The PermaSense Project

Low-power Sensor Networks for Extreme Environments

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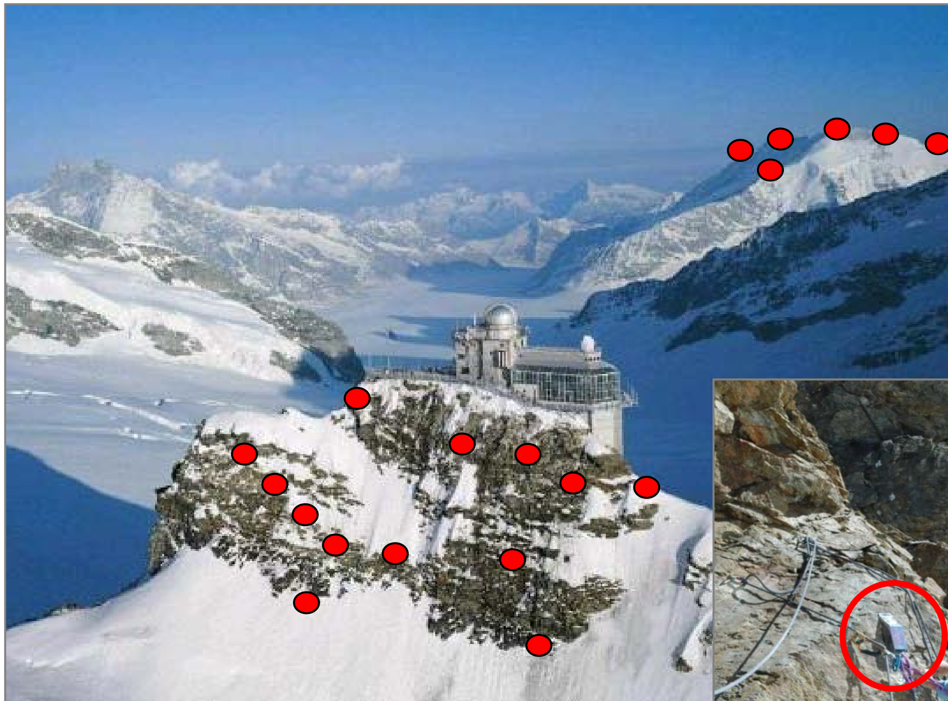
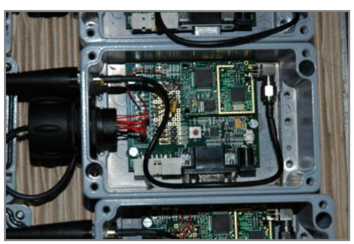
National Competence Center in Research –
Mobile Information and Communication Systems

PermaSense – Alpine Permafrost Monitoring



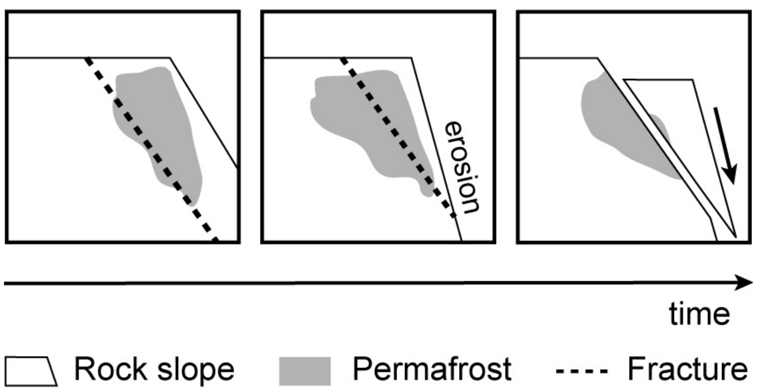
- Cooperation with Uni Basel and Uni Zurich

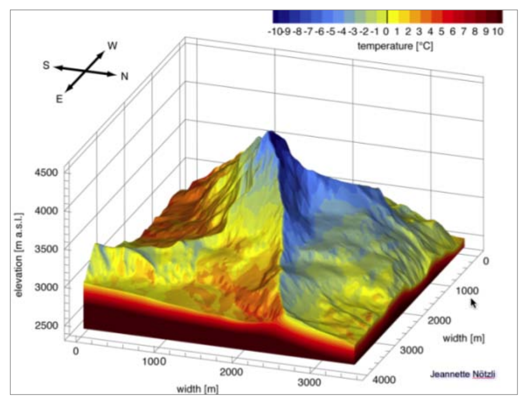


PermaSense – Aims and Vision

Geo-science and engineering collaboration aiming to:

- provide **long-term high-quality** sensing in **harsh environments**
- facilitate near-complete **data recovery** and **near real-time delivery**
- obtain **better quality** data, more effectively
- obtain measurements that have **previously been impossible**
- provide **relevant information** for research or decision making, **natural hazard early-warning systems**



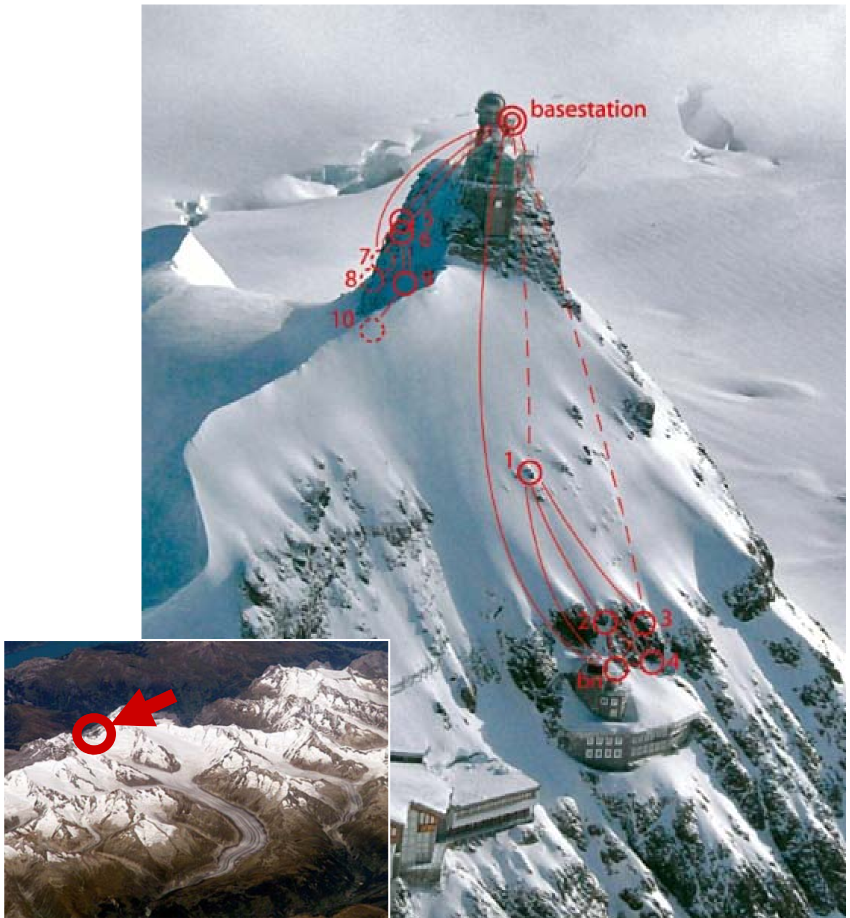


To Better Understand Catastrophic Events...

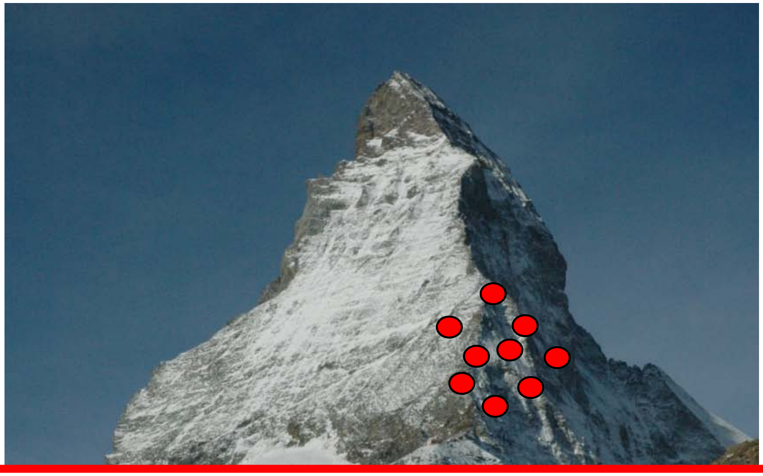
Eiger east-face rockfall, July 2006, images courtesy of Arte Television

PermaSense Deployment Sites 3500 m a.s.l.

A **scientific instrument** for **precision sensing** and data recovery in environmental extremes



PermaSense – Key Architectural Requirements



- Support for ~25 nodes
- Different sensors
  - Temperatures, conductivity, crack motion, ice stress, water pressure
  - 1-60 min sensor duty-cycle
- Environmental extremes
  - −40 to +65° C, $\Delta T \leqq 5°$ C/min
  - Rockfall, snow, ice, rime, avalanches, lightning
- Near real-time data delivery
- Long-term reliability
  - ≧99% data yield
  - 3 years unattended lifetime

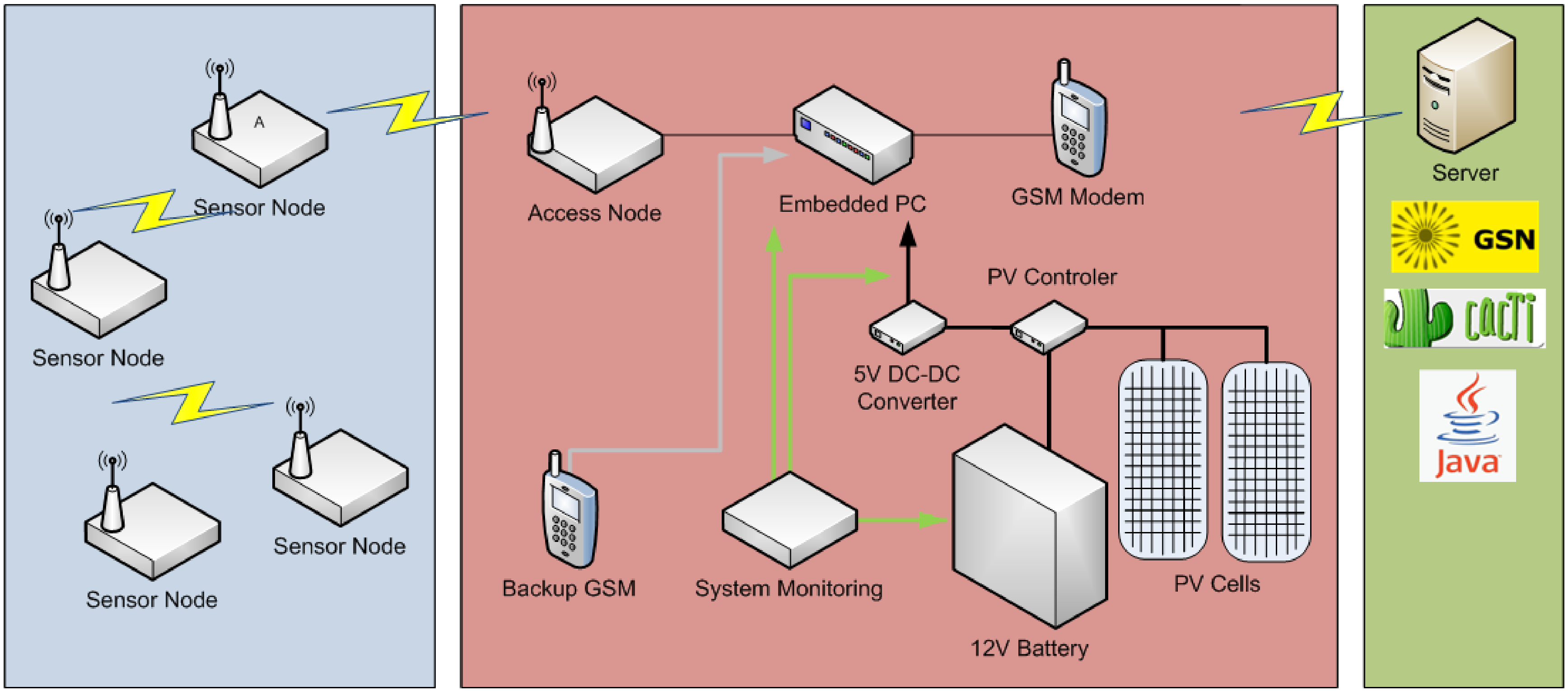
Relation to other WSN projects

- Comparable to other environmental monitoring projects
  - GDI [Szewczyk], Glacsweb [Martinez], Volcanoes [Welsh], SensorScope [Vetterli], Redwoods [Culler]
- Lower data rate
- Harsher, higher yield & lifetime
- Data quality/integrity

