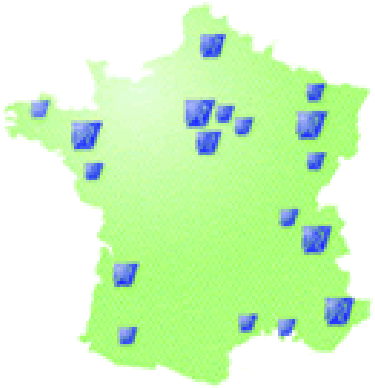
French public research institute (twitter.com/inria)

- Roughly 2700 employees in various sites in France
- Approx. 120 project-teams
- Around 200M€ annual budget
- Public/private financing



Inria focuses on computer science & control, including, but not limited to:

- Modeling, simulation, optimization of complex dynamic systems
- Security & reliability of computing systems
- Communication & ubiquitous computing (including IoT & CPS)
- Computational sciences
- Theoretical & empirical research approaches

End-to-End Open Source IoT with RIOT

www.riot-os.org

Emmanuel Baccelli & Alexandre Abadie

Inria

on behalf of the RIOT Community

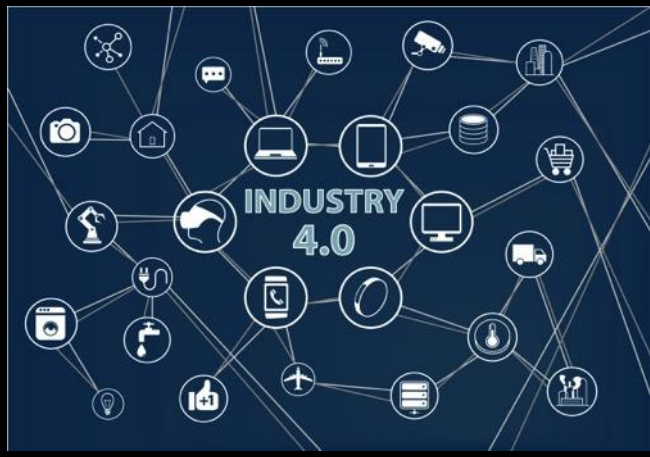
Agenda

- Which IoT are we talking about?
- Why an OS for Low-End IoT devices?
- How?
- What is RIOT?

