School of Engineering
InES Institute of Embedded Systems

IoT Everywhere?
Harvesting energy to power future IoT nodes

Marcel Meli: ZHAW, Institute of Embedded Systems marcel.meli@zhaw.ch

Wireless Tech Talk 2019, Lausanne.

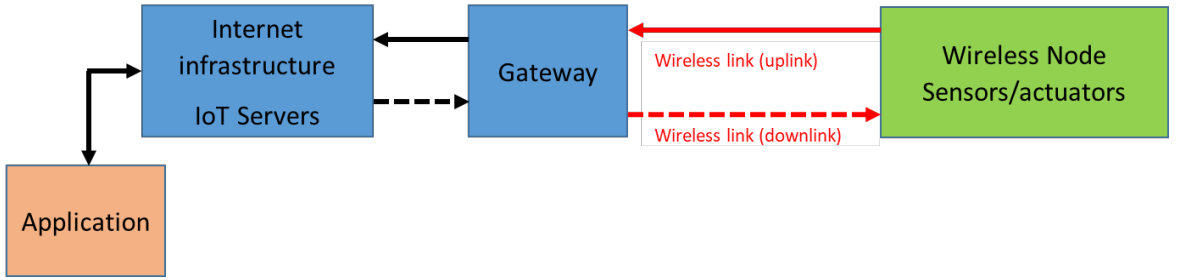
Organised by the CSEM

Agenda and some definitions

- **Motivation**
- **Issues**
- **Examples of EH**
  - Some EH techniques that will be used in IoT in the coming years . Amanda (H2020 project)
- **Some (simplified) definitions:**
  - LPWAN. Long range wireless systems. Will normally cover a wide area. Low data rate.
  - ALOHA. Random access of communication channel. Collisions problems. More nodes, more collisions.
  - EH (Energy Harvesting) Conversion of energy from one form (mechanical, thermal, light, RF…) to electrical energy in order to power the electronics. The primary energy form depends on the application context.
  - TEG (ThermoElectric Generator).Need temperature differences

Motivation

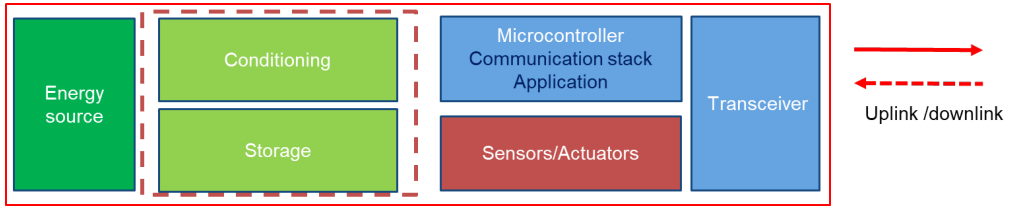
- **What are we dealing with in this talk?**
  - The IoT chain has many elements
  - Our focus: “Long Range Wireless Nodes”



- **According to Market Intelligence: millions of IoT nodes in the future**

- **Some potential problems:**
  - Installation, reliability, power

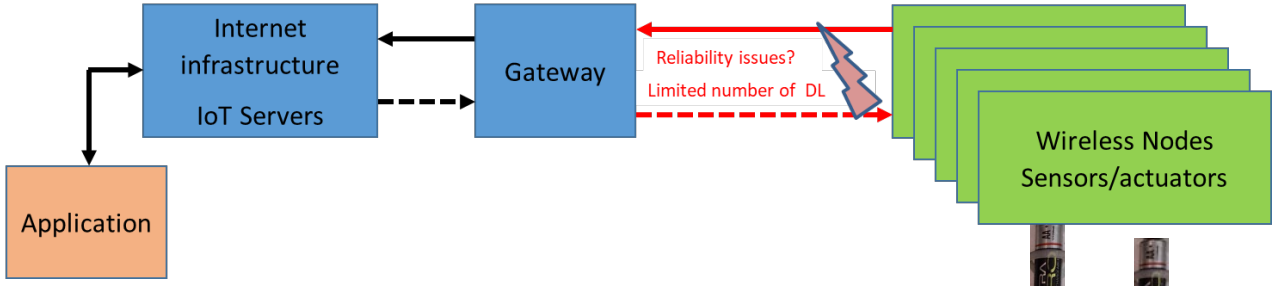
- **Some applications are held back by some of these issues**
  - It is important to consider them and their impact on the future of IoT



Issues

- **Traffic jam/data loss in unlicensed band?**
  - ALOHA limits. Collisions affect throughput
  - low-cost, but reliability issues
  - Limited downlink (DL) resources
  - Various methods help, but is that enough for the millions of nodes?

https://edtimes.in/heres-how-delhi-police-plans-to-make-delhi-traffic-jam-free-by-2020/