Reliable Sensor Networks Architecture

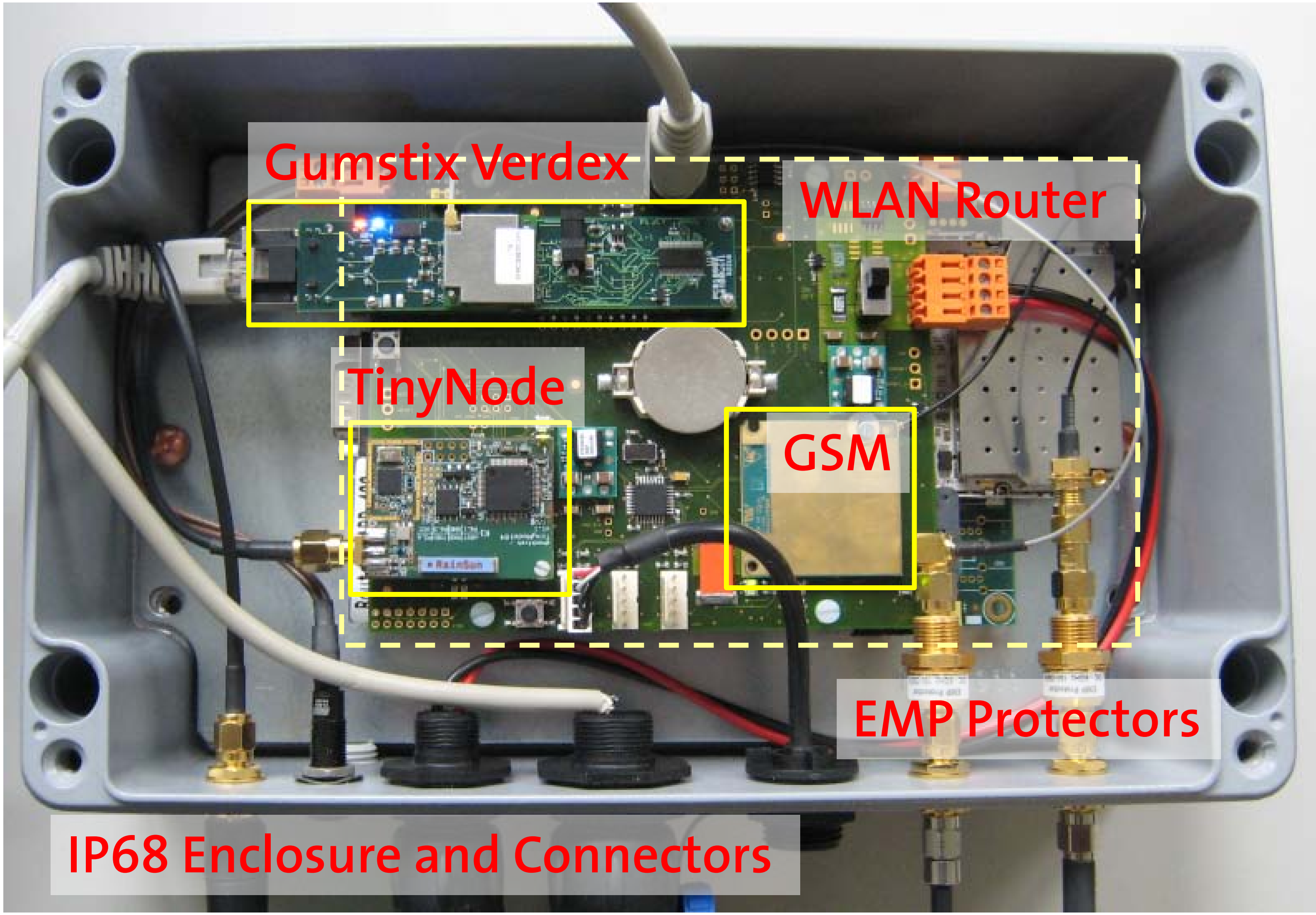
PermaSense Technology

PermaSense – System Architecture



Sensor network **Base station** **Backend**

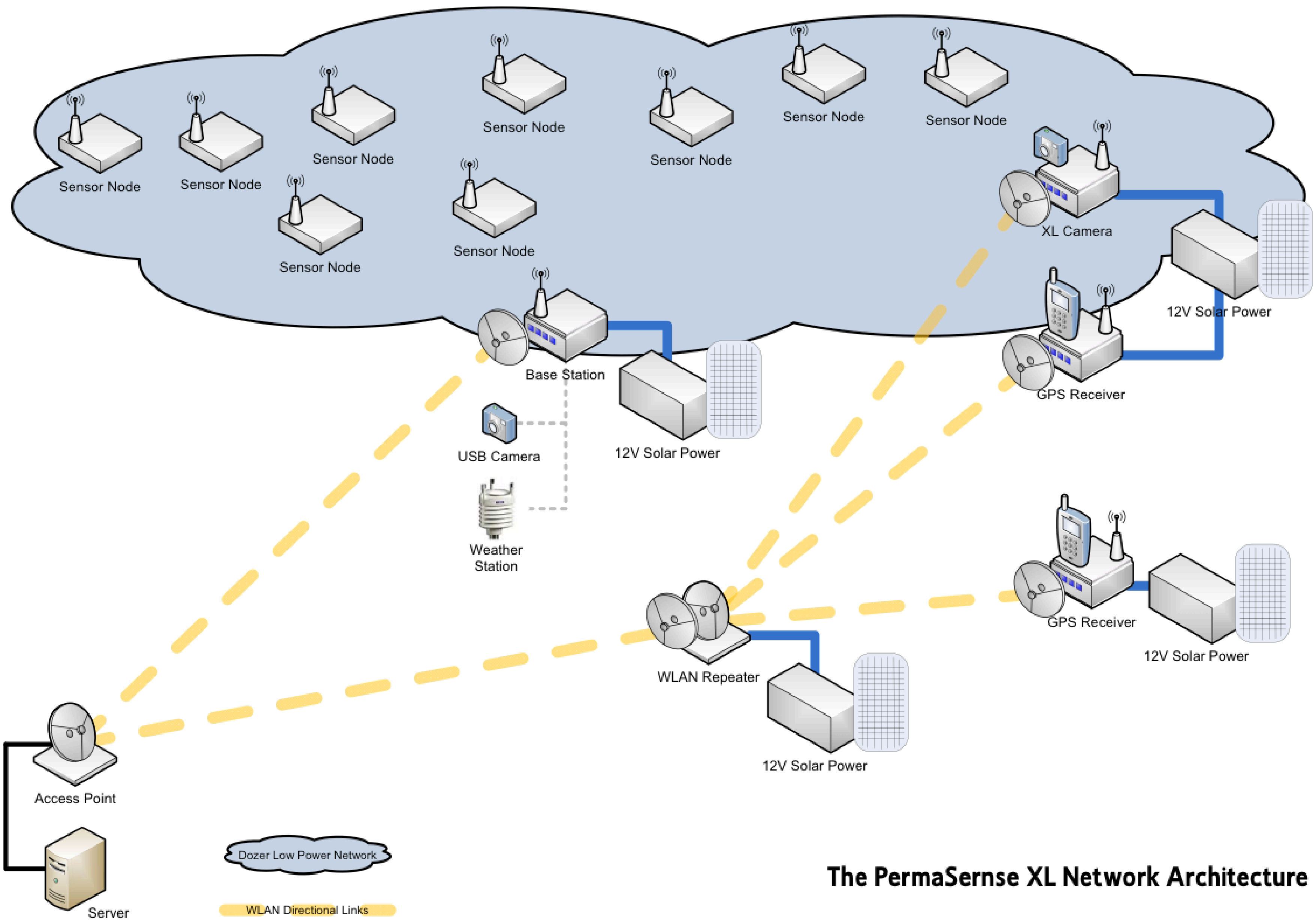
Base Station with Stacked Mikrotik WLAN Router



PermaSense – Base Station Overview

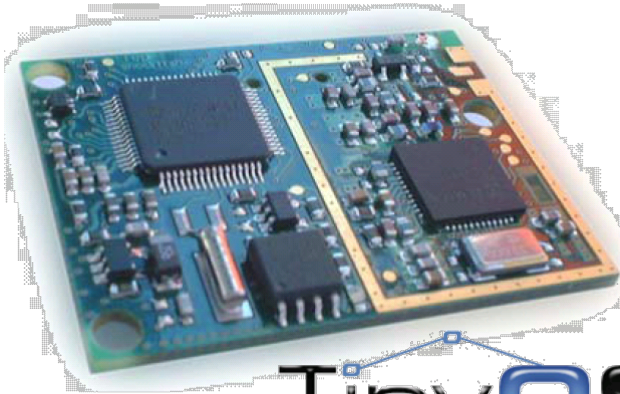
- Powerful embedded Linux (Gumstix)
- 4 GB storage, all data duplicated
- Solar power (2x 90W, 100 Ah, ~3 weeks)
- WLAN/GPRS connectivity, backup modem

The Big Picture – Network System Integration

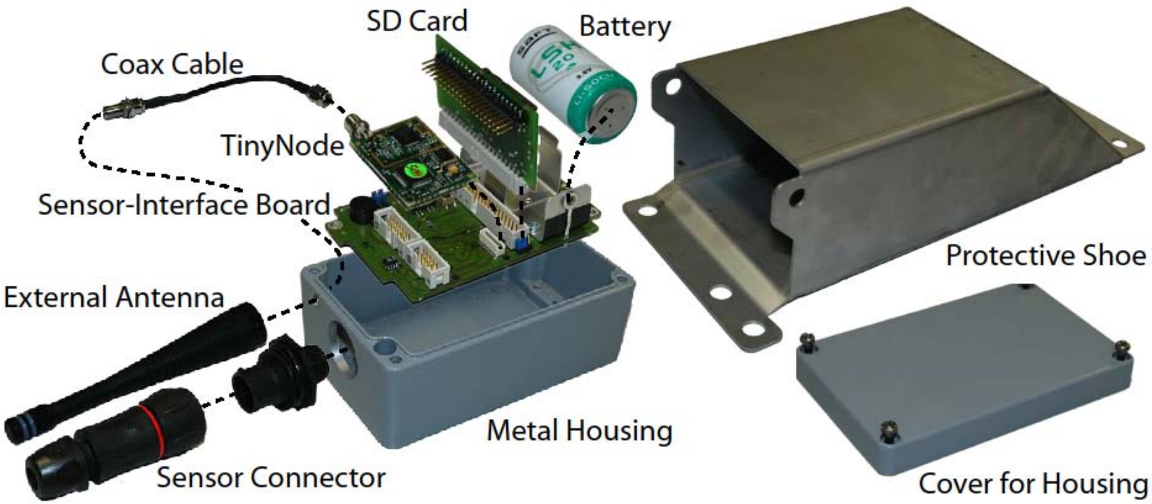


The PermaSernse XL Network Architecture

PermaSense – Sensor Node Hardware

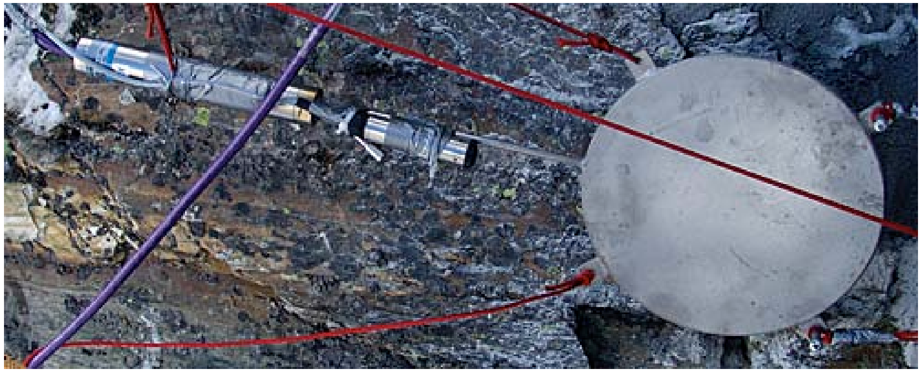


- Shockfish TinyNode584
  - MSP430, 16-bit, 8MHz, 10k SRAM, 48k Flash
  - LP radio: XE1205 @ 868 MHz
- Waterproof housing and connectors
- Protective shoe, easy install
- Sensor interface board
  - Interfaces, power control
  - Stabilized measurements
  - 1 GB memory
- 3-year life-time
  - Single battery, 13 Ah
  - ~300 µA power budget



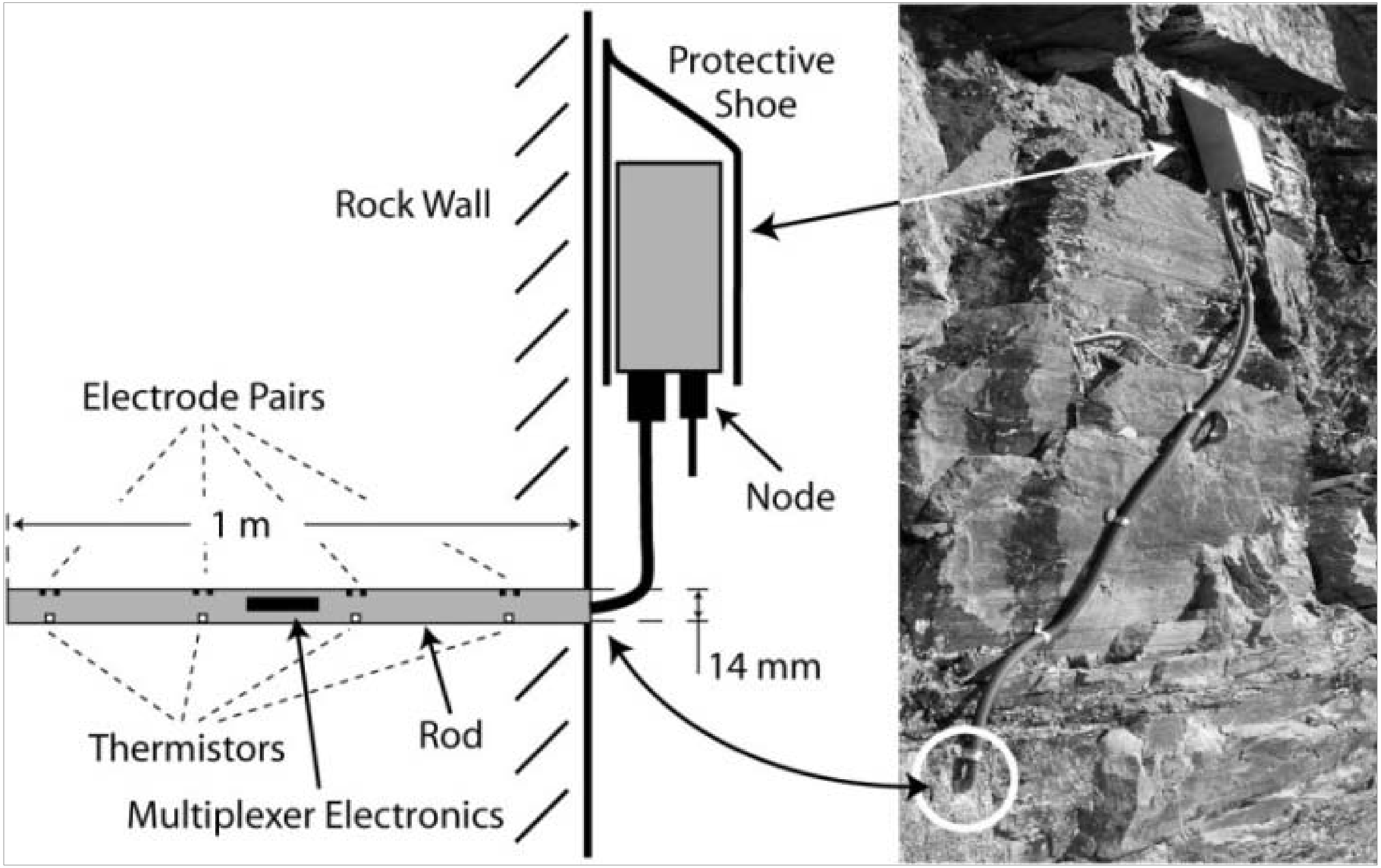
PermaSense Sensors

- Sensor rods (profiles of temperature and electric conductivity)
- Thermistor chains
- Crack meters
- Water pressure
- Ice stress
- Self potential