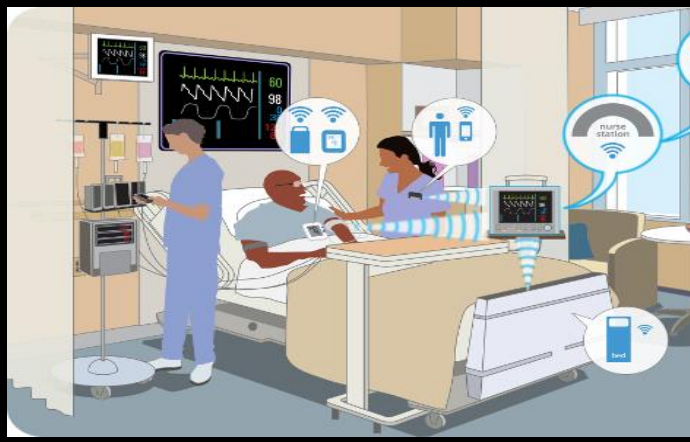
Many Expected IoT Applications

Building Automation

Industrial Automation



Wearable technology

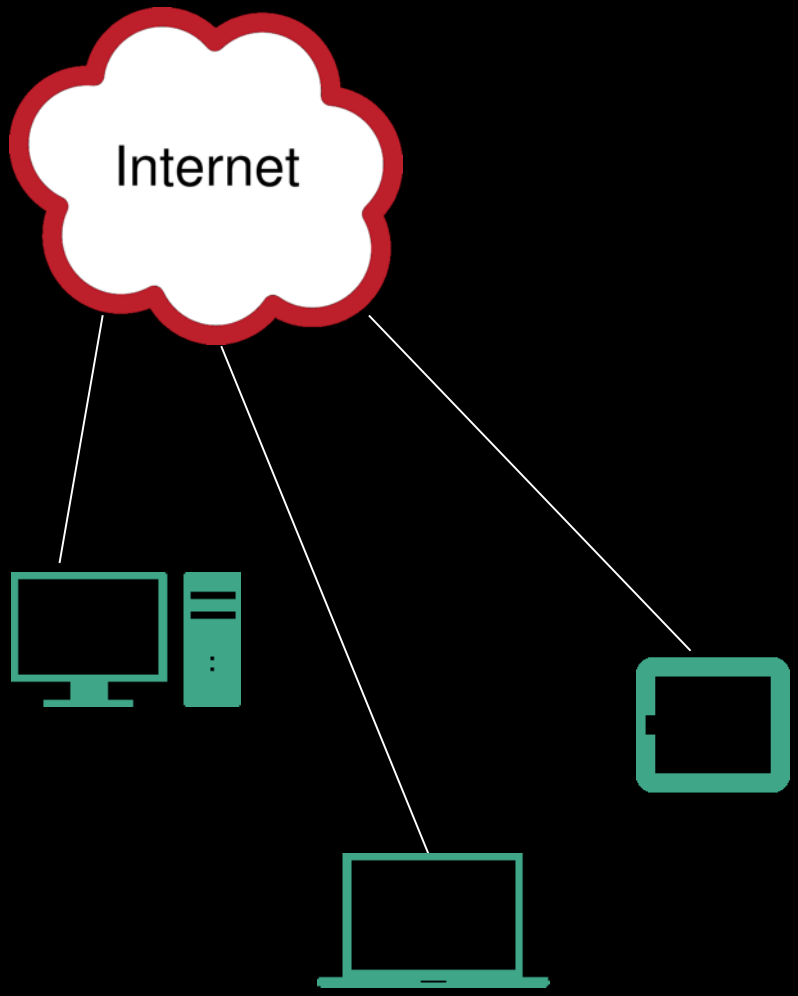


Smart Homes

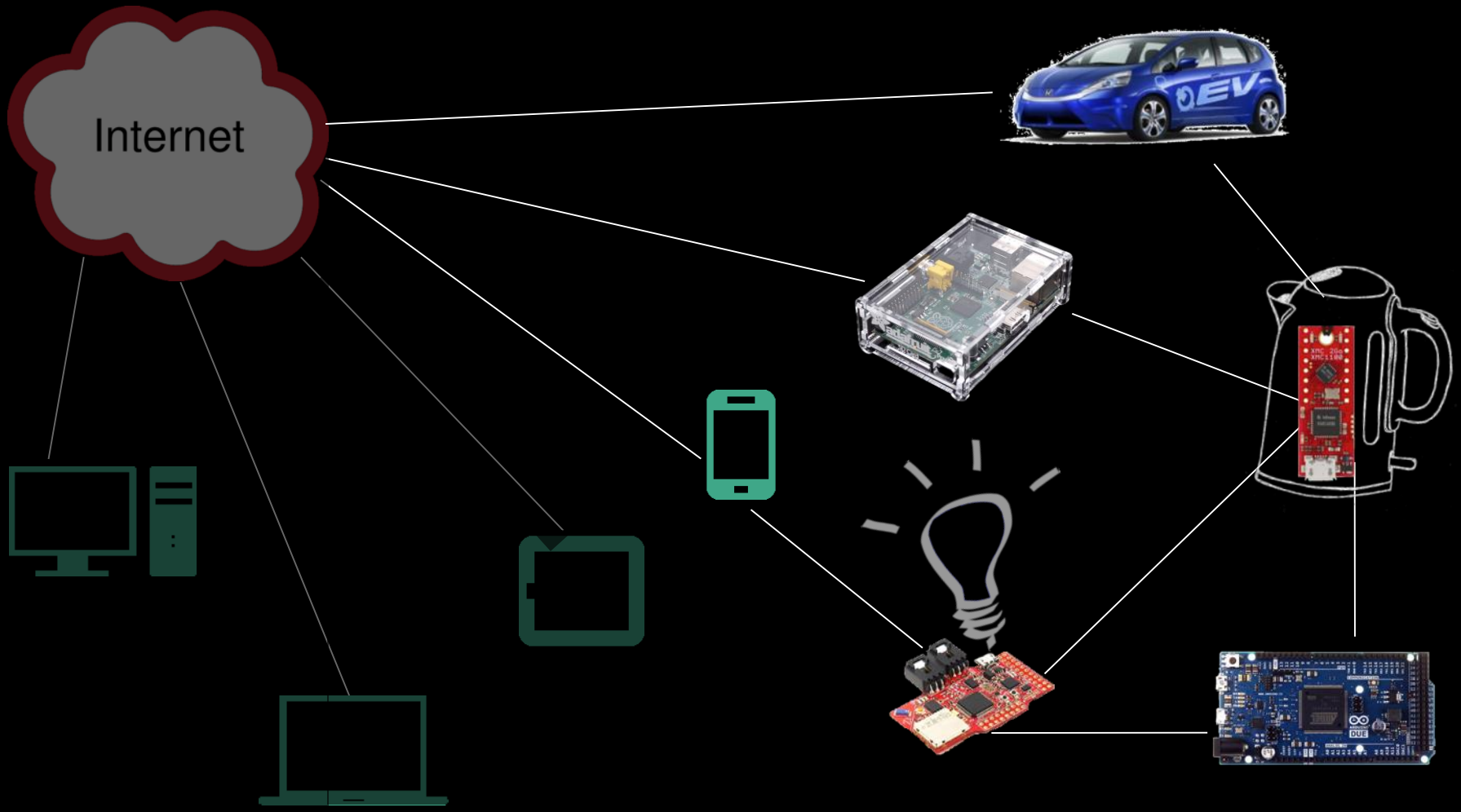
eHealth

Connected Vehicles

Zoom: IoT Hardware



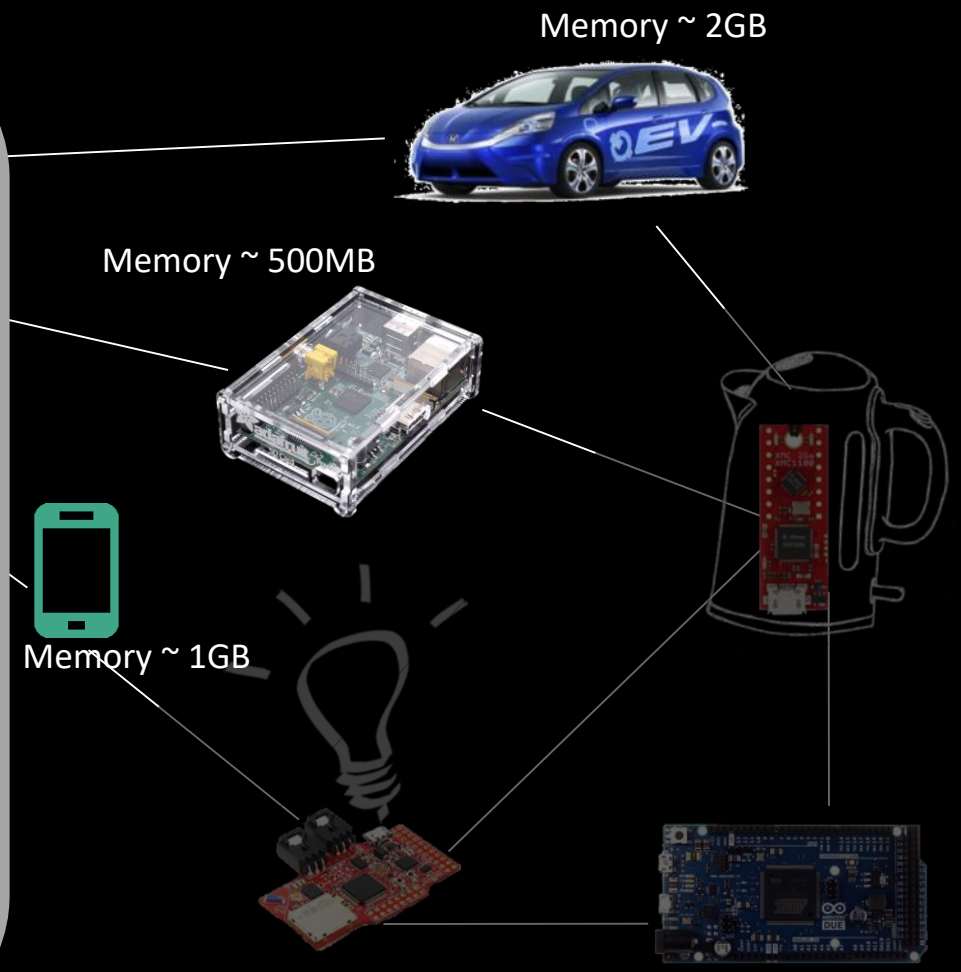
The Internet of Things (IoT)



High-end IoT Hardware

- single-board computers
  - ✓ RaspberryPi, connected cars, smartphones…
- resources similar to average Internet devices
  - ✓ memory, computation power, network throughput…

