Energy-Aware Urban Sensing with RIOT

5th RIOT Summit
Technology Context | Deployment Report | Future Prospects
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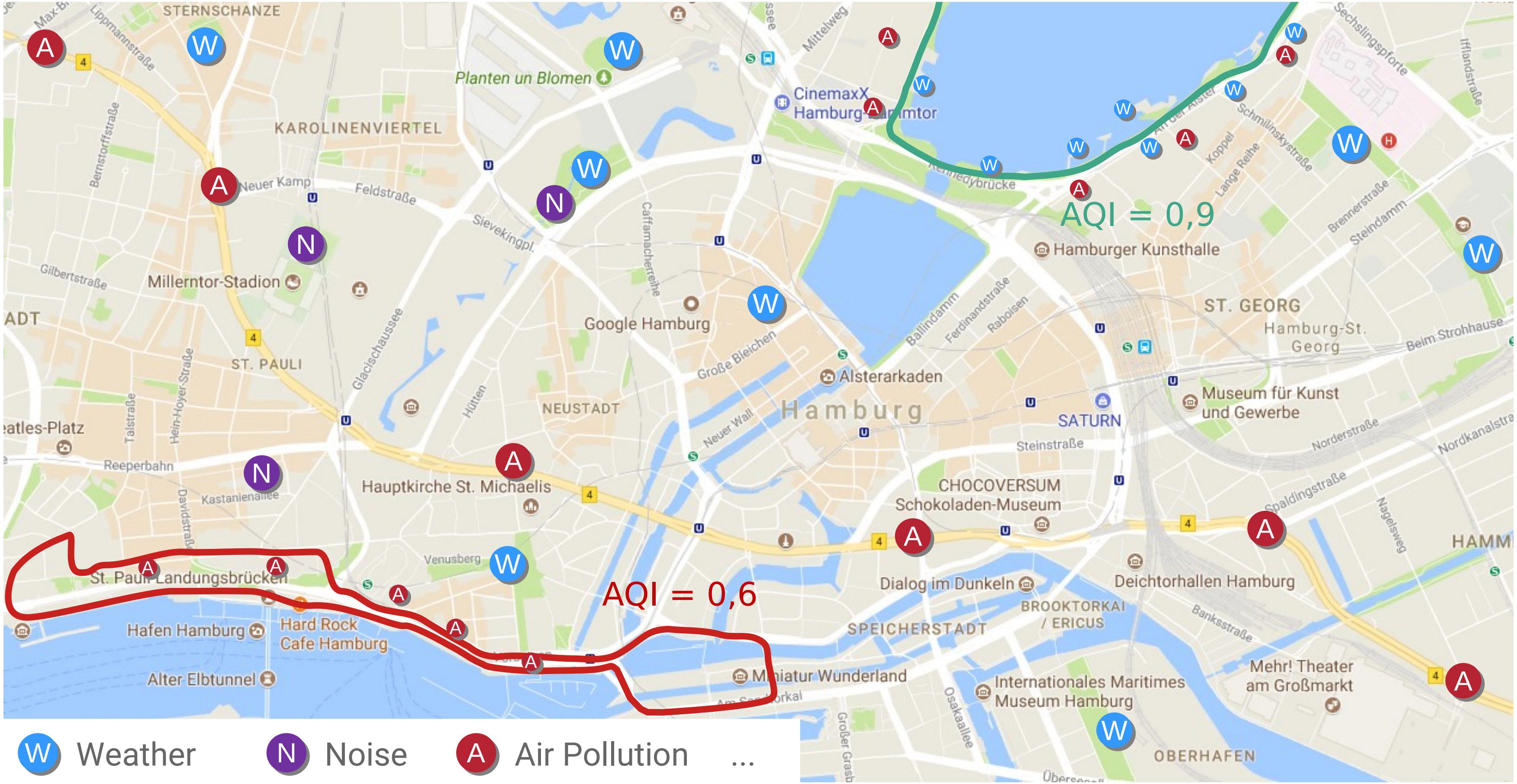
Agenda

- Urban Sensing
- Energy-Neutral Sensing
- Eco-Box
- Deployment
- Future Topics
- Discussion

Urban Sensing

What’s that?