- **Powering millions of IoT nodes**
  - Mains? mobility + cable problems
  - Batteries? Not always good
    - Replacement/maintenance costs
    - Ecological issues / temperatures

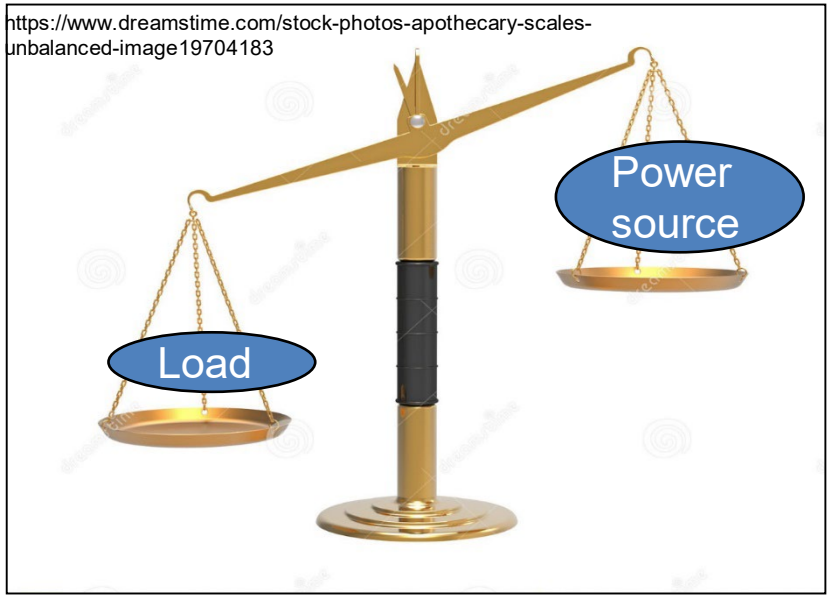
https://www.michiganradio.org/post/recycling-typical-household-battery-not-easy-you-might-think

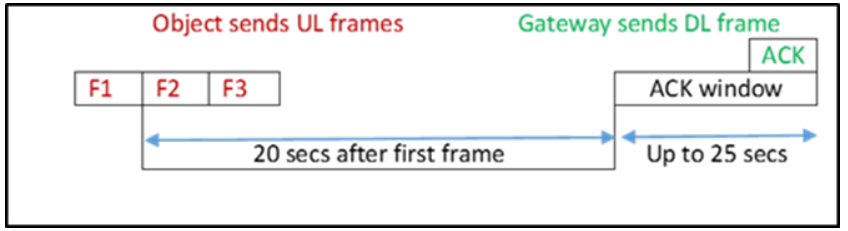
Issues: balance and low-power design

- **Energy harvesting can help. No batteries to replace!**
  - Need appropriate elements:
    - source, harvester, electronics, storage

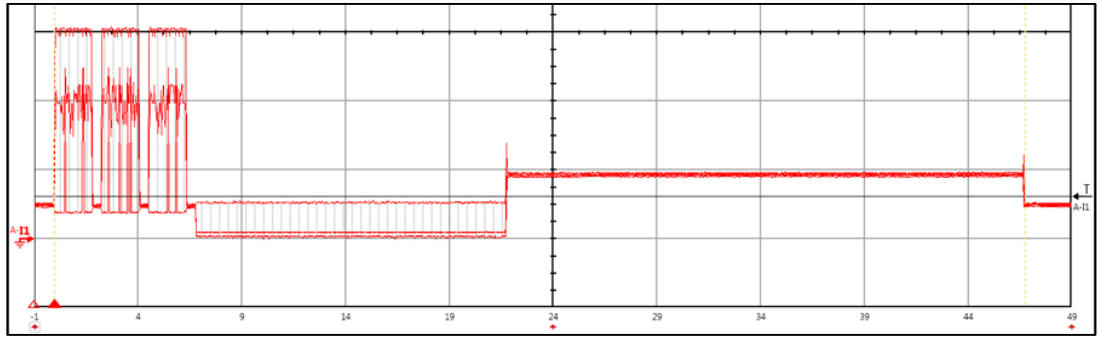
- **Energy problems when balance is lost**
  - Load needs more energy than is available
  - Some factors
    - Energy needed by the load
    - Effects of leakages, ageing

- **Compromises needed (must first work)**
  - Range/payload → more energy
  - Complexity affects transceiver costs
    - Sigfox: 3 frames → better reliability but more energy
    - LoRa: High SF → better range but more time and energy

