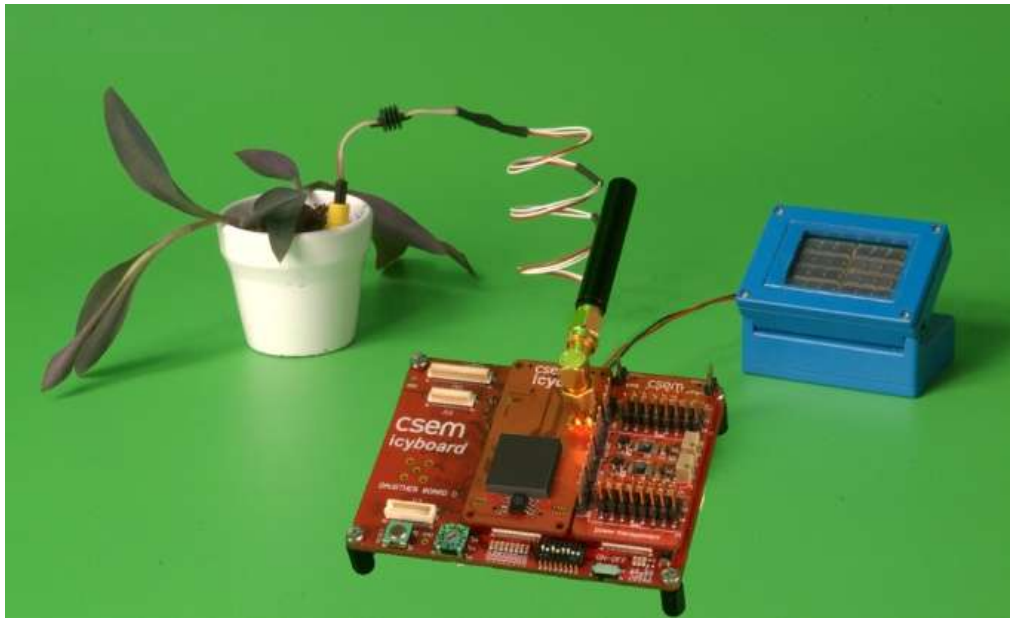
Solar Energy for Wireless Sensor Networks

Philippe Dallemagne

CSEM



FSRM, October 27th, 2010

Outline

- CSEM
- Wireless sensor networks
- Saving energy with CSEM ultra-low power technologies
- Harvesting/scavenging energy
- Solar energy
- The WiseField case
- Other examples of outdoors deployments realised by CSEM

Centre Suisse d'Electronique et de Microtechnique

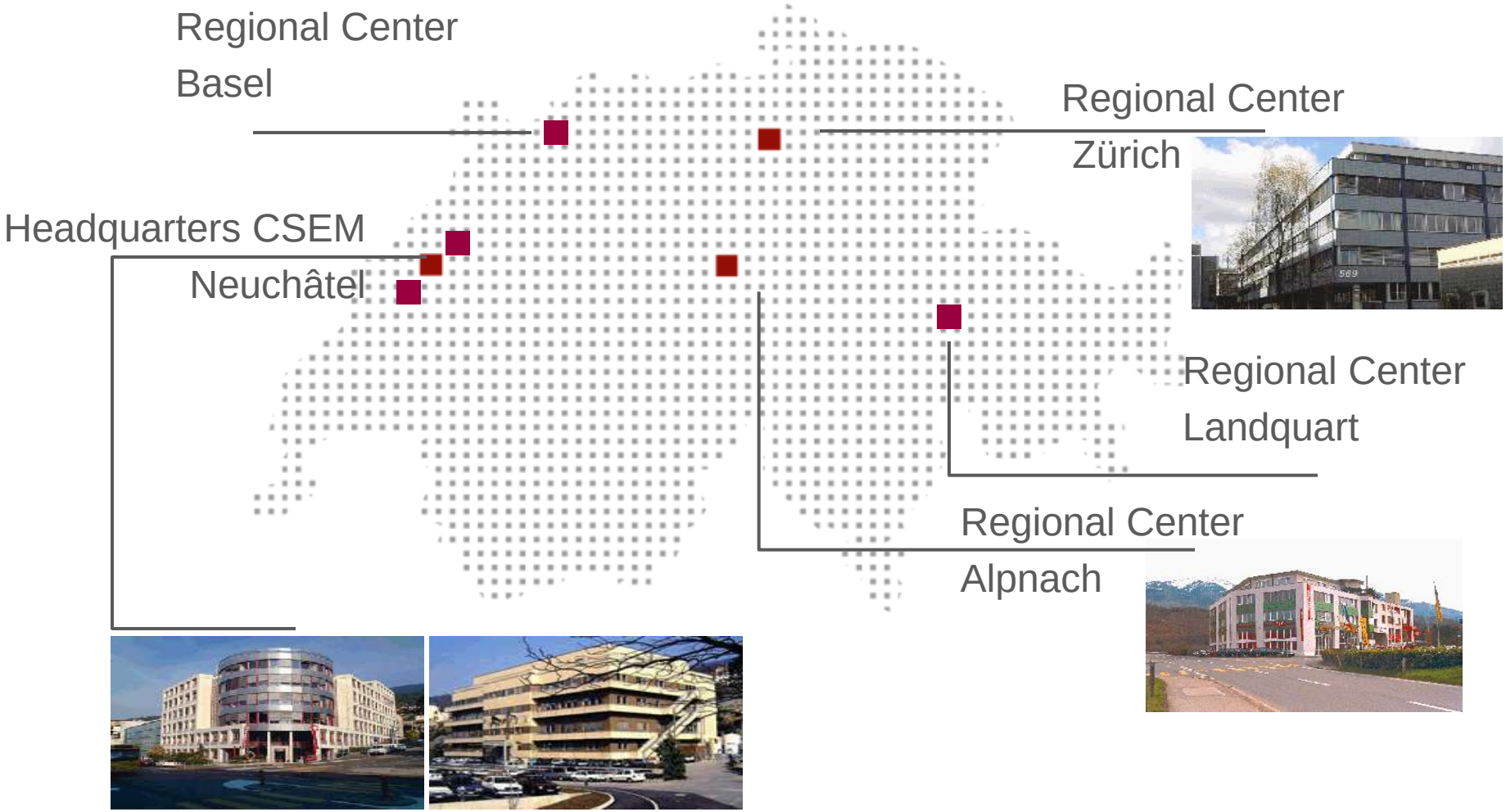
CSEM

… is a research and development company, active in the domains of micro-, nano- and information technology

… is a private company, with mainly industrial, but also public shareholders, not-for-profit

… has revenues (2009) of 70 MCHF, today ~ 400 employees, five centers in Switzerland & international activities

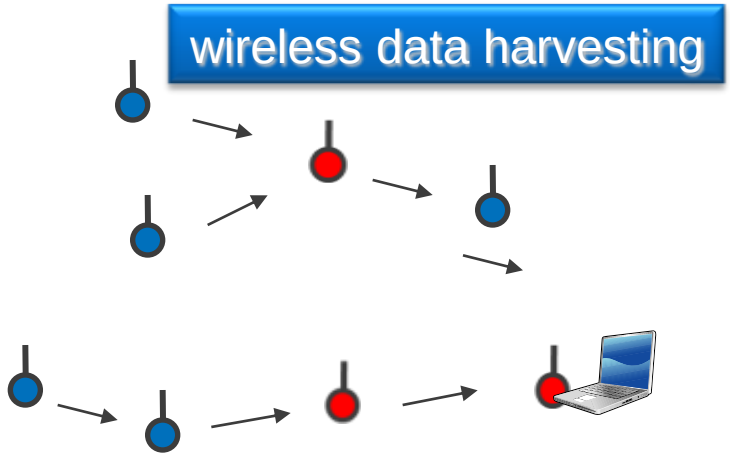
CSEM locations



Wireless Sensor Networks

Wireless sensor networks (WSN)

- What we understand by a wireless sensor network:
  - ✓ Very low power consumption
  - ✓ Short-range
  - ✓ Large coverage with multihop
  - ✓ Self-organized (no configuration)
  - ✓ Self-healing