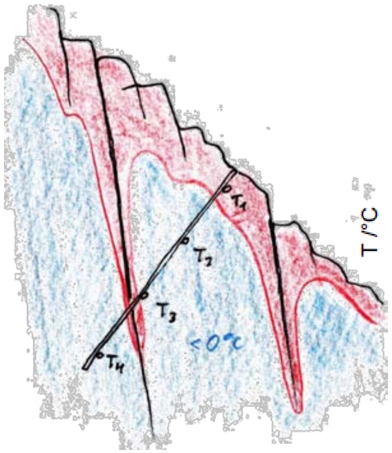
- Data: Simple sensors, constant rate sampling, few integer values

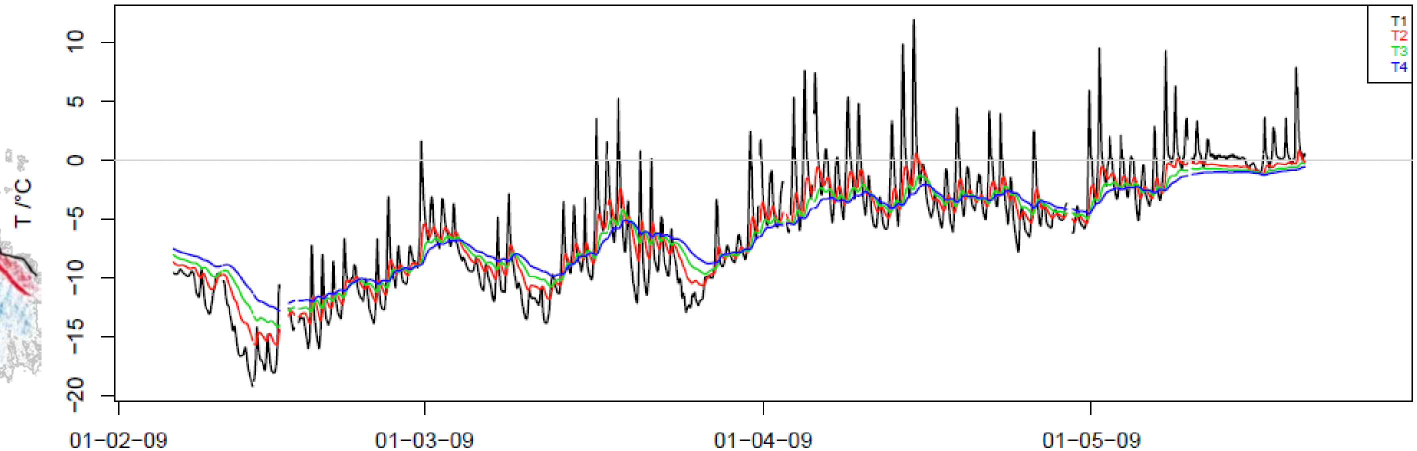
PermaSense Sensors – Sensor Rod Example



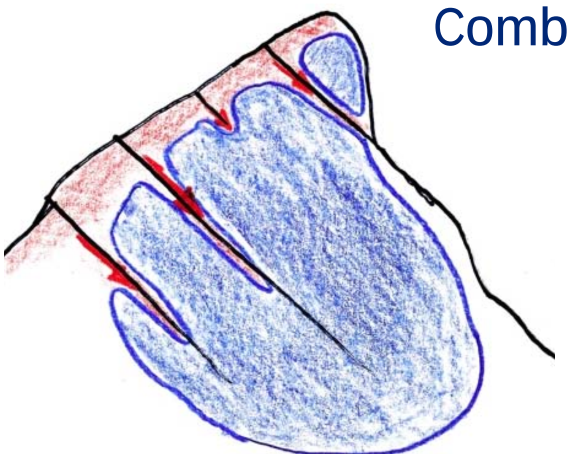
Geoscience: Fast localized thaw by advection

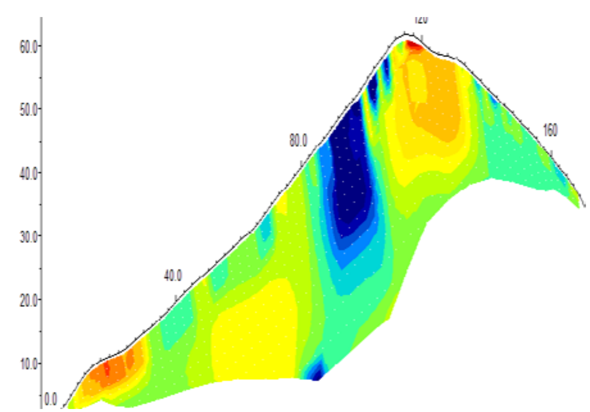
Near-surface temperature/conductivity





Combination with lab experiments and models

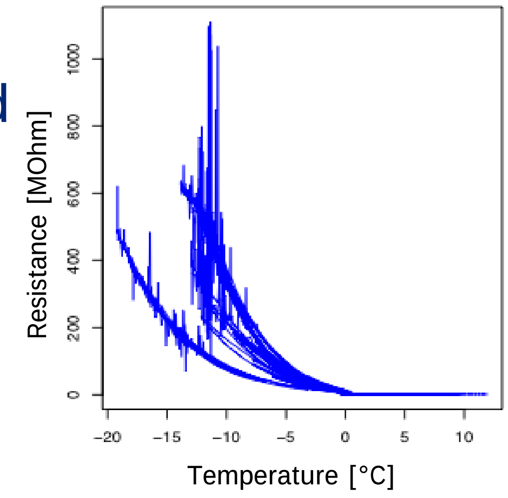




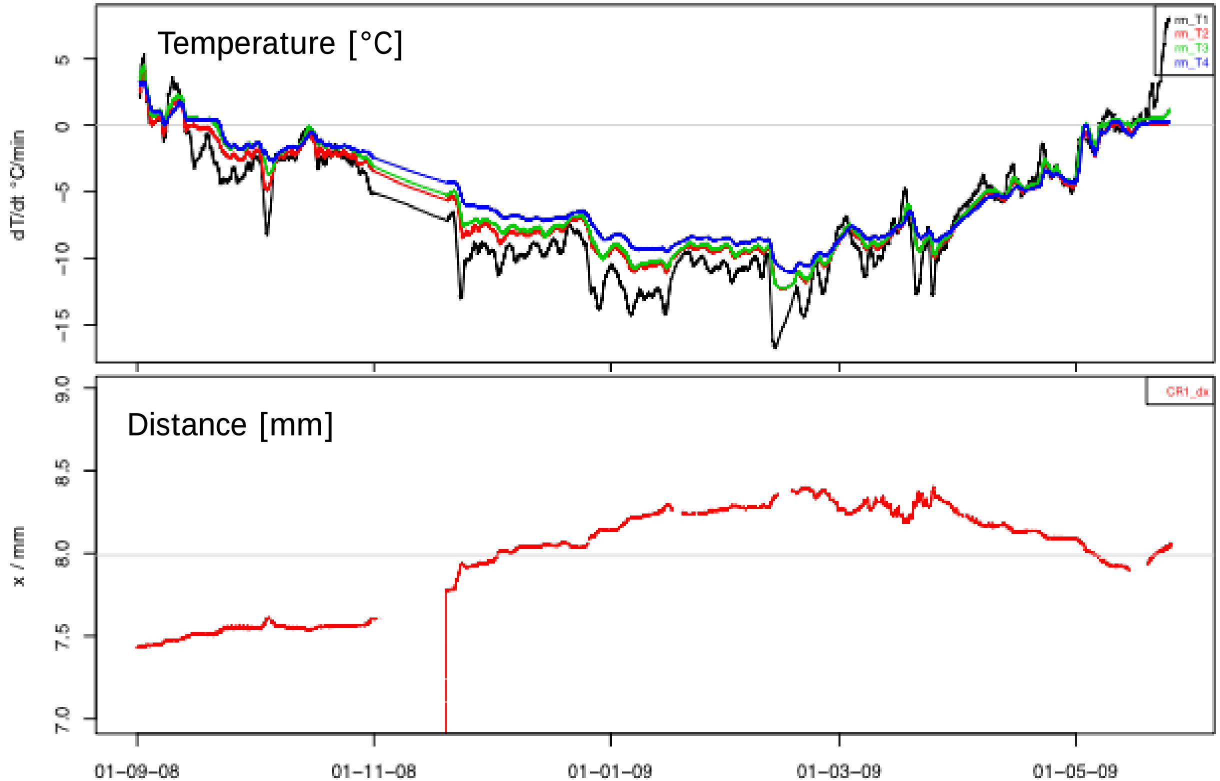
PermaSense Sensors – Crack Meter Example

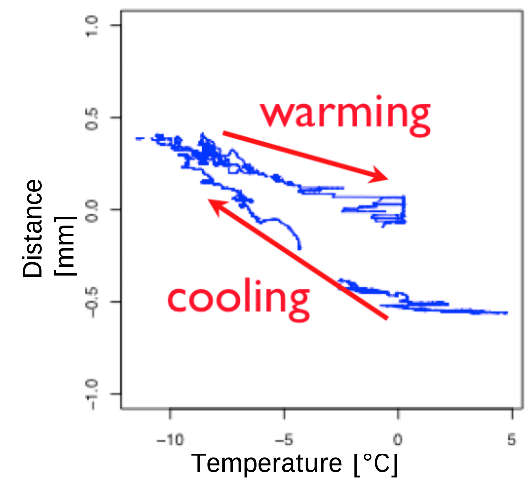
Geoscience: Cryogenic rock movement / weathering

Moisture saturation and freezing dynamics captured by sensor rod



Dilatation data with cleared thermal signal





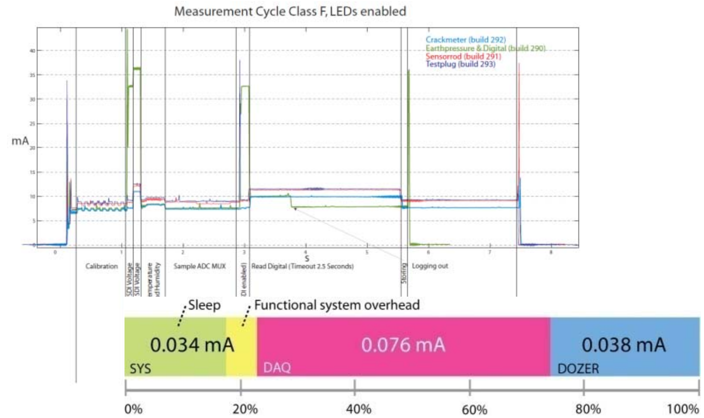
[NICOP2008]

Installation work on Matterhorn 09/2007

PermaSense installation 2007, images courtesy of Arte Television

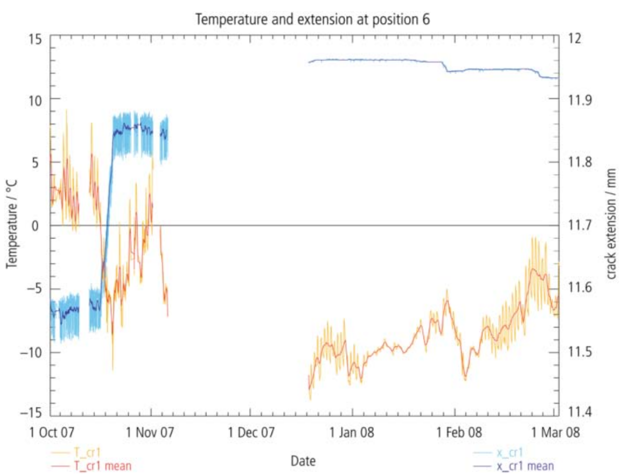
Key PermaSense Challenges

System Integration



Correct Test and Validation

Actual Data



Interdisciplinary Team

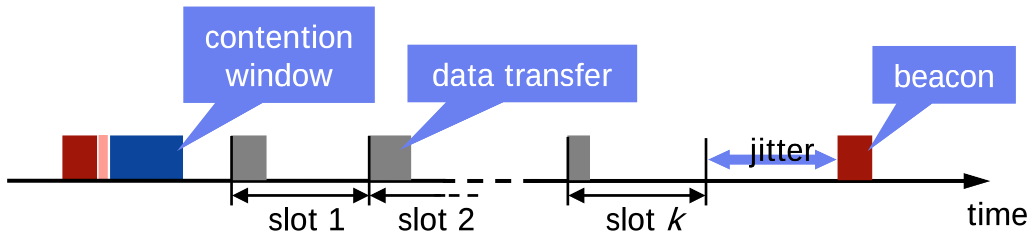
Counting Beans with Energy

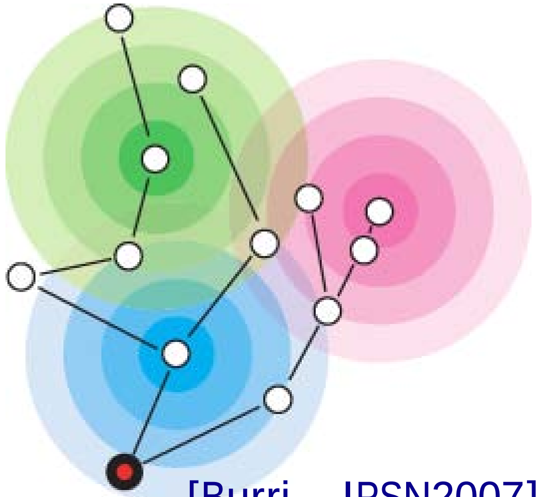
Reliable Low-power Wireless


It’s a thin line to success…

Dozer Low-Power System Integration

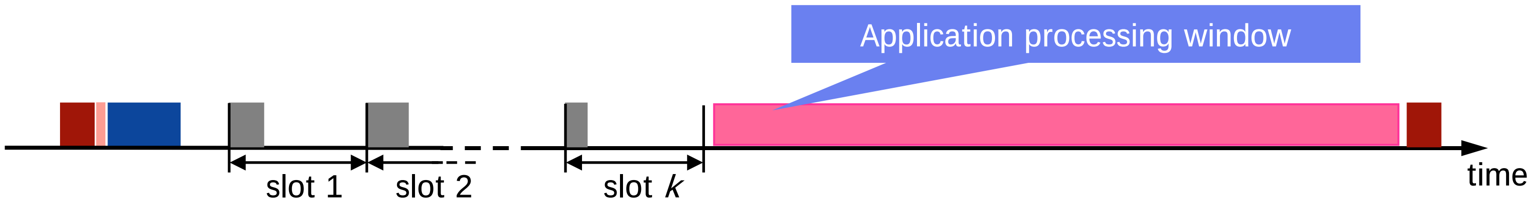
- Dozer ultra low-power data gathering system
  - Beacon based, 1-hop synchronized TDMA
  - Optimized for ultra-low duty cycles
  - **0.167%** duty-cycle, **0.032mA**



