Life Under your Feet:

A Wireless Soil Ecology Sensor Network

R. Musaloiu-E[†]., A. Terzis[†] , K. Szlavecz[‡] , A. Szalay[*], J. Cogan[*], J. Gray[◇]

[†] Computer Science Department, JHU

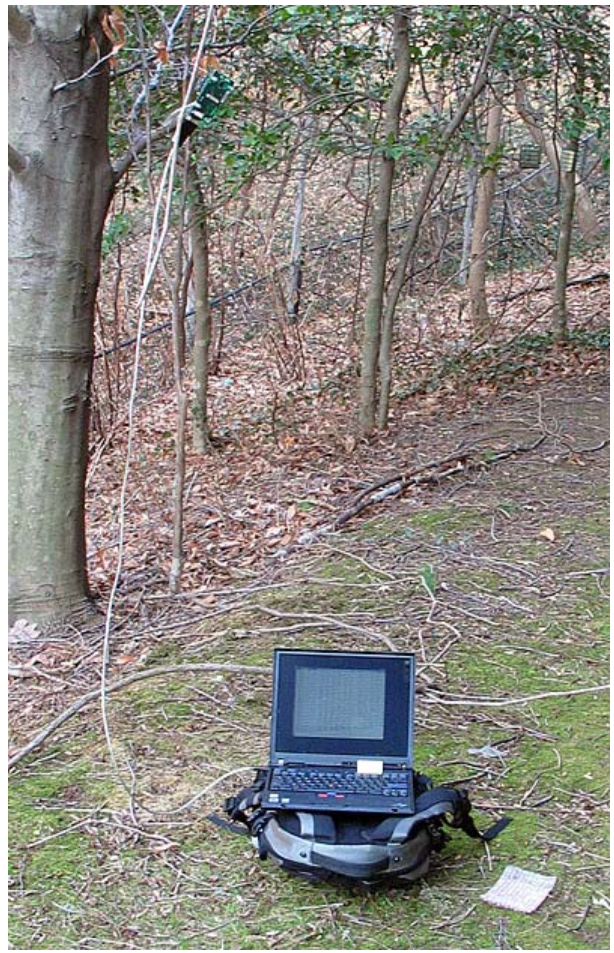
[‡] Earth and Planetary Sciences Department, JHU

[*] Physics Department, JHU

[◇]Microsoft Research

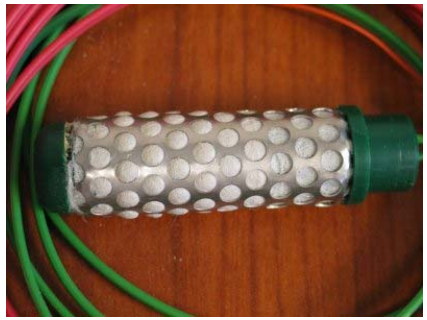
In the Beginning…

- The Cast
  - An ecologist: *Katalin Szlavecz*
  - An undergrad student working in a summer project: *Joshua Cogan*
- The Stage
  - The urban forest near the JHU campus
  - Off-the-self soil moisture and temperature sensors
  - A few Mica2 motes
- The Goal
  - *Test whether WSNs can be used to collect soil monitoring data at spatial and temporal scales larger than that of data loggers*



First Step

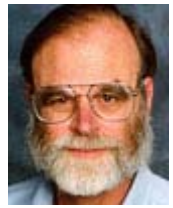
- The sensors were thoroughly tested in the lab
  - 2 out of 6 sensors misbehaved
  - Relatively precise (+/- 0.5°C)
  - … but offset of 1.5°C from a NIST approved thermocouple.
- Next step: teach the motes to play their part.