- The resulting driving forces for our WSN developments
  - ✓ ultra low-power operation through HW and SW co-design
  - ✓ simplicity for network deployment and maintenance
- In the field for a few years now

Typical applications for WSNs

- industrial control and automation
  - ✓ automated meter reading
  - ✓ energy monitoring distributed sensing
  - ✓ Object tracking
- security and public safety
  - ✓ structural health monitoring
  - ✓ parking surveillance
- agricultural monitoring
  - ✓ sensor-based growth optimization
  - ✓ animal telemetry
- environmental monitoring
  - ✓ air & water quality monitoring
  - ✓ fire detection

.Outside
.Outside

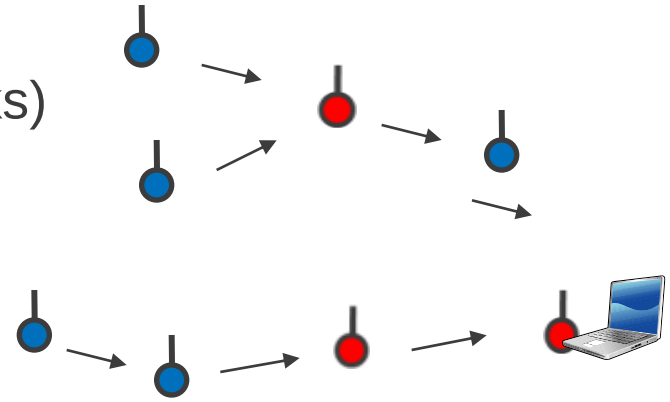
Continuous monitoring in the long term

- Ultra-low power electronics
  - CPU, memory, etc.
  - Wireless
  - Sensors
  - Energy management
- Ultra-low power software
  - Operating software & resource management (do you need an OS?)
  - Protocols and communication
- Wide area coverage
  - propagation (antenna) & multihop/mesh routing
- + casing
- + planning & deployment procedures
- + Batteries & energy scavenging

CSEM technologies (WiseNET)

Protocols

- MAC : WiseMAC, WideMAC, WideMAC-HA, CSMA, etc.
- Routing (self configuring)
  - Cluster-tree (small number of sinks)
  - Opportunistic (mobile nodes)
- Application layer
  - SNMP like (Set / Get / Event)
- Code update
  - Reliable, patch based, OS independent
- Localisation



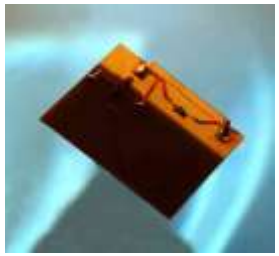
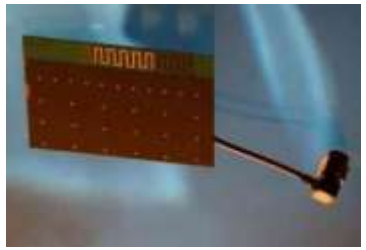
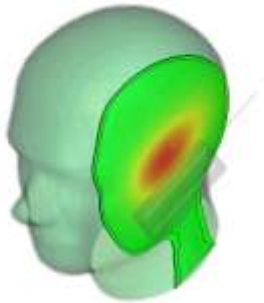
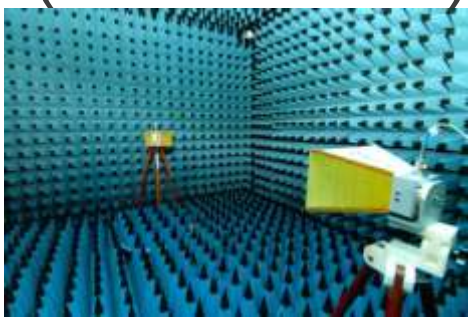
Saving energy: WiseMac – an ultra low-power wireless protocol

sources of energy waste at the MAC layer:

- **idle listening** ➔ listening when no data is available
- **overhearing** ➔ listening to data dedicated to others
- **oversending** ➔ emitting while there is no receiver
- **collisions** ➔ two parties are sending at the same time
- **protocol overhead** ➔ data that is not directly used for the application

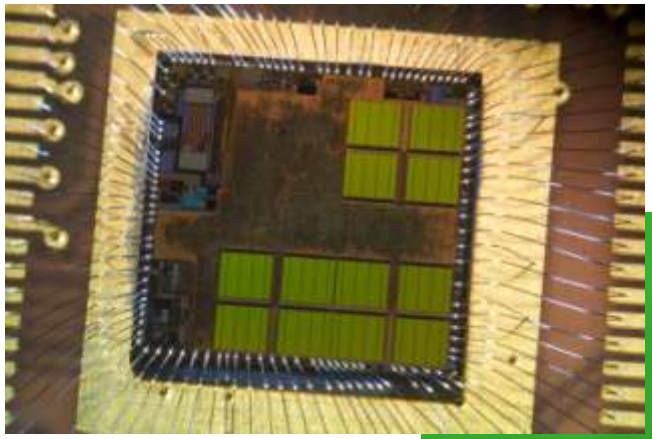
Saving energy: Designing efficient antennas

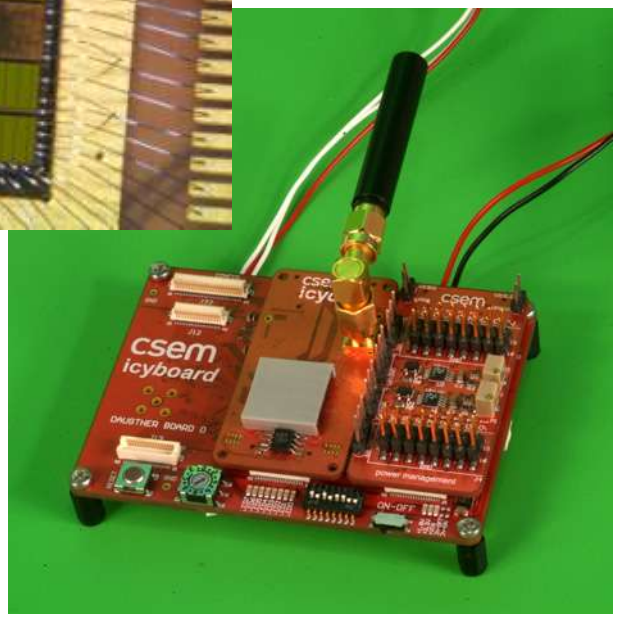
- CAD antenna design offer
  - Design, simulation and optimization on 3D antenna geometry
  - Current and field distribution analysis on surface and in volume
  - Far field radiation pattern analysis, gain and efficiency computation
  - SAR control and improvement on human body
- Anechoic chamber measurement facilities (HF to 30 GHz)

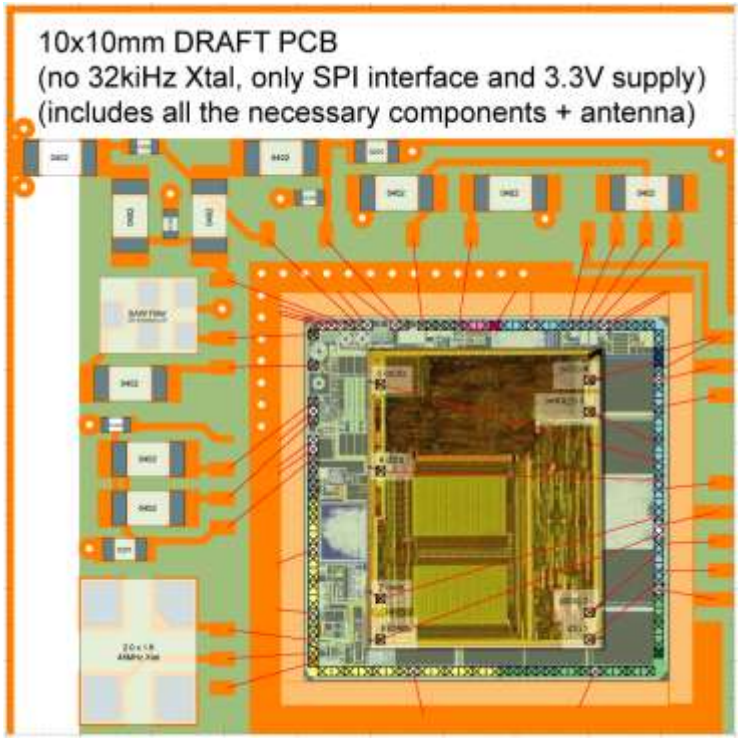





Saving energy: icy*com* overview

- **S**ystem-**o**n-**C**hip with **RF + processor + power management + …**
- **S**oftware **D**evelopment **K**it based on **gcc** + **gdb** uses **JTAG** for On-Chip Debug