SANE – Smart Networks for Urban Citizen Participation



W Weather N Noise A Air Pollution …

Energy-Neutral Sensing

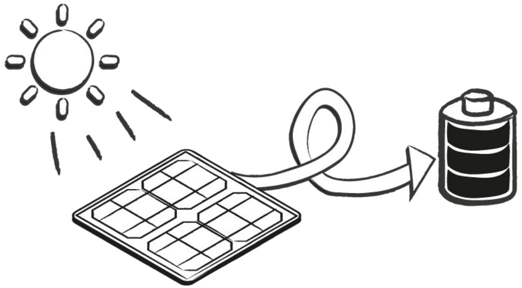
Concepts, Technology, Problems

Energy-Neutral Sensing

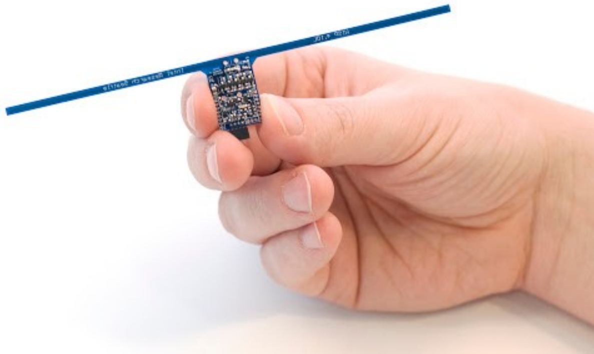
- Harvest energy from the environment
- All kinds of energy sources
  - Solar
  - Heat
  - Movement (wind, water, vibration)
  - Radio frequencies
  - Chemical reactions
  - ...
- Self-sufficient
- No maintenance
- Virtually infinite lifetime

Energy-Harvesting Principles

- Energy neutral operation
  - Rechargeable Batteries, Super Capacitors
  - Energy management: proactive, rather long-term
  - Duty-cycling
  - “Continuous” state

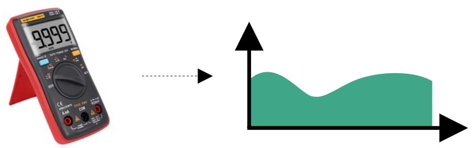


- Intermittent
  - Capacitors
  - Energy management: mostly reactive, rather short-term
  - Task splitting & checkpointing
  - “Non-continuous” state

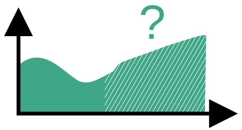


Energy Awareness

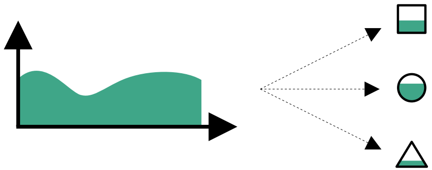
- **Assessment**
  - How much energy is available ?
  - How much power is drawn by the system ?



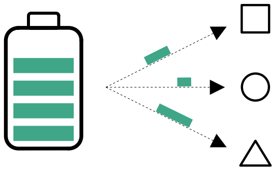
- **Prediction**
  - How much energy will be available in the future ?



- **Attribution**
  - What is responsible for that consumption ?