→ **Can run usual TCP/IP protocols**
→ **Can run usual OS such as Linux**

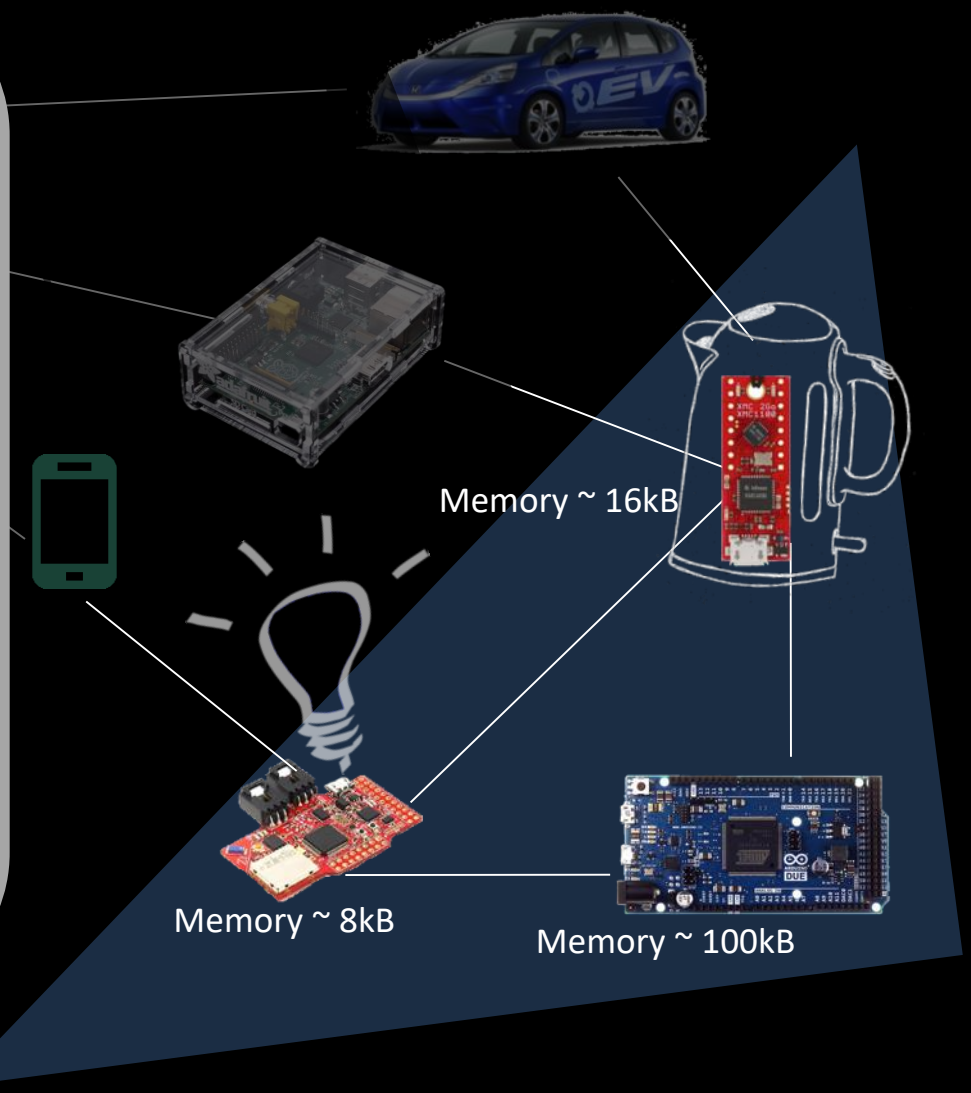


Low-end IoT Hardware

- **Smaller & cheaper**
  smart objects
- **Low-power**
  MCUs & radios

Energy: Milliwatt instead of Watt
CPU: Megahertz instead of Gigahertz
Memory: Kilobytes instead of Gigabytes

→ **Cannot run TCP/IP protocols as is**
→ **Cannot run usual OS such as Linux**



Zoom: the Internet

- How can the Internet work at such large scale?
- How does it allow quick-paced progress?

➡ organic growth, made possible by combining:

1. Open standard protocol specifications
2. Open source development platforms
3. Extremely flexible algorithms

Agenda

- Which IoT are we talking about?
- Why an OS for Low-End IoT devices?
- How?
- What is RIOT?

Why a software platform for Low-end IoT devices?

- Linux, Android… bare-metal?

Memory ~ 32kB

Memory ~ 8kB

- But as IoT software evolves…
  - more complex pieces, e.g. an IP network stack
  - evolution of application logic

- … non-portable IoT software slows innovation

  90% of IoT soft. should be hardware-independent

  → this is achievable with a good software platform (but not if you develop bare-metal)

Why Open Source?

- ✓ faster innovation by spreading IoT software dev. costs
- ✓ long-term IoT software robustness & security
- ✓ trust, transparency & protection of IoT users' privacy
- ✓ less garbage with less IoT device lock-down

Agenda

- Which IoT are we talking about?
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How to achieve a good software platform?

- Experience (e.g. with Linux) points towards:
  - **open source**
  - **free core**
  - **driven by a grassroots community**

Indirect business models

Geopolitical neutrality

- But technically, departure from Linux is needed

Main Challenges of an OS for IoT

Subj. to low-end IoT device resource constraints:

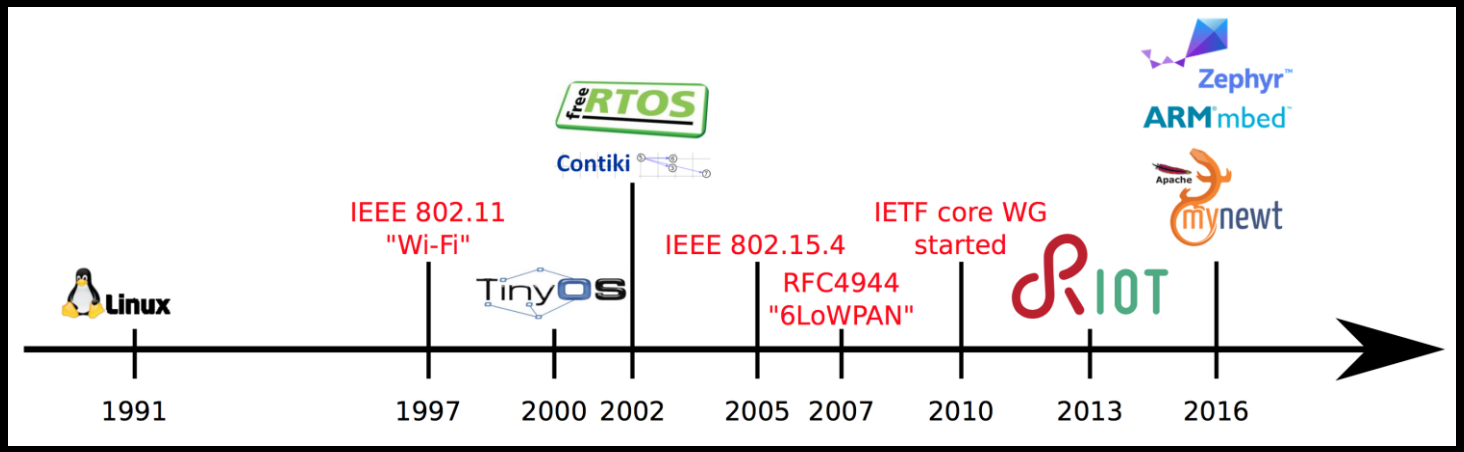
- ✓ Kernel performance
- ✓ System-level interoperability
- ✓ Network-level interoperability
- ✓ Trust

Software platform on low-end IoT devices?