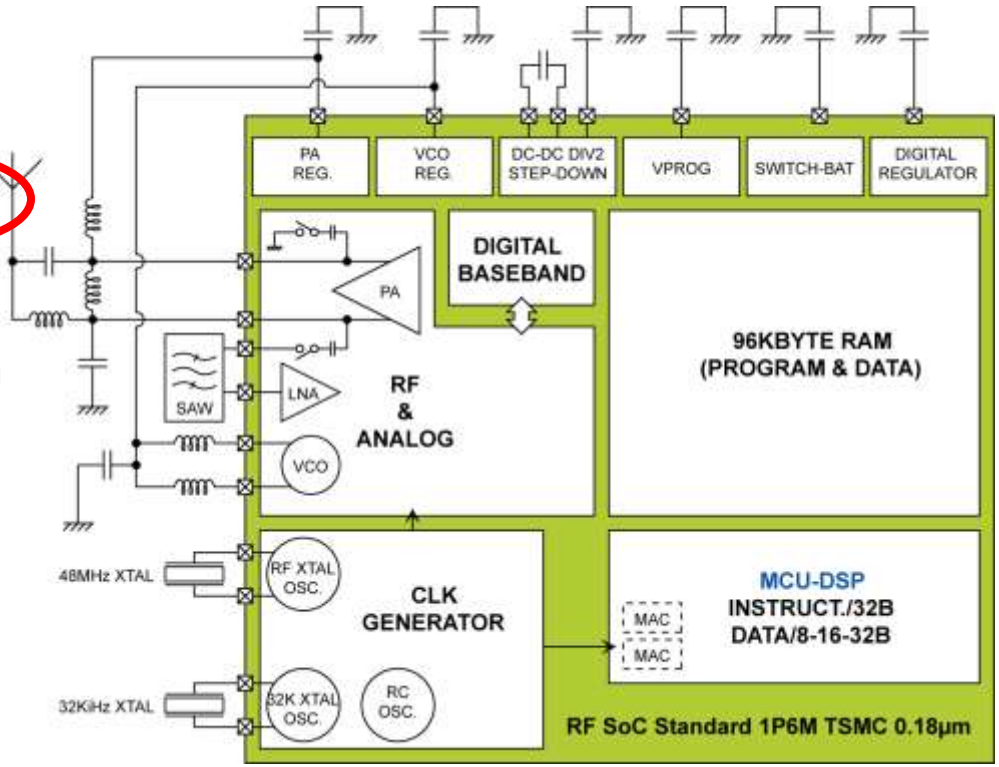






Saving energy: icy*com* overview

- With Lithium voltage: **2.0 ~ 3.6V**
- Sleep mode with 32 kiHz Xtal osc.: **< 4 µA**
- 865-928 MHz transceiver:
  - Continuous Rx: < **2 mA**
  - Rx channel sampling: **< 1 µC**
  - **-110 dBm** at 25 kbit/s in FSK
  - Tx current: **20 mA** @ **+10 dBm**
- 32-bit **icy*flex1*** processor :
  - **DSP** functionality
  - **2 MAC** in parallel
  - Dynamic current: **60 µA/MHz**
  - **96 kiByte** SRAM memory



Saving energy:CSEM SoC & WiseMAC

- forwarding 32 bytes every 30 seconds
- wake-up period of 250 ms

WiseMAC

S-MAC

IEEE 802.15.4 MAC

WiseNET SoC platform

Use WiseMAC!

~27µW

135µW

968µW

XE1203 platform

Use icy*com*!

304µW

2318µW

7659µW

Saving energy: icy*com* with WiseMAC

- With Lithium Thionyl Chloride AA (50.5 mm, diameter 14.5 mm, 3.50 USD)
  2.3 Ah,
  1% per year self discharge**,**
  2.7 ~ 3.6V
- Sleep mode with precise RTC : **4 µA**
- 865-928 MHz Rx channel sampling every 250 ms: **4 µA**
- 865-928 MHz Rx continuous for 100 kBytes/day : **1 µA**
- 865-928 MHz Tx 10 kBytes/day at 25 kbit/s: **1 µA**
- Sensors and associated processing: **5 µA**

➔ autonomy of 16.4 years

Energy harvesting/scavenging

Energy scavenging or harvesting: Definition and usage

- Definition
  - Parisitic energy (e.g. MIT « Parasitic Power Shoes Project »)
  - Similar to energy scavenging (« process of extracting electrical energy from ambient sources »)
  - vs. Microgeneration (micro-turbines or micro-engines)
- + and -

  + unlimited self-sustainability

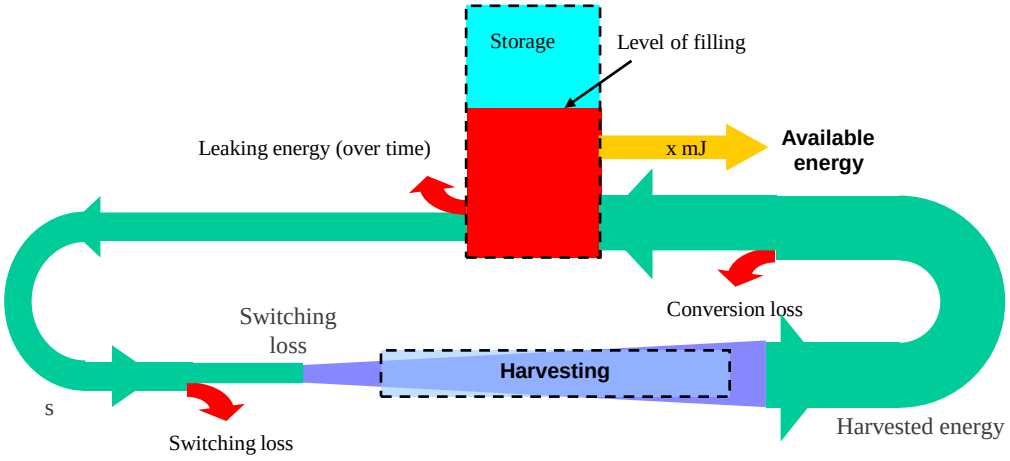
  + ubiquitous, already exisiting power sources

  - uncontrolled provisioning (need for temporary storage)

  - uncontrolled level (need for step-up, transformers, storage, etc.)

Energy usage cycle

- Energy follows a cycle
  - It is never created, just transformed
  - It is captured (harvested), transformed into electricity, stored (into chemical or mechanical devices), provided again as electricity, adapted to the desired level, transformed into Work and finally dissipated into heat



- Sometimes, some of the harvested energy is reused into the harvesting system to make it work

Goal

- “harvesting/scavenging” technologies that can provide an average of 100 mW/cm3 indefinitely (S. Roundy, 2003)
  - Sustainable
  - Environment-friendly
  - Reliable
- Other concerns, other scales:
  - CSEM: a common definition for threshold is 50-100 µW/device
    - More for sensors (200 µW…)
  - Add to this the consumption of additional components: sensors, etc.
    - And leakage

Sources

- Radio waves
  - Electric or magnetic fields, radioactivity
  - Transducer: antennas,
- Kinetic (vibration)
  - (Micro)waves, machinery, traffic vibrations, earthquakes
  - Transducer: induction, electrostatic, piezo, etc.
- Thermal
  - Soil, heat pipes, radiators, etc.
  - Transducer: Seebeck effect for generation
- Acoustic
- Wind, Water
  - Turbine
- Natural static electricity
  - Dress, shoes, storm, car, airplane, etc.

