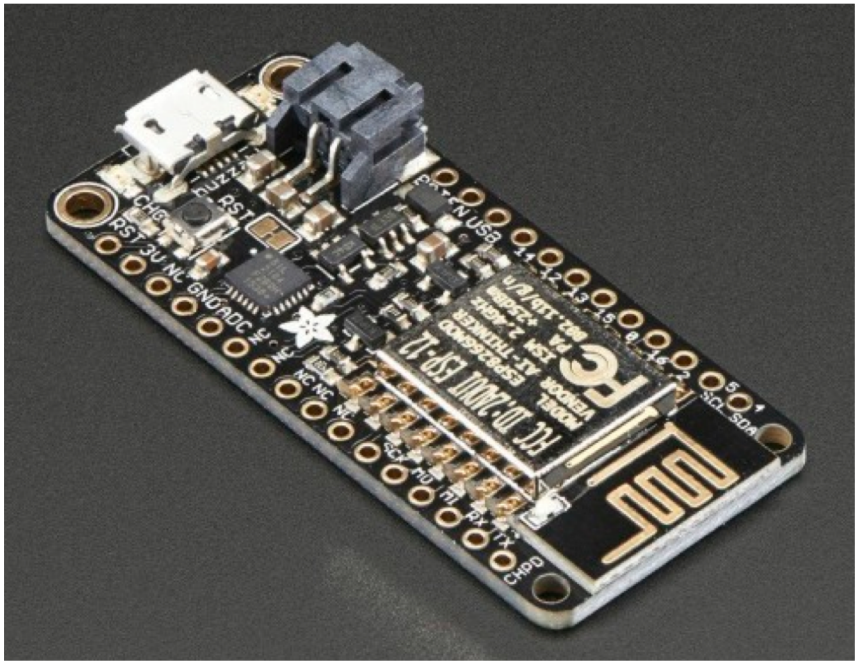
Cloud

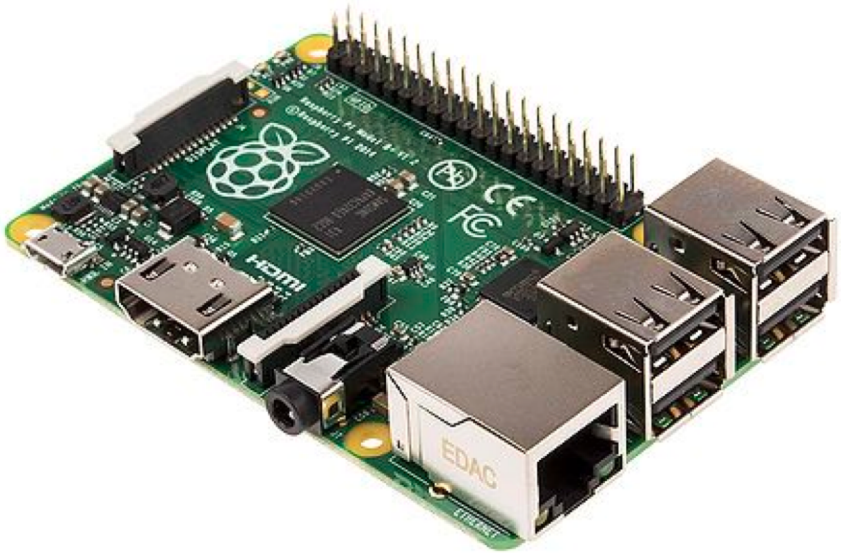
Ref: J. Rabaey,
UC Berkeley Swarm Lab

Processors



Processors II





Memory:

Clock rate:

Throughput:

Power Dissipation

ESP32

- <1 … 200 mA

Rpi 3B+

- 350 … 980 mA

https://www.pidramble.com/wiki/benchmarks/power-consumption

1 Ah battery (assume same supply voltage)

- 5 hours … days

- 1 … 3 hours

CPU Power Dissipation

- Computation only
  - no wireless,
  - no peripherals
- $P_{CPU} = P_{static} + P_{dyn}$
- $P_{CPU} = P_{static} + \underbrace{f_{clk} \times {P_{dyn}}/{f_{clk}}}_{P_{dyn}}$
- → Dynamically adjust f_{clk} to save power