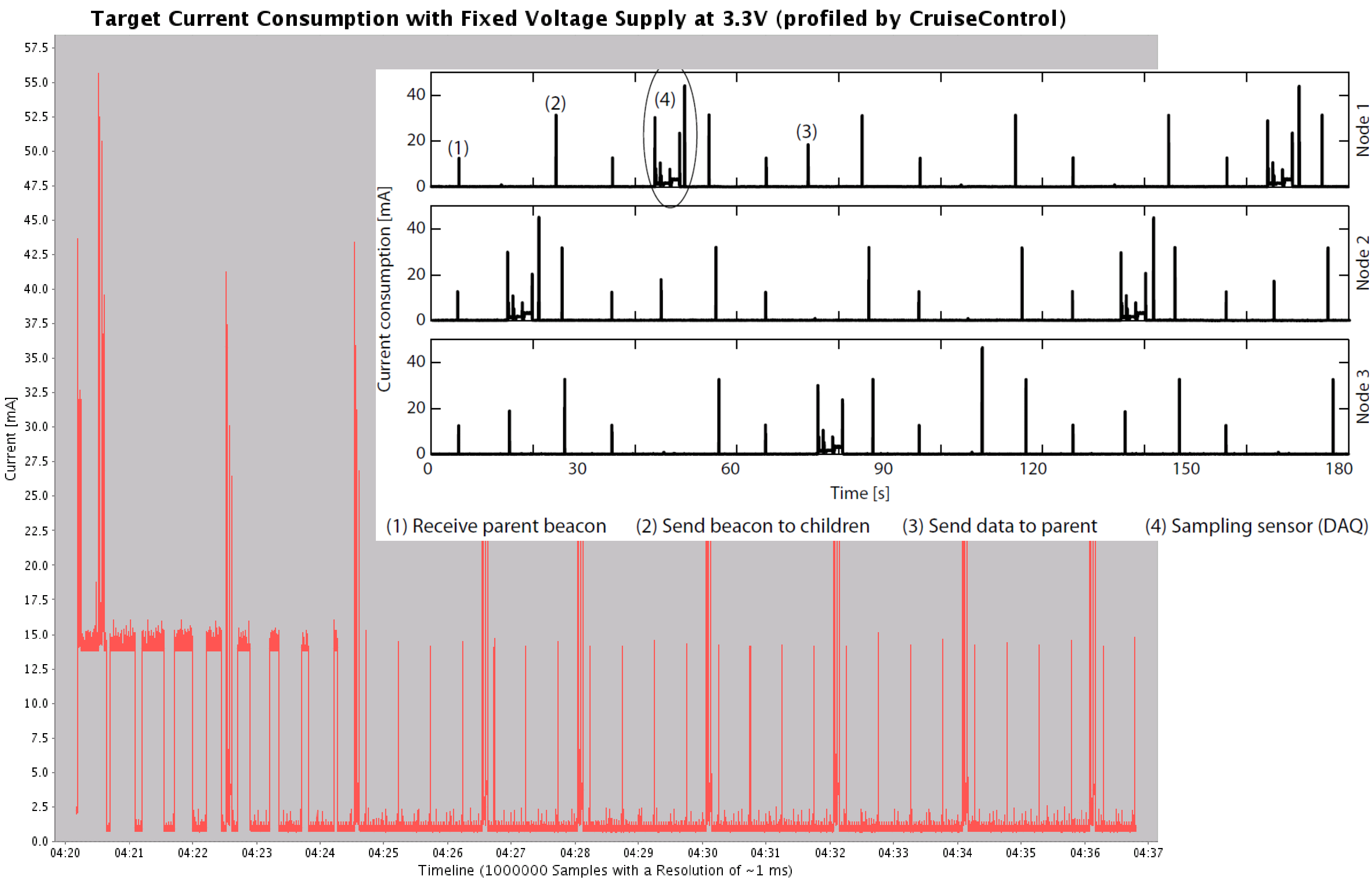


[Burri – IPSN2007]

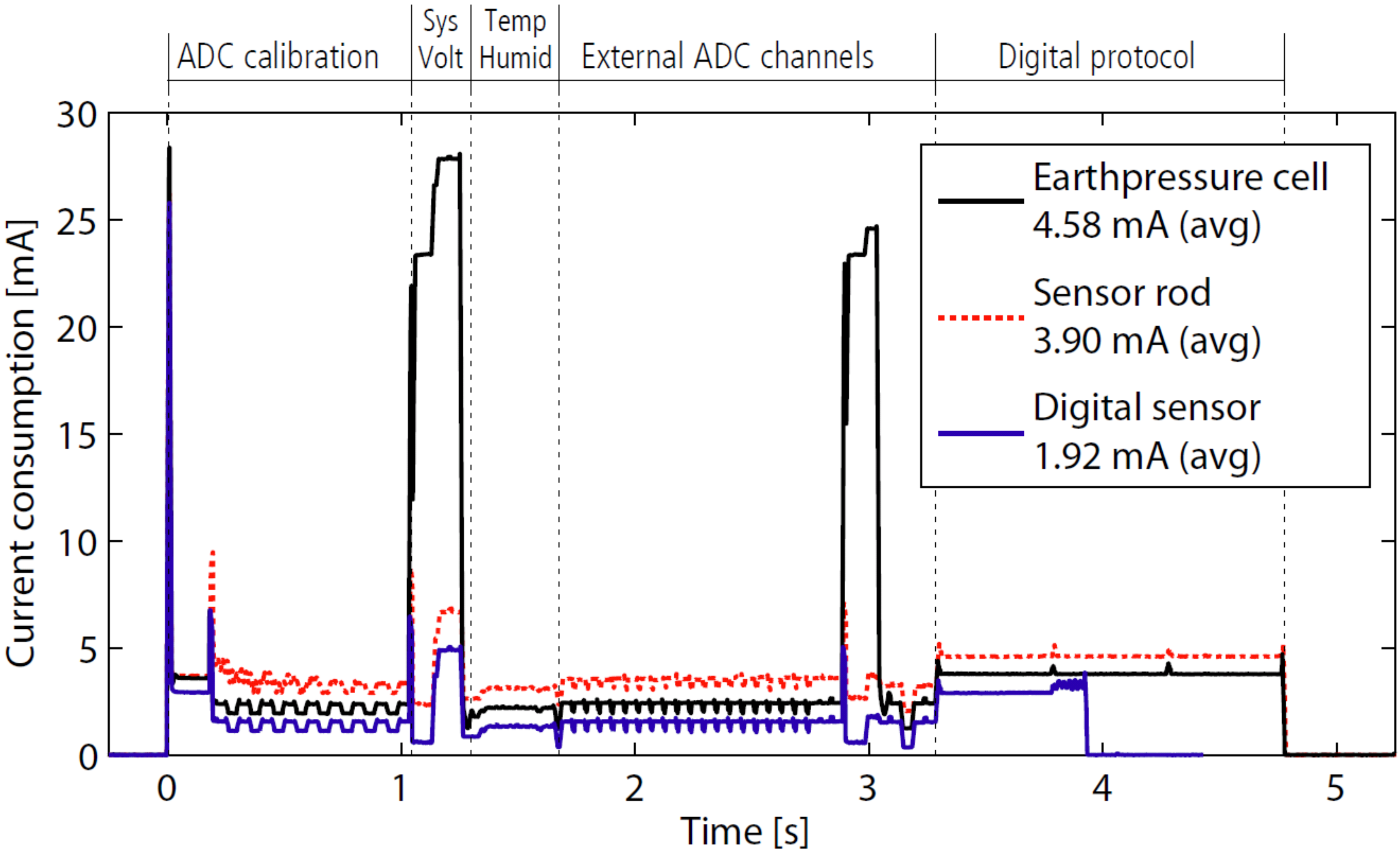
- System-level, round-robin scheduling
  - "Application processing window" between data transfers and beacons
  - Custom DAQ/storage routine



Visualization Using Simultaneous Power Traces



Wireless is Not the Only Contributor – Sensing

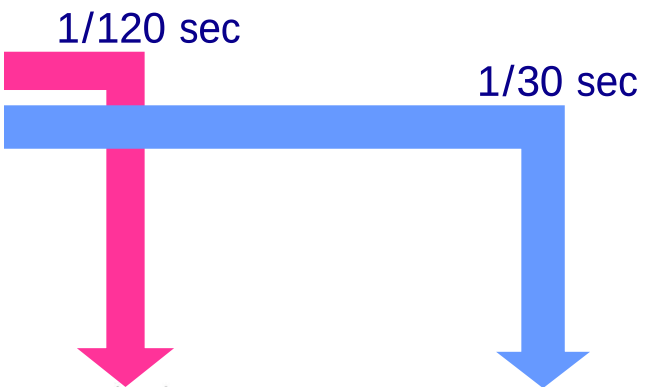


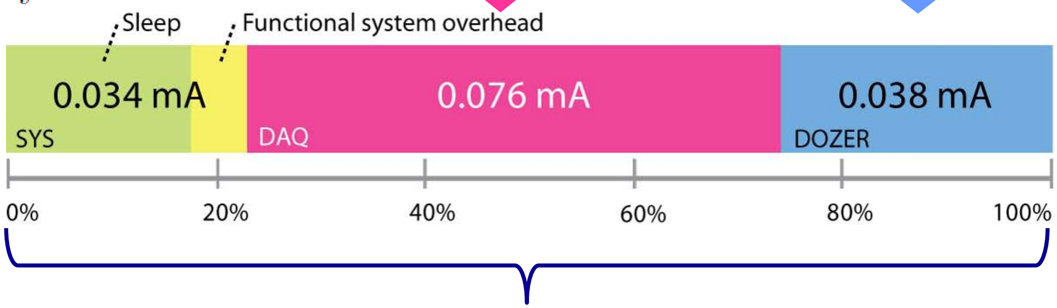
PermaDozer – Total Power Performance Analysis

Operating Mode Characterization	[mA]
Sleep	0.026
DAQ active[a]	2.086
Dozer RX idle	13.64
Dozer RX	14.2
Dozer TX	54.6
Measured Average Values	**[mA]**
DAQ only (2min)	0.110
Dozer only (30sec/2min)[b]	0.072
PermaDozer total (30sec/2min)	**0.148**

[a] Averages power consumption measured over a complete DAQ routine execution without attached sensor

[b] Dozer only includes communication, not including network initialization and access to flash memory