Solar energy potential

- Solar-based energy generators:
  - Photovoltaic (PV), photothermal and photoelectrochemical solar energy conversion
  - Subject encompasses physics, chemistry, optics, materials...
- Solar Cells
  - Structure: single crystal, polycrystalline and amorphous materials
  - junctions: homo-junctions and hetero-junctions, Schottky barriers, liquid junctions…
  - combination in systems: individual cells and complete systems

Solar cell parameters

- **Solar power**: from 1000 to 200 W/m^2 (~600 average)
- **Efficiency**
  - Amorphous: 5-7 %
  - Polycristalline: 10-15 % (observed: 12 %)
  - Monocristalline: 15 %
  - Flexible: 5-8 % (observed: 7 %)
  - Multi-junction: 28-29 % (optimal T°), realistic: 16 %
- Required **surface** estimation for 1 W output ($S = P_{output}/(P_{received}.Efficiency)$)
  - Amorphous: 16.10^{-3} m^2
  - Polycristalline: 8.10^{-3} m^2
  - Monocristalline: 6.10^{-3} m^2
  - Flexible: 14.10^{-3} m^2
  - Multi-junction : 6.10^{-3} m^2

WiseFIELD

- Target
  - Environmental monitoring, in particular for agriculture
  - Autonomous, self-recharging ultra-low power wireless system
  - At least several years of maintenance-free operation
- Components
  - CSEM's icycom System-on-Chip
  - CSEM-designed solar cell recharging module
  - CSEM's WiseStack protocols
  - Commercial sensors

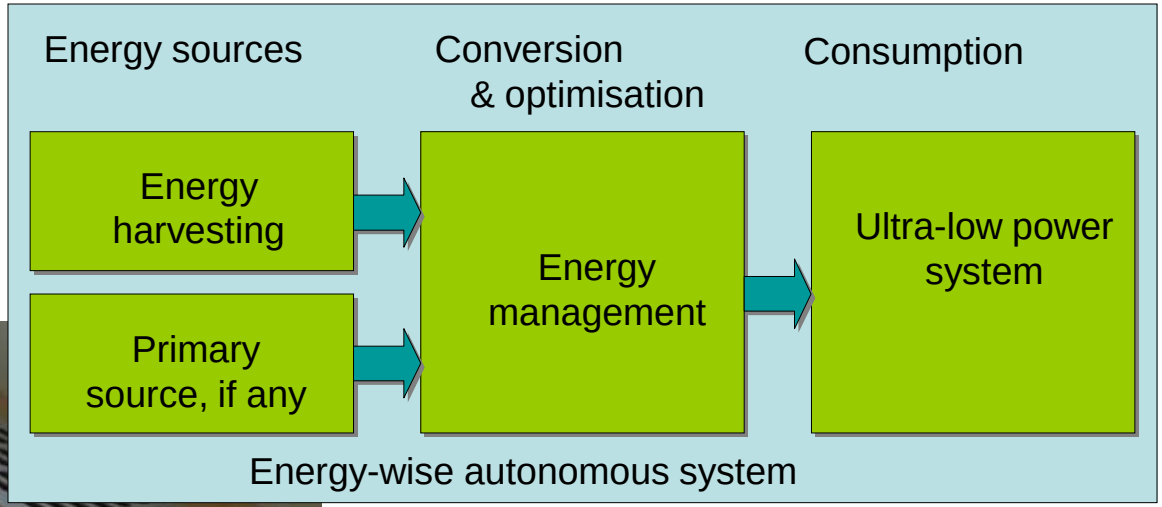
Parameters to be measured

- Sensors (wireless network)
  - Soil humidity
  - Air temperature & humidity
  - Leaf-wetness sensors
  - Sun (through solar cell)
- Weather station
  - Temperature
  - Atmospheric pressure (single point of measurement)
  - Rain (single point of measurement)

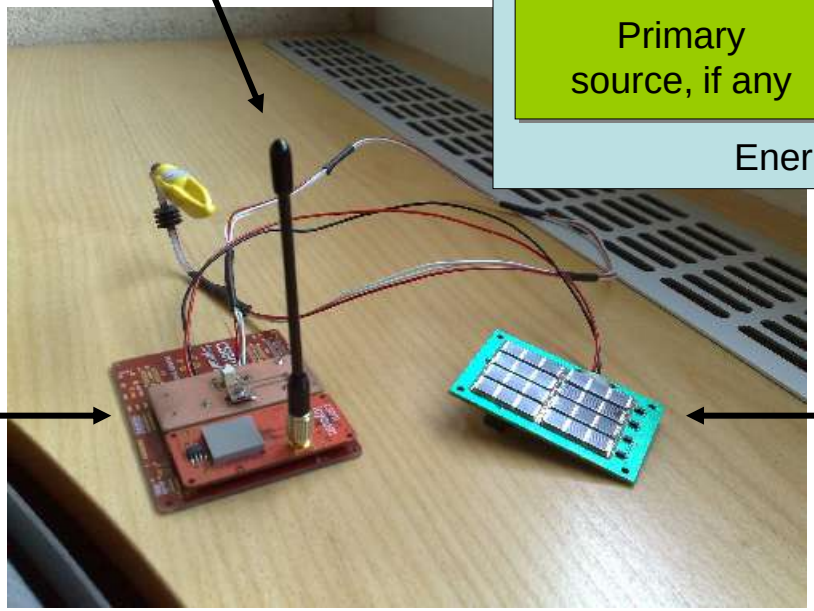
Ecowise wireless communication modules

- Ultra-low power
  - Combination of ultra-low power components
    - Icycom, 4^{ith} generation of CSEM chips
    - WiseMAC on e of the most power efficient WSN protocol
  - Autonomy
    - Up to 10 years with a Lithium battery
    - No limit with energy scavenging devices (now solar, tomorrow others)