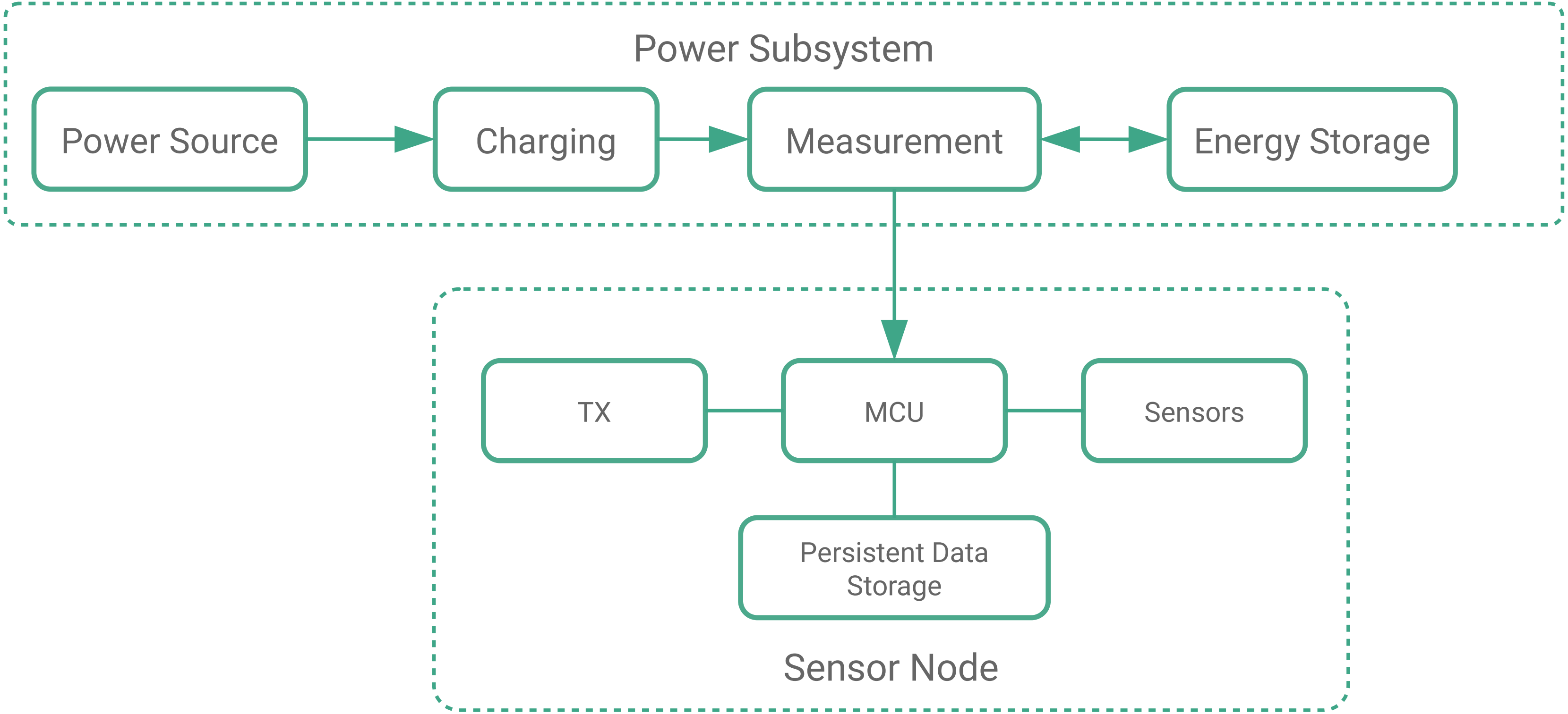
- **Allocation**
  - How much do we want to spend for what ?
  - How to actively control that ?



Eco-Box

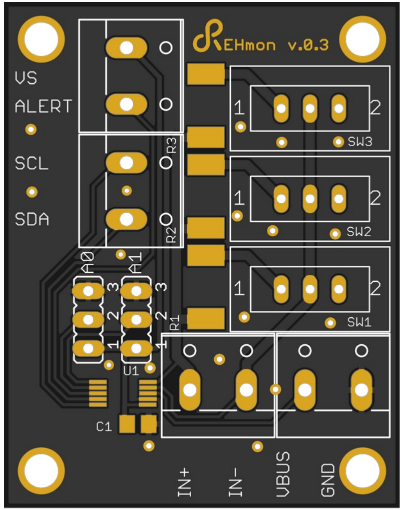
Modular Energy-Neutral Sensing

Eco-Box Architecture Overview



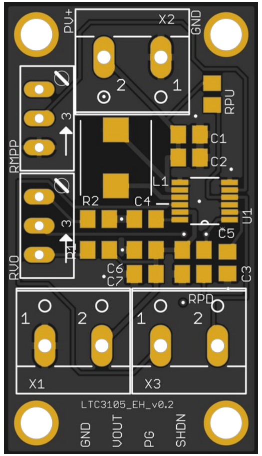
Eco – Measurement Module

- Bi-directional shunt monitor (INA226)
- Measures current and voltage
- I²C interface
- Current range selectable e.g. {40, 100, 500} mA
- Calibration
- Configurable conversion time and averaging
- Interrupt features for unattended operation



Eco – Charging Module

- 400 mA DC-DC step-up converter (LTC3105)
- Input working range: 225 mV – 5 V
- Flexible adjustment for different PV-cells
  - MPPC ≤ 5 V
- Suitable for various batteries or super caps
  - Vout: 2.2 V – 5.1 V