Second Step

- More actors:
  - CS faculty (Andreas Terzis)
  - CS grad student (Razvan Musaloiu-E.)
  - DB experts: Alex Szalay and Jim Gray
- More setup:
  - MicaZ motes
  - MSSQL
  - Skyserver DB software
- The goal
  - Build an *end-to-end data collection system*

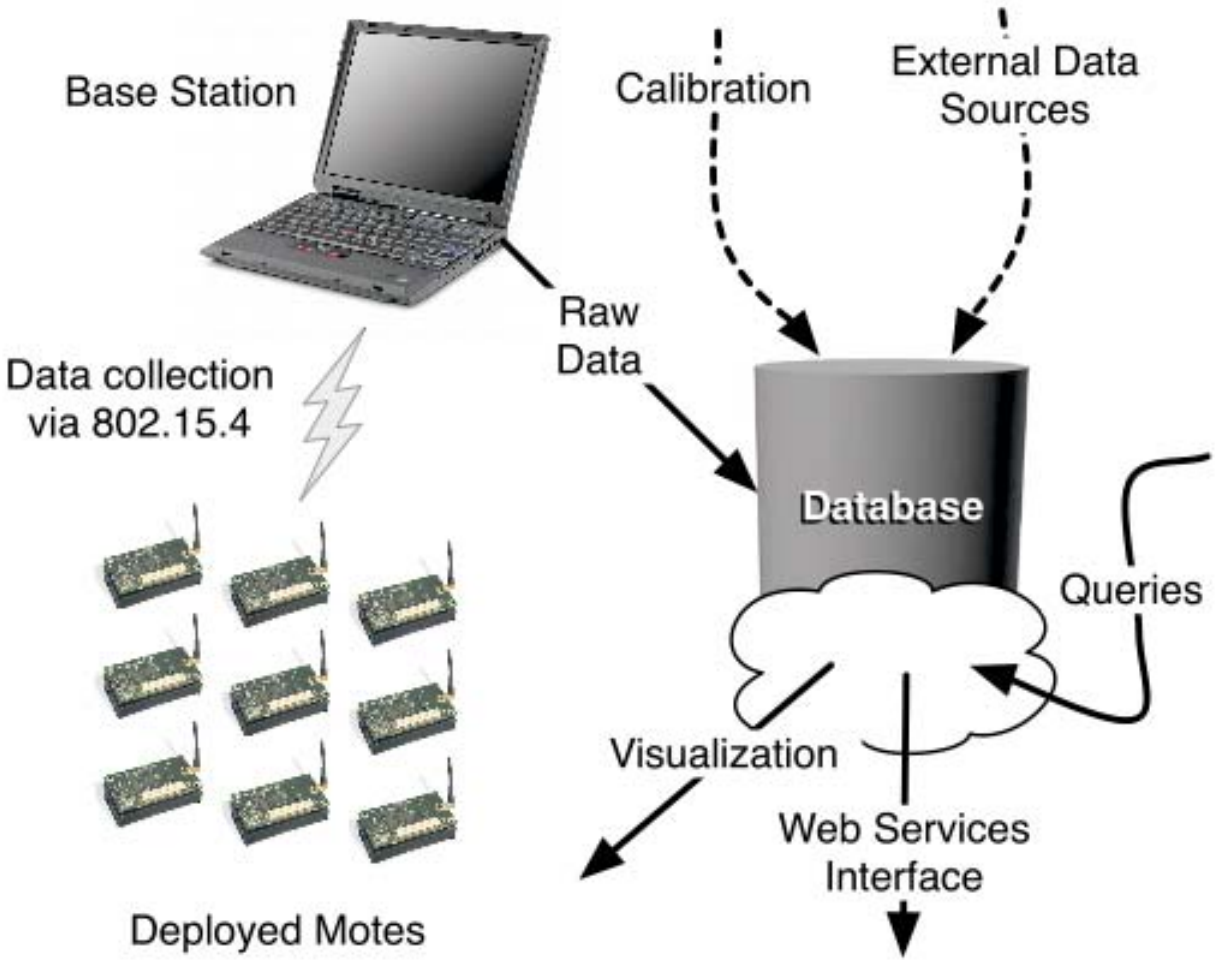




System requirements

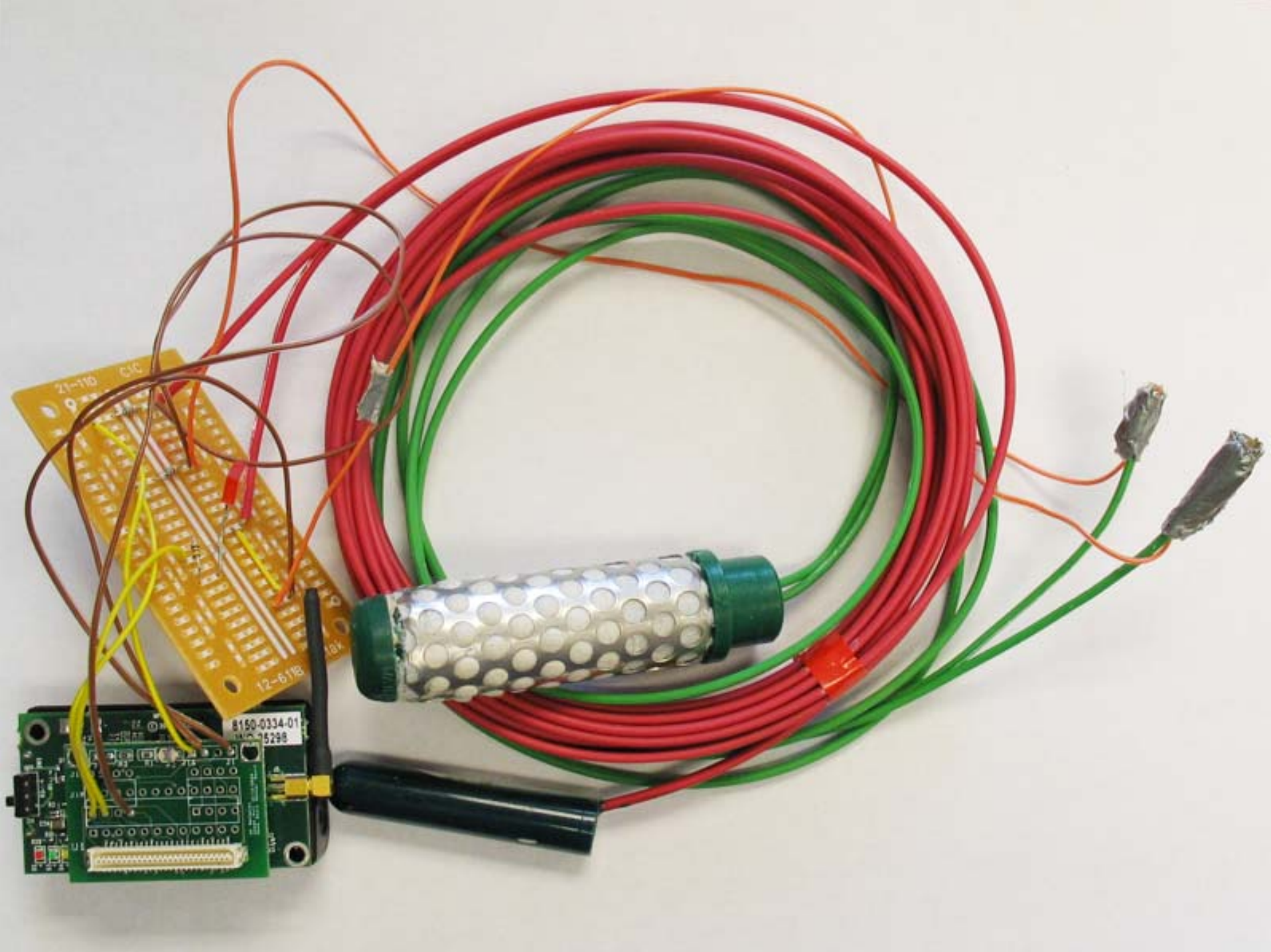
- Measurement fidelity
  - *All* the raw measurements should be collected and persistently stored
- Measurement accuracy and precision
  - Temperature data error < 0.5 C, volumetric moisture data error < 1%.
- Fusion with external sources
  - Comparing measurements with external data sources is crucial
- Additional Requirements
  - Sampling Frequency: *minutes*
  - Experiment Duration: *years*
  - Deployment Size: *networks should be deployed in ways that capture the heterogeneity of land use*