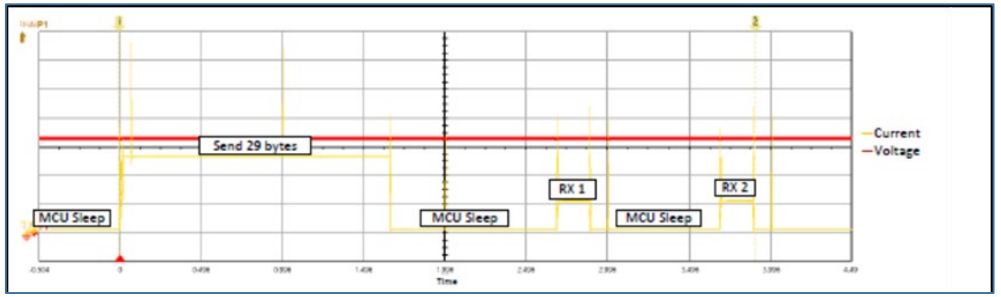




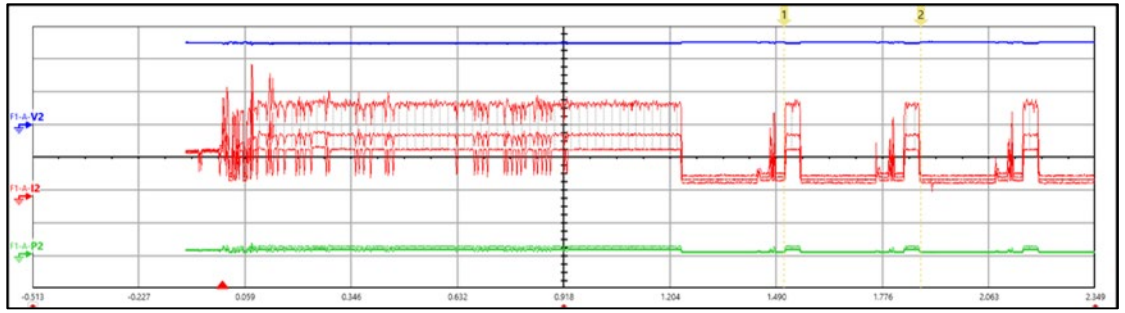
Issues: an idea about load requirements



Energy for Sigfox. @3.3 V, **6** bytes payload, ST S2-LP TRX
Each Tx costs about 117mJ. Rx window is long. Costs >700mJ if needed
1 frame 3x → more than 300 mJ



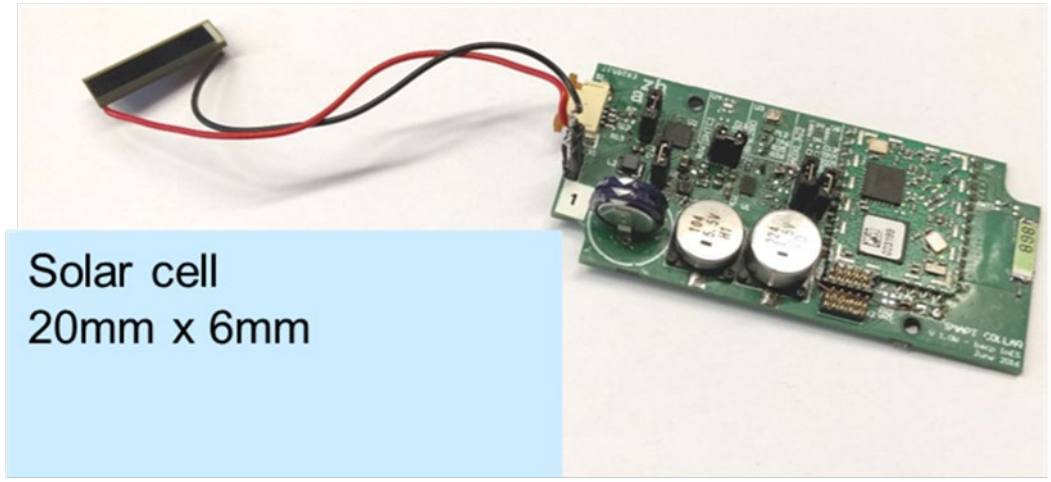
Energy for LoRa. @3.3 V, Sx1276 transceiver + micro
29 bytes payload, 193 mJ (startup, Tx, Rx1, Rx2)



Energy for Nb-IoT. nRF9160.
- Energy of similar order as LoRa
- **More data** (higher data rate)
- Current peaks very high → no so good for small batteries
- Active Tx current (+23 dBm) > 250 mA (peaks of 380 mA)

Some EH possibilities

- **Costs might be an issue (in general, less energy → lower costs)**
  - With careful low power design, LEDs, Photodiodes, Small solar cells could be used
  - Printed batteries on IoT (Wearables) are also possible.