Ecowise : the complete system



Antenna



CSEM

Icycom

+

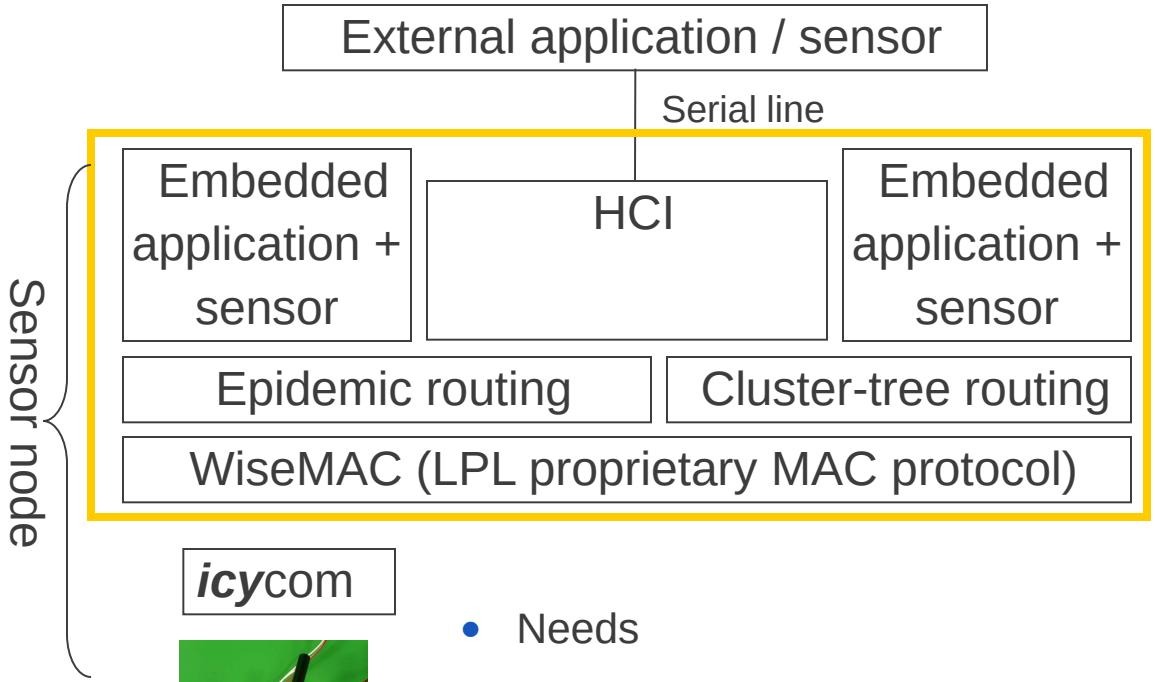
WiseMAC

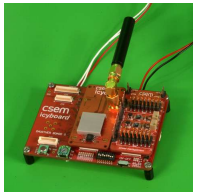
Solar cell

+ energy management

+ energy storage

Energy budget

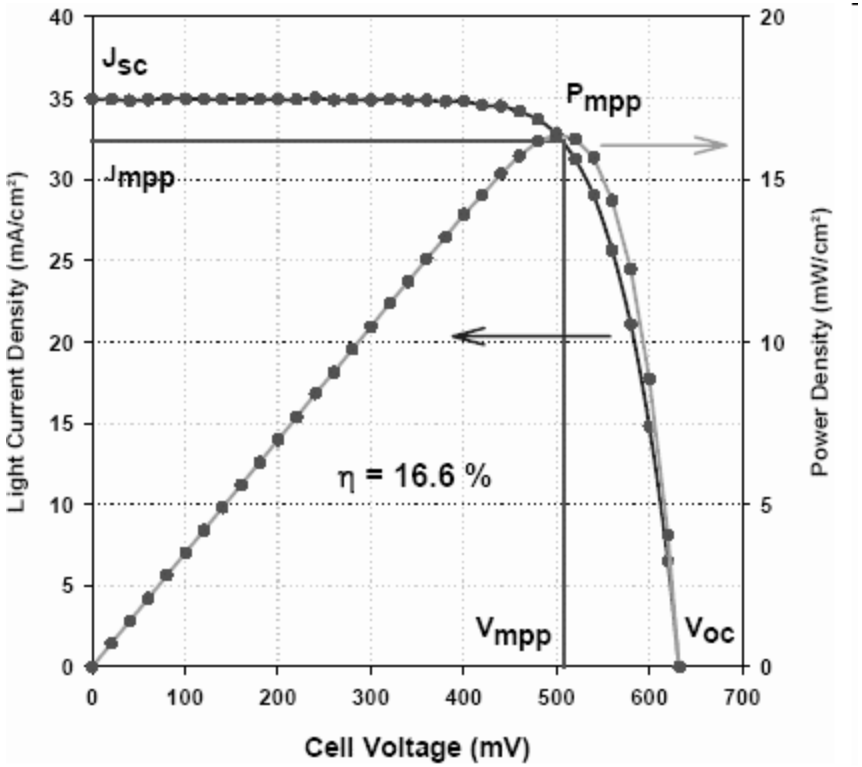




- Needs
  - Duty cycling
    - Operating and sensing periodically for short durations
  - Average power: < 0,2 mW (over-provisioning)
  - we need 20mW peak output from the battery

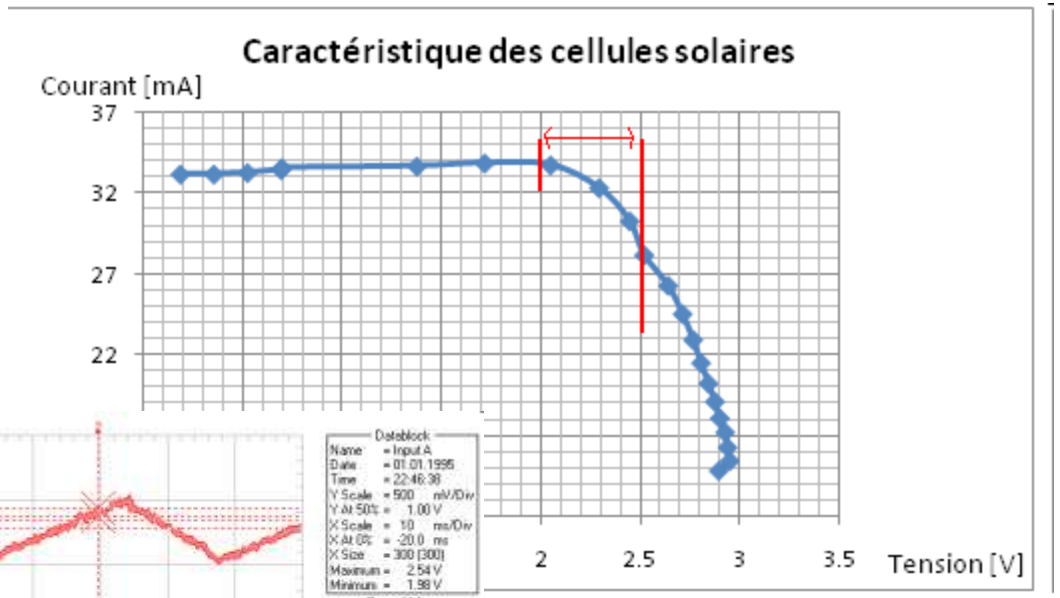
Choice of the solar cell

- IXOLAR monocrystalline Solar Bit
  - P_{max} = 16.6 mW/m^2
- Optimal point
  - 1,5 V
  - 12 mA
- Step-up converter
  - 4,2 V
- Comparator
  - Switches off the cell output when Voltage too low

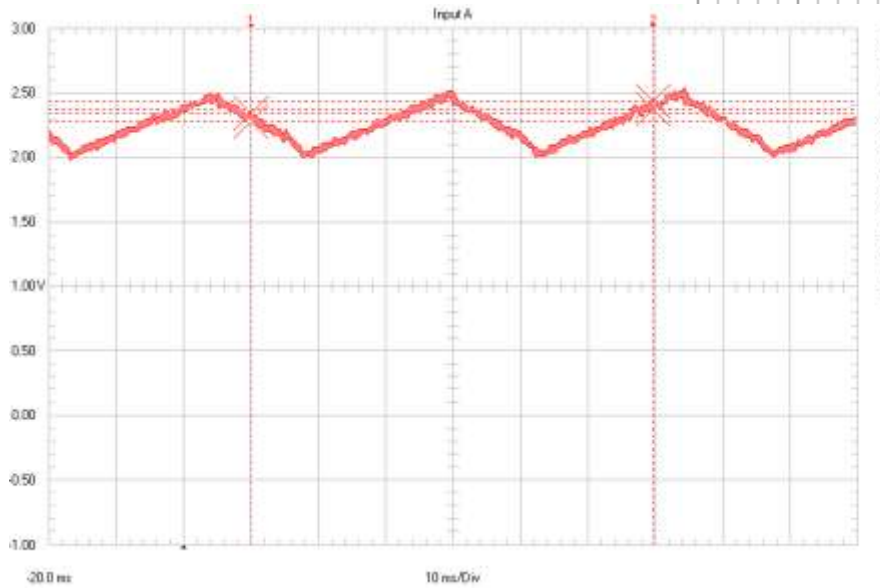


Choice of the solar cell

- Domain of operation



- Output under 100 ohms load and 100 W light



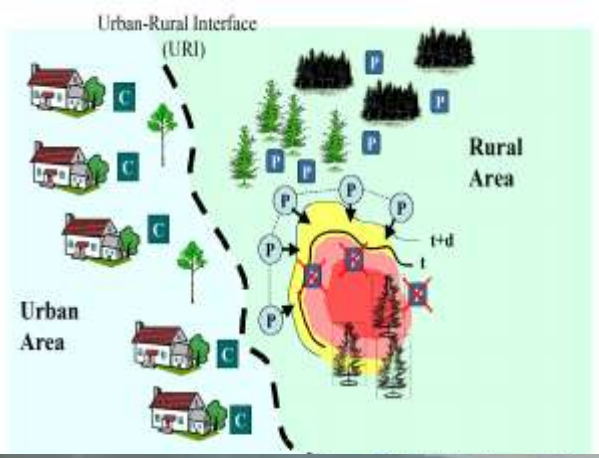
- Considering an efficiency of 10%
  - Cell: 10 cm^2
- P.S.: Clean the panel…