- The good news:
  - no need for advanced GUI (simple shell is enough!)
  - no need for high throughput performance (kbit/s)
  - no need to support dozens of concurrent applications
- The bad news:
  - kBytes of memory!
  - typically no MMU!
  - extreme energy efficiency must be built-in!

Software platform on low-end IoT devices

- Contiki
- RIOT
- TinyOS
- mbedOS (ARM)
- Zephyr (Intel)
- LiteOS (Huawei)
- ...
- **... and closed-source alternatives**

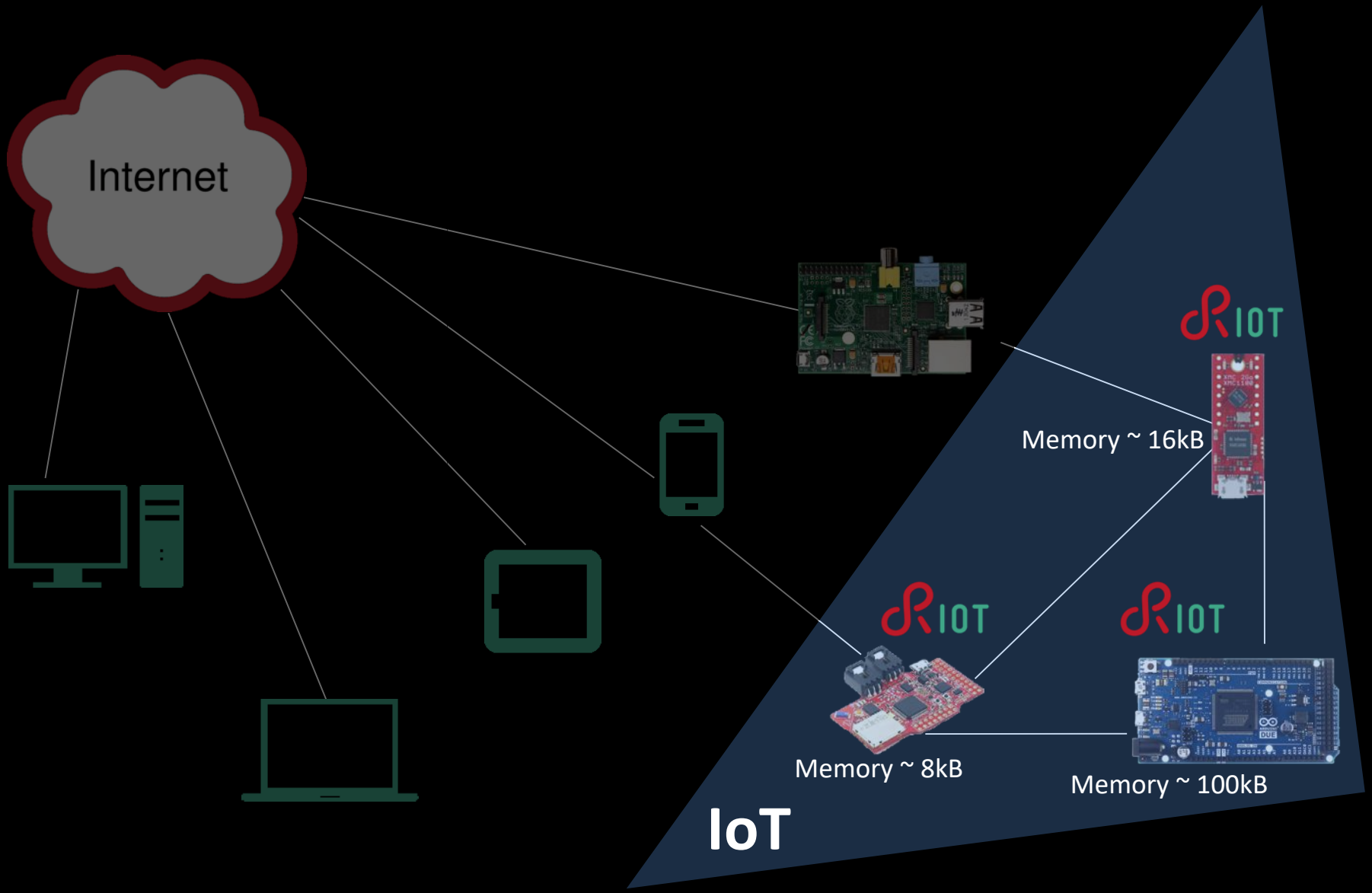


Reference: O. Hahm et al. "*Operating Systems for Low-End Devices in the Internet of Things: A survey*," IEEE Internet of Things Journal, 2016.

Agenda

- Which IoT are we talking about?
- Why an OS for Low-End IoT devices?
- How?
- What is RIOT?

RIOT : an OS that fits IoT devices



RIOT : an OS that fits IoT devices

- RIOT is the combination of:

  - ❑ needed memory & energy efficiency to fit IoT devices

  - ❑ functionalities of a full-fledged operating system

    - Advanced, consistent APIs across 32-bit, 16-bit, 8-bit hardware
    - Full-featured, extensible network stacks
    - Large pool of 3rd party software libraries

Agenda

- Which IoT are we talking about?
- Why an OS for Low-End IoT devices?
- How?
- What is RIOT?
  - Aspect 1: kernel performance
  - Aspect 2: system-level interoperability
  - Aspect 3: network-level interoperability
  - Aspect 4: trust

Challenge: Constrained Devices

ENERGY

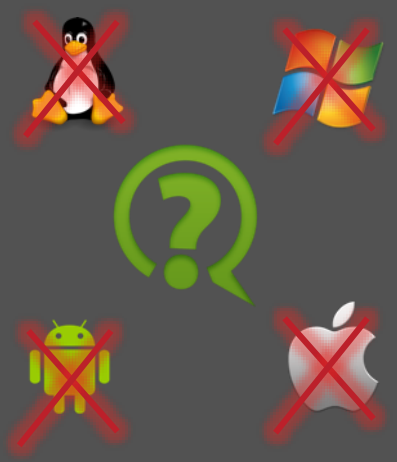
- Milliwatt instead of Watt

CPU

- Megahertz instead of Gigahertz

Memory

- Kilobytes instead of Gigabytes



RIOT Kernel Performance

- Micro-kernel architecture (contrary to Linux)
  - Ultra-low memory footprint
  - Tickless scheduler → energy efficiency
  - Deterministic O(1) scheduler → real-time
  - Low latency interrupt handler → reactivity

Result (on ARM 32-bit)

