# Topic 01: Case Studies in Embedded Sensor Applications

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ICTP-ITU School on Wireless Networking for Scientific Applications in Developing Countries

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# Outline

- Embedded wireless sensor networks: what? why?
  - Overview of potential applications
- Case studies (* indicates amount of detail):
  - Great Duck Island habitat monitoring (****)
  - Redwood tree micro-climate monitoring (**)
  - Volcano monitoring (**)
  - Bridge monitoring (**)
  - Industrial motor monitoring (*)

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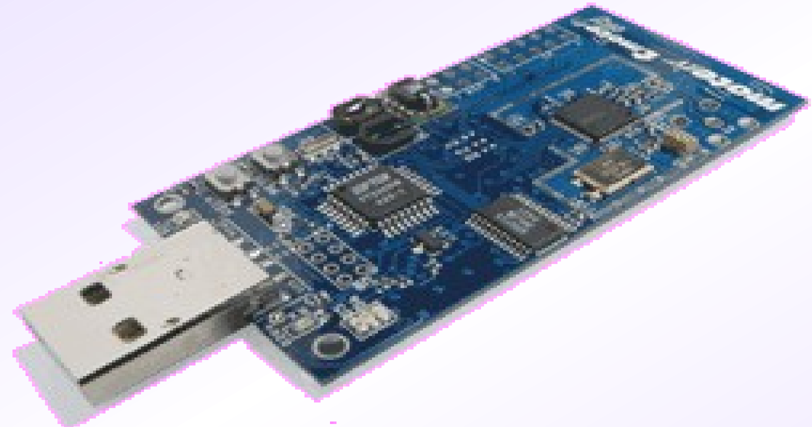
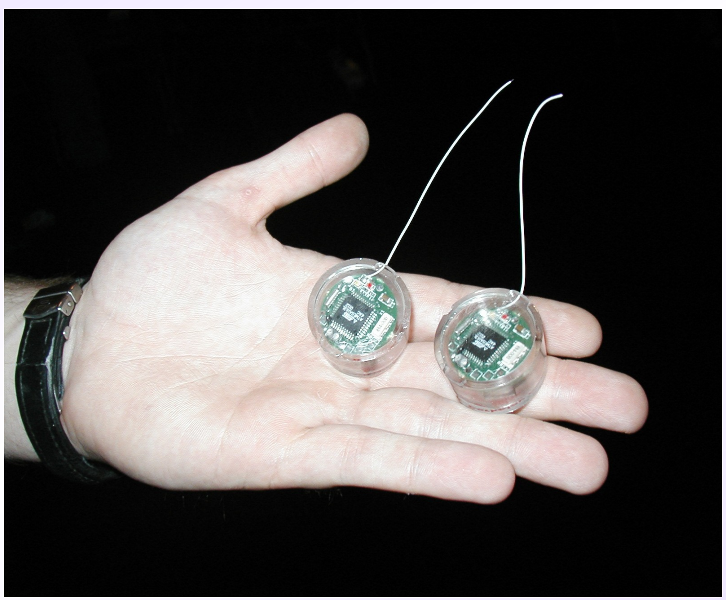
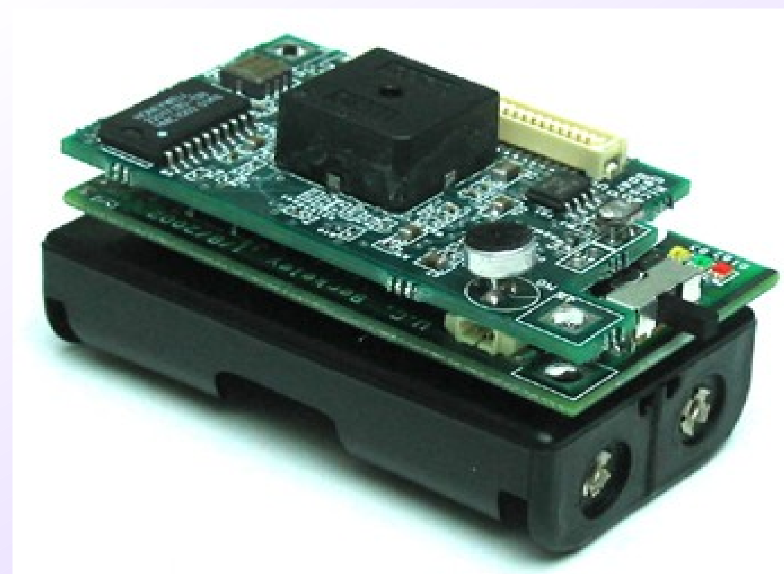
# Wireless Sensor Networks

- What are sensors?
- Why “wireless” sensor “networks”?
- What do we need to make a wireless sensor network node?
  - Sensor
  - Processing
  - Memory
  - Radio
  - Called a sensor mote

# Sensor Motes





Pictures courtesy Google

# Embedded Wireless Sensor Networks

- Trends in semi-conductor technology
  - Moore's Law
  - More silicon per unit area
  - More processing per unit area
  - Miniaturization becomes possible
- Miniaturization of: computing, radios, sensors
- Reference: "Overview of Sensor Networks", D. Culler, D. Estrin, M. Srivastava, IEEE Computer Aug 2004

# Sensor Network Applications

- Monitoring space
- Monitoring things
- Monitoring interaction of things in an encompassing space

# Applications: Monitoring Spaces

- Environmental and habitat monitoring, precision agriculture, indoor climate control

Biological: Habitat

Chemical: Rivers

Physical: Agriculture

Pictures courtesy Google

# Monitoring Things

- Structural monitoring, condition based equipment maintenance, patient health monitoring/diagnostics

Bridge Health

Equipment Maintenance

Medical Diagnostics

Pictures courtesy Google

# Monitoring Interaction of things in an encompassing space

- Wildlife tracking, disaster management, manufacturing process flow

Animal Tracking

Disaster Management

Pictures courtesy Google

# Taboo Application Space

- Non-technical, political point (any technology space which requires funding cannot be purely technical)
- For these lectures, we will talk about no military applications
- Why is this taboo?
  - What is the most technologically advanced military doing today?
  - My opinion: such applications will only add to human suffering

# Processing, Storage, Battery

- Microprocessors:
  - 1 mW at about 10MHz speed
  - Duty cycle of 1% ==> 10 micro-watts
- Memory:
  - About 10KB of RAM, 100KB of ROM
- Battery:
  - Typically about 1AH per cu.cm.
  - Solar power: 10mW per sq.cm. outdoors, 0.01-0.1mW per sq.cm. indoors
  - Mechanical vibrations: 0.1 mW

# Sensors, Radios

- Sensors:
  - Size, power consumption depends on kind of sensor
  - Typically a few mW
  - Can be quite high too
- Radios:
  - About 10-20mW for upto 10m range
  - Multi-hop network
  - Tx of 1 bit == about 1000 instructions

# Sensor Mote Requirements

- Typically long running, even up to one year
- Some basic processing and networking
- No electricity
- Interaction with environment rather than user

# Issues in Sensor Networks

- MAC, routing, data dissemination
  - Energy conservation
  - Lots of literature in this domain
- Localization, time synchronization
- Topology, power control
- Operating system or software support
- Need to look at case studies to appreciate these...