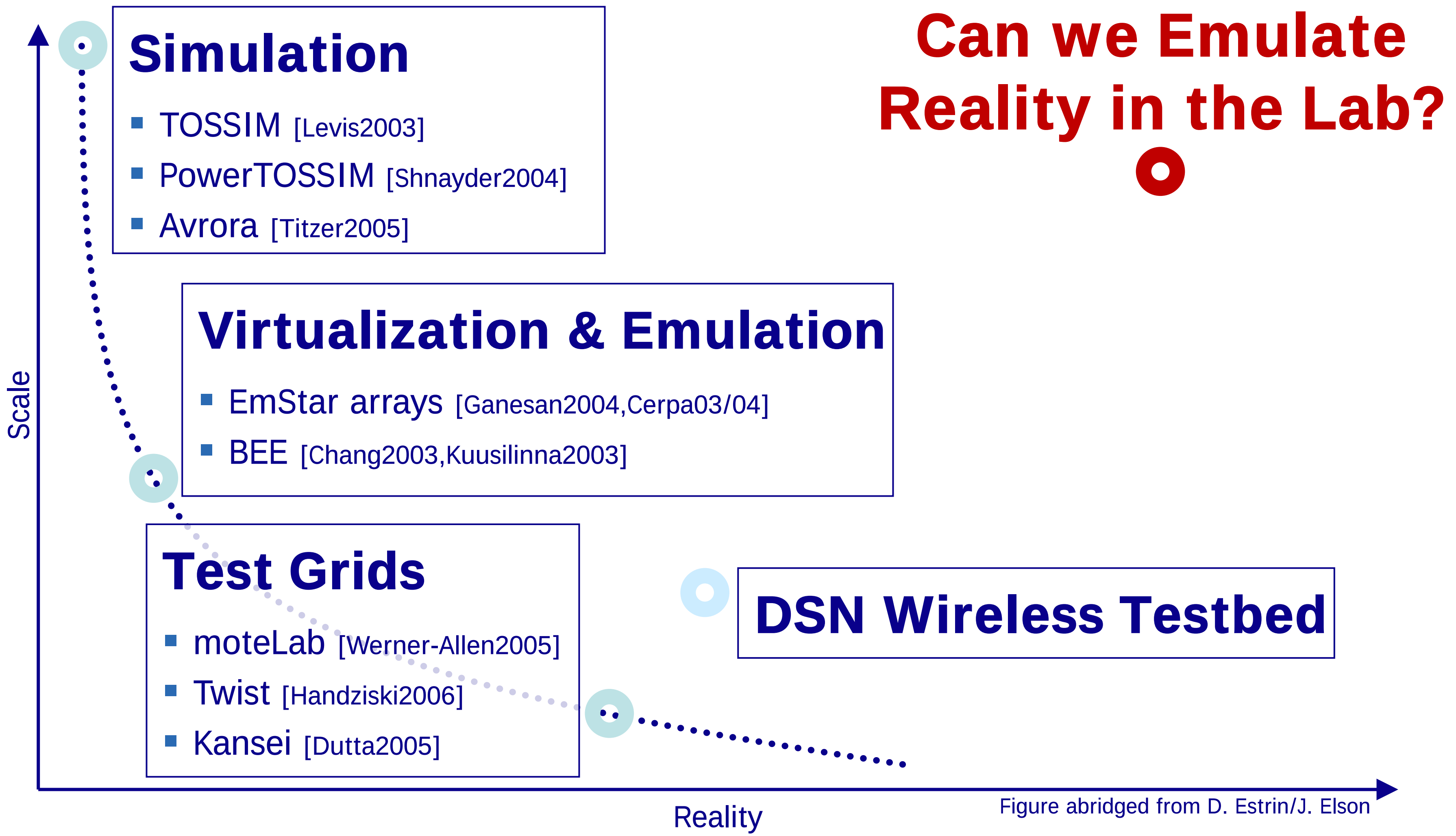


148 uA average power

Getting Even More Physical on Real Devices

Emulating the Environment

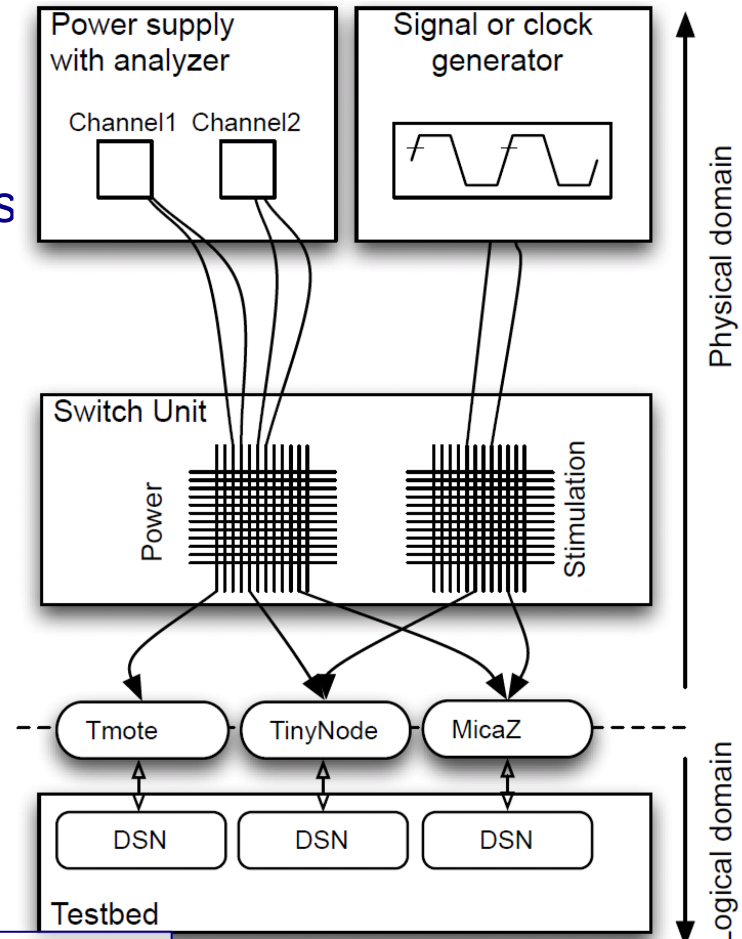
WSN Design and Development Tools




Remember: We can’t bring
our patient to the lab!

Physical Emulation Architecture

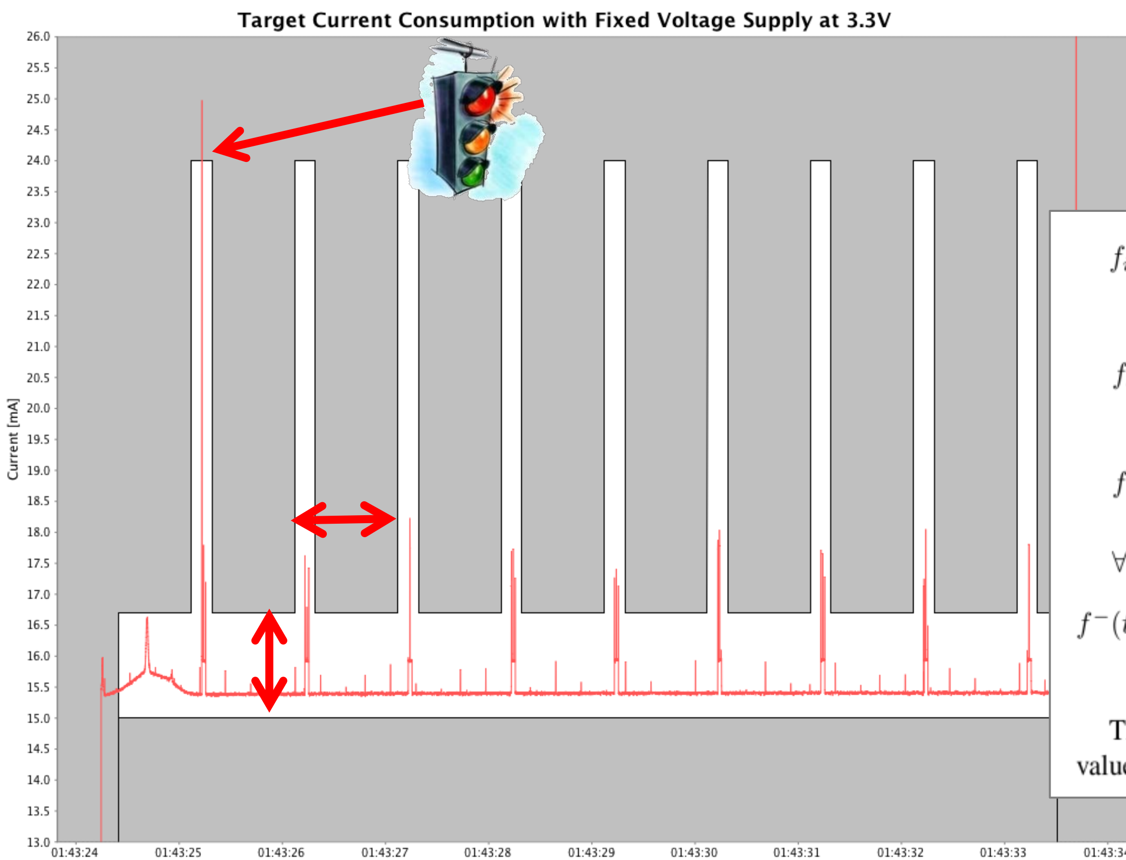
- Influence of power sources/quality
- Detailed physical characterization
- Emulation of environment and resources
  - Temperature Cycle Testing (TCT)
  - Controlled RF attenuation
  - Sensor stimuli and references



Integration and automation with DSN Testbed

[EmNets2007]

Validation of Detailed Traces using Formal Bounds



$$f_i(t) = \begin{cases} a_0 + a_1 \cdot x + \ldots & \text{if } t \in [t_{i-1}, t_i) \\ 0 & \text{if } t \notin [t_{i-1}, t_i) \end{cases}$$

$$f_i^-(t) = \begin{cases} f_i(t) - \Delta y^- & \text{if } t \in [t_{i-1}, t_i) \\ 0 & \text{if } t \notin [t_{i-1}, t_i) \end{cases}$$

$$f^-(t) = \sum_{i=1}^{n} f_i^-(t)$$

$$\forall \tilde{t} \in [-\Delta t, \Delta t], \forall i \in \mathbb{N}:$$

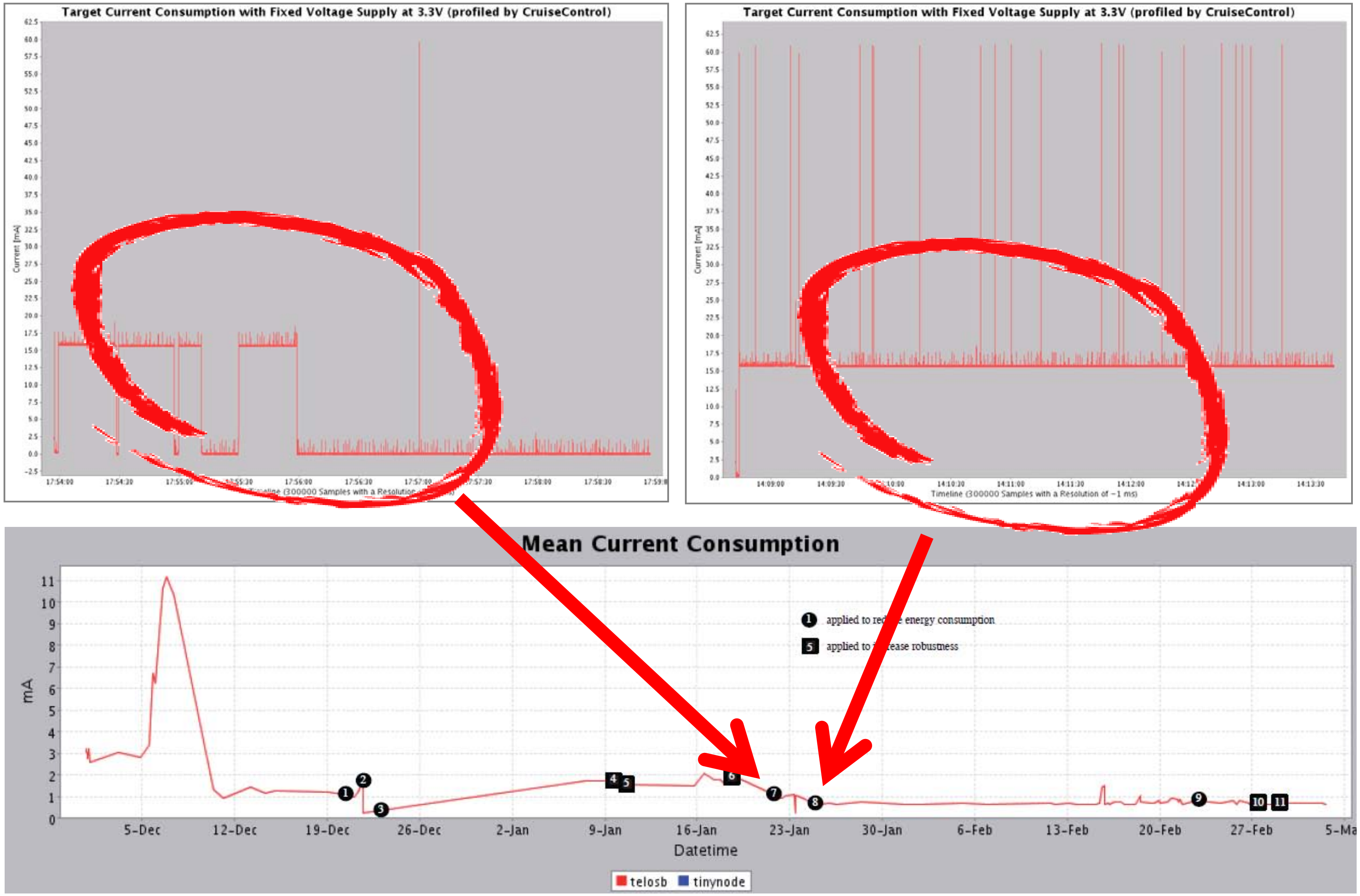
$$f^-(t + \tilde{(t_k)}) = \begin{cases} f^-(t_i^-) & \text{if } - f(ti^-) + f(t_{i+})) \leq 0 \\ f^-(t_i^+) & \text{if } - f(ti^-) + f(t_{i+})) > 0 \end{cases}$$

The upper bound f^+ follows accordingly with a bound value Δy^+.