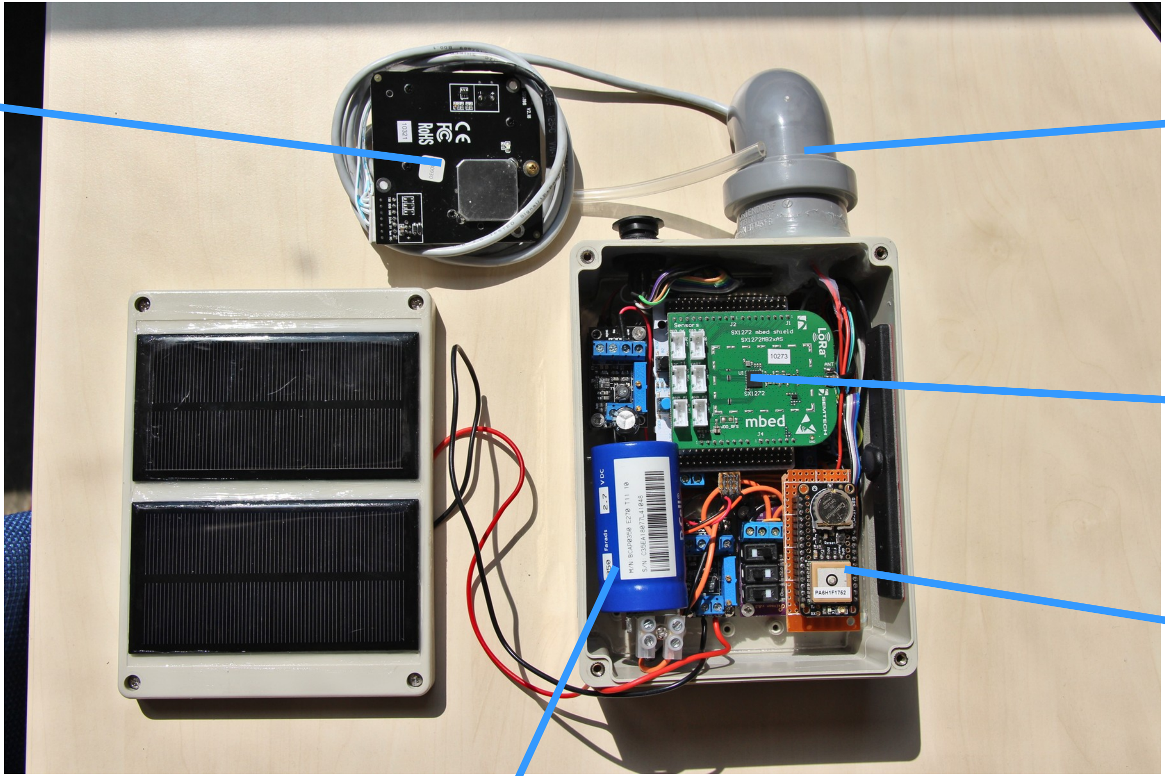


Super Capacitors

- Very high power density
- Rather low energy density
- Subject to self-discharge
- Voltage drops when supplying current
    - Internal charge redistribution
- “Virtually” infinite component lifetime
- Robust Against
    - Temperature
    - Deep discharge
    - Current Spikes, ...