System Architecture

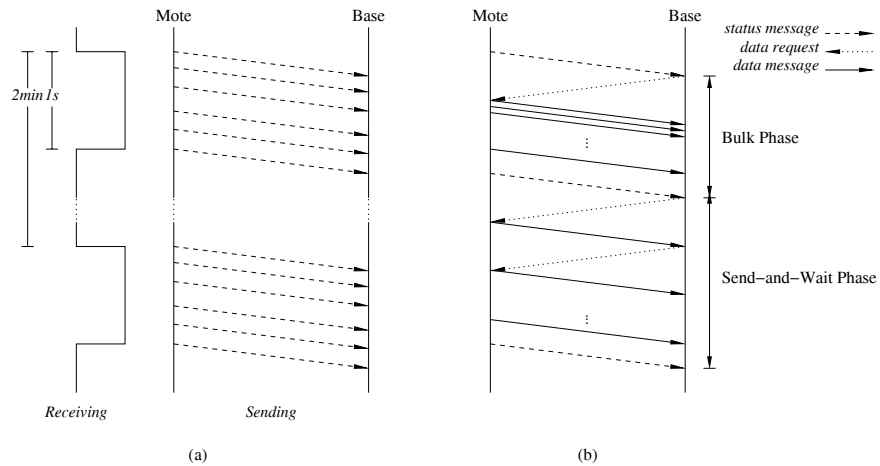


Sensor Node Hardware

- Sensors:
  - Watermark soil moisture
  - Irrometer soil thermistor
  - Onboard Temperature and Light
- MicaZ motes
- Waterproof cases, cables, connectors, ...


8150-0334-01

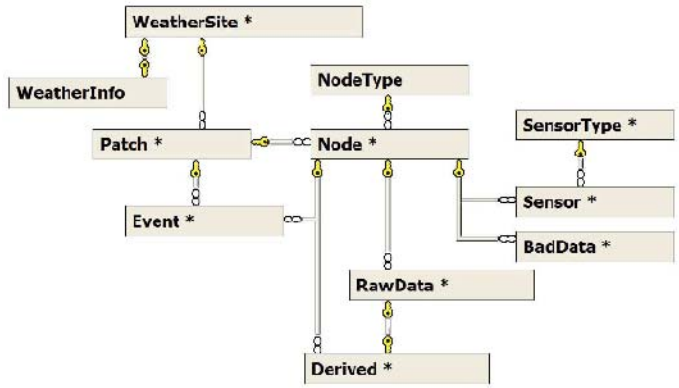
Mote Software



- Sensors are sampled every minute
- Raw measurements are stored in flash
  - Storage overrun in > 20 days
- Data retrieved using NACK-based sliding window protocol
- Each mote sends every 2 min a status messages to base-station: (#meas, bat voltage)
  - Web-accessible real-time monitoring

Database Design

- DB Design derived from experiment and WSN setup
- Self-documenting framework
- Raw data follow a multi-stage validation process
- Stored data available through Web pages and Web Services
- Datacube for analysis
- 7M datapoints collected