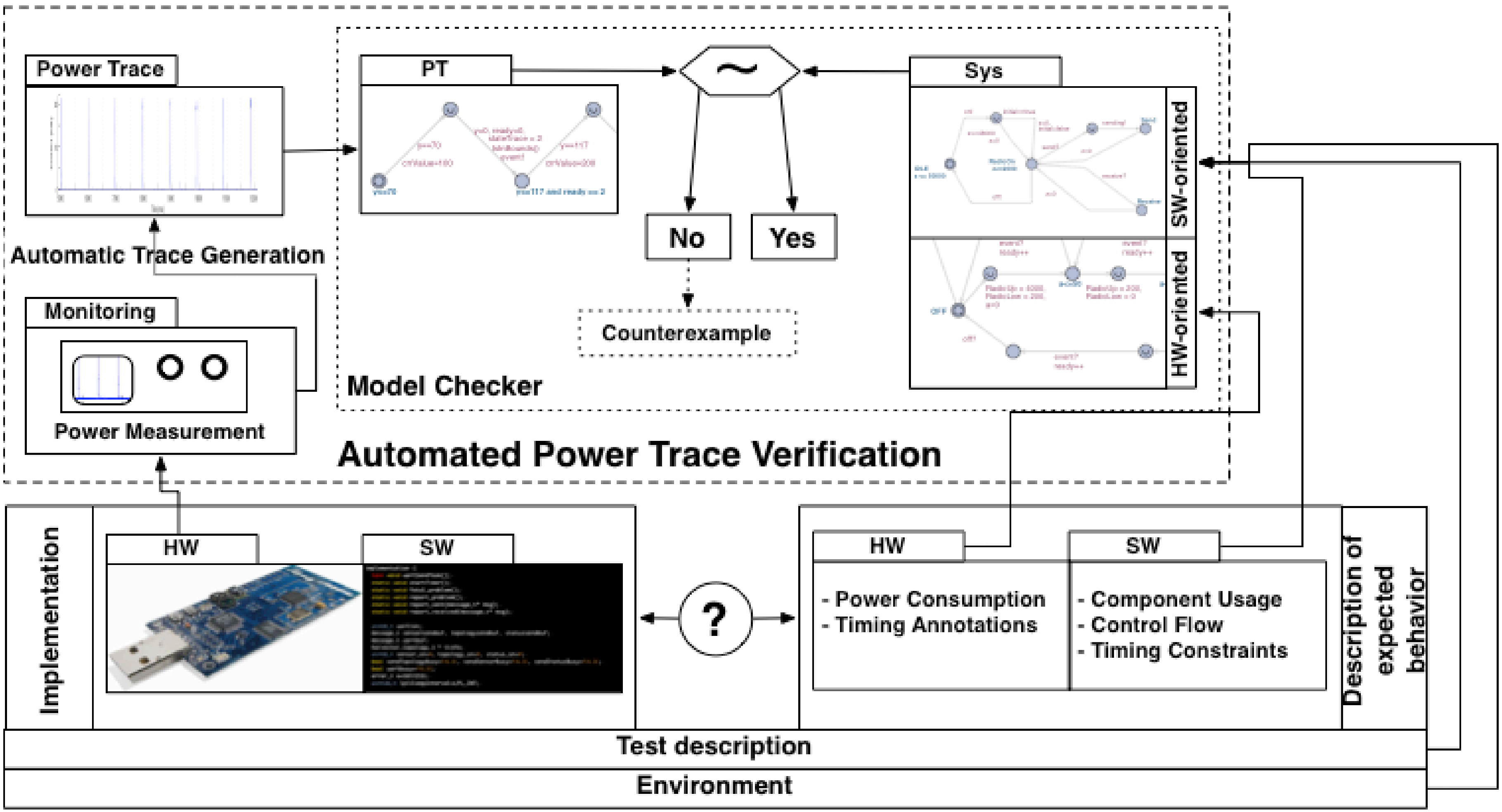
- Assertions based on reference traces/specification
- Integrated with each build (regression testing)

[WEWSN2008, SUTC2008]

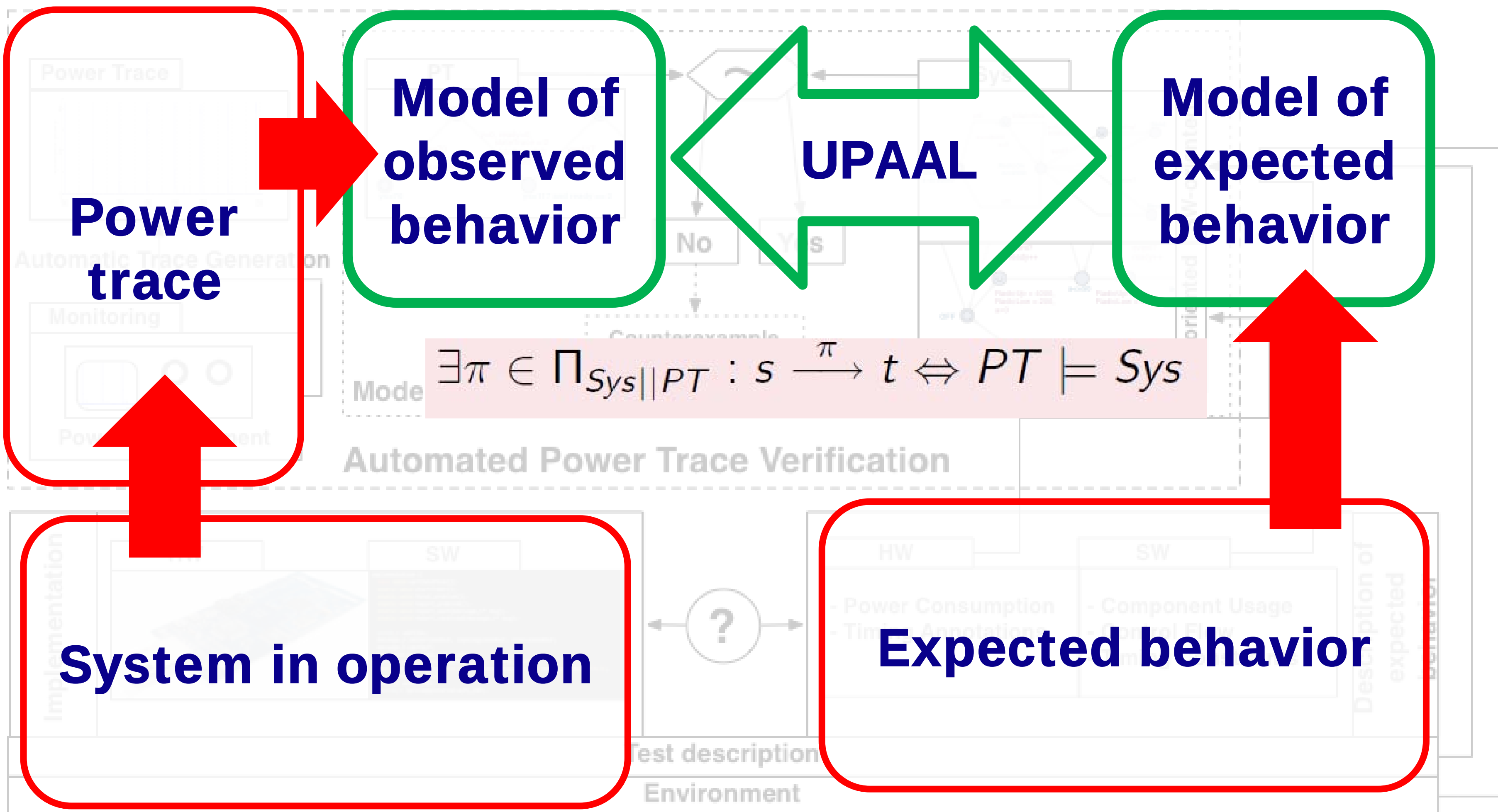
Visualizing Behavior – Quantification of Change



Conformance Testing using Timed Automata



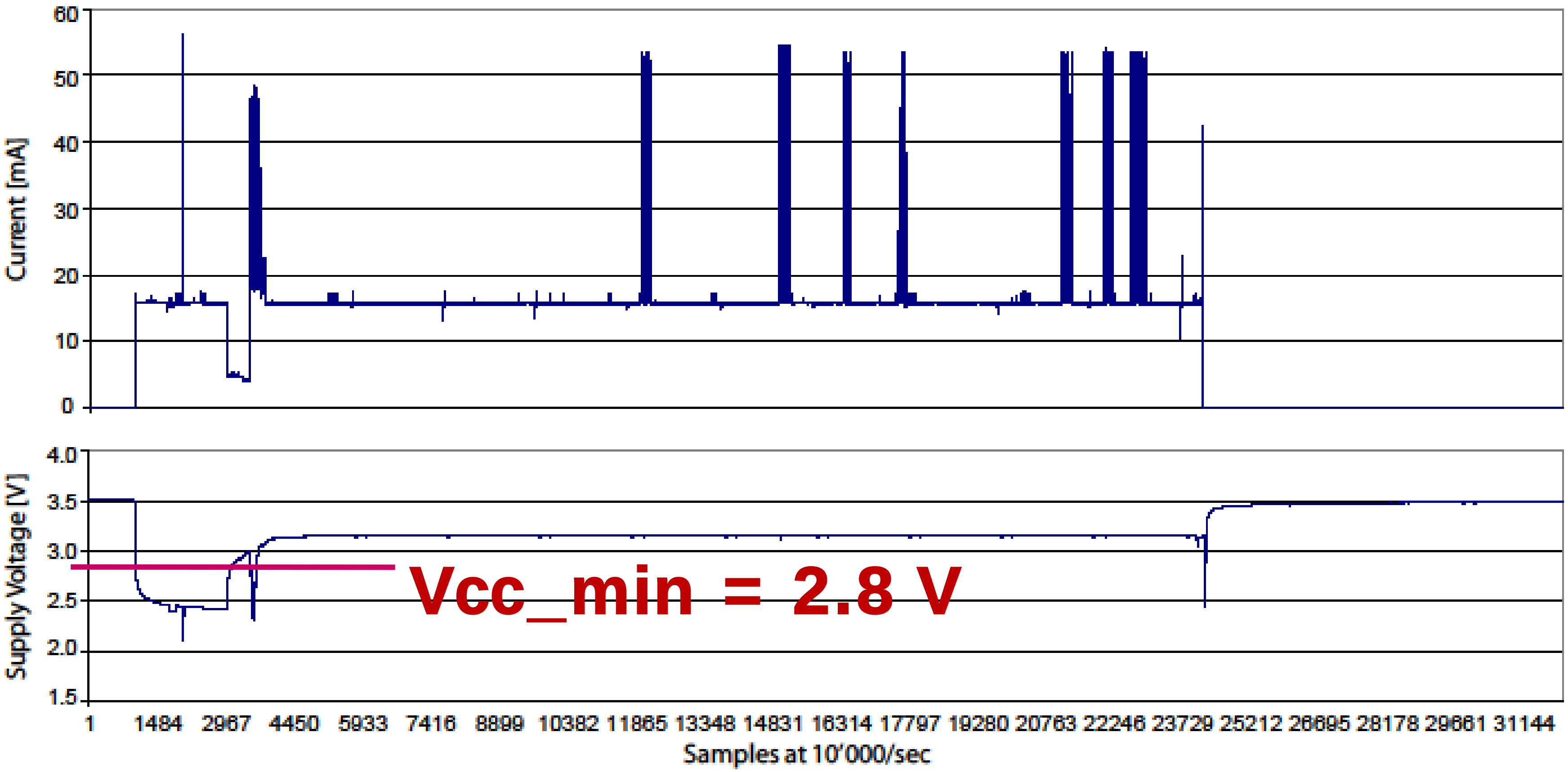
Conformance Testing using Timed Automata



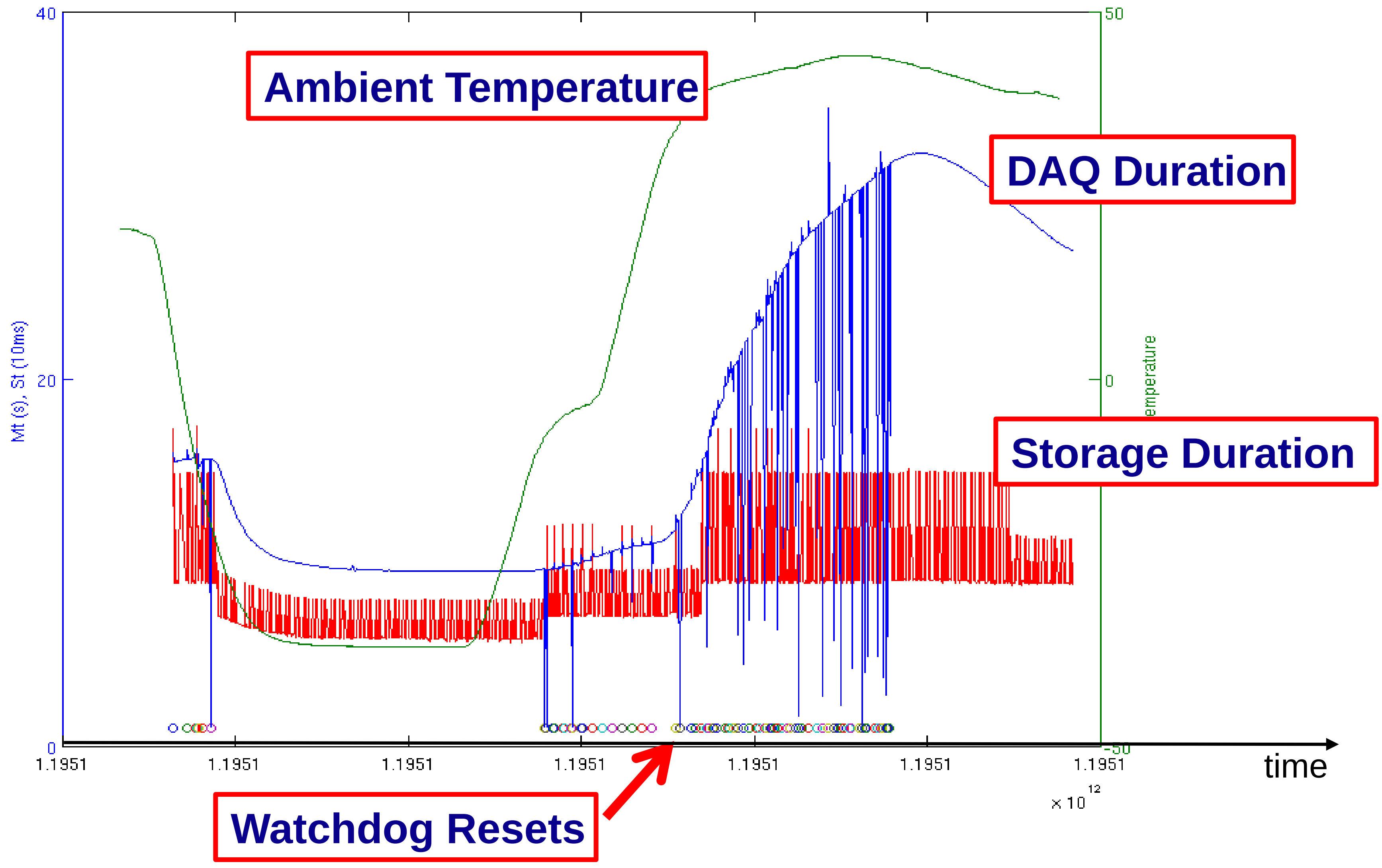
[FORMATS 2009]


Why should we care?