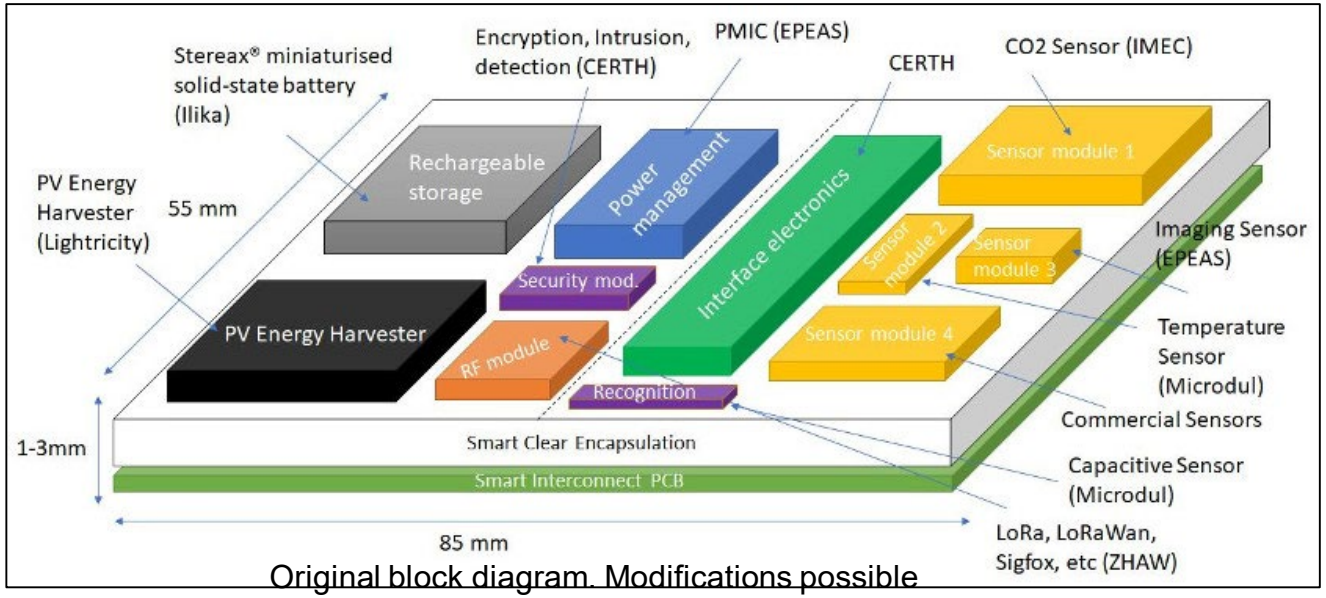
ZHAW-InES: LoRa node powered using small solar cell
Tens of frames sent per day, depending of luminosity

ZHAW-InES: BLE node powered using LEDs as harvesters

EH: Amanda project (January 2019 – December 2021)

School of Engineering
InES Institute of Embedded Systems

- **Amanda is a H2020 (EU) funded project (Research and Innovation Action)**
  - Autonomous self powered miniaturized intelligent environmental sensing and asset tracking in smart IoT environments
  - Smart card format. Seeks to bring EH (photovoltaic) to IoT for different applications
  - Energy harvesting, sensing, short/long range wireless, security, positioning, ...



Original block diagram. Modifications possible

AMANDA
The world in your hands

The AMANDA project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 825464

Trees as energy source?