Power Efficiency: P_{dyn}/f_{clk}

- Examples (trend: down)
  - ESP32 ~300 μW/MHz
  - STM32F4 240 μW/MHz
  - RISC-V 34 μW/MHz
  - High performance Intel i7 … 5 mW/MHz
  - E.g. (STM32F4) 10 MHz → 2.4 mW
    100 MHz → 24 mW

- Low power:
  - Dynamically vary clock rate
  - (Deep) sleep when not in use
    - Many modes (e.g. RAM retention, peripherals, …)

Speed

- Maximum clock rate (e.g.)
  - Laptop, data center CPU 4 GHz
  - Rpi 1.2 GHz
  - Microcontroller 240 MHz

Speed II

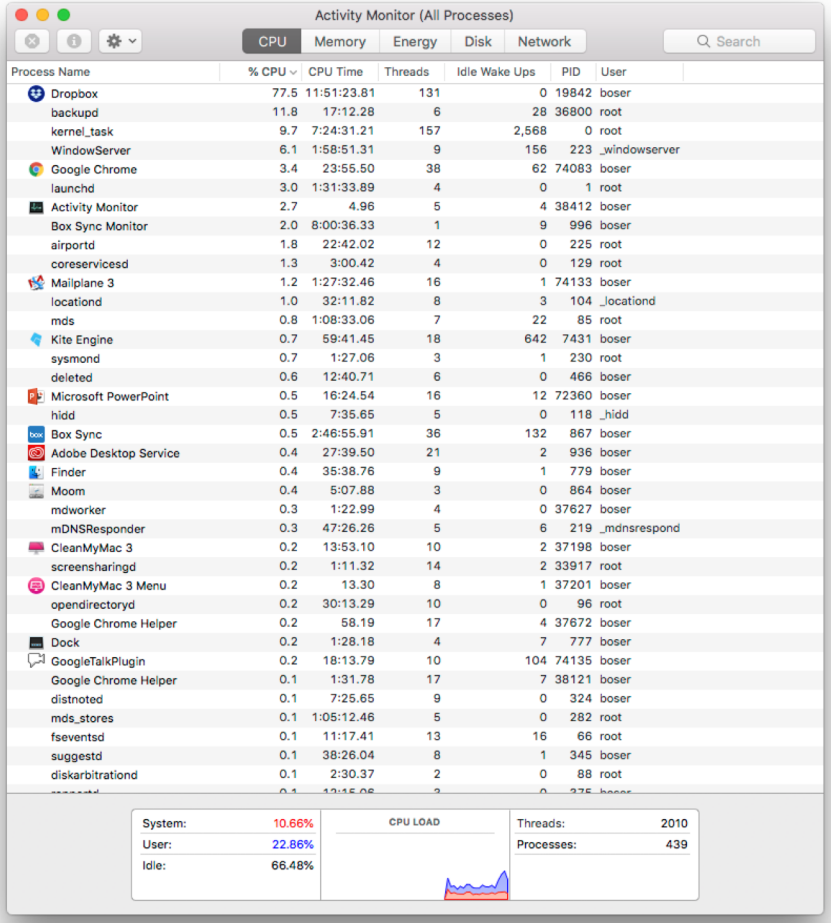
Interrupt Latency

- Time from sensor detecting an obstacle to program reacting

Laptop (or Datacenter CPU) Latency

- ms … seconds (rarely)
- Mostly ms, but
  - Occasional “freeze-up”
  - Annoying … to fatal
  - Do not use a laptop to control a quadcopter
- Why is this?