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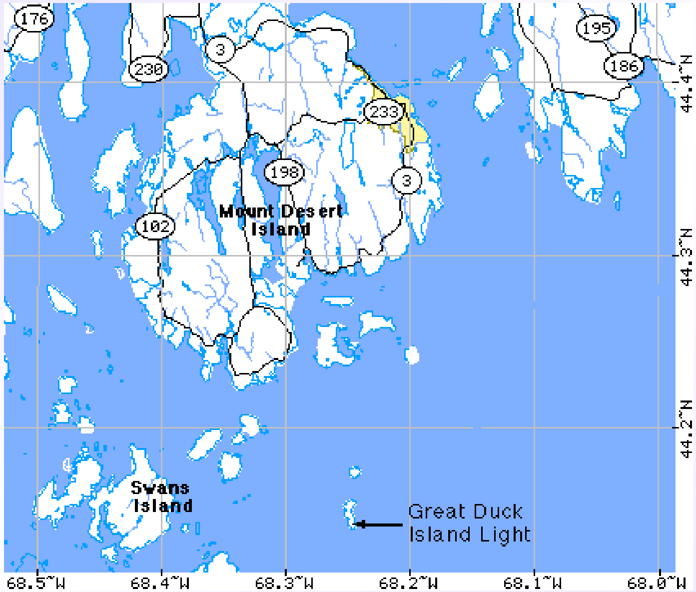
# A Detailed Study of a Sensor Network Application

- Reference: "Wireless Sensor Networks for Habitat Monitoring", A. Mainwaring, J. Polastre, R. Szewczyk, D. Culler, J. Anderson, WSNA (Wireless Sensor Networks and Applications), Sep 2002
- Monitoring seabird nesting environment (Leach's Storm Petrel)


Picture: Courtesy Google

# Great Duck Island, Maine


Pictures: Courtesy Google




# Habitat Monitoring and Sensor Networks

- Impacts of human presence on plants and animals
- Minimal disturbance is crucial while monitoring
  - Especially seabird colonies
  - 20% mortality of eggs due to a 15-min visit
  - Repeated disturbance ==> birds may abandon
  - Leach's storm petrels desert nesting burrows if disturbed in first 2 weeks of incubation
- Natural answer: wireless sensor networks

# Motivation: Life Scientists' Perspective

- Usage pattern of nesting burrows over the 24-72 hour cycle when one or both members of a breeding pair alternate incubation and feeding at sea
- Changes in burrow and surface environmental parameters during the 7-month breeding season
- Differences in micro-environments with and without large numbers of nesting petrels

# Motivation: Sensor Networks Perspective

- Application-driven approach better than abstract problem statements
  - Separate actual problems from potential ones
  - Relevant versus irrelevant issues
- Develop an effective sensor network architecture
  - Learn general solutions from specific ones

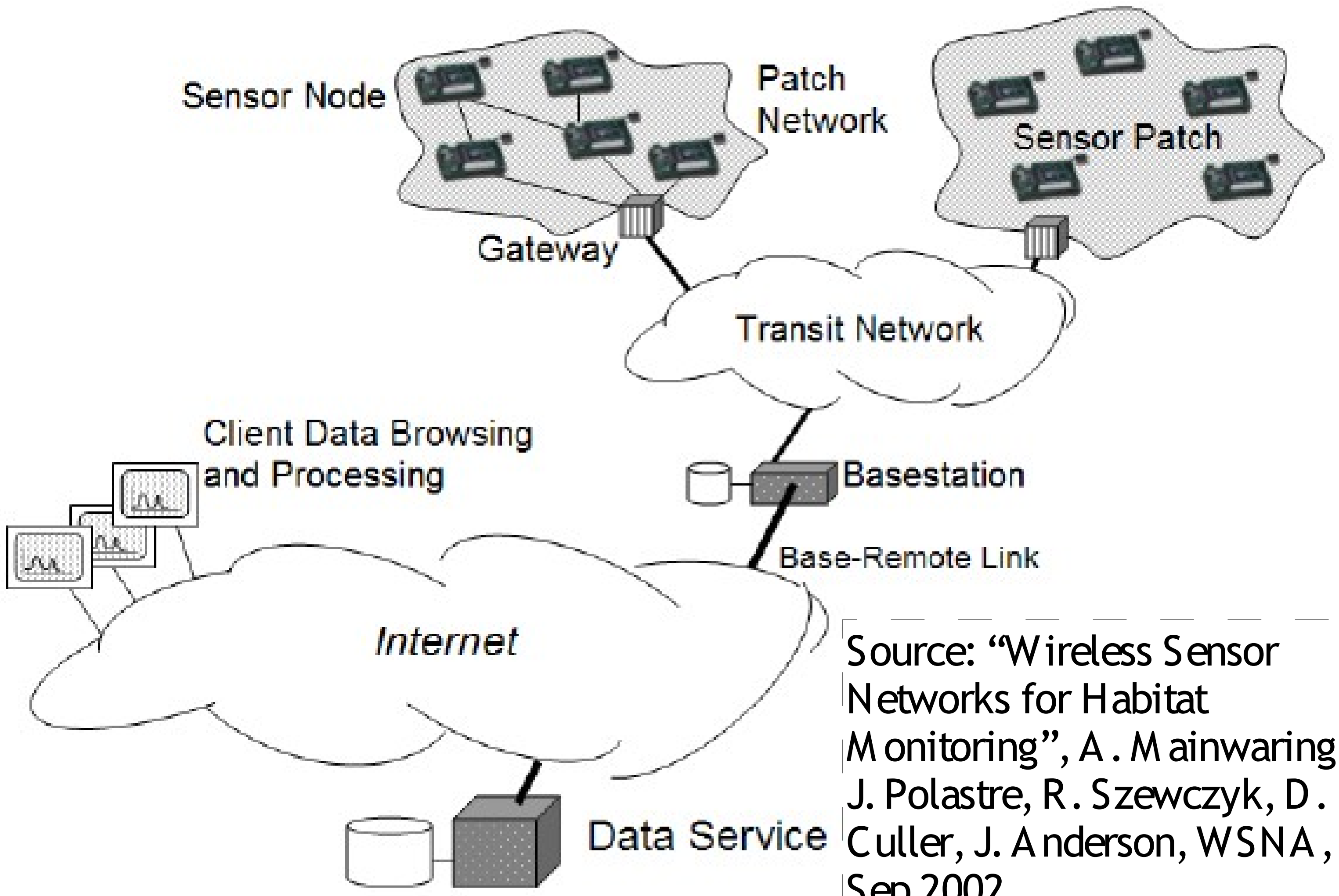
# Data Acquisition Rates

- Presence/absence data: using temperature differentials
  - Every 5-10 min
- General environmental parameters:
  - Every 2-4 hours
- Popular vs unpopular sites:
  - Every 1 hour, at the beginning of the breeding season