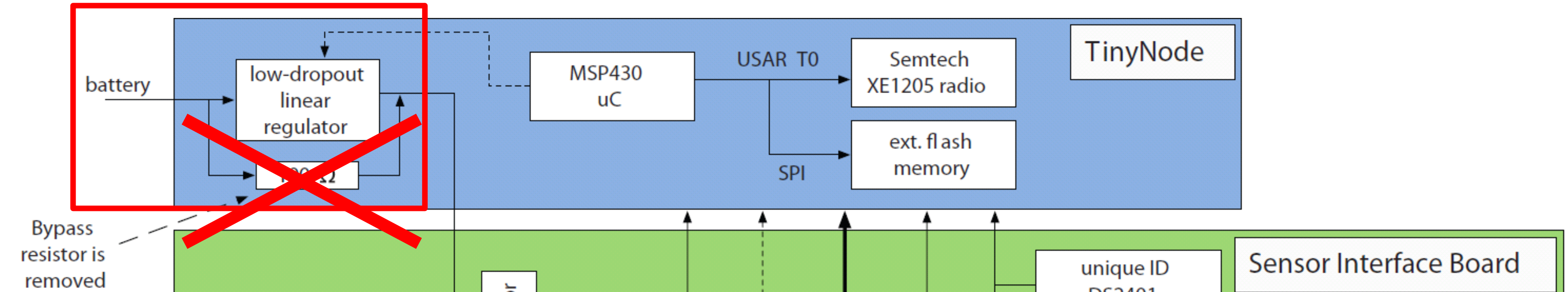
Communication Details – Dangerous Voltage Drops



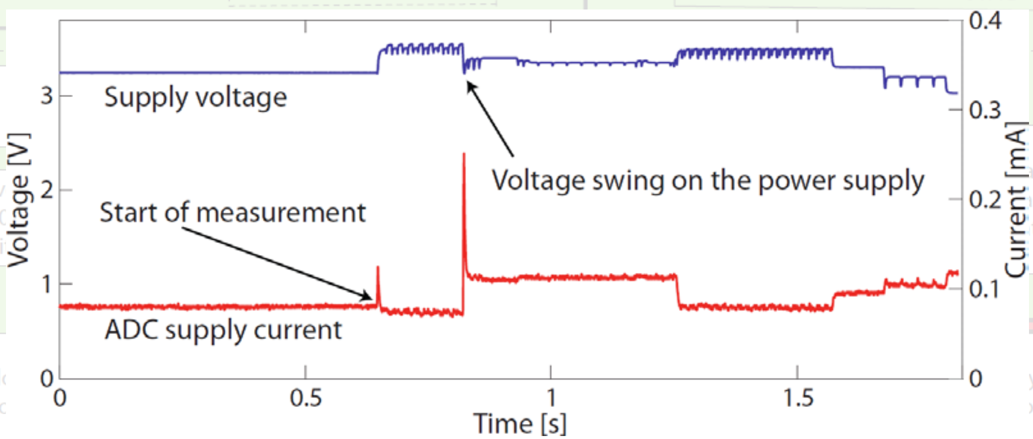
Physical Reality Impacting Performance



Power Optimization – A Squeeze with Implications

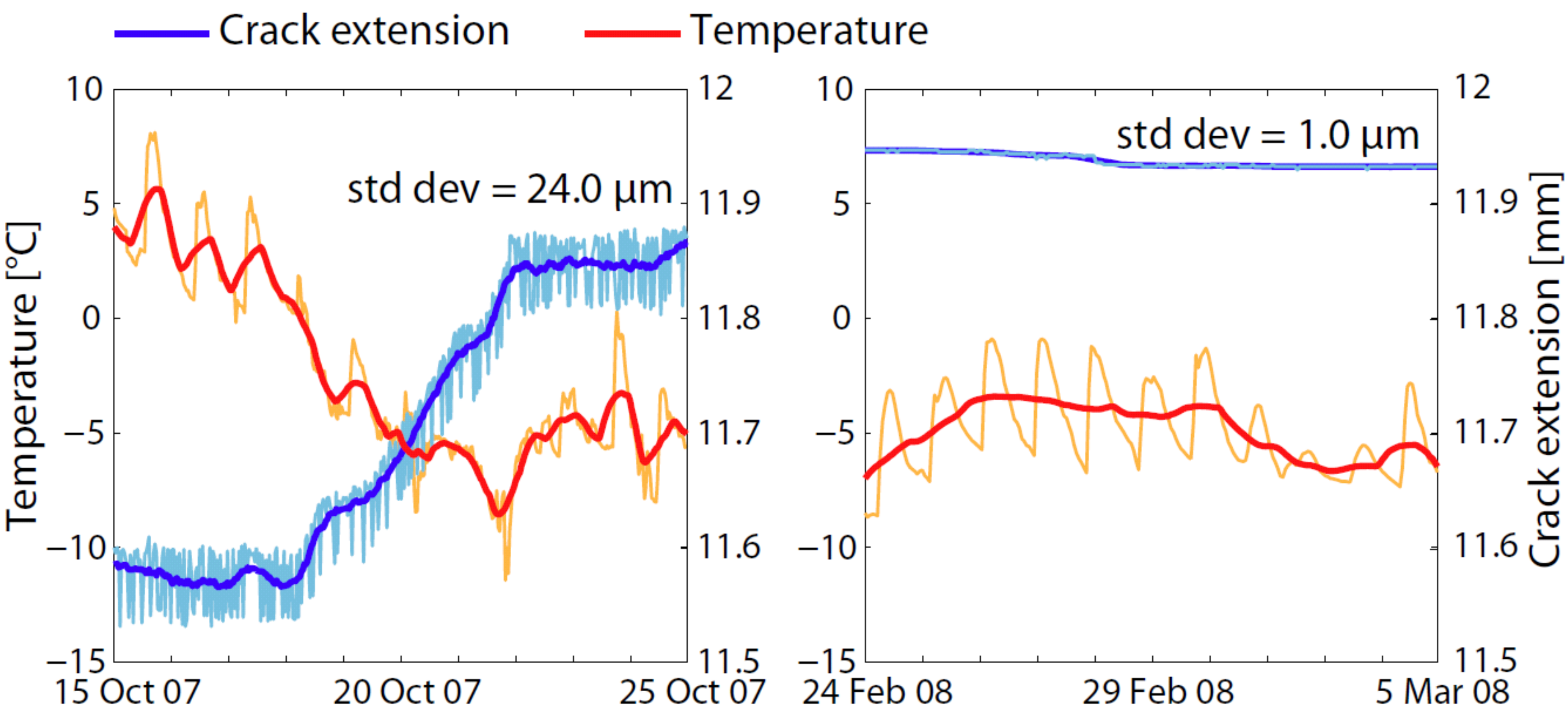


- Regulator uses 17uA quiescent current
- Bypass used to shutdown regulator -> ~1uA in standby



- No Bypass increases ADC accuracy: std dev 0.8844 -> 0.0706

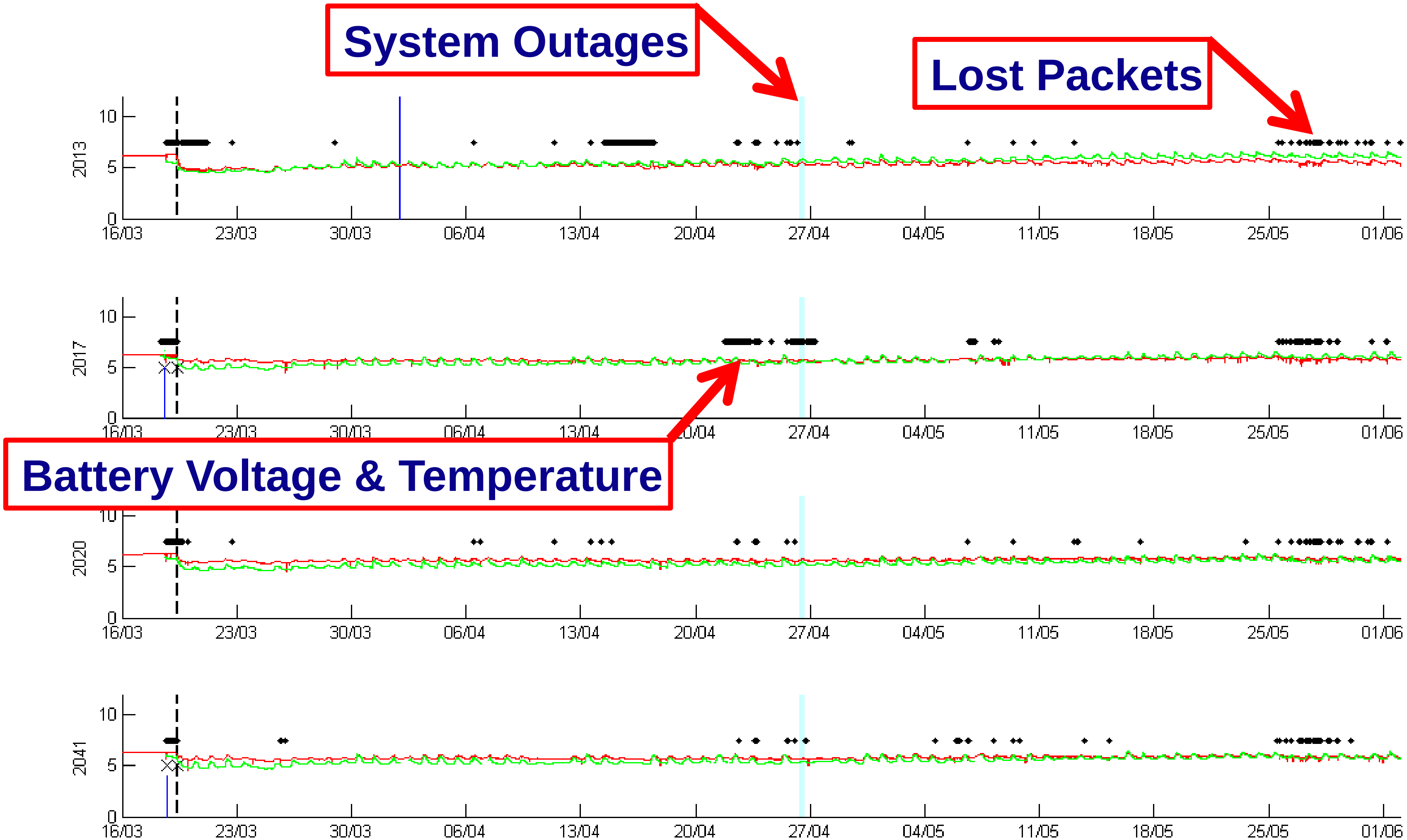
The Result – Power Quality Increases Data Accuracy



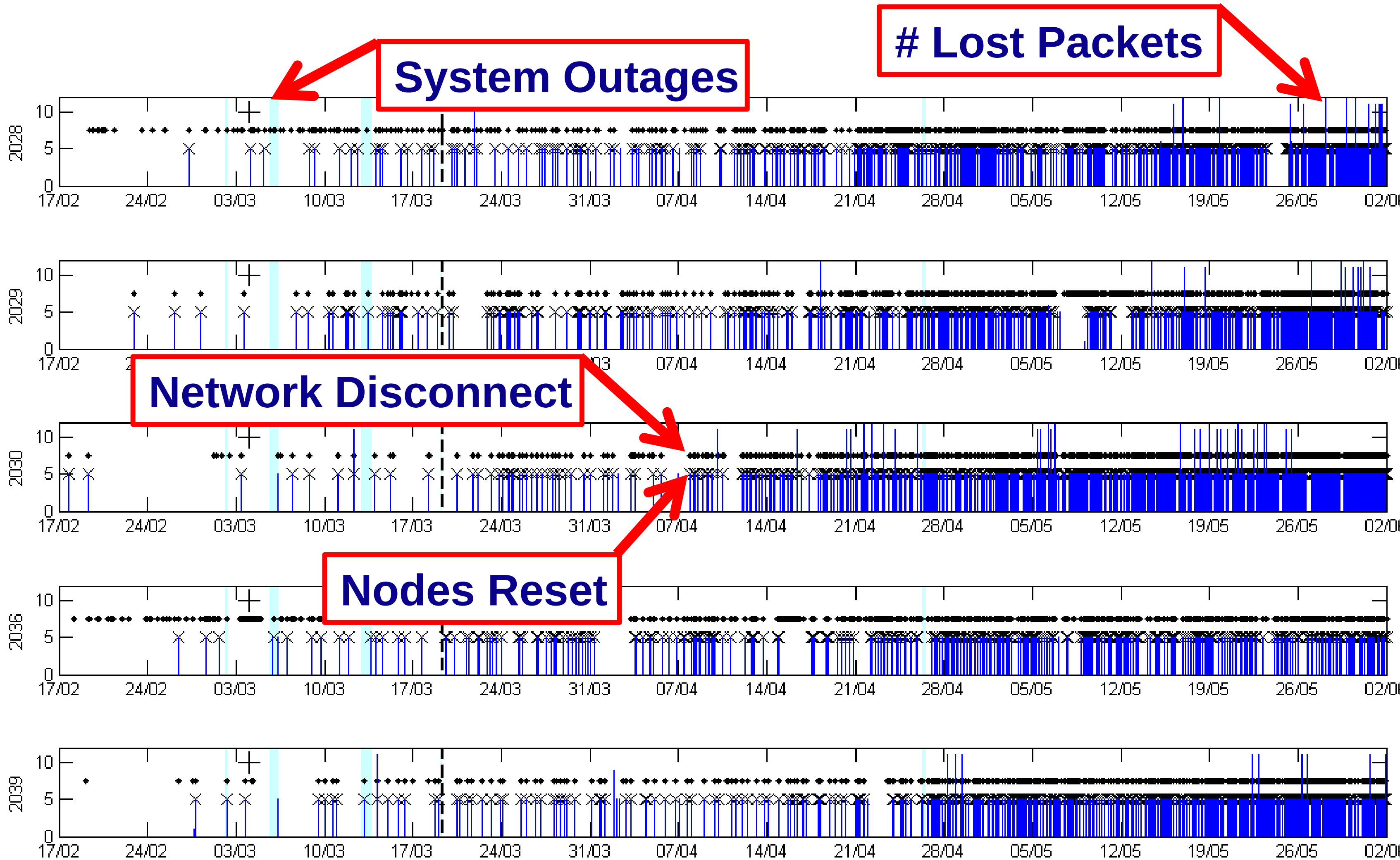
Before **After**


Seeing is believing...