≈ 50 x

Eco-Box for Mobile Deployments



SDS011

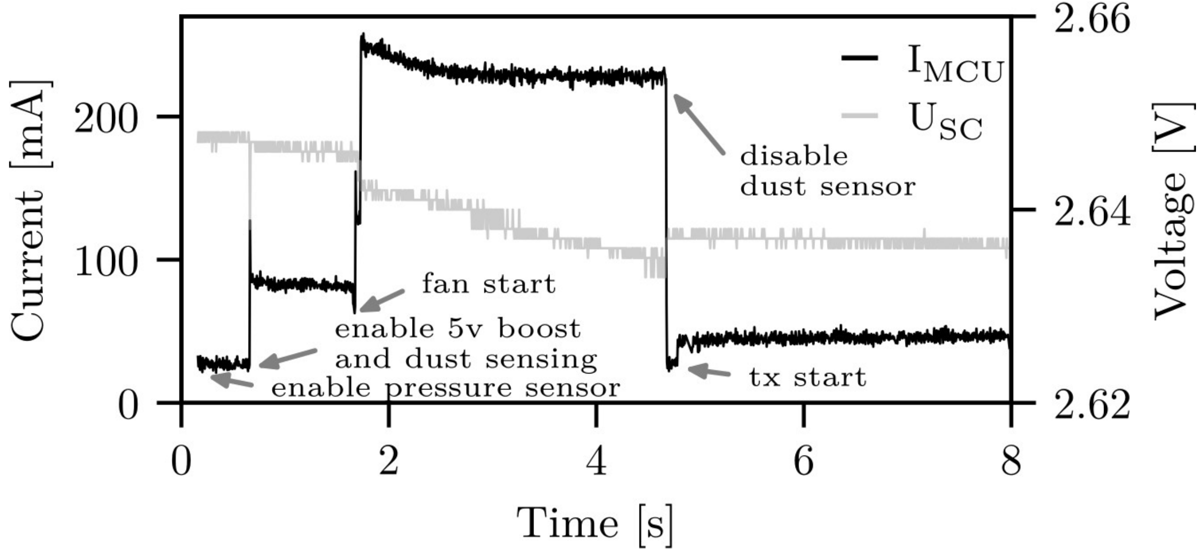
BME280

SX1272

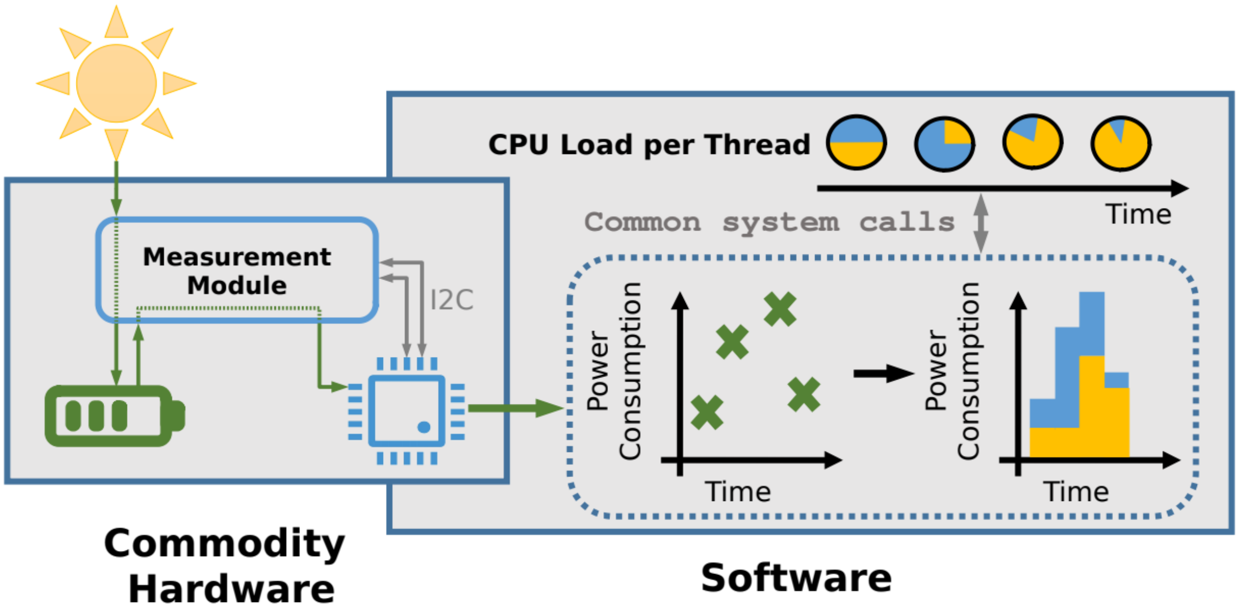
MTK3339

350 F 2.7 V

Eco Measurement Example



Eco Principle



Deployment

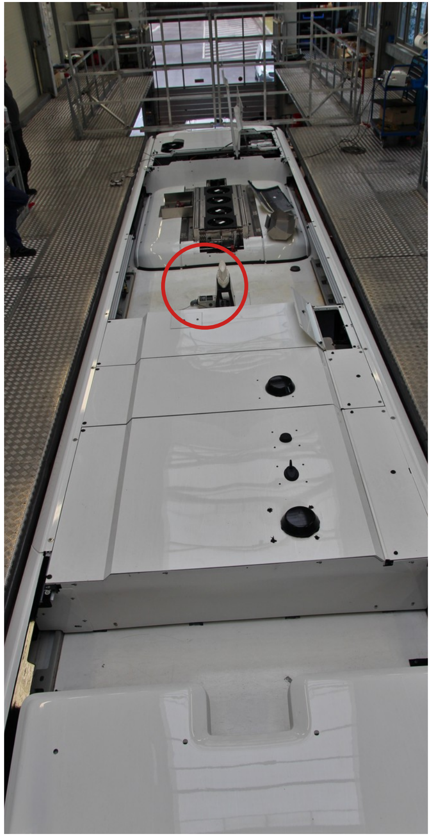
Background & Scenario - Mobile Urban Sensing