# System Goals

- Sensor network longevity: 9 months
  - Solar power where possible
  - Stable operation crucial
- Inconspicuous deployment
- Sensors: light, temperature, infrared, relative humidity, barometric pressure
- Remote data acquisition, management, and monitoring over the Internet
  - Interactive "drill-down"
  - In-situ operations also

# System Architecture




Source: "Wireless Sensor Networks for Habitat Monitoring", A. Mainwaring, J. Polastre, R. Szewczyk, D. Culler, J. Anderson, WSNA, Sep 2002

Figure 1: System architecture for habitat monitoring

# Remarks on the Architecture

- Hierarchical network
- Solar panel at gateways and base-station
- In-situ retasking possible
  - Example: collect temperature beyond a certain threshold, no need for all temperature readings
- Base-station has satellite connectivity
- Base-station has RDBMS, backed up every 15-min to server at UCBerkeley

# The Hardware Platform

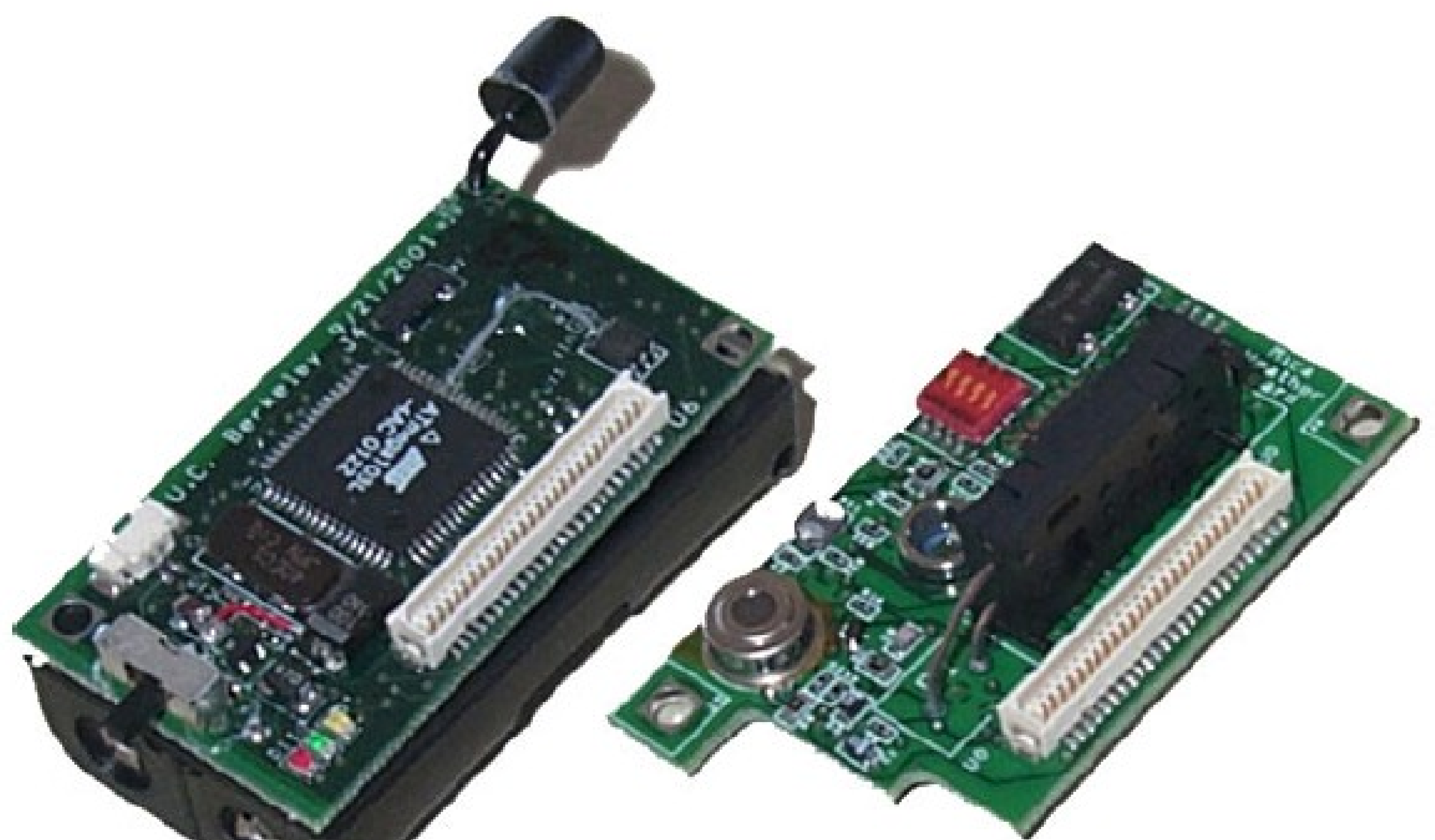


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Figure 2: Mica Hardware Platform: The Mica sensor node (left) with the Mica Weather Board developed for environmental monitoring applications

# Features of the Platform

- Mote called Mica:
  - 4MHz Atmel Atmega 103 microcontroller
  - Single channel 916 MHz radio from RF Monolithics (40Kbps)
- Battery: pair of AA + DC boost converter
- Size: 2.0 x 1.5 x 0.5 inches
- Separate sensor board called the Mica weather board

# Packaging and Deployment

Source: “Wireless Sensor Networks for Habitat Monitoring”, A. Mainwaring, J. Polastre, R. Szewczyk, D. Culler, J. Anderson, WSNA, Sep 2002

Figure 3: Acrylic enclosure used for deploying the Mica mote.

# Sensor Characteristics

| Sensor | Accuracy | Interchangeability | Sample Rate | Startup | Current |
|---|---|---|---|---|---|
| Photoresistor | N/A | 10% | 2000 Hz | 10 ms | 1.235 mA |
| $I^2C$ Temperature | 1 K | 0.20 K | 2 Hz | 500 ms | 0.150 mA |
| Barometric Pressure | 1.5 mbar | 0.5% | 10 Hz | 500 ms | 0.010 mA |
| Barometric Pressure Temp | 0.8 K | 0.24 K | 10 Hz | 500 ms | 0.010 mA |
| Humidity | 2% | 3% | 500 Hz | 500-30000 ms | 0.775 mA |
| Thermopile | 3 K | 5% | 2000 Hz | 200 ms | 0.170 mA |
| Thermistor | 5 K | 10% | 2000 Hz | 10 ms | 0.126 mA |

Table 1: Mica Weather Board: Characteristics of each sensor included on the Mica Weather Board.