Multitasking



Parallel Processing

- Multi-core CPU
- Pre-emptive multitasking
  - Operating system periodically (every few ms) switches to next task waiting for execution (transparent to task)
  - Varies with system load
  - Desktop OS'es: Windows, OSX, Linux
- Co-operative multitasking
  - Tasks relinquish CPU when done
  - Interrupts for "immediate attention" (< 10 μs)
- Variants, e.g. "real time" operating systems
  - ESP32

Determinism

- Real time applications:
  1. Require “guaranteed” response time (e.g. driverless car)
  2. In addition to throughput (e.g. image scene analysis)
- Operating systems generally do not satisfy (1)
- Solution:
  - No operating system (aka “bare metal”)
  - Application program as full control
    - Cooperative multitasking
    - Schedule tasks that are not time critical when appropriate
      - E.g. check for MQTT subscriptions between time critical events
    - BEWARE of
      - Service interrupt handlers (e.g. WiFi) → dedicated hardware?
      - Resource hogs (bugs)
      - “pre-emptive”

Hierarchical Solutions for Real Time Control

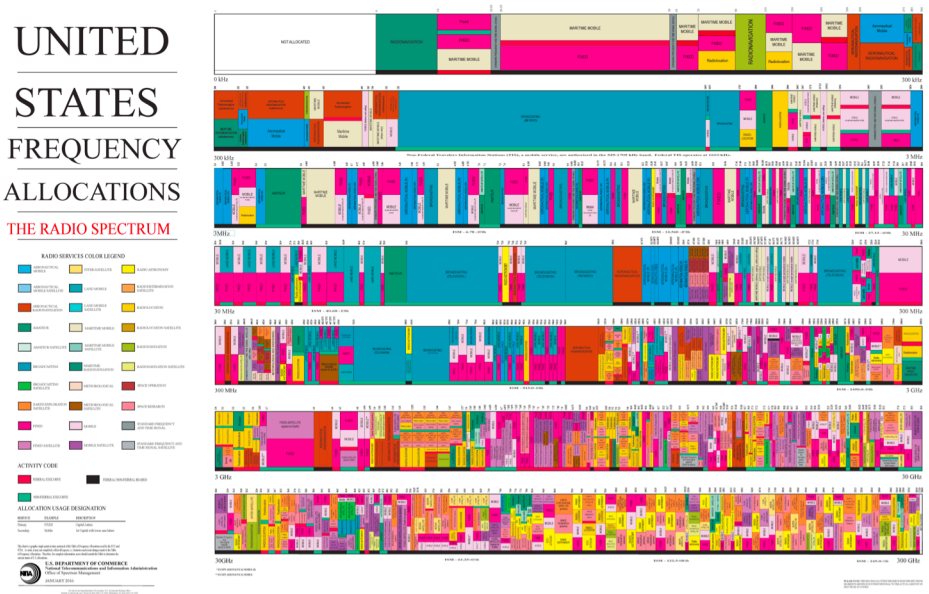
- Small dedicated processor(s) for real time control
  - E.g. ESP32, ARM, …
  - No OS (real time OS in some cases)
- Middle level for more complex tasks, more compute power (e.g. image analysis)
  - E.g. Rpi, Beagle Bone, …
- Application processor, Cloud for number crunching, data storage, …
  - Resource intensive
  - Not real time
- Tends to also optimize power dissipation
  - Adapted e.g. in smartphones

(Wireless) Connectivity

- Spectrum
- Standards
- Performance
  - Range
  - Throughput
  - Power dissipation
  - Cost
- Complex optimization
  - Fragmentation
  - Interoperability