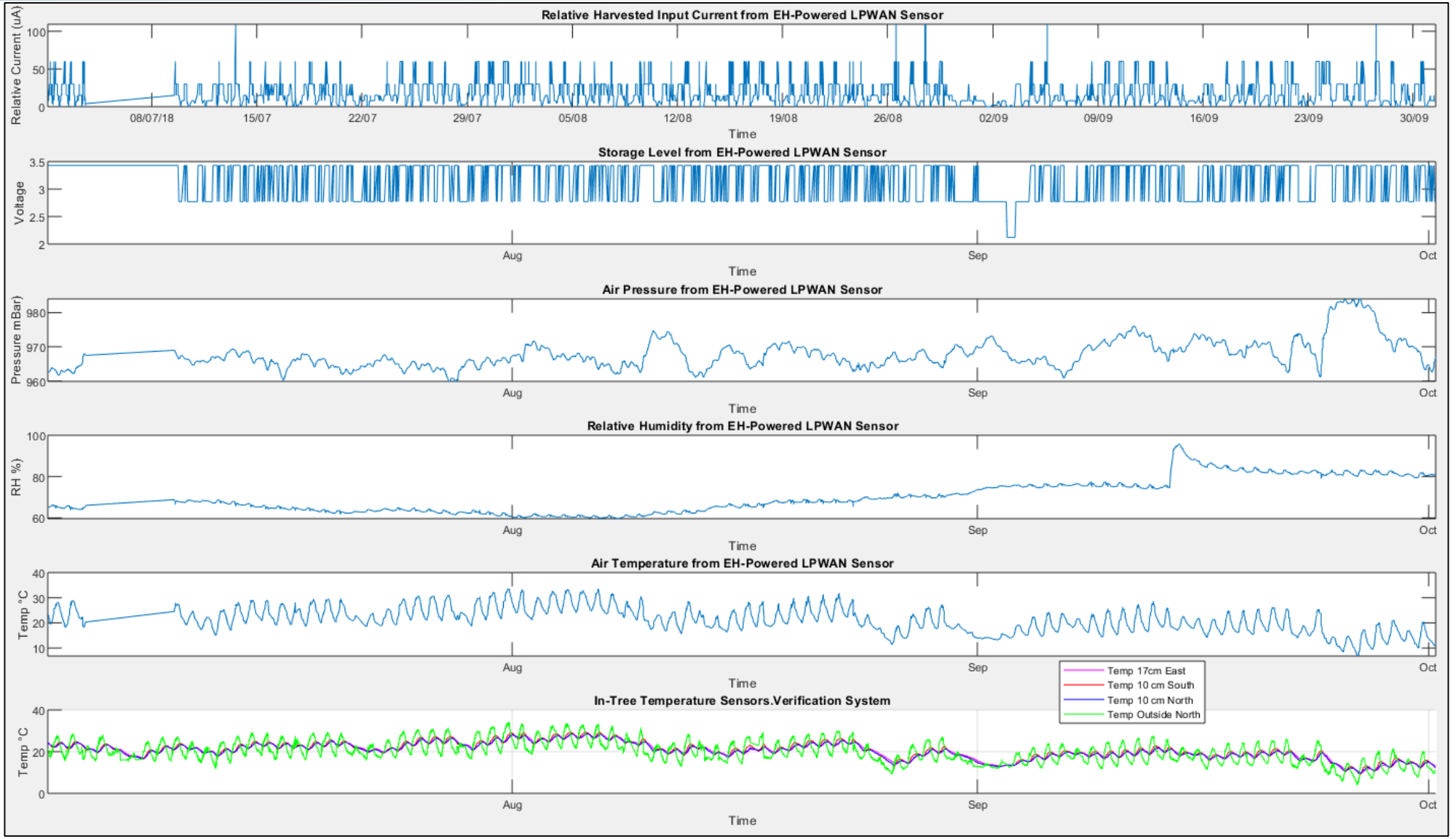
School of Engineering
InES Institute of Embedded Systems

- **Several IoT applications require nodes to be outdoors**
  - Smart cities, Agriculture. Other applications are waiting to follow
  - Trees in several places. Could this be a future energy source?
- **We are investigating the use of trees to power IoT nodes**
  - How? Temperature differences Tree/Air surrounding the tree
    - Day-night cycle → changes in ambient temperature
    - Low-power node with long range radio designed and fitted on tree
    - The node is totally energy autonomous. Measures P, RH, T
    - For control, a system powered with batteries measures some parameters
- **First results are good**
  - The system has been active for more than a year.
  - Works well all seasons .Less energy in winter (when there is fog?)

ZHAW-InES: IoT node powered by EH from tree. Verification system powered by batteries

Harvesting energy from trees. Some results (Jul-Sep 2018)