Source: "Wireless Sensor Networks for Habitat Monitoring", A. Mainwaring, J. Polastre, R. Szewczyk, D. Culler, J. Anderson, WSNA, Sep 2002

# Energy Budget

**Total energy available: 2200 mAh**
**== 8.148 mAh/day x 9 months**

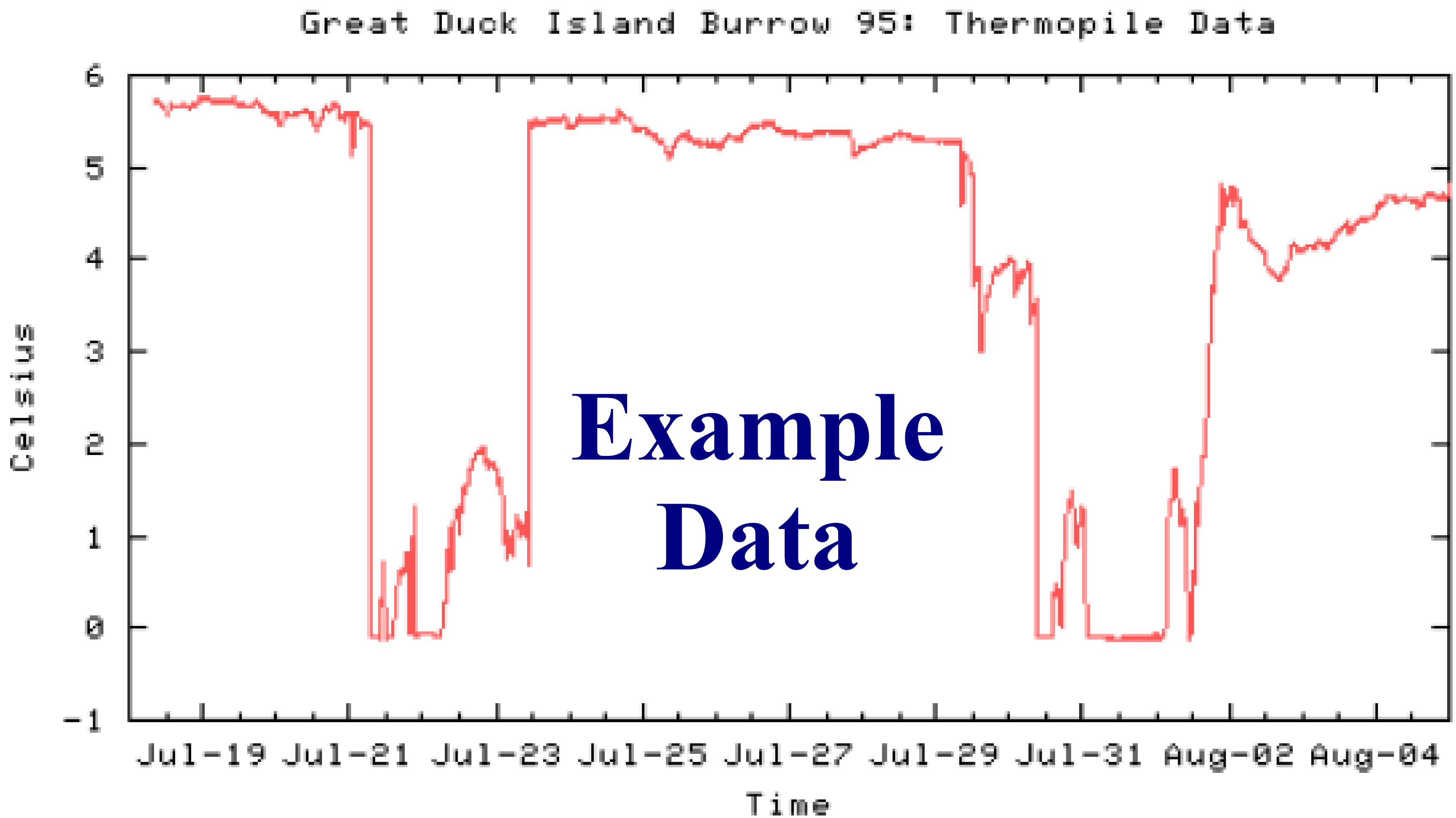
| Operation | nAh |
|---|---|
| Transmitting a packet | 20.000 |
| Receiving a packet | 8.000 |
| Radio listening for 1 millisecond | 1.250 |
| Operating sensor for 1 sample (analog) | 1.080 |
| Operating sensor for 1 sample (digital) | 0.347 |
| Reading a sample from the ADC | 0.011 |
| Flash Read Data | 1.111 |
| Flash Write/Erase Data | 83.333 |

Source: "Wireless Sensor Networks for Habitat Monitoring", A. Mainwaring, J. Polastre, R. Szewczyk, D. Culler, J. Anderson, WSNA, Sep 2002

Table 2: Power required by various Mica operations.

# Gateway: Design Choices

- 802.11b based
  - CerfCube platform: StrongArm-based
  - IBM micro-drive with 1GB storage
  - 2.5W power consumption
  - 12dBi omni-antenna ==> 1000 feet range
- Mote-mote connection
  - 14dBi directional antenna ==> 1200 feet range
- Packet reception rate was similar in either case, but former requires solar panel




Source: “Wireless Sensor Networks for Habitat Monitoring”, A. Mainwaring, J. Polastre, R. Szewczyk, D. Culler, J. Anderson, WSNA, Sep 2002

Figure 4: Thermopile data from a burrow mote on GDI during a 19-day period (July 18, 2002 to August 5, 2002).