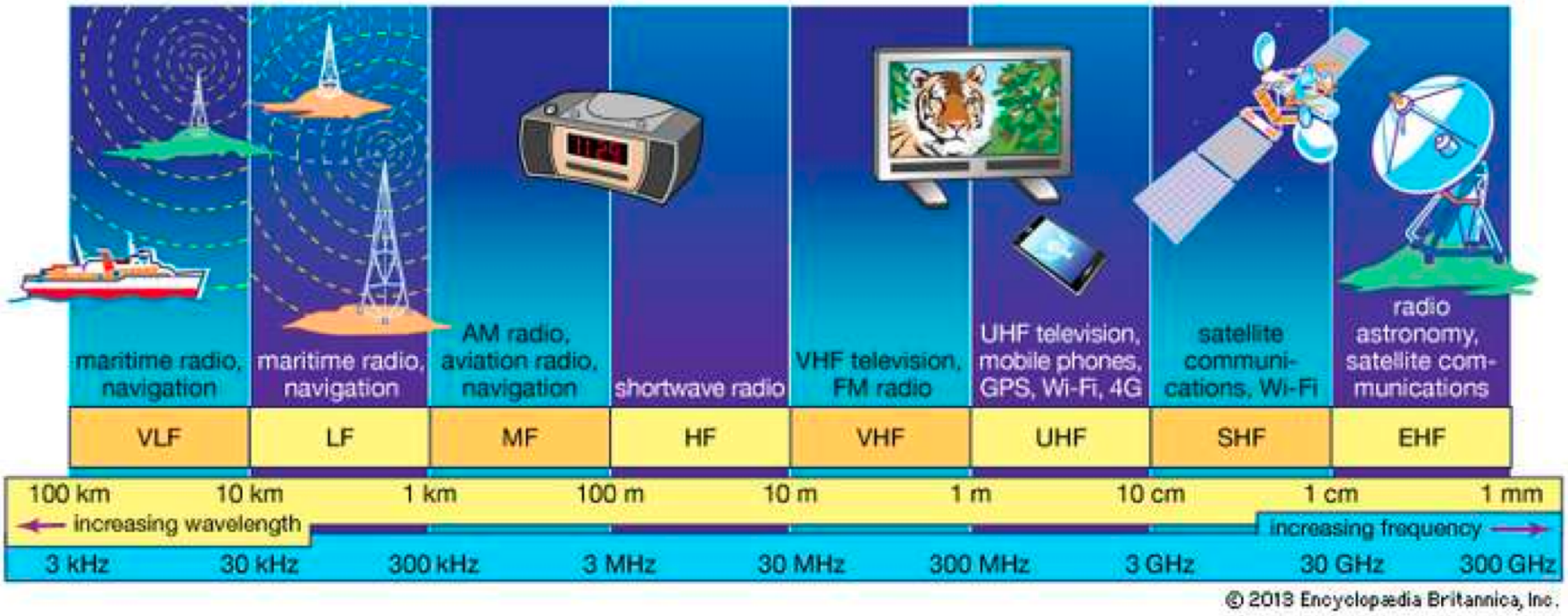
RF Spectrum

- Electromagnetic waves
- Characterized by frequency (wavelength)
- Finite resource
- Carefully controlled by governments → licensing