Calibration workflow

Calibrations in the Lab

Temperature sensor
A/D units

Reference voltage
A/D units

Moisture sensor
A/D units

Light Intensity
A/D units

Air Temperature
A/D units

CPU clock

UTC DateTime

Voltage

Voltage

Voltage

Mote Resistor Calibration

Temperature Sensor Calibration

Resistance

Resistance

Soil Temperature

Moisture Sensor Calibration

Water Deficit
Soil Matrix Potential

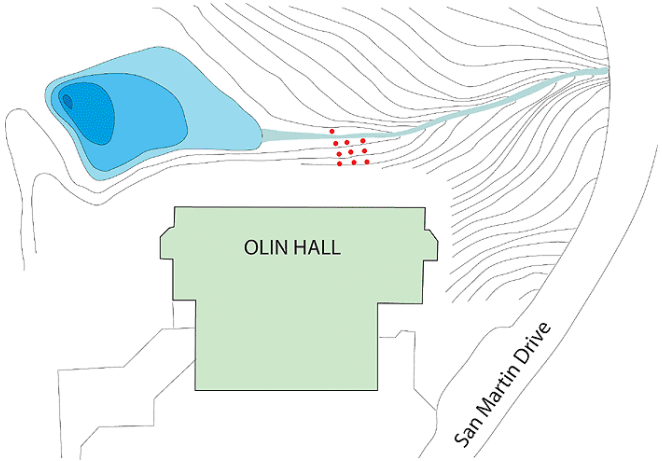
Temperature Conversion

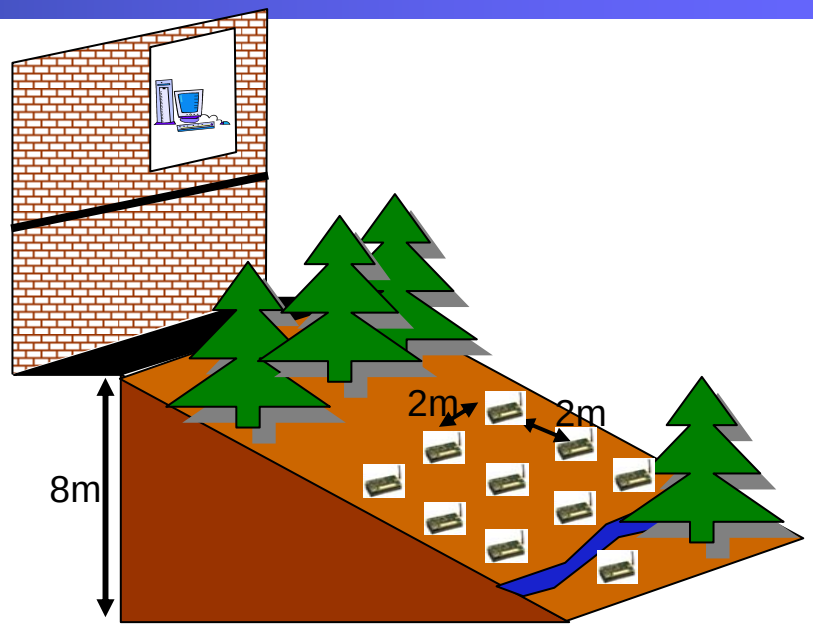
Soil Water Potential-> Volumetric Conversion