Temperature difference due to bird (verified using recorded bird call)

# Communication Protocols

- MAC protocol, routing protocol
- Current implementation: single-hop communication to gateway
  - Periodically scheduled
- Possibilities:
  - Determine routing tree, wake up adjacent levels periodically
  - Wake up nodes along a path or subtree periodically
- Low power MAC: extend start symbol to match the wake-up frequency

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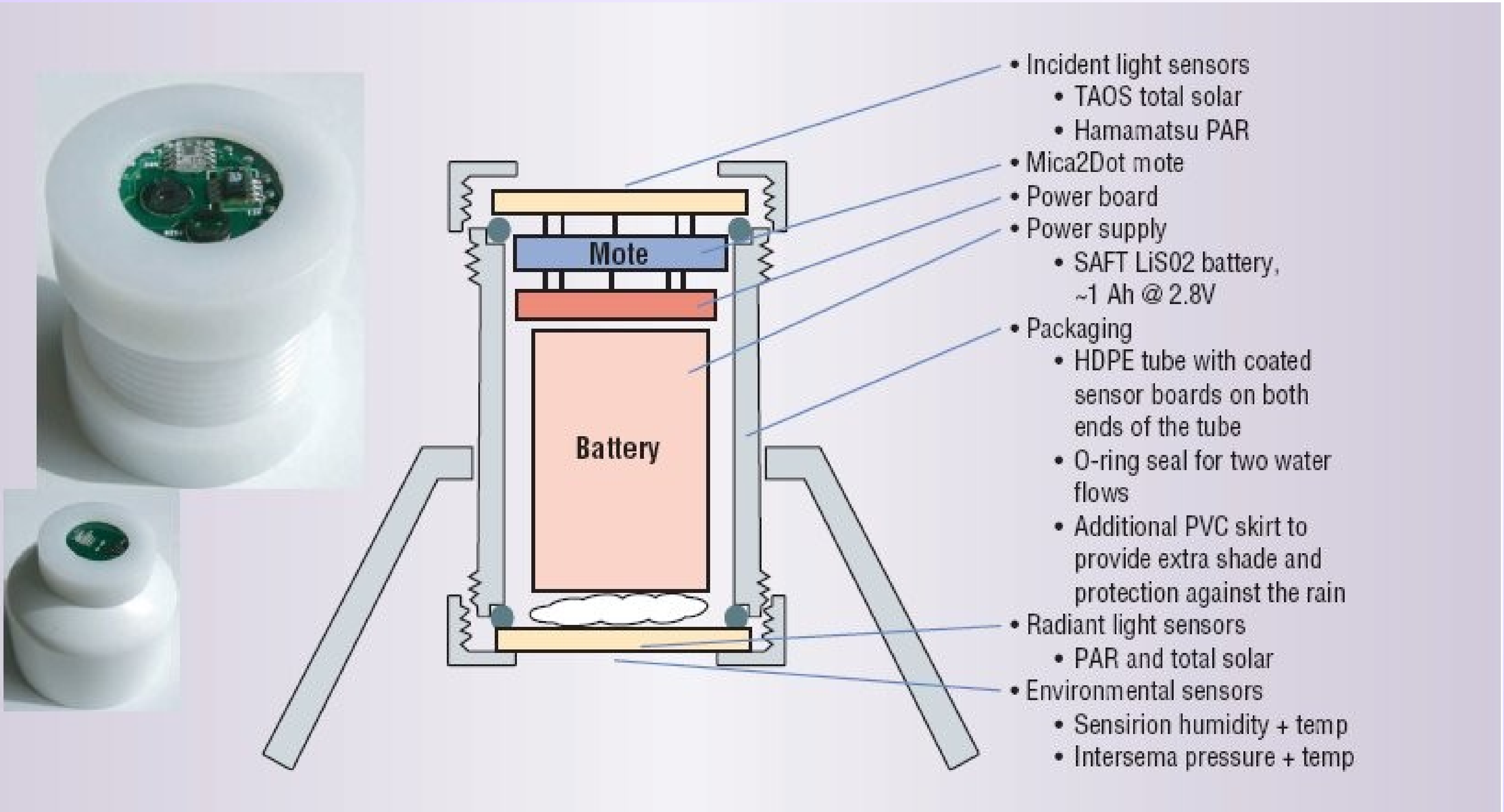
# Environment Monitoring: Example

- Redwood trees: microclimate monitoring
  - Rate of photosynthesis
  - Water and nutrient transport
  - Growth patterns
- Prior approach: suite of instruments, wires
- Can use wireless sensors instead

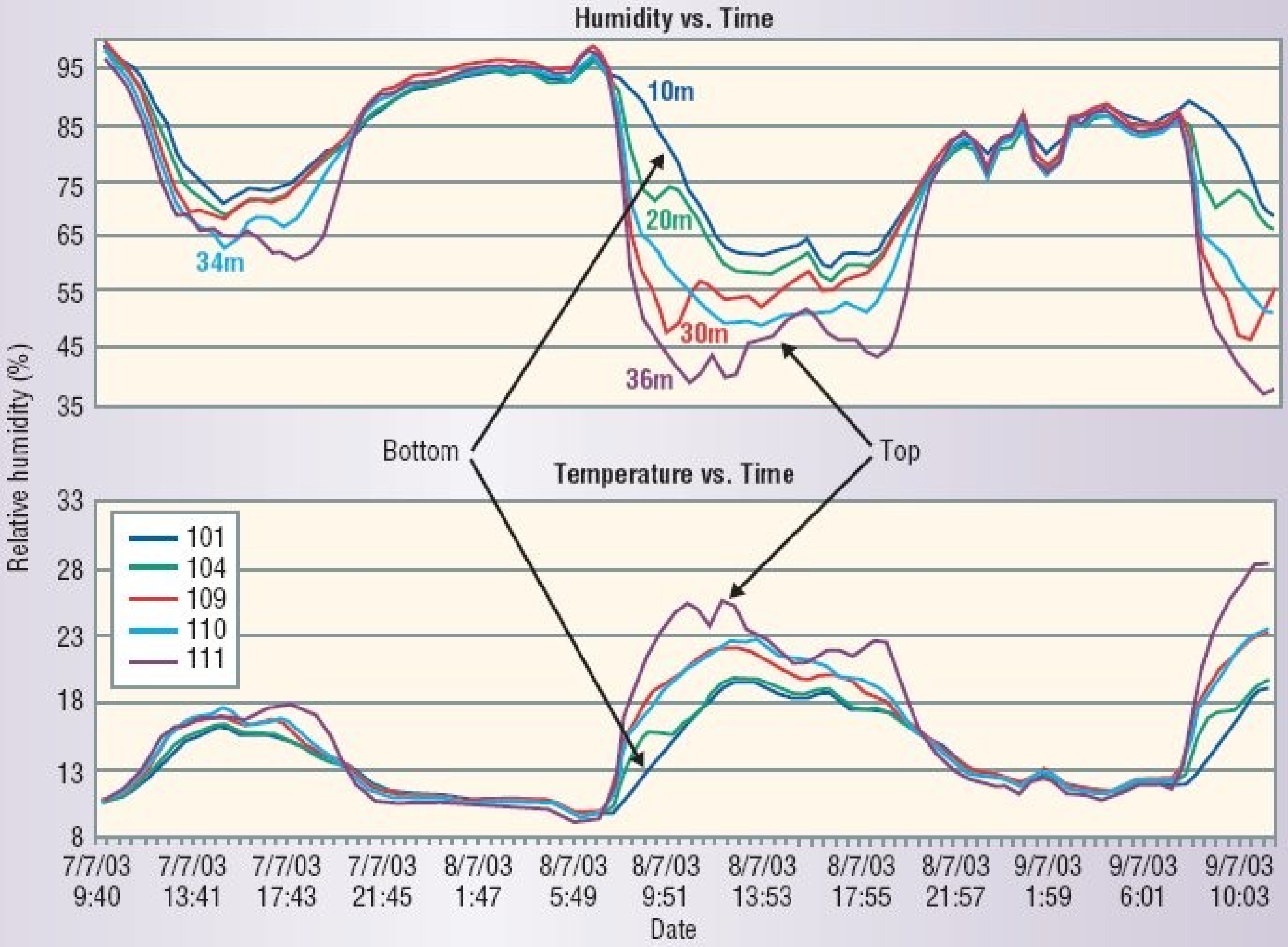
Source: Overview of Sensor Networks, D. Culler, D. Estrin, M. Srivastava, IEEE Computer Aug 2004