- ✓ around 1kB of RAM
- ✓ less on 16-bit

Fits on low-end IoT devices

RIOT Kernel Performance

- Typical approach: event-driven, single stack
- RIOT approach: multi-threading
  - ✓ minimal Thread Control Block (TCB)
  - ✓ minimized stack usage
  - ✓ Ultra-efficient Inter-Process Communcation (IPC)
  - ✓ (Note: multithreading is optional)

Result (on 16-bit at 8MHz)

- ✓ Min. TCB: 8 bytes
- ✓ Min. Stack Size: 96 bytes
- ✓ Up to 16,000 Messages/s with IPC (≙ 10,000 Packets/s for 802.15.4)

Fits on low-end IoT devices

Agenda

- Which IoT are we talking about?
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- What is RIOT?
  - Aspect 1: kernel performance
  - Aspect 2: system-level interoperability
  - Aspect 3: network-level interoperability
  - Aspect 4: trust

Challenge: Interoperability

- System-level interoperability
  - Hardware-independent IoT software
  - Usability of third-party software, well-known tools

RIOT System-level Interoperability

- Typical approach: specialized programming
  Exotic Paradigms & Programming Languages
- RIOT approach: standard programming
  ANSI C, no macro ‘magic’, standard multi-threading

Result: Low Porting Effort

- ✓ Emulation Support: RIOT as a Process
- ✓ Third-Party Library Package
- ✓ Third-Party Development Tools

Valgrind

GDB
The GNU Project Debugger

Package	Diff Size Overall	Relative
libcoap	639 lines	6.3 %
libfixmath	34 lines	0.2 %
lwip	767 lines	1.3 %
micro-ecc	14 lines	0.8 %
relic	24 lines	<0.1 %

RIOT : system-level Interoperability

- Consistent, powerful API on 8-bit, 16-bit, 32-bit
  - 60+ IoT boards/devices supported, various radios…

Configuration	Hardware Specific: Platform	Drivers	Kernel	Net	Σ
ROM					
minimal	1,754	0	854	0	2,816
WSN default	4,684	6,183	2,233	4,105	37,002
gnrc_minimal	2,732	4106	2,140	12,298	27,524
gnrc	3,675	4138	2,700	30,985	74,752
RAM					
minimal	656	0	2,022	0	2,880
WSN default	681	0	2,022	2,066	6,344
gnrc_minimal	676	0	2,022	2,990	7,016
gnrc	676	0	2,022	15,815	20,828

RAM/ROM usage on a Cortex-M IoT device

With a simple application over a IPv6/6LoWPAN stack in RIOT, 95% of the code is hardware-independent and/or reusable.

Agenda

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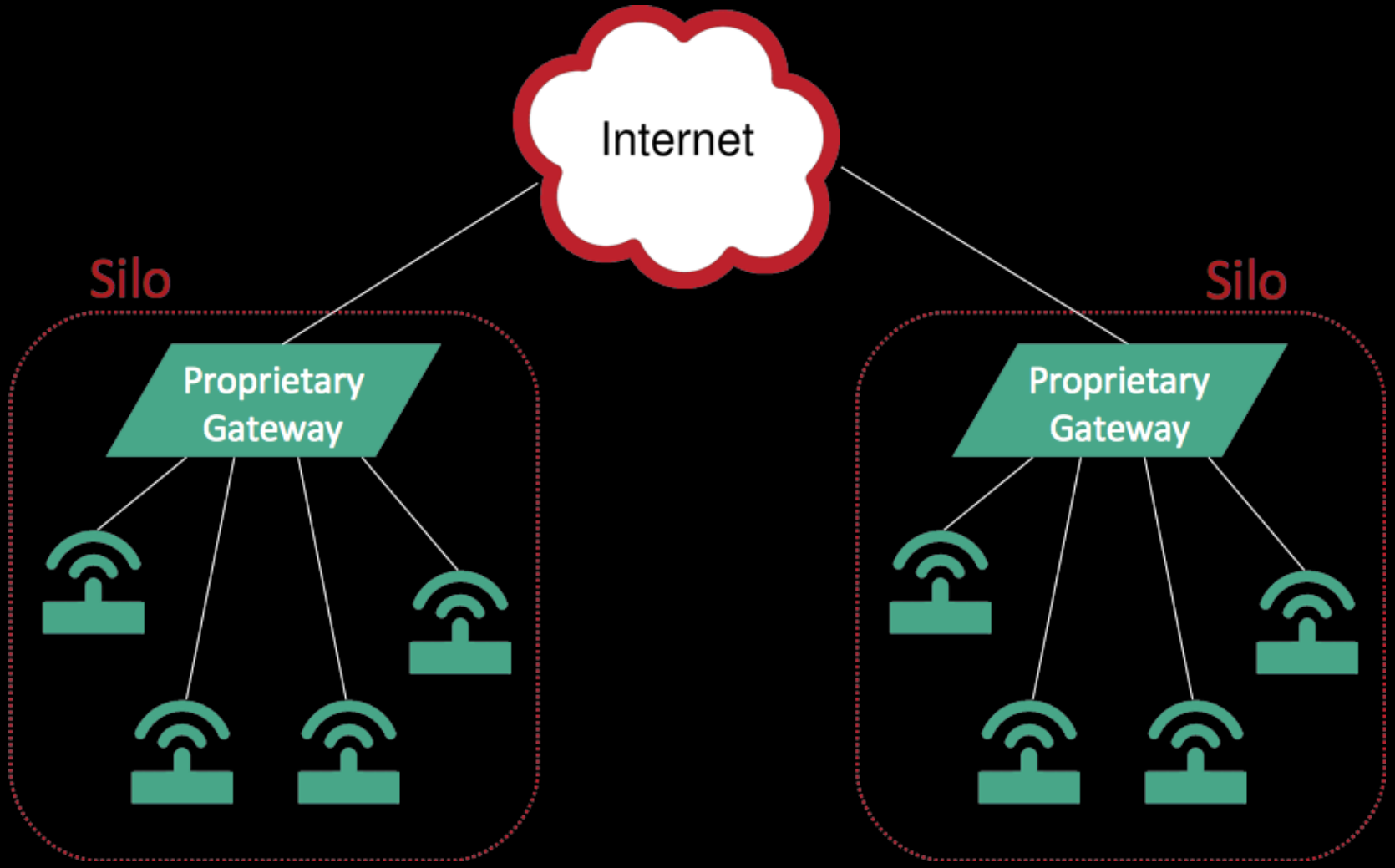
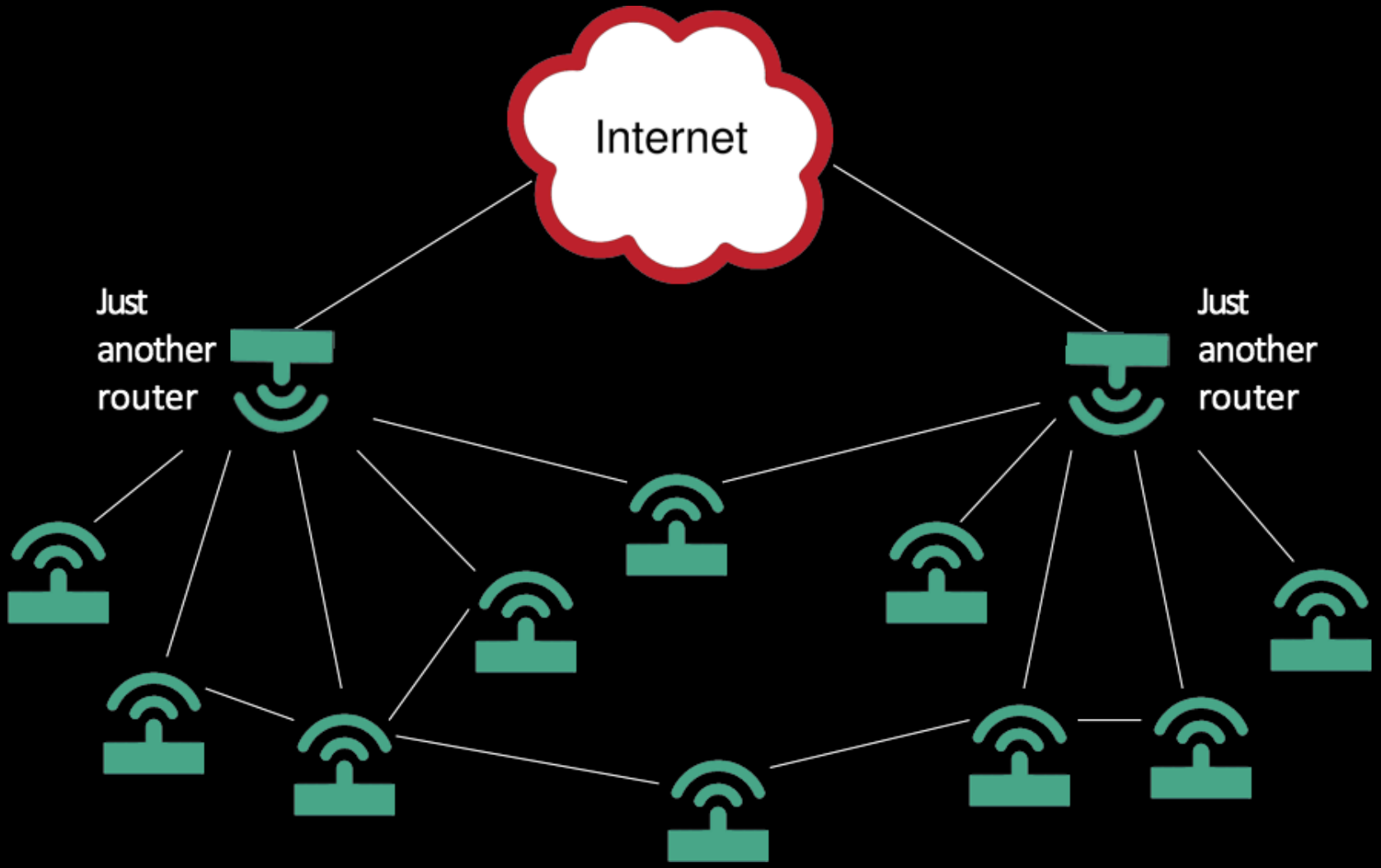
Challenge: Interoperability