Air Temperature
Celsius

Water Content
Volumetric

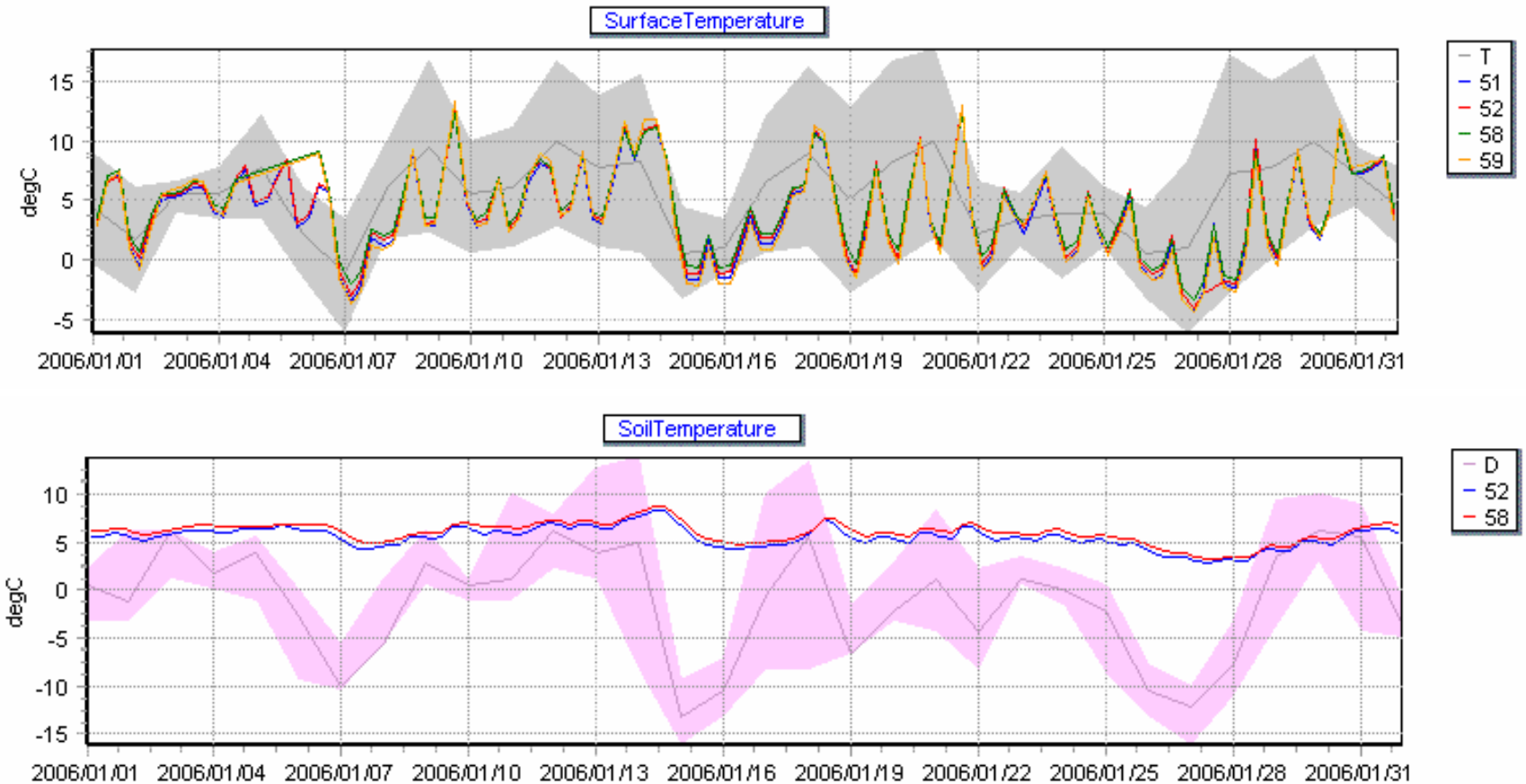
Deployment Site



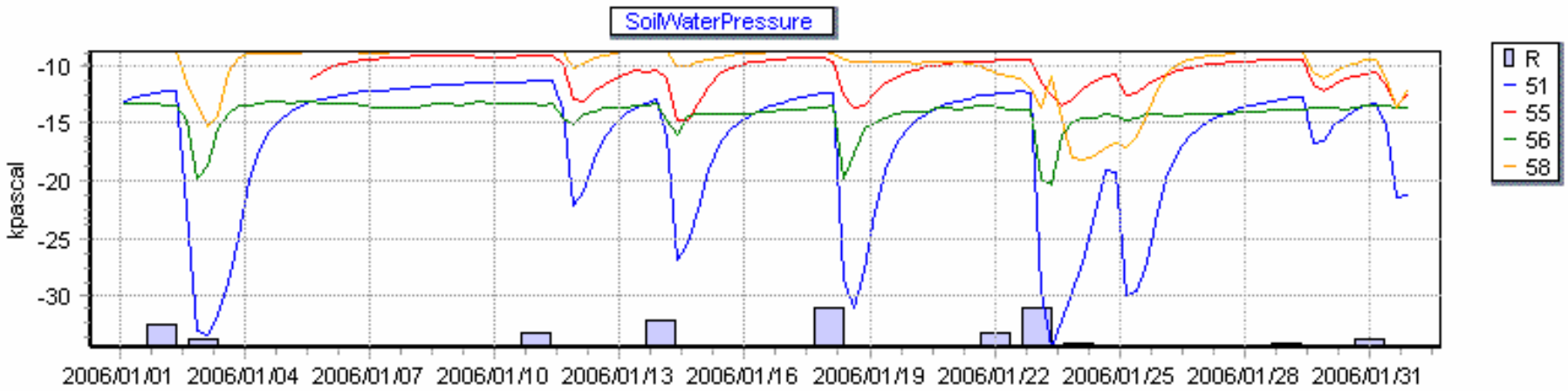


- 10 motes deployed on a slanted grid, ~2m apart
- 147 days of deployment
- Basestation within direct radio range
  - *Some links had unexpectedly poor quality*
  - *Had to collect some of the data using laptop*