School of Engineering
InES Institute of Embedded Systems

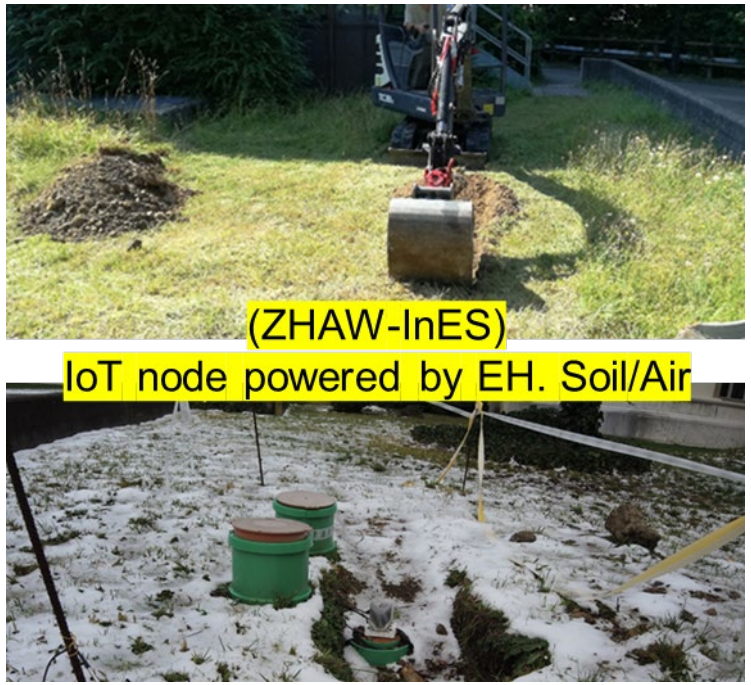


Some EH possibilities

School of Engineering
InES Institute of Embedded Systems

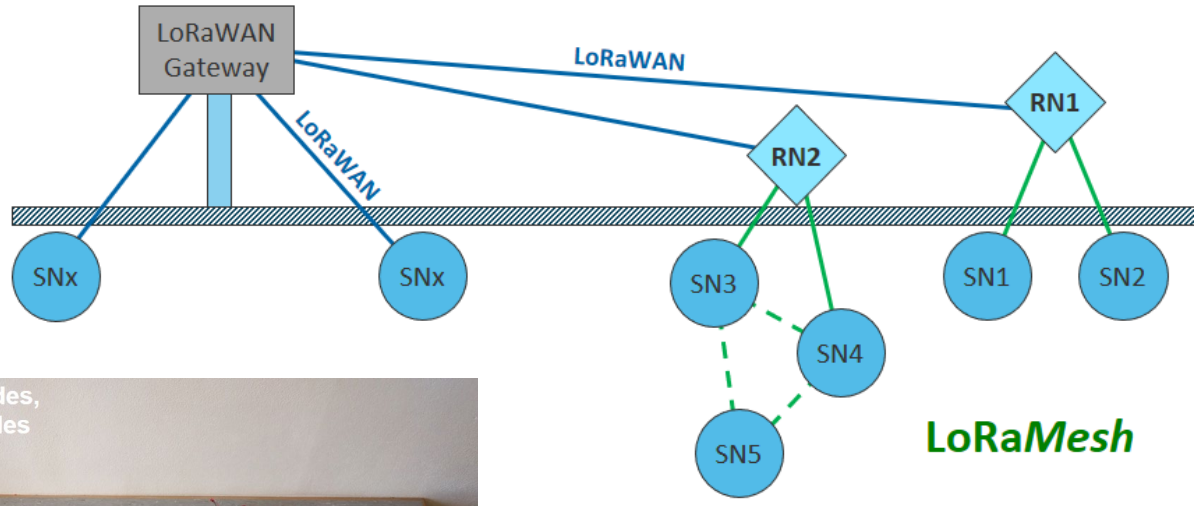
- **But you do not always have trees**
  - IoT nodes here? Or in a similar place?
  - Very hot/cold → not so good for batteries
  - Dig!! Not to plant trees, not for oil

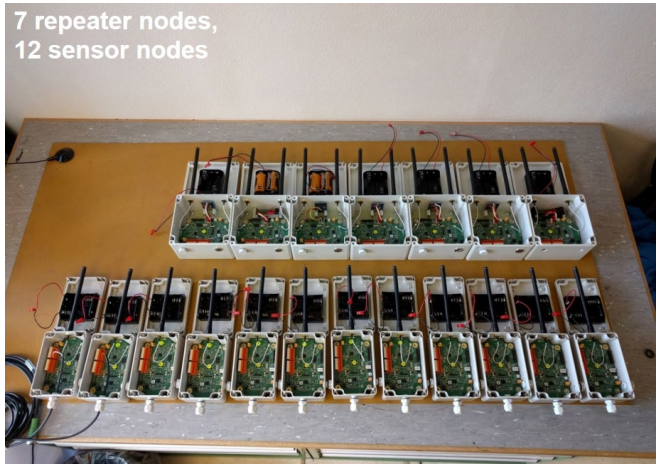
- **Dig for energy**
  - Temperature differences between soil and air
    - Harvest small amount of electrical energy
    - Low power design is crucial
  - We are using that method to power IoT nodes
    - Results are good
    - The system has been active in rain, snow, sunshine ...



LoRaMesh Field Tests

- **“Digitales Feldlabor Fehraltorf”**
  - Providing access to previously unreachable sensor nodes





LoRa*Mesh*

IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Synchronous LoRa Mesh Network to Monitor Processes in Underground Infrastructure

https://doi.org/10.1109/ACCESS.2019.2913985

ADAWIM

- **Autonomous and Distributed Architecture for Water Infrastructure Monitoring**
  - Shows that IoT in difficult environment (such as water infrastructure) is possible.
  - Above ground and Underground nodes. Man holes, …. Etc
  - Wireless communication and energy harvesting
- **Press Release and Youtube video**

https://www.zhaw.ch/de/medien/medienmitteilungen/detailansicht-medienmitteilung/news-single/selbstversorgende-sensoren-spueren-wasserlecks-auf/

What else are we doing in IoT? Several things

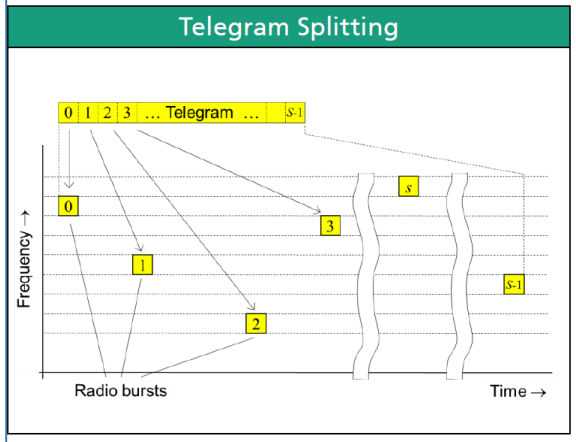
School of Engineering
InES Institute of Embedded Systems