- System-level interoperability
  - Hardware-independent IoT software
  - Usability of third-party software, well-known tools
- Network-level interoperability
  - End-to-end connectivity per default
  - Device-to-device connectivity

Network-level Challenge:
The IoT today looks mostly like this



Network-level Challenge:
The IoT we want looks more like that



The IoT we want is… the Internet!

Internet building blocks: Challenged by IoT…

… because of resource constrains on IoT devices

- Memory, CPU, energy

… because of low-power communication characteristics

- Lossy / duty cycles
- Super-small frames
- Spontaneous wireless architecture

→ **Adapted standard IoT protocols needed**

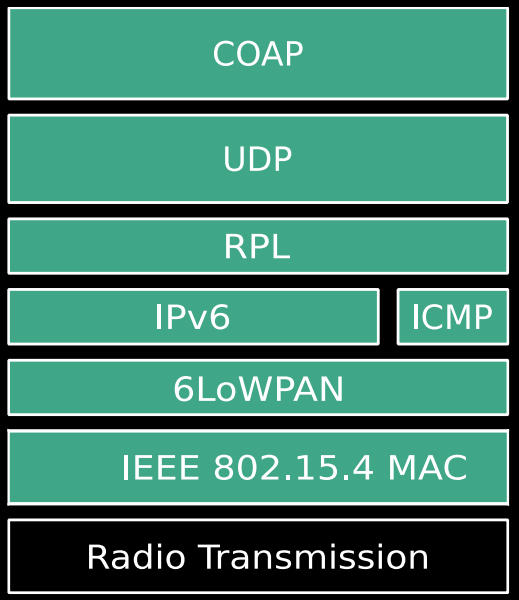
Standard IoT protocols? On the way!
Work in progress at IETF, IEEE, W3C, OMA…

New specs for link layer technologies
- Low-power radios, PLC, BACnet
- IEEE 802.15.4, Z-Wave, BLE, LoRa (and IEEE 802.11)
- More to come…

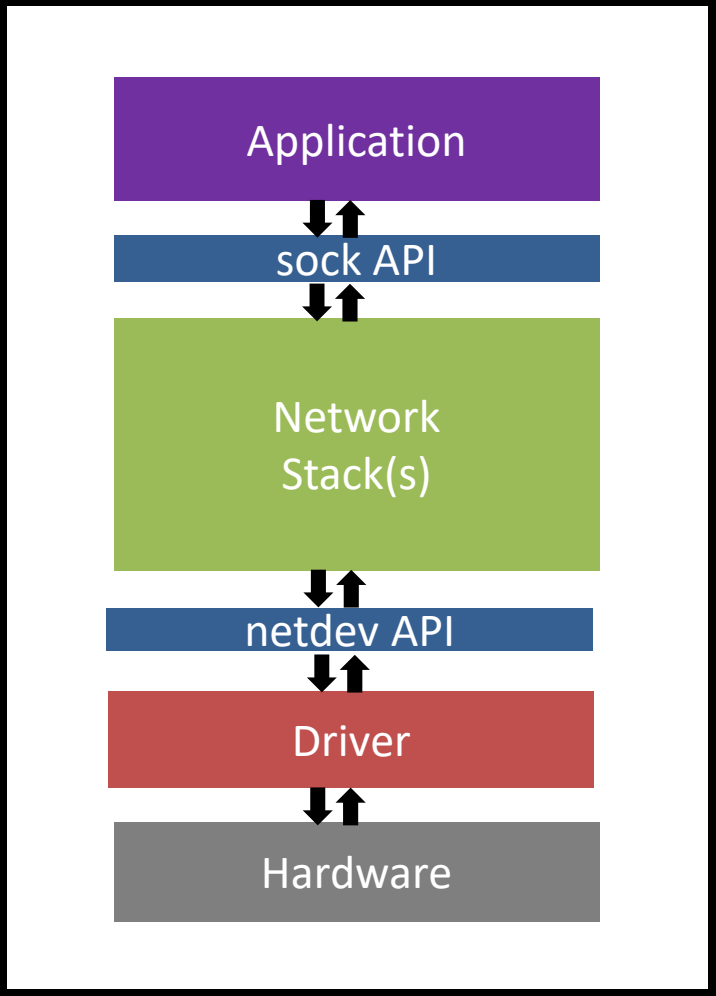
New specs for network layer protocols
- Fitting IoT requirements and interoperable with IP
- 6TiSCH, 6LoWPAN, RPL, OLSRv2, AODVv2
- More to come…