Deployment Scenario

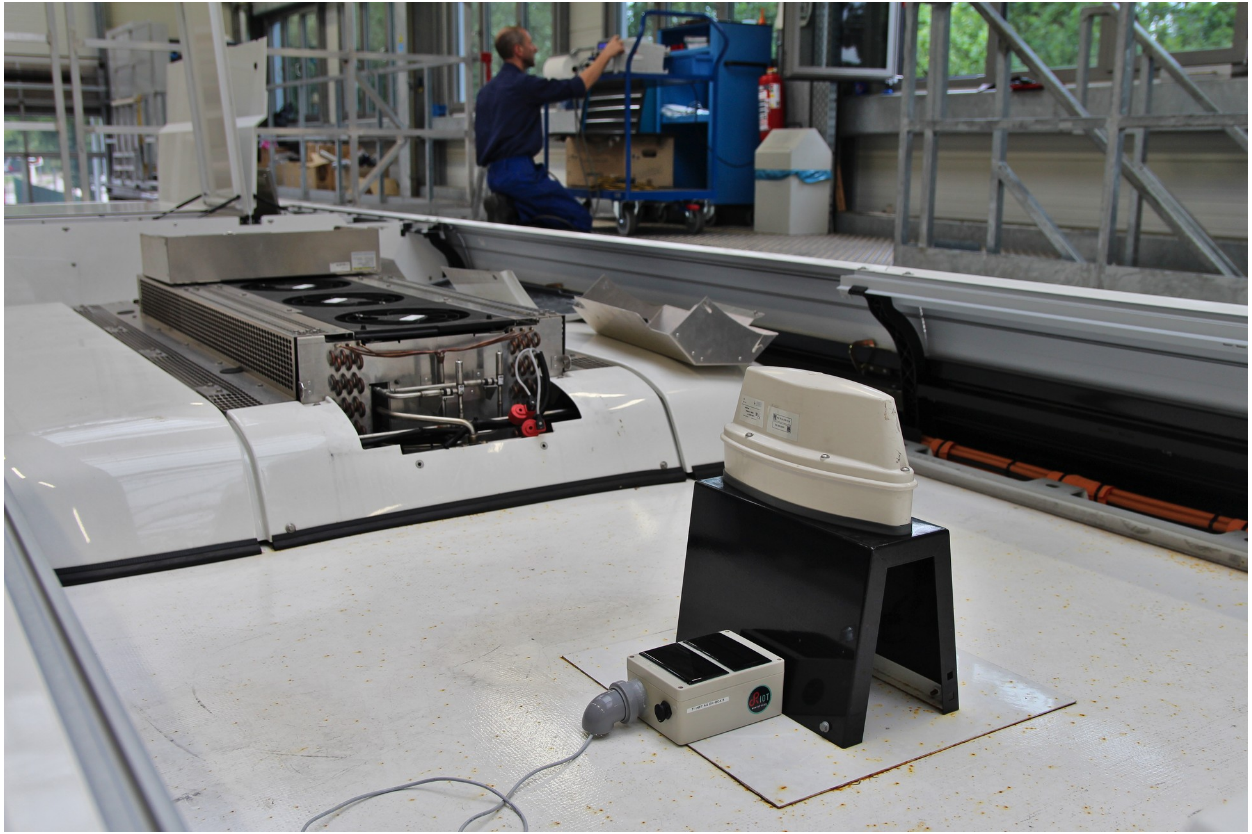
- New public transport fleet of emission-free electric buses

* https://www.daimler-truck.com/innovation-sustainability/efficient-emission-free/ecitaro-hamburg.html

Deployment Scenario



Deployment Scenario



Some Stats on the Deployment

📅 Still ongoing: Day 411

📊 Collected Data

- Temperature, Pressure, Humidity, PM10, PM 2.5, Position, Speed, time-to-fix, visible satellites, Energy stats, …

🧮 Measurement-cycles overall

- 1.010.000 (~every 32.5 s)

😱 Node resets (Powerloss, Hardfault)

- 7 | 4 times during first two days | none since January

📨 Data transmitted: ~4.5 MB (~250 Packets per day)

💾 Data received: ~670 kB (~38 Packets per day) 😲

💻 Even a laptop-sized battery would not have lasted for this 😎

Some Stats on the Deployment

- 🌡️ Temperatures reached: -8.1 °C to 52.1 °C
    - Max. diff within a day: 39.6 °C
- 🛰️ Time to get a GPS fix (MTK3339)
    - Avg: 10.8 s (Min: 0.4 s, Max: 71.2 s, SD: 8.1 s)
- 😷 PM10 (Particles up to 10 µm)
    - 70% of daily average measurements over EU limit
    - SDS011: no lab-equipment, just an indication!
- 🚌 Bus-drivers speed highscore: ~96 km/h