- **LPWAN: Work related to existing systems (LoRa, Sigfox, NB-IoT, … etc**
  - More Energy Harvesting
  - Use of printed batteries with Long Range Wireless (e.g. for wearables)
  - Working on a solution to improve the downlink
    - Virtually inexistent for Sigfox, very asymmetric for LoRaWAN
    - Potential to further reduce energy requirements and/or improve reliability

- **Looking into other wireless systems**
  - e.g. MIOTY (Fraunhofer IIS)
    - Telegram Splitting
    - https://behrtech.com/

Telegram Splitting Multiple Access

The Concept



- Telegram Splitting (TS) divides a compact telegram transmission into S equally sized radio bursts
- For Multiple Access (MA) the radio bursts are distributed over time and frequency
- For correct decoding only 50% of the radio bursts need to be collision free
- This reduces the collision probability of telegrams and increases the resilience against interference

Conclusions

School of Engineering
InES Institute of Embedded Systems

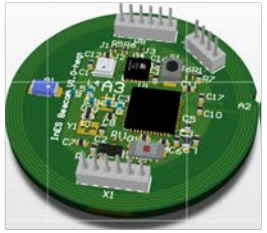
- **Energy Harvesting is becoming a viable way of powering IoT networks**
  - Works with several types of wireless systems
  - Optimisation needed on load side and on EH side
- **Reliability of Long Range wireless system is being improved**
  - Also for systems in unlicensed bands
  - There are new systems coming
- **More applications will profit from those improvements**
- **New applications will surface**
- **ZHAW-InES is working towards those goals**
- **contact**
  - marcel.meli@zhaw.ch
  - https://www.zhaw.ch/en/engineering/institutes-centres/ines/low-power-wireless-embedded-systems/

Other examples of our work in low-power and EH

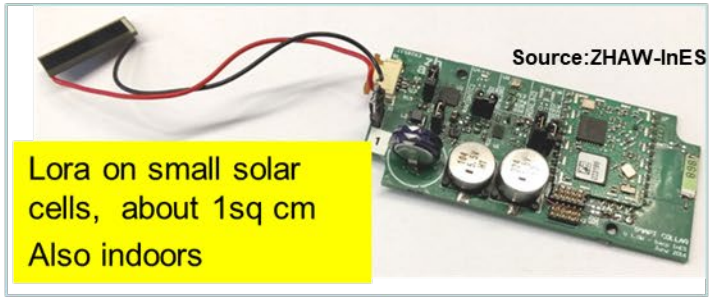
School of Engineering
InES Institute of Embedded Systems

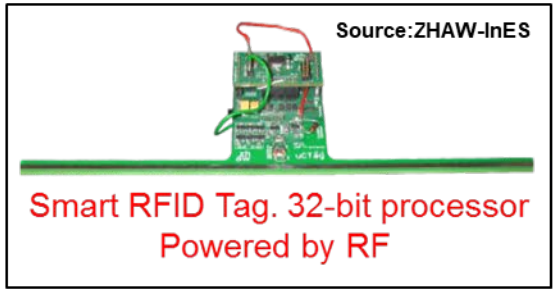
Diversity of energy sources: mains, batteries, piezo, solar, heat, RF, electrodynamic, printed batteries, …
Diversity of wireless systems: Bluetooth Smart, RFID, 802.15.4, ZigBee, proprietary, Sigfox,LoRa, Nb-IoT…
Diversity of microcontrollers: state machines, 8-bit, 16-bit, 32-bit, asynchronous, …