US Dept. of Commerce

RF Spectrum Properties



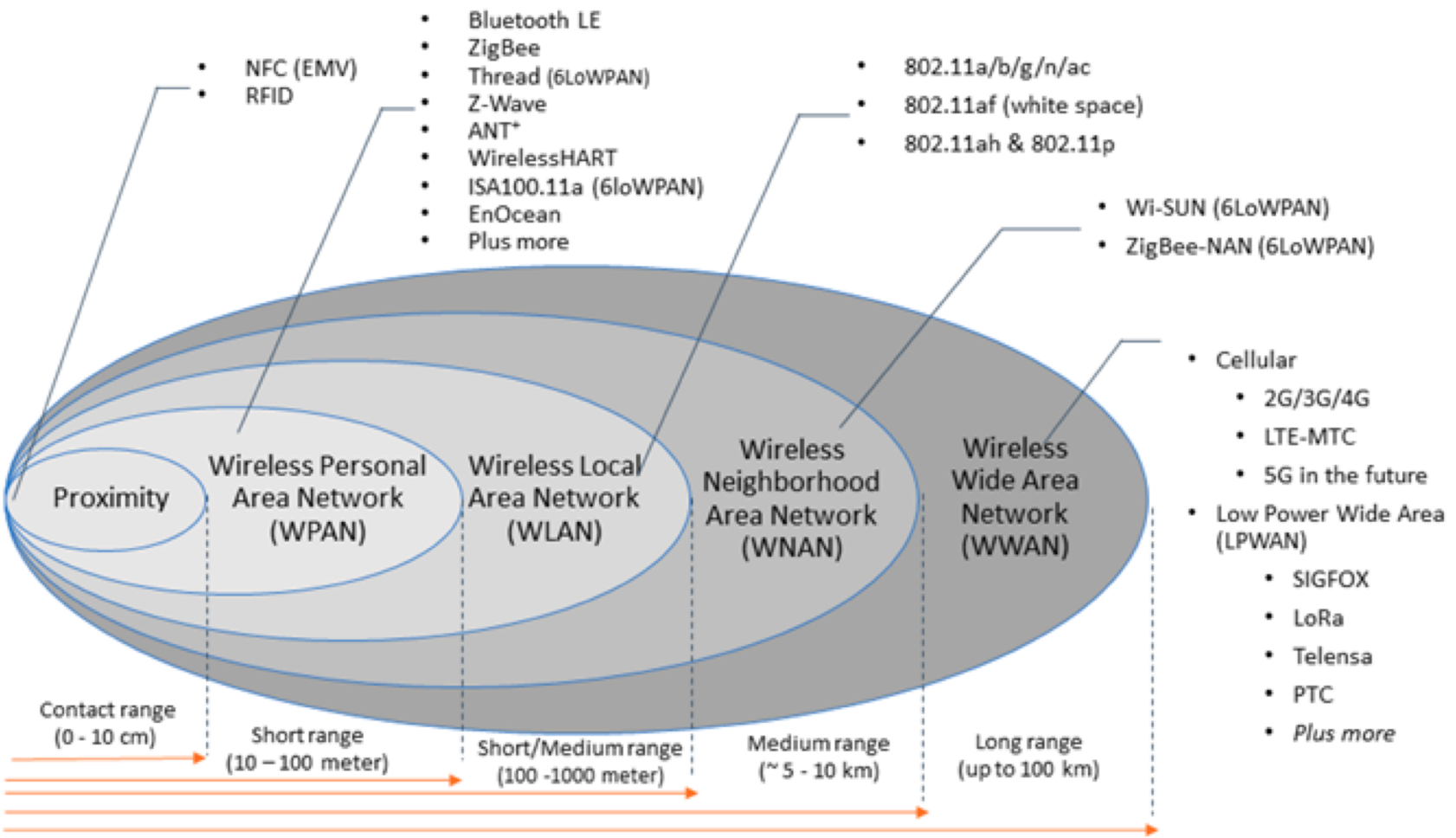
- Range
- Obstacles, line of sight
- Antenna size

Encyclopedia Britannica

2.4 GHz Unlicensed Band

- 2.4 GHz == frequency of operation
  - 2.4 … 2.483 GHz
  - Not speed (bps)
- Open to all
  - Subject to conditions (e.g. max transmit power)
- Crowded
  - Wifi
  - Bluetooth
  - Zigbee
  - Microwaves (2.5GHz)
- Fixed capacity: more users, lower throughput
  - cf lab …

Wireless Communication Standards



Example: IEEE 802.11 (WLAN)

- Ubiquitous
- Direct internet connectivity
  - Versatile
  - Difficult to manage security
- Medium
  - Range (~ 20 … 100+ meter, + roaming), “LAN”
  - Fast (Mbps+)
  - Power dissipation
    - Transmit: ~ 800mW
    - Receive: ~ 200mW
  - Very situation & metric dependent
    - Energy per bit, packet