# The Sensor Node




Source: Overview of Sensor Networks, D. Culler, D. Estrin, M. Srivastava, IEEE Computer Aug 2004

# Some Measurements



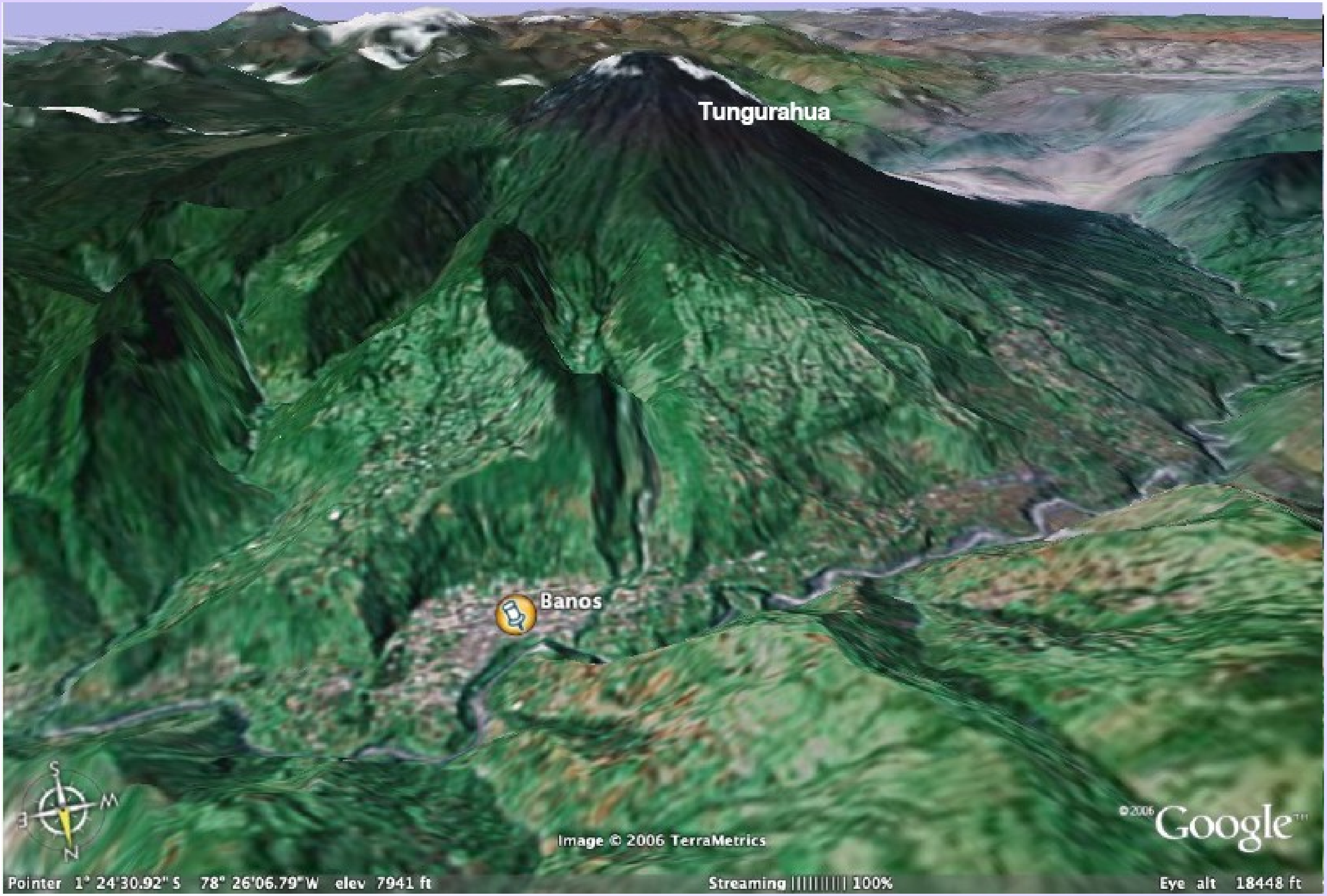

Source: Overview of Sensor Networks, D. Culler, D. Estrin, M. Srivastava, IEEE Computer Aug 2004

# Wireless Sensor Network for Volcano Monitoring

- Reference: “Deploying a Wireless Sensor Network on an Active Volcano”, Geoffrey Werner-Allen, Konrad Lorincz, Matt Welsh, Omar Marcillo, Jeff Johnson, Mario Ruiz, Jonathan Lees, IEEE Internet Computing, Mar/Apr 2006