New specs for application layer protocols
- Fitting IoT requirements and interoperable with web
- CoAP, LwM2M, MQTT-SN, CBOR
- Security with DTLS, OSCOAP
- More to come…

New network paradigms
- Content-centric networking for IoT
- More to come…



Network Stacks Available with RIOT



- ✓ default (6LoWPAN) stack
  - GNRC: in-house stack
- ✓ 3rd-party packages
  - lwIP stack
  - uIP (emb6) stack
  - Thread (OpenThread) stack
  - …
- ✓ experimental stacks
  - CCN-lite
  - NDN-RIOT

Agenda

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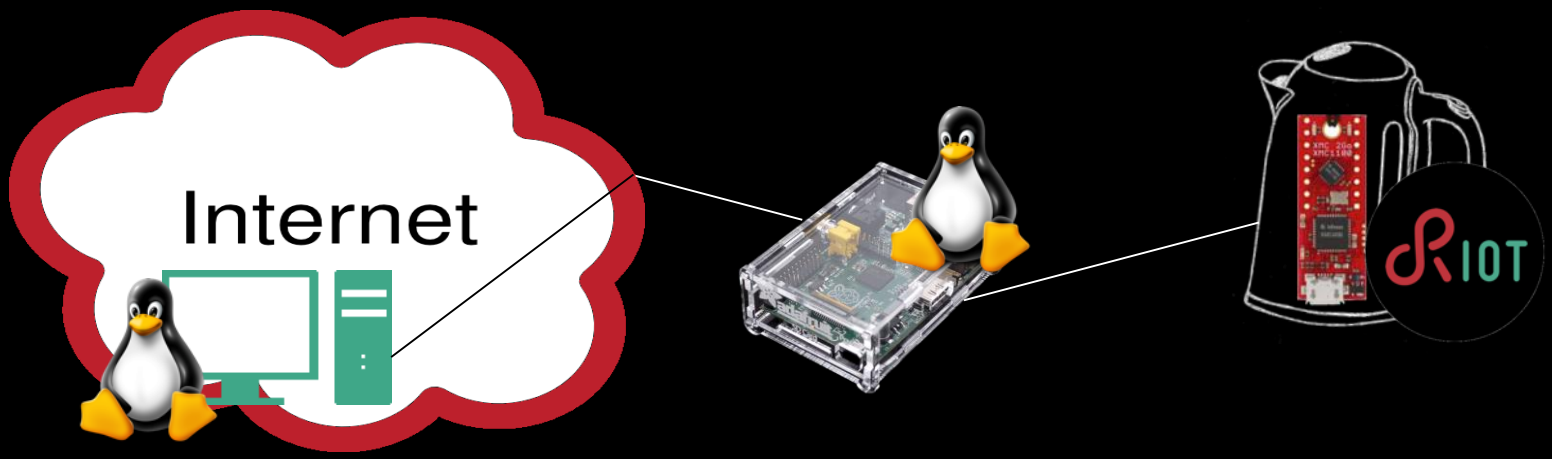
Some level of trust with IoT?



Combining RIOT & Linux, IoT is possible with

- ✓End-to-end open source
- ✓End-to-end secure & open communication standards
- ✓From anywhere in the Internet all to the way to (low-end) IoT devices

Some level of trust with IoT?

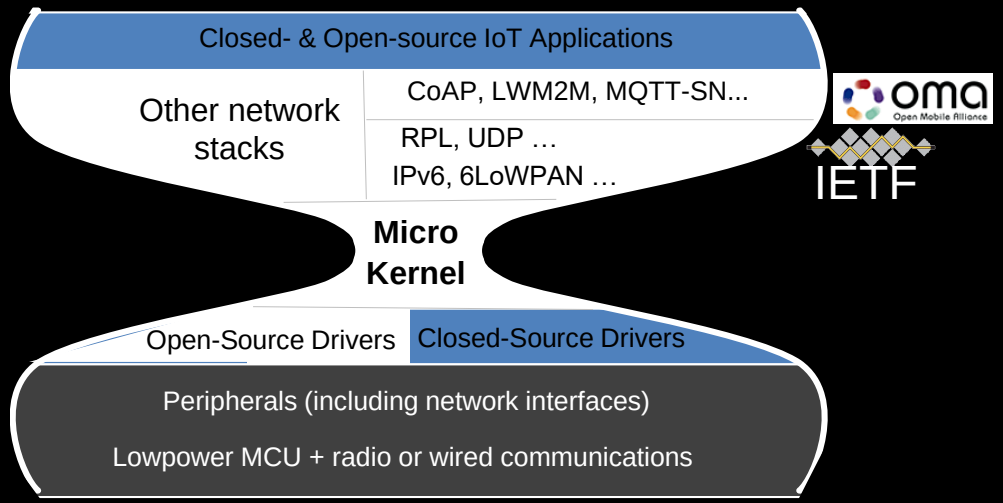
- Started in 2013 as a research project
  - ‘’soft’’ copyleft license (LGPLv2.1)
  - Grassroots open source community
- 130+ code contributors world-wide
  - Makers, academics, SME, bigger industrial
  - RIOT Foundation (for-common-good organization)
  - RIOT Summit: gathering community yearly

RIOT in a nutshell

Free, open-source plaftorm for portable IoT software

RIOT offers a platform functionally equivalent to Linux, based on:

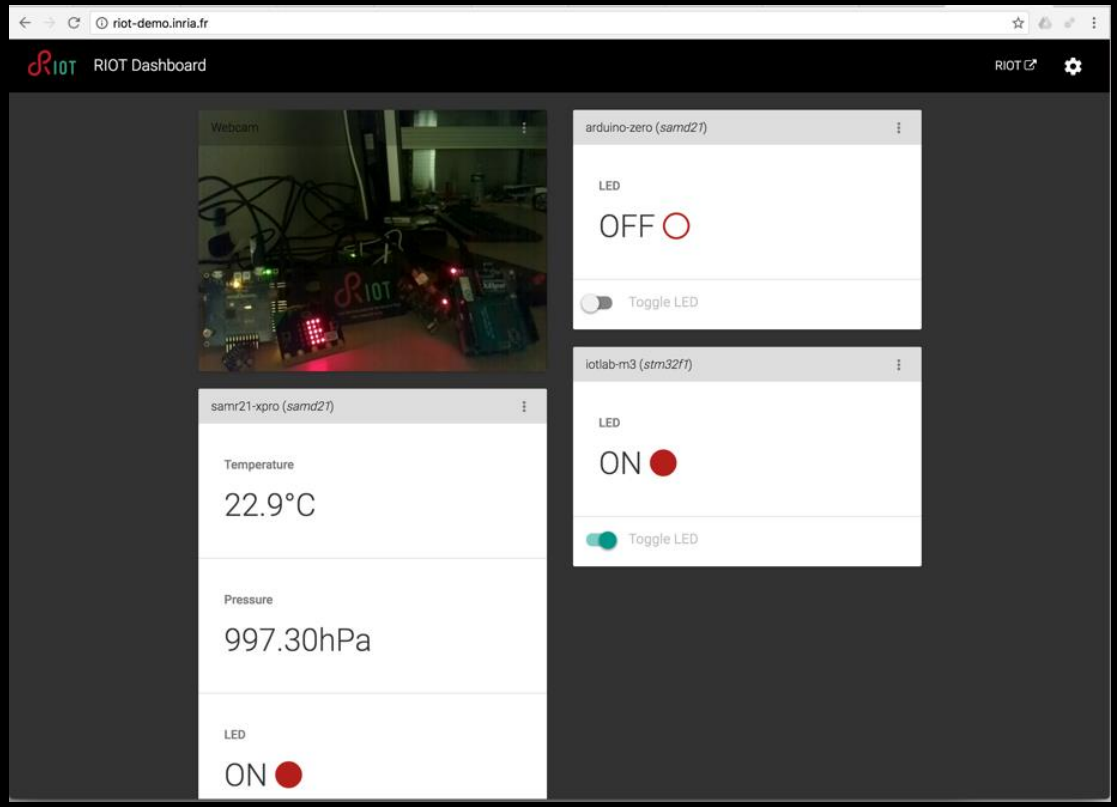
- open-source,
- open-access protocol specs,
- community-driven dev.



RIOT in Action

http://riot-demo.inria.fr

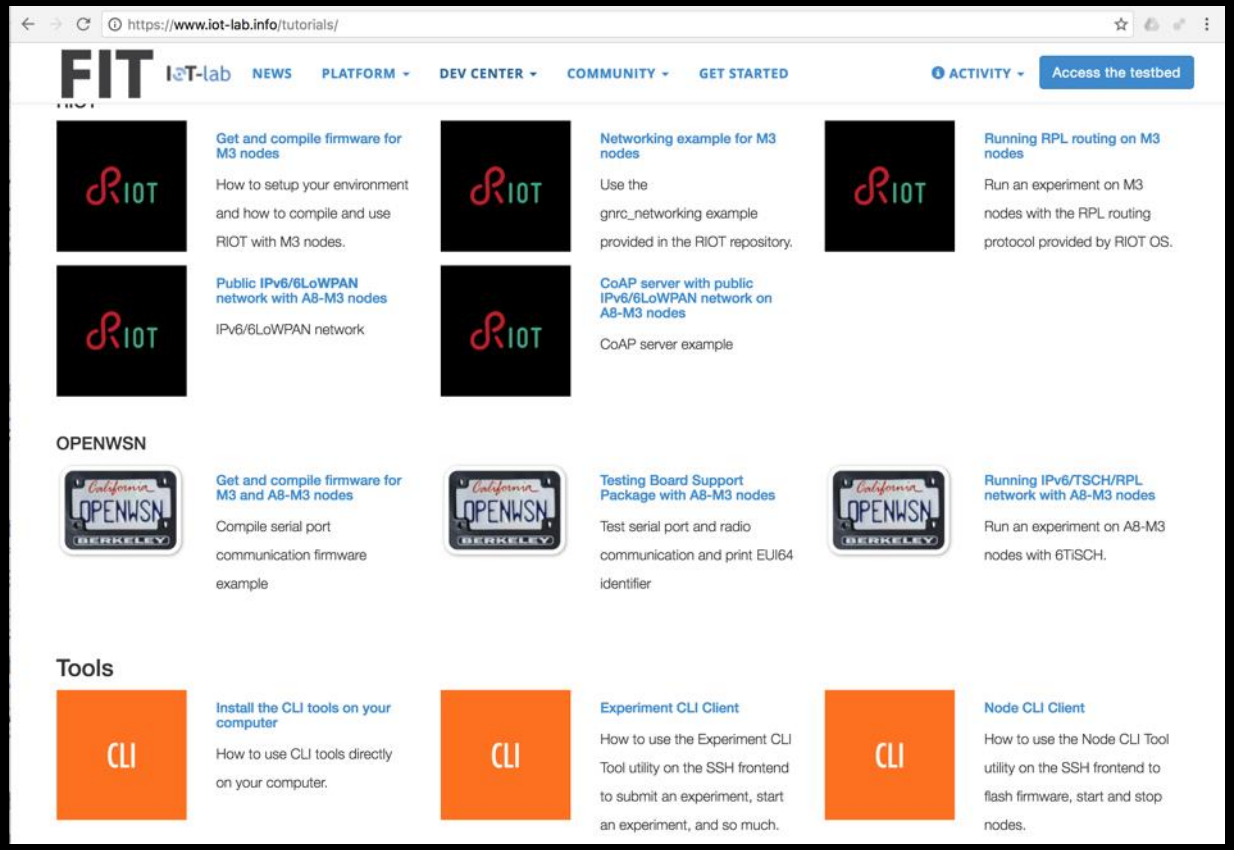
- ✓ COTS low-end IoT hardware
- ✓ Web server dashboard
- ✓ COAP/IPv6/6LoWPAN
- ✓ End-to-end open source
- ✓ End-to-end open communication standards



RIOT in Action

RIOT supported on open access testbeds: https://www.iot-lab.info

FIT IoT-lab



Closing words

- We’re seeing a lot of activity on OS for low-end IoT
- We’re seeing huge progress in IoT on:
  - connectivity
  - interoperability
- Main IoT challenges ahead:
  - Large scale orchestration/management
  - Security (avoid IoT botnets armageddon?)
  - Privacy (reconciled with IoT and big data?)

Thanks!

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Contributing: https://github.com/RIOT-OS/RIOT

Support & discussions on IRC: irc.freenode.org #riot-os