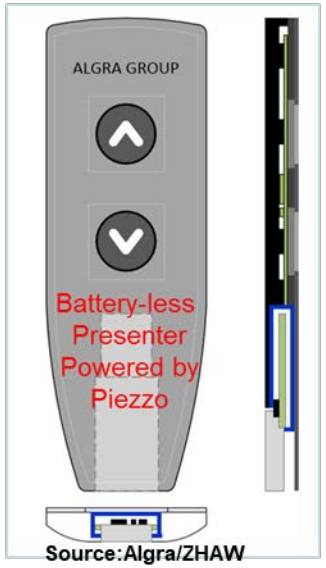
Source:ZHAW-InES



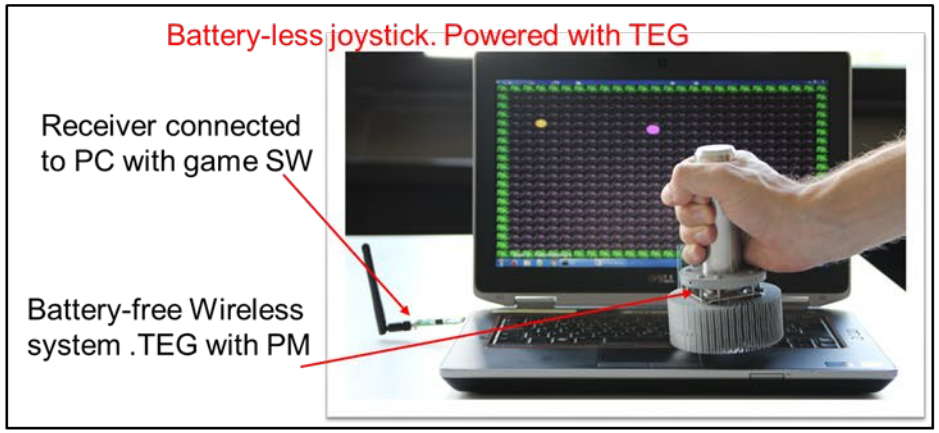
BLE sensor with NFC and optical pairing



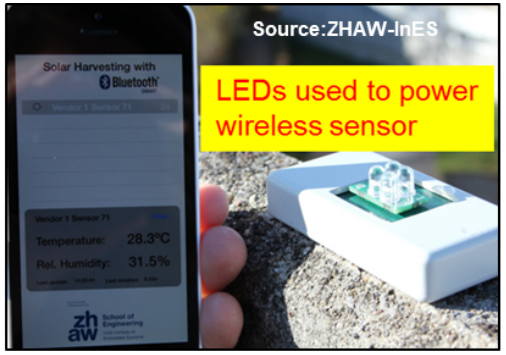


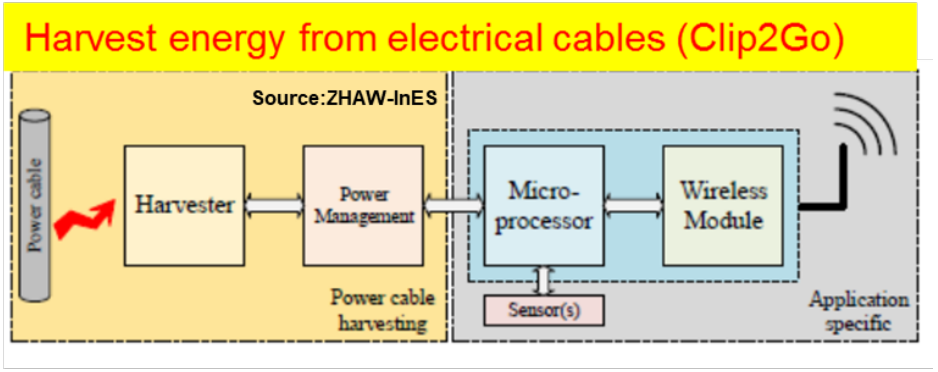


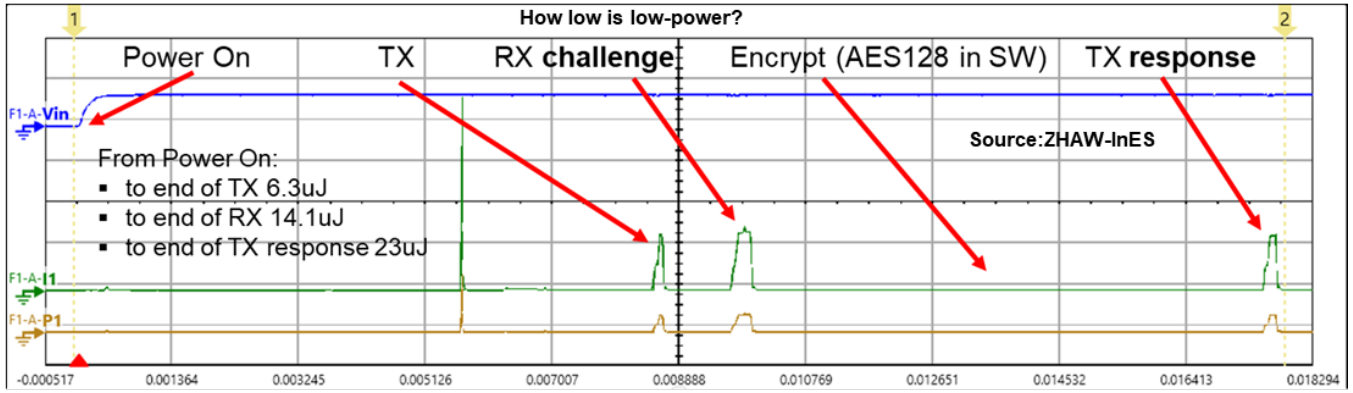
Source:ZHAW-InES



Other examples of our work in low-power and EH







Total of about 23uJ needed for **Challenge Response** wireless communication at 2v, Tx power=0dBm