Ecology Results (Temperature)

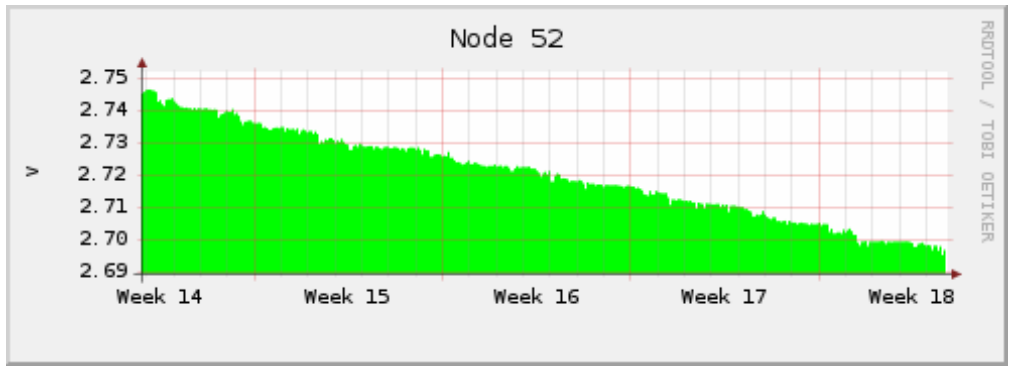


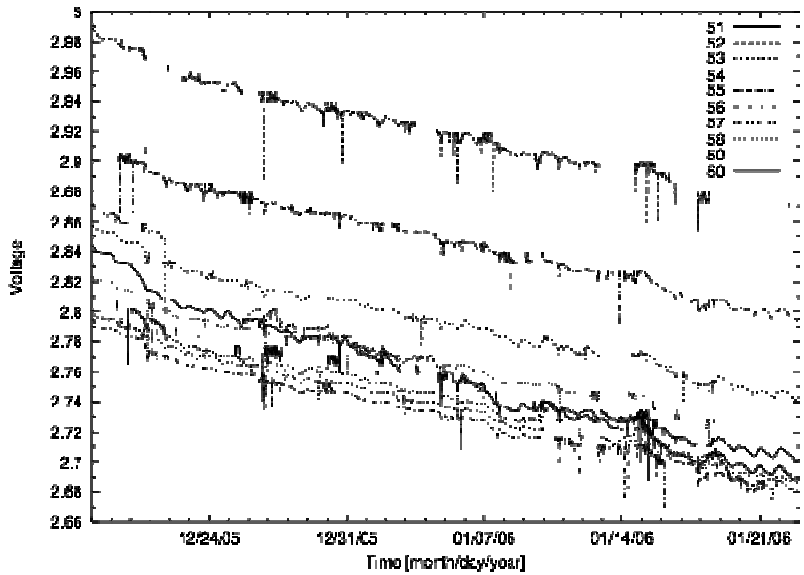
Ecology Results (Soil Moisture)



Energy consumption

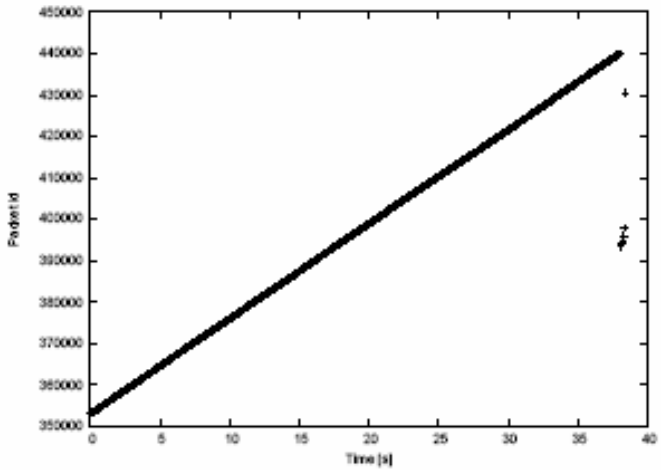
- Motes go to sleep when not collecting data/sending reports
- Easy to calculate average current draw
- Powered by AA alkaline batteries
- Linear discharge curve
- *Possible to predict node lifetime*