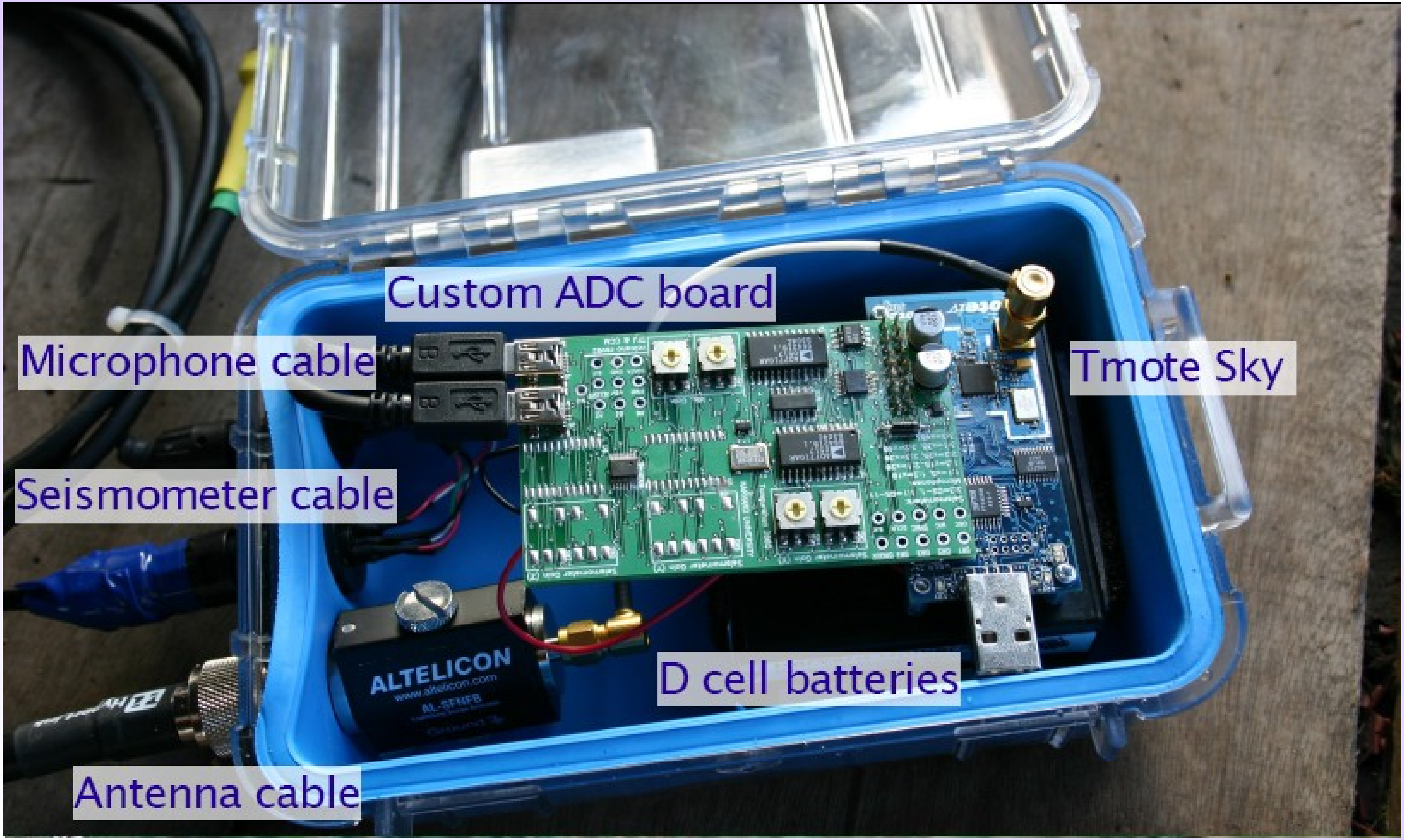
Source: “Deploying a Wireless Sensor Network on an Active Volcano”, G. Werner-Allen et. al., IEEE Internet Computing, Mar/Apr 2006

# Tungurahua, Ecuador




Source: "Deploying a Wireless Sensor Network on an Active Volcano", Presentation by Matt Welsh, Harvard University

# Monitoring Equipment




Source: “Deploying a Wireless Sensor Network on an Active Volcano”,
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# Sensor Network Architecture

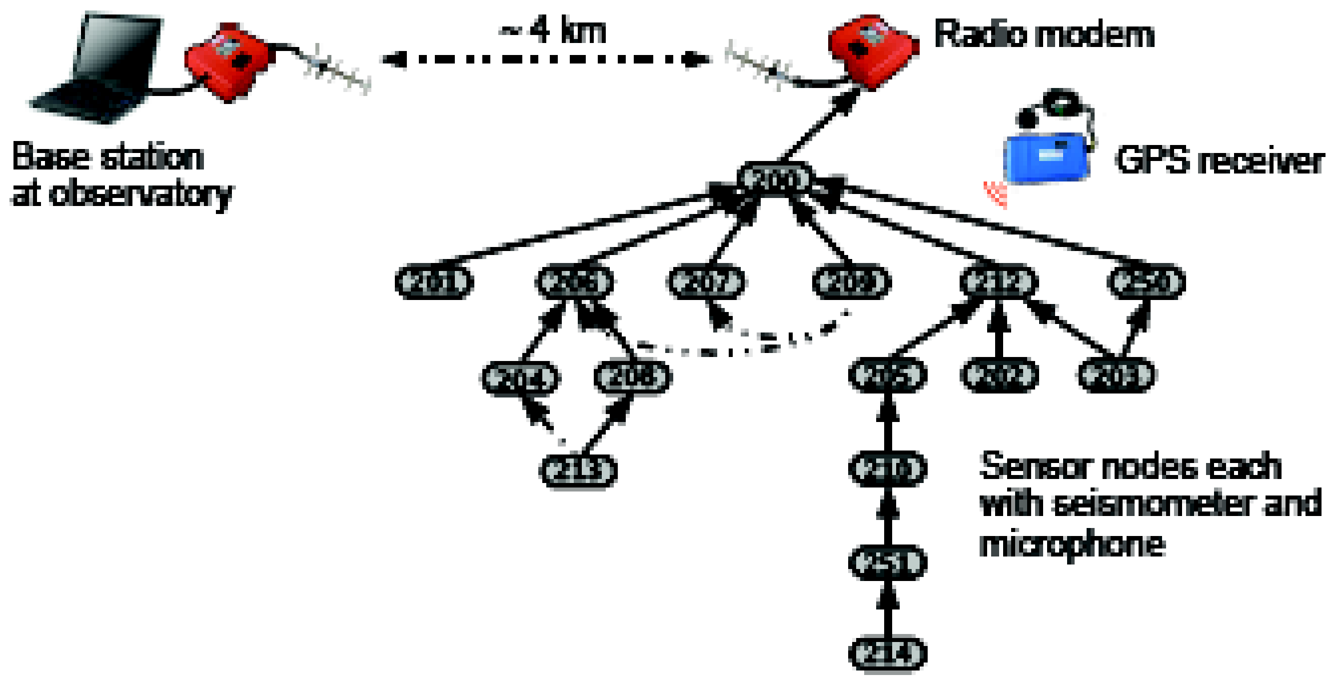



Figure 2: **Sensor network architecture.** *Nodes form a multihop routing topology, relaying data via a long-distance radio modem to the observatory. A GPS receiver is used to establish a global timebase. The network topology shown here was used during our deployment at Reventador.*

Source: “Fidelity and Yield in a Volcano Monitoring Sensor Network”, G. Werner-Allen et. al., OSDI 2006