Choice of the battery

- Battery
  - Li-Po or Li-Ion
  - Input current to be supported by the battery: up to 40 mA
    - Powercell PD3032
    - 180 mAh
- + Regulator
- + Connector

Other examples of outdoors WSN Deployments by CSEM

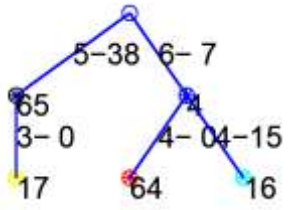
Fire and Flood detection at Wild Urban Interface

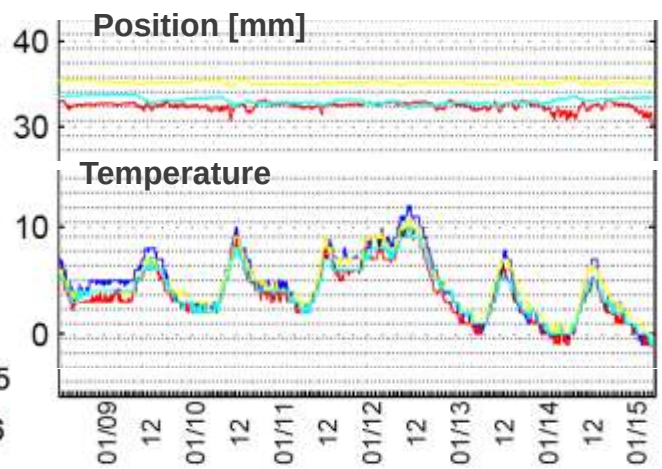


- Detection & prediction of fire, flood & their evolution
- network of temperature, rain, wind, humidity sensors
- Multiple sinks in urban premisses

Rock movements monitoring

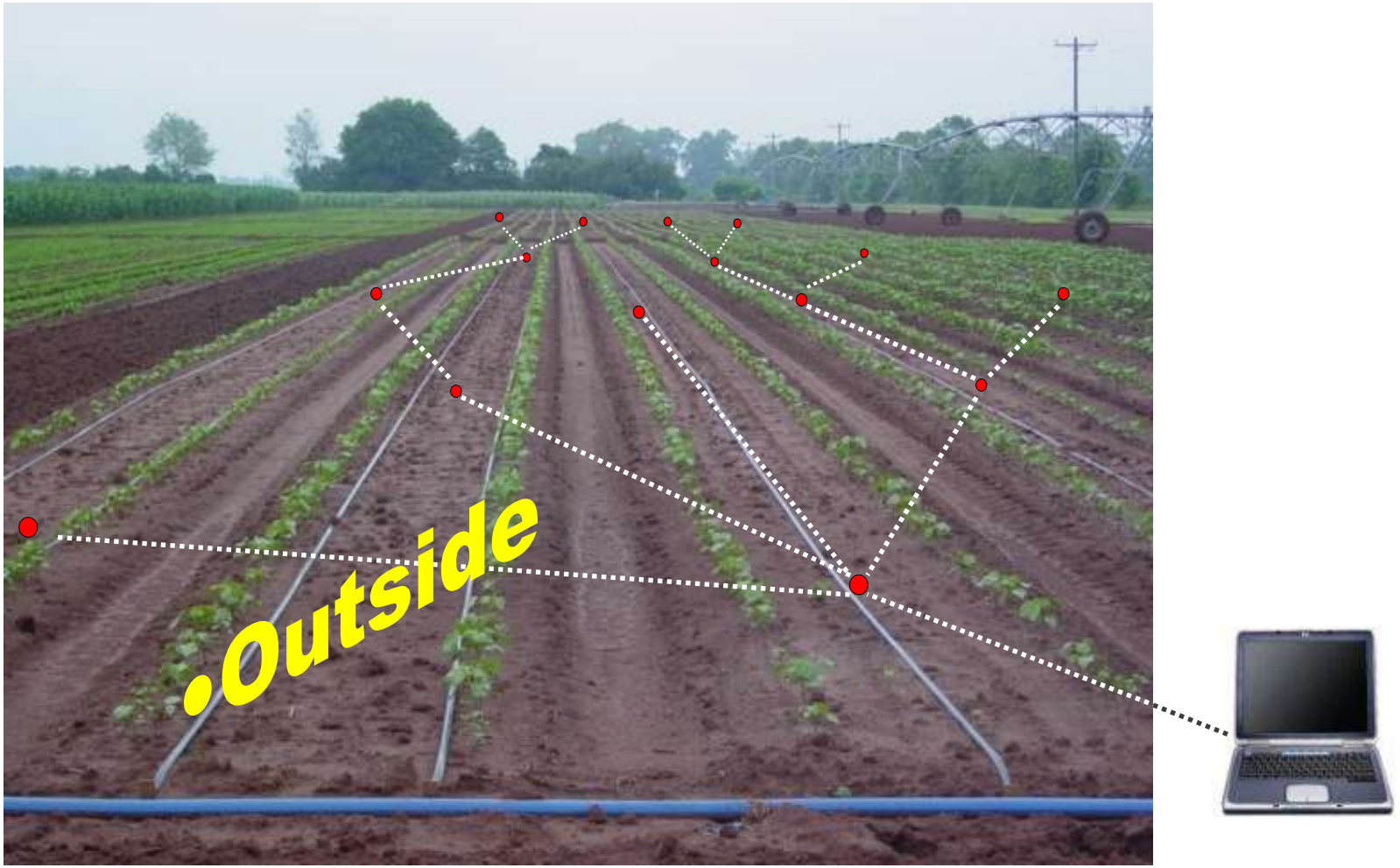
- Pilote test network: Chandoline, Vallis, Switzerland, in cooperation with Crealp (Research center on alpine environment) and MADD Technologies Sarl. In operation since decembre 15th 2006.





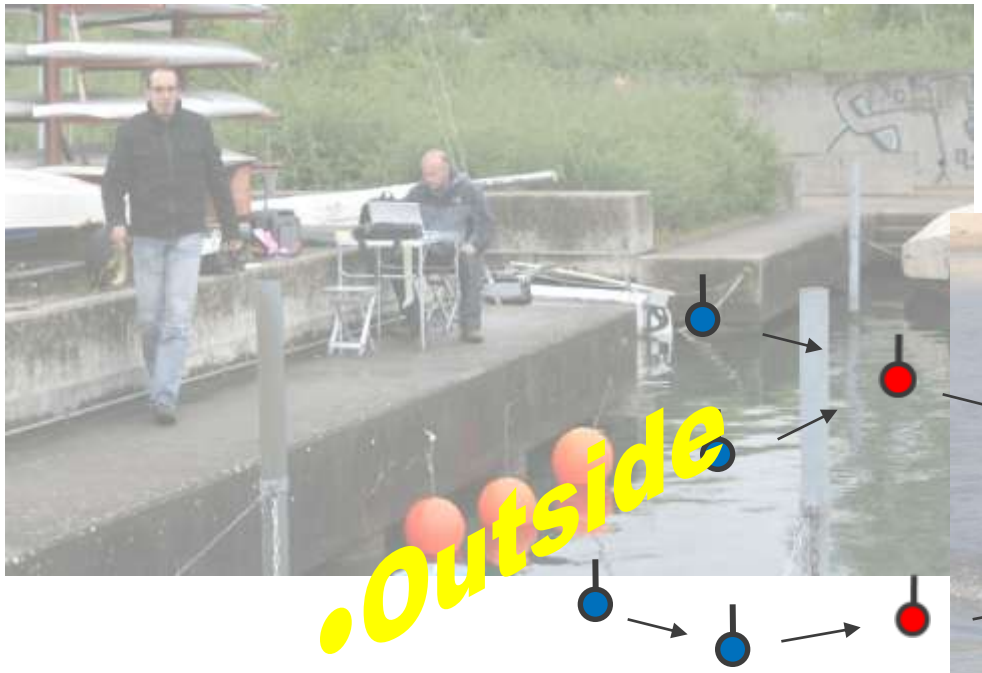
Sustainable Agriculture

WiseField: Optimal irrigation through soil moisture measurement



Water quality monitoring

- WSN with mobile nodes, opportunistic data collection, uses localisation
- Interface to sophisticated sensors, energy scavenging