Experience – Node Health Data From The Field

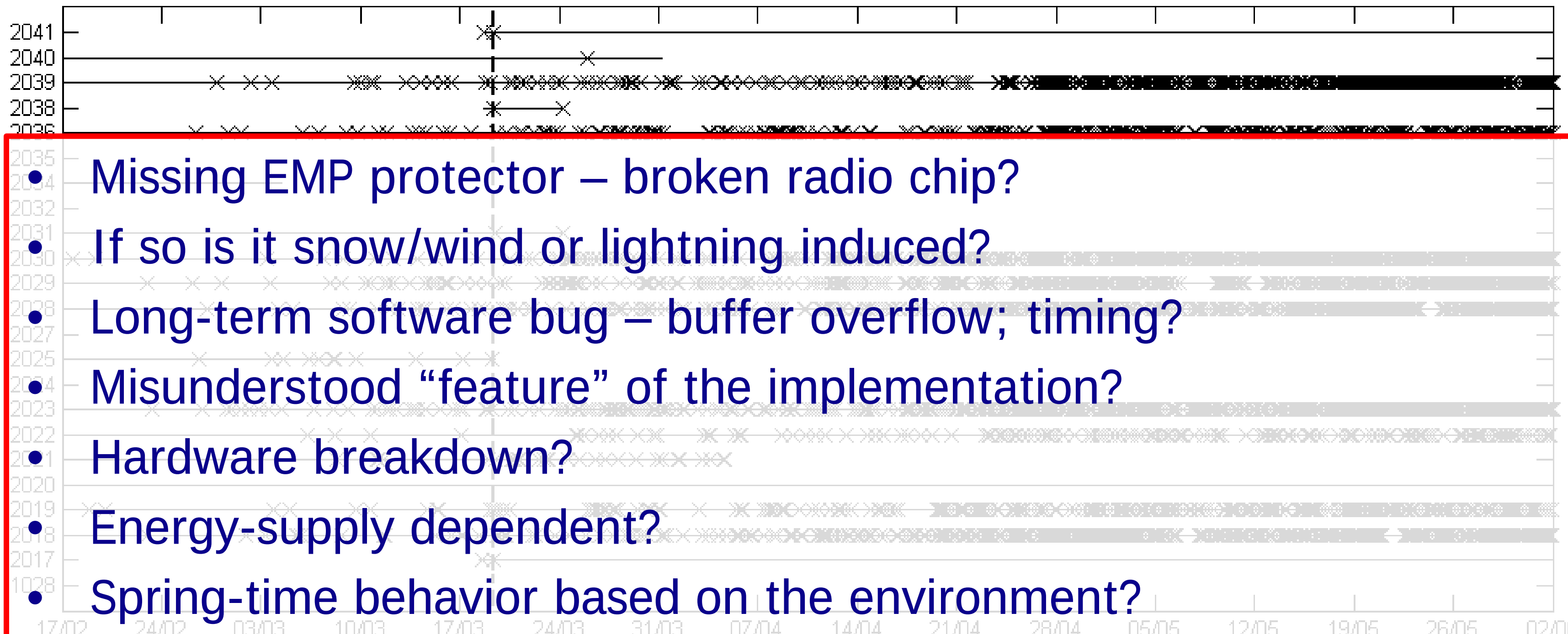


Node Health Data – Root Cause Failure Analysis




Visibility is key!

Understanding the Exact Causes is Hard...



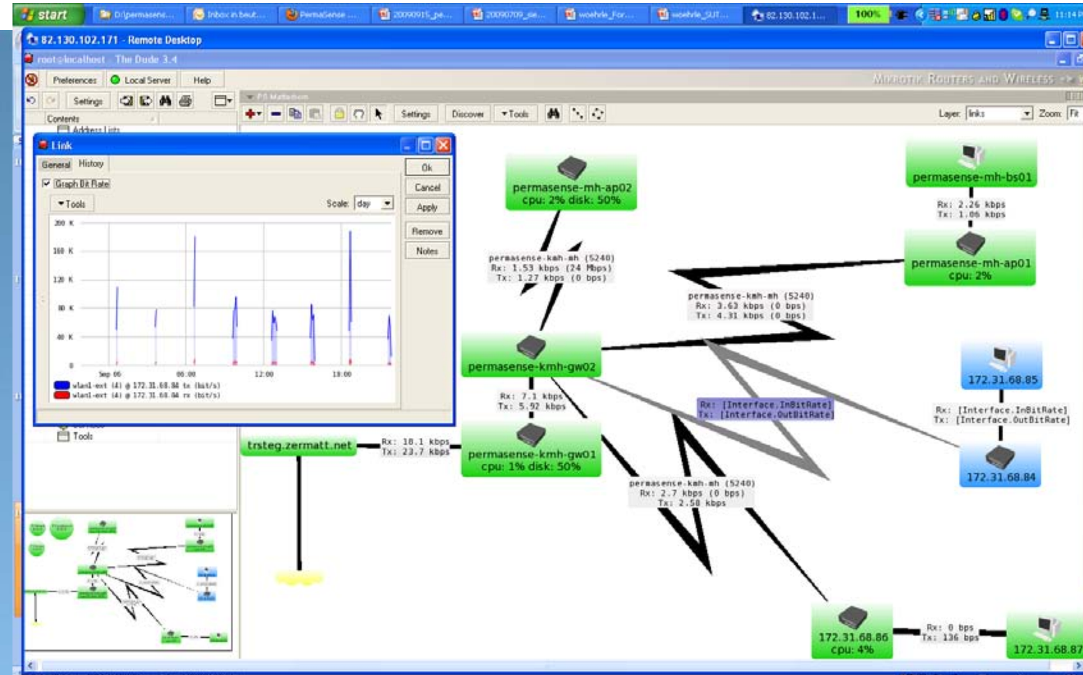
- Missing EMP protector – broken radio chip?
- If so is it snow/wind or lightning induced?
- Long-term software bug – buffer overflow; timing?
- Misunderstood “feature” of the implementation?
- Hardware breakdown?
- Energy-supply dependent?
- Spring-time behavior based on the environment?
- Cosmic rays at 3500 m a.s.l. ?
- Can external effects trigger the reed contact on the reset?
- ...

Probably not feasible to test / reproduce this in the lab!

Up and coming stuff

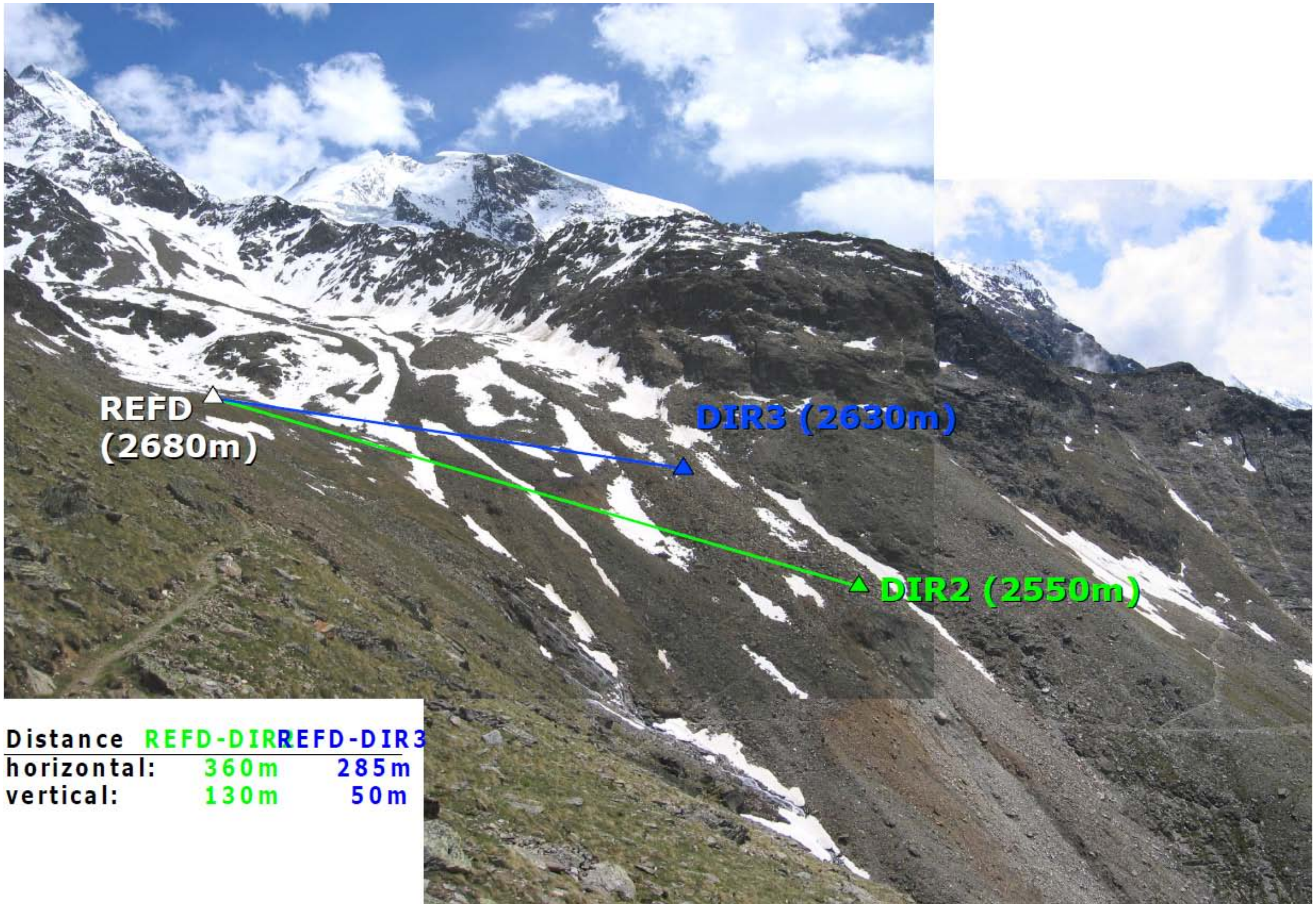
NEXT GENERATION PERMASENSE SENSING

WLAN and high-resolution imaging



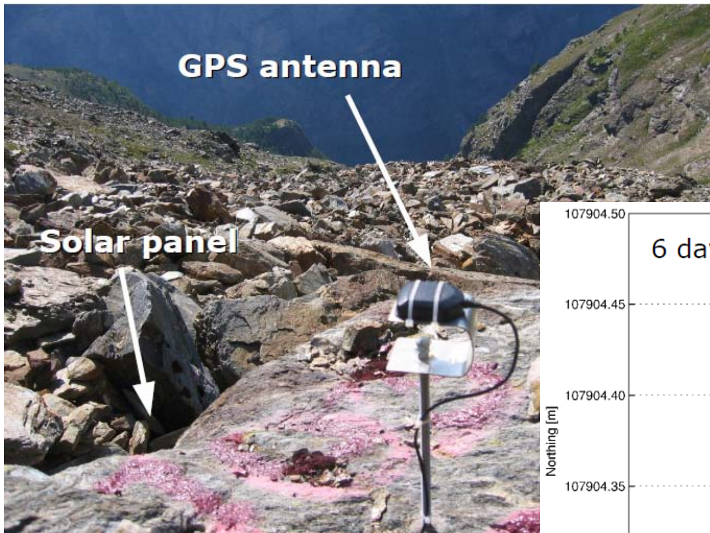
[EWSN 2009]

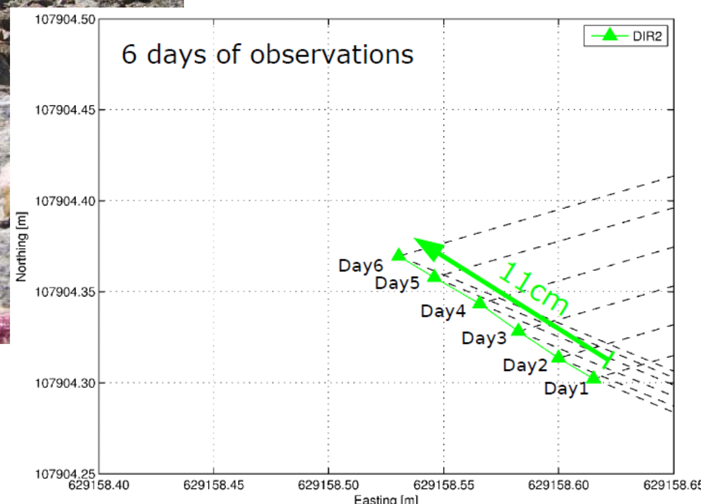
Precision GPS Movement Detection

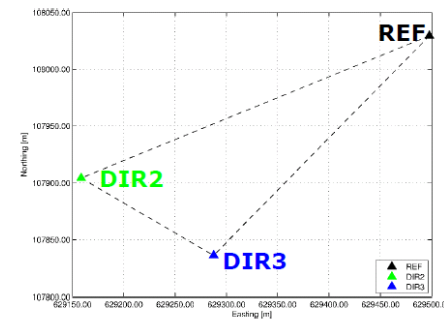


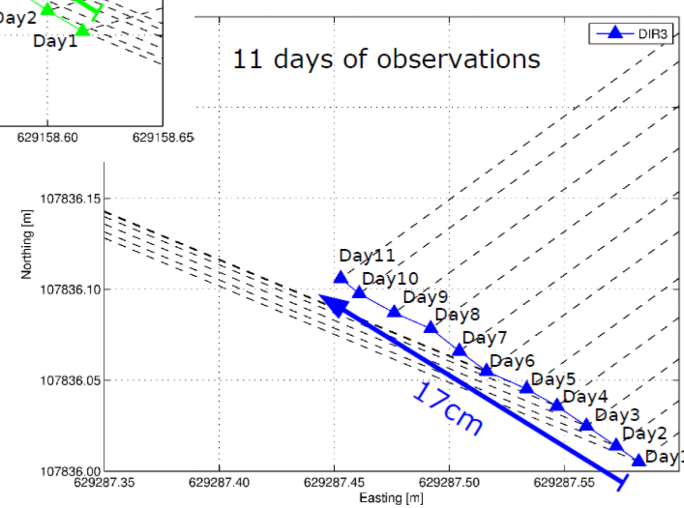
Distance	REFD-DIR	REFD-DIR3
horizontal:	360m	285m
vertical:	130m	50m

Using Commodity GPS Receivers and WSNs









June 2009


http://www.permasense.ch
Interested to join our team?
beutel@tik.ee.ethz.ch