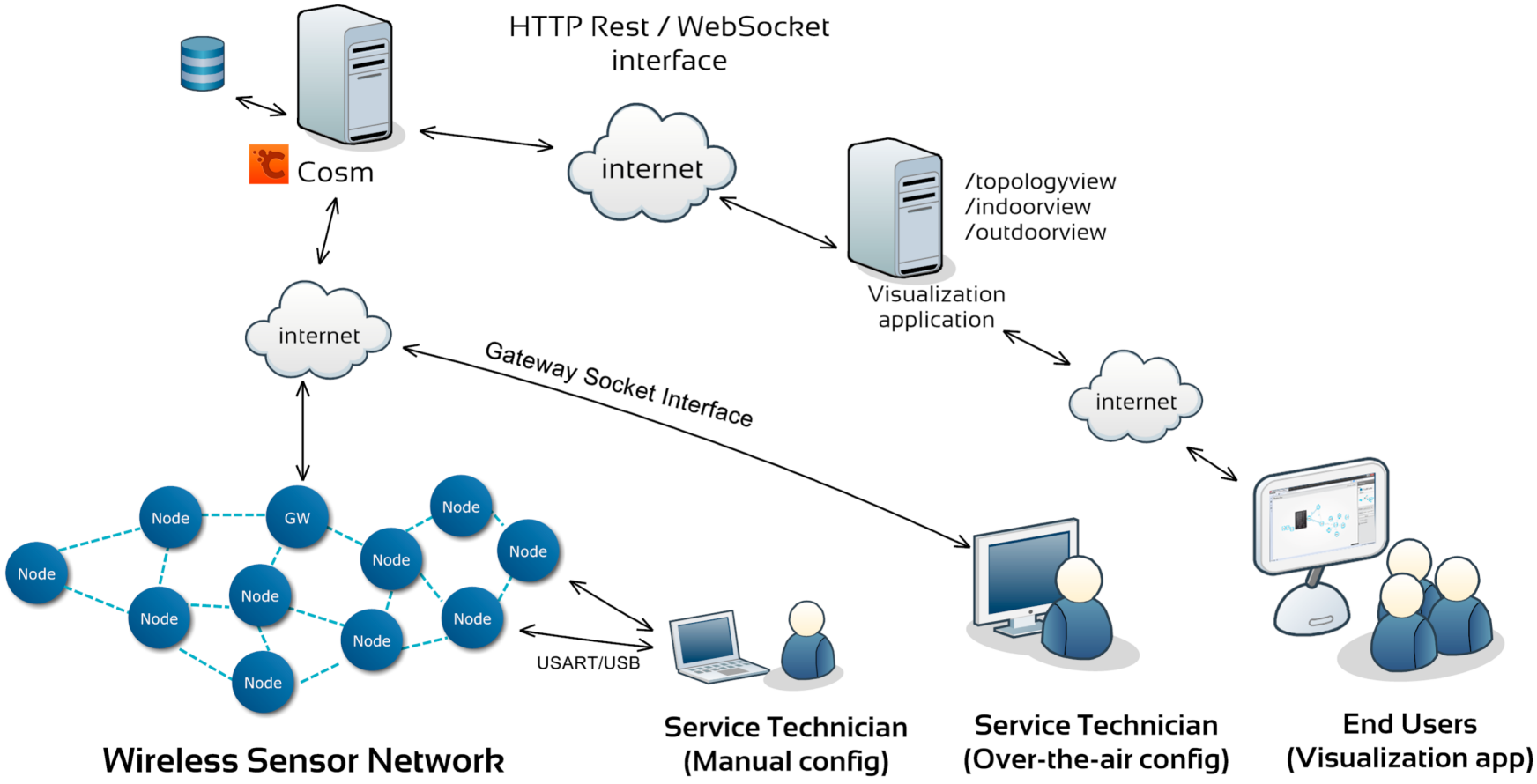
WWAN

- Cellular
  - Ubiquitous in urban areas
  - Roaming for wide coverage
  - Licensed
  - Not optimized for small packets
    - 5G promises to fix this
  - High power dissipation (1W+)
- LPWAN
  - Low power, high range (many km)
  - Fragmented
  - LoRa, Sigfox, …

Low Power: 802.15

- Bluetooth, ANT, Zigbee, …
- Low power
  - E.g. nRF52840
    - Transmit & Receive: 15mW
    - Fast power cycling
    - (Scales with TX power …)
- Low range, throughput
  - 10 … 50 meter
  - 100 … 2000 kbps

Wireless Sensor Networks



Further Power Optimization

- Network “sleep”
  - Radio on only at scheduled times
  - Requires synchronization (good clocks)
  - Plus a whole host of problems solved
- Really soon, now …

Summary

- Processor
  - GPIO
  - Performance: throughput, latency
  - Power dissipation
  - Size, cost
  - A complex optimization problem
    - → many options
- (Wireless) Connectivity
  - Range, throughput, power dissipation
  - Size, cost
  - Standards
  - A complex optimization problem …
- EE 149, …