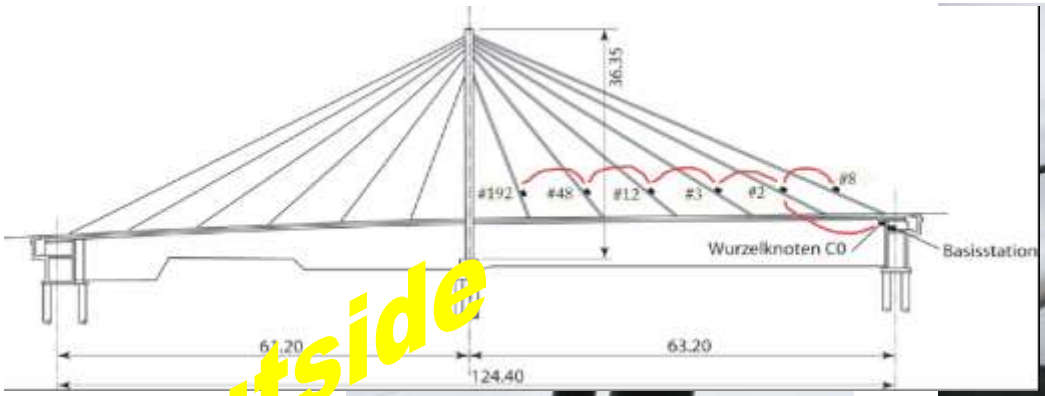


River water level measurement

- Remote water level sensor without access to telecom network
- Around 500m hop length

Bridge health monitoring

- In collaboration with EMPA
- 6 nodes in line (25 ultimately), DSP co-processor for measuring vibrations

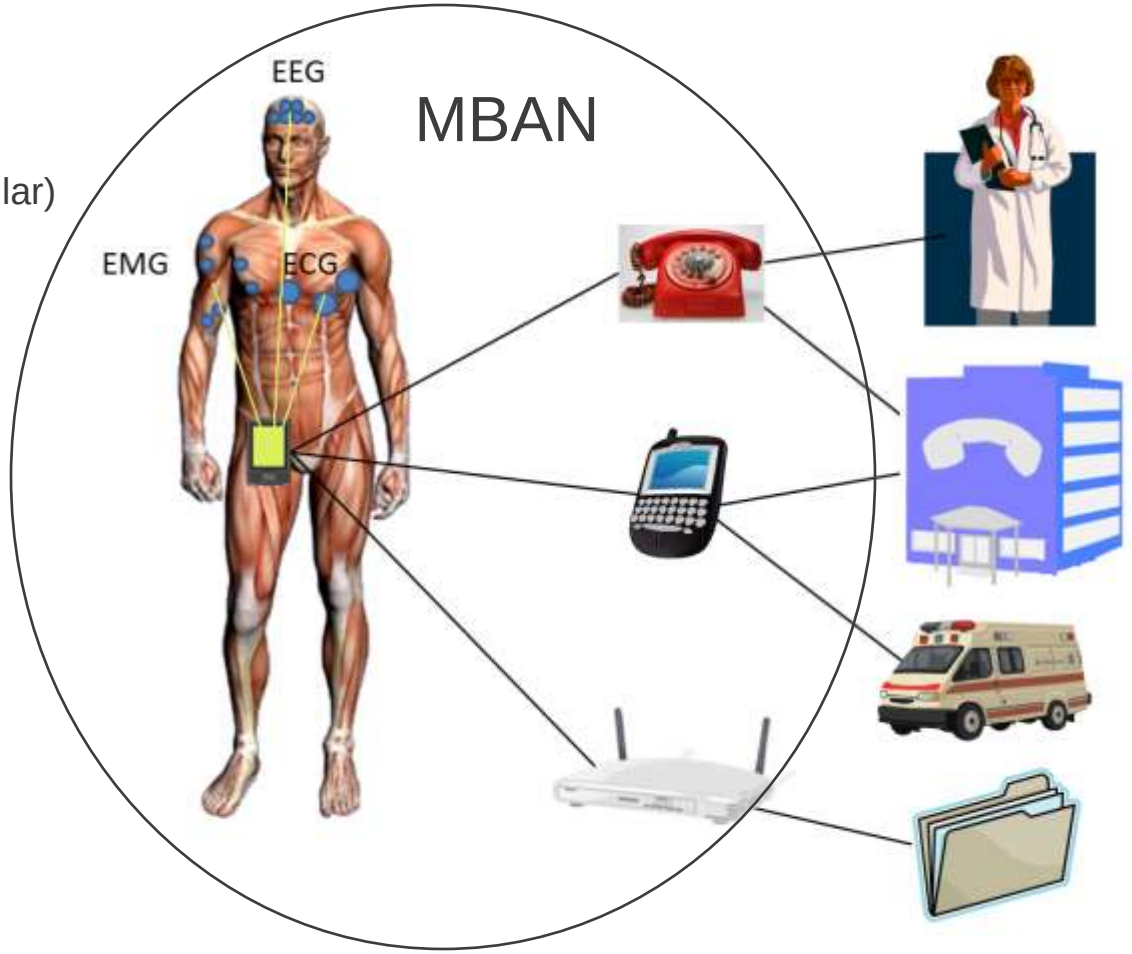


.Outside

Wearable health and medical BAN applications

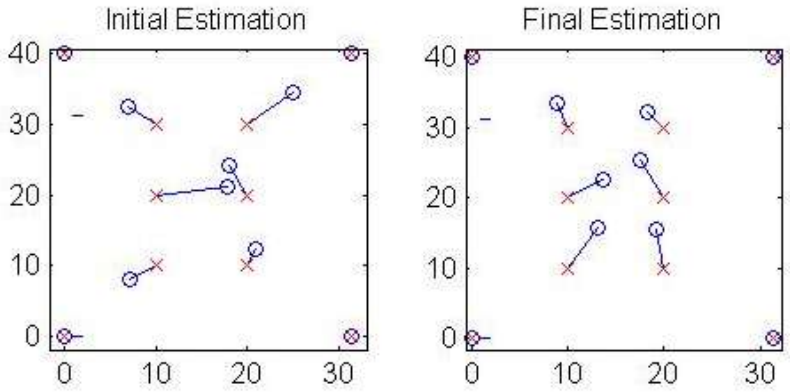
- Bio-Medical
  - EEG Electroencephalography
  - ECG Electrocardiogram
  - EMG Electromyography (muscular)
  - Blood pressure
  - Blood SpO2
  - Blood pH
  - Glucose sensor
  - Respiration
  - Temperature
  - Fall detection
- Sports performance
  - Distance
  - Speed
  - Posture (Body Position)
  - Sports training aid