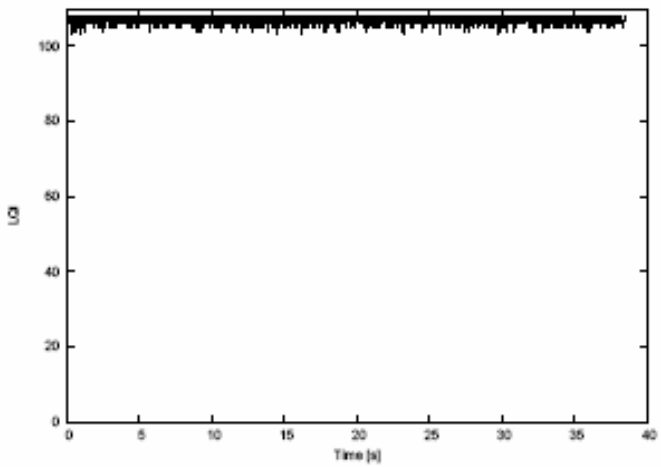




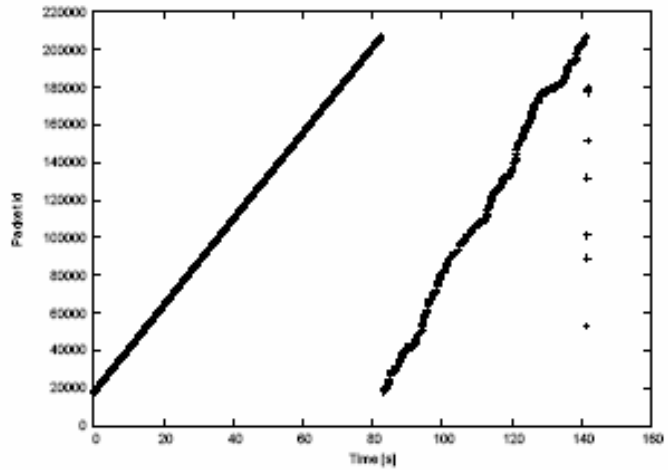
Data Transmission Performance

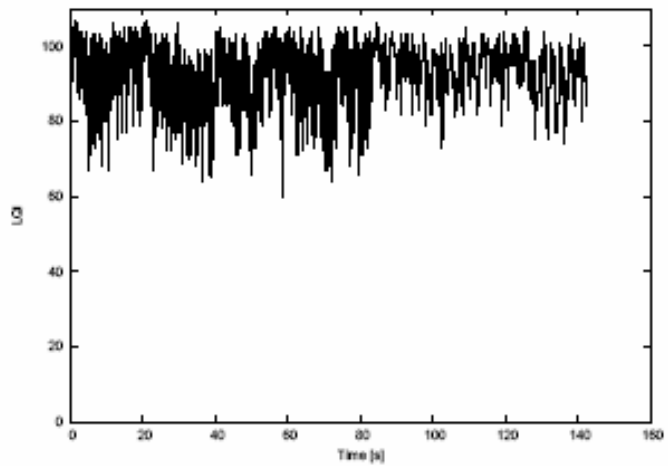
Good Link





Lossy Link





Problems we encountered

- Waterproofing the boxes
- Moisture sensor behavior in the wild
- Power consumption
- Data provenance
- Reprogramming

Conclusions

- Sensor Networks are still expensive in time, money and know-how
- Need for data analysis tools
- Need for increased confidence in collected measurements
- **End-to-End system that transforms raw measurements to *scientifically significant* data**

Questions?

- For more information
  http://www.lifeunderyourfeet.org/