Lessons Learned from the Deployment

📶 LoRa coverage

- hard to **realistically** gauge without tests (TTN Gateway Map, TTN Mapper)
- Fire & forget not applicable for mobile setting
- Proactively buffer at blind spots and transmit later
- Dynamically adapt transmission parameters

⏫ OTA-updates

🤨 Proprietary “smart” low-power modes of GPS modules can be a joke

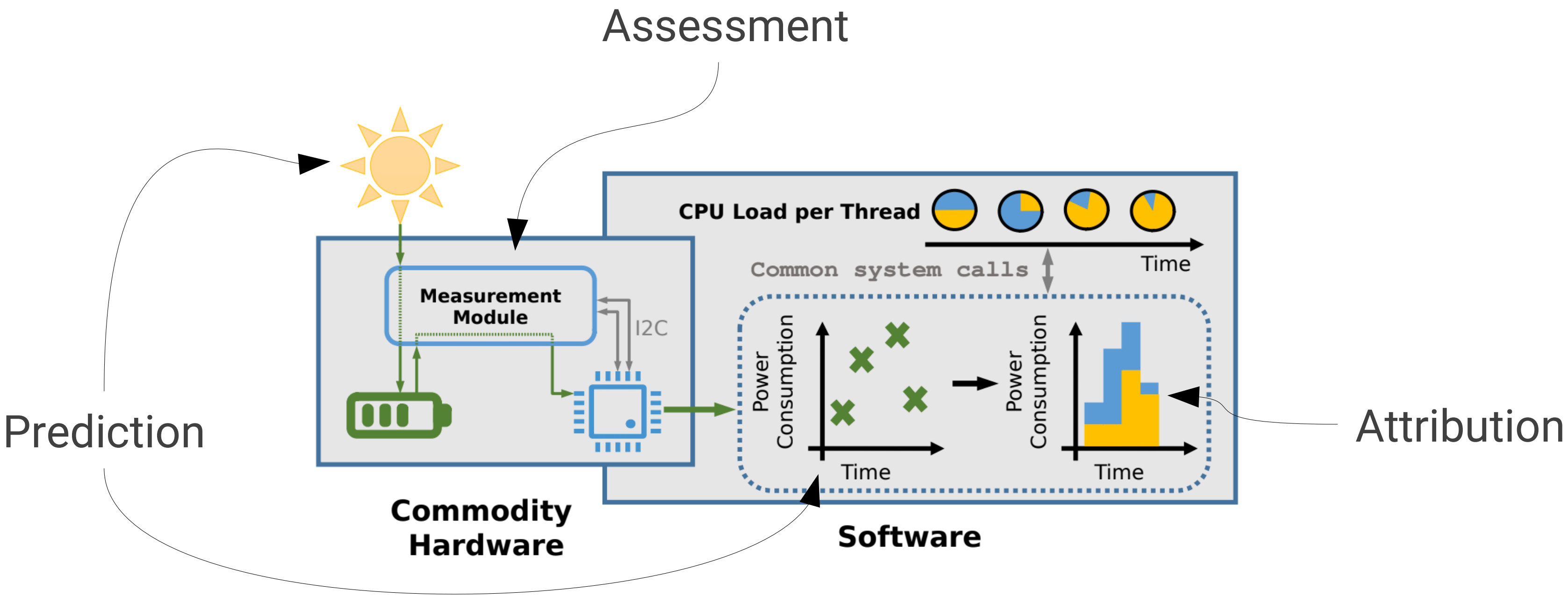
- Better count in some MOSFETS

💾 Add persistent storage whenever possible

Future Topics

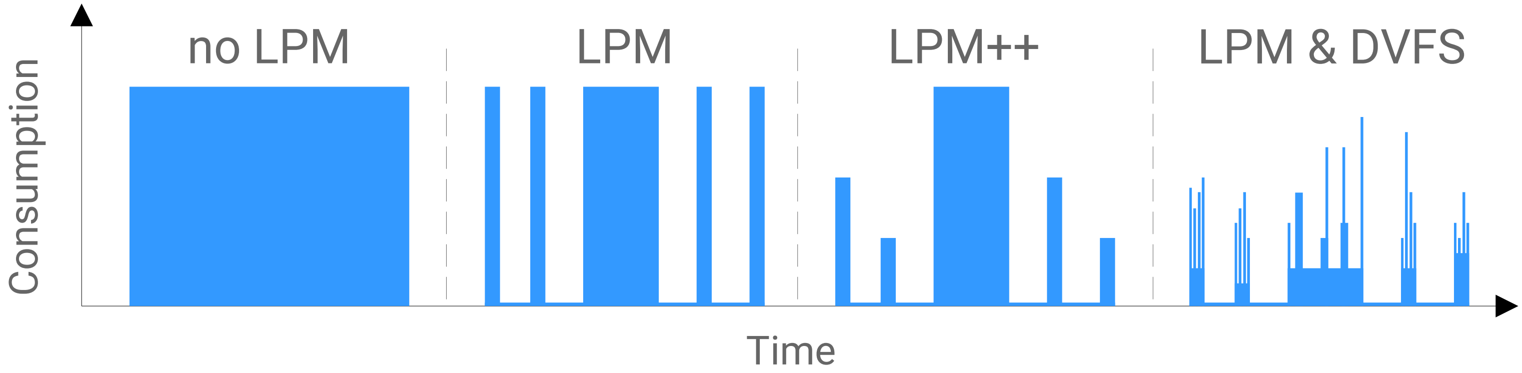
To Improve Energy-Awareness in RIOT

Future Energy-Awareness Topics for RIOT



- What about Allocation ?
  - Can we do more than duty-cycling ?

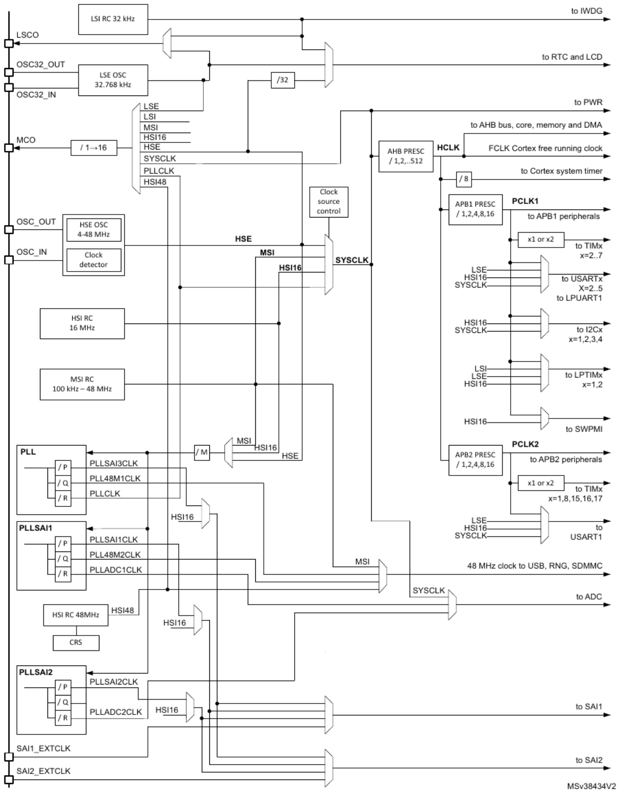
Future Energy-Awareness Topics for RIOT



- Dynamic voltage and frequency scaling
  - Reduce core clock and voltage when utilization is low
  - Save significant energy when node can not sleep or is not fully utilized
- Generic online clock-reconfiguration

Generic Online Clock Configuration

- Requires
  - Light weight generic clock tree model for topology & configuration
  - Efficient encoding of properties, constraints & dependencies
  - Proper integration
    - Utilization metrics, device handles, hooks for DVS & drivers
- Enables
  - Significant energy savings
  - Determine drift & calibration
  - Tree exploration for testing and evaluation
  - Time-sharing of otherwise conflicting configurations
  - ...



Wrap-Up

- RIOT suitable for scenarios with very dynamic energy constraints
  - Huge amount of onboard features, packages and drivers get things going quickly
- Energy-neutral sensing helps to improve sensing density
- Higher level energy management as OS-service helpful
- Generic online clock reconfiguration

Additional Reading

For more details see:
Michel Rottleuthner, Thomas C. Schmidt, Matthias Wählisch,
Eco: A Hardware-Software Co-Design for In Situ Power Measurement on Low-end IoT Systems, in Proc. of ACM ENSsys@SenSys 2019

Thanks for Listening!

Questions & Discussion