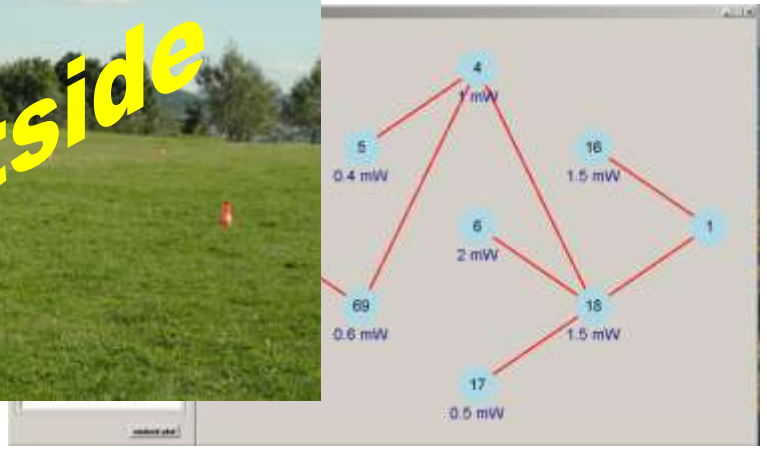
Outside



In/Out-door localisation

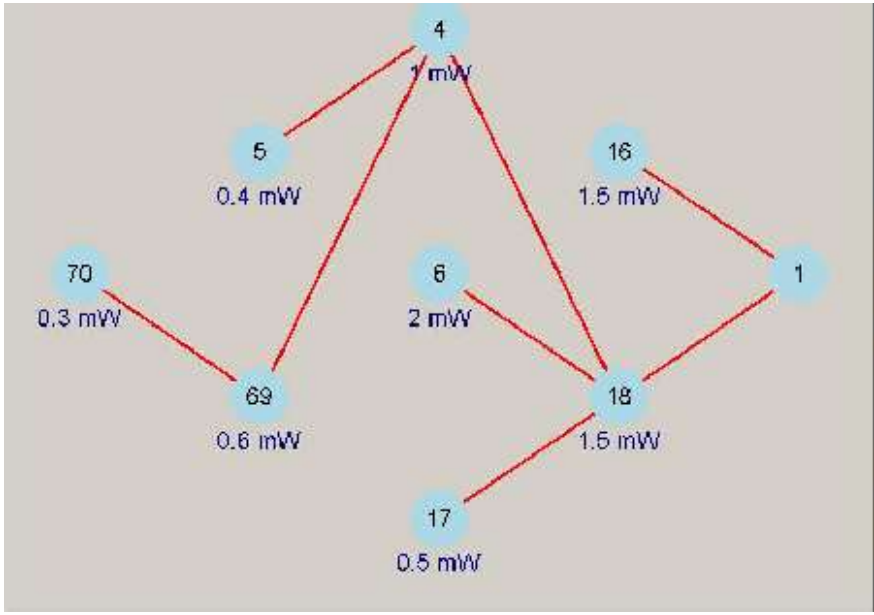
- With WLANs (802.11 / Bluetooth)
- With Wireless sensor networks
  - Absence of infrastucture
    - ✓ Information carried hop by hop
  - Battery operated (over years)
  - Based on RSSI
  - Highly scalable
  - Centralized or decentralized operations
  - No training



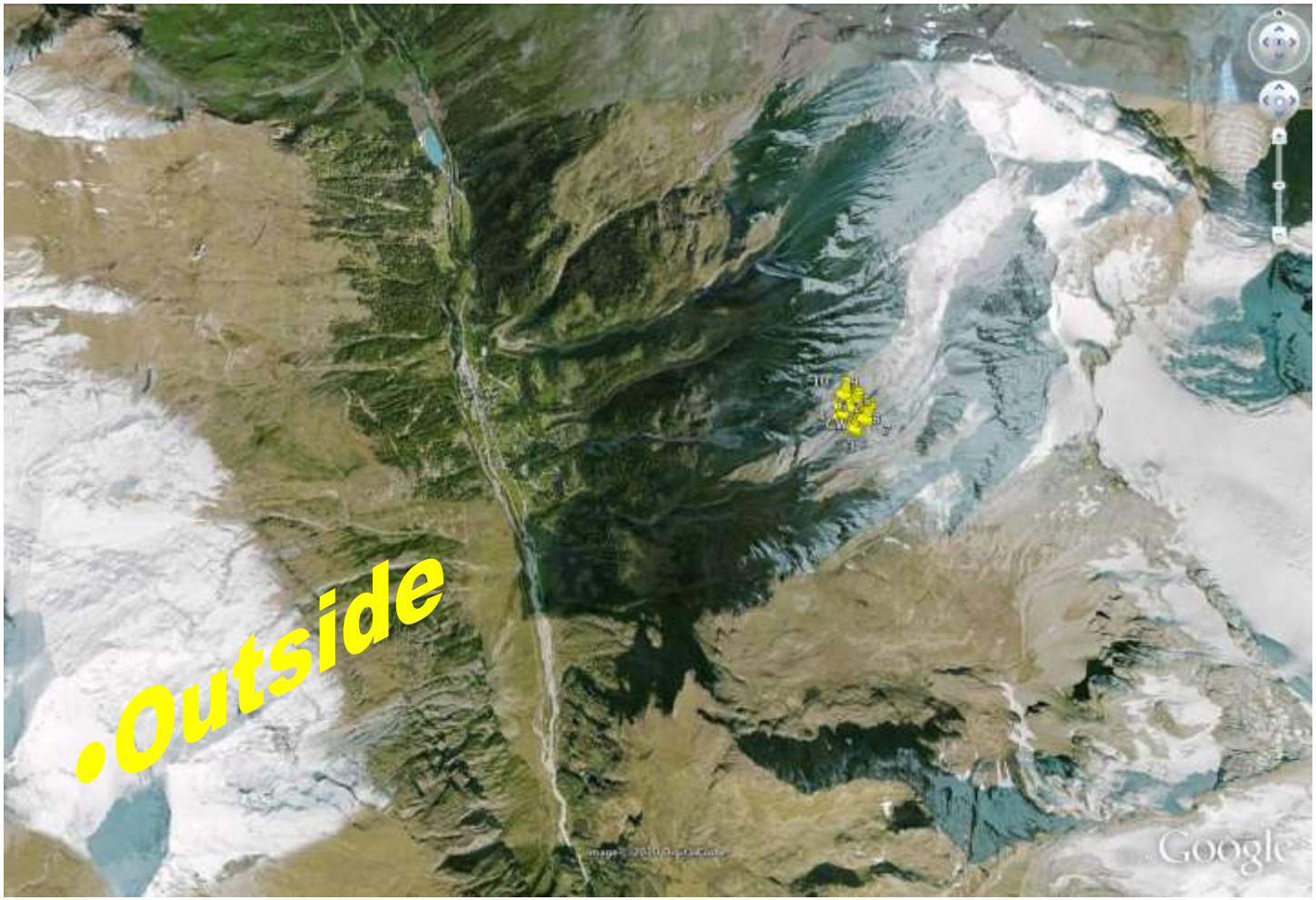


People, animal and object localisation

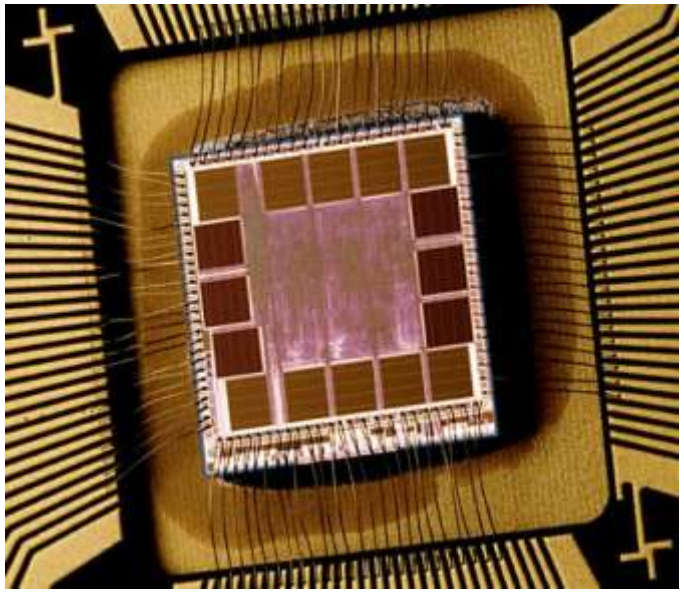
- Based on RSSI and a few anchor point
- Measurement and communication infrastructure are identical
- Accuracy around 30% of distance to anchor points



Glacier deployment in Valais (Bonnard)



Thank you for your attention!



The **icy*flex*** 32-bit processor