# Deployment Map

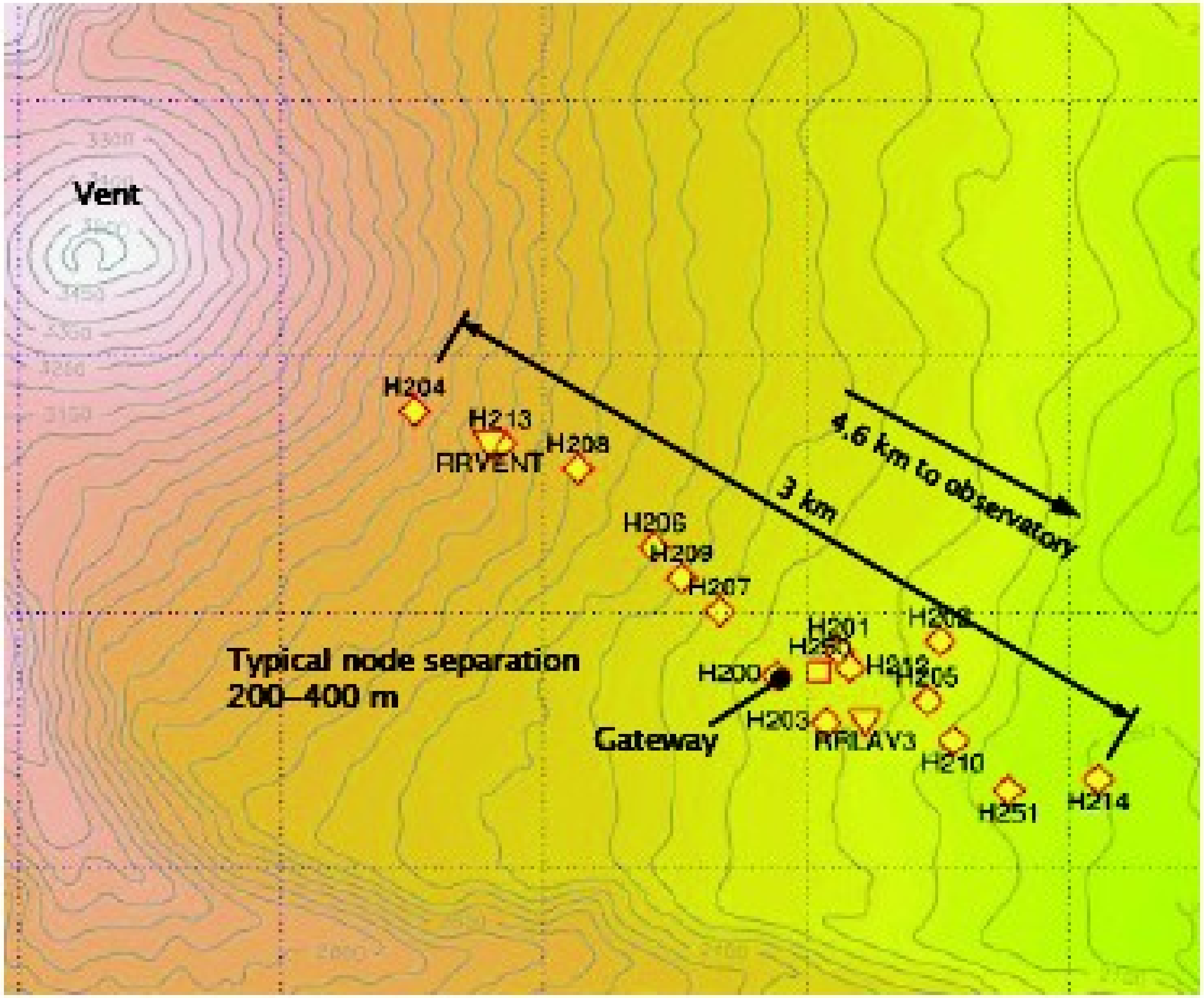


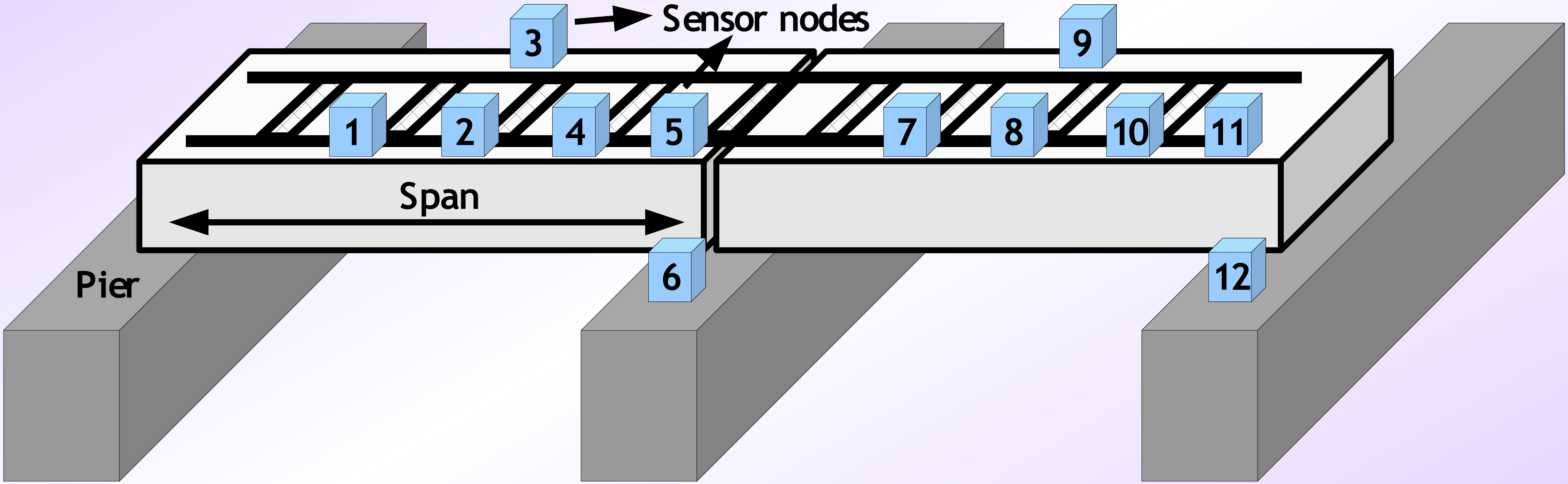

Figure 3: **Map of sensor deployment at Volcán Reventador.** *In addition to the 16 sensor nodes, two broadband seismometers with data loggers (RRVENT and RRLAV3) were colocated with the network.*

Source: "Fidelity and Yield in a Volcano Monitoring Sensor Network", G. Werner-Allen et. al., OSDI 2006

# Challenges Encountered

- Event detection: when to start collecting data?
- High data rate sampling
- Spatial separation between nodes
- Data transfer performance: reliable transfer required
- Time synchronization: data has to be time-aligned for analysis by seismologists

# BriMon: Wireless Sensor Network based Bridge Monitoring




**Two main issues: (1) Event detection, (2) Data transfer**

Project at IIT-Kanpur: http://www.cse.iitk.ac.in/users/braman/brimon.html

# BriMon Field Trip (1/2)

# BriMon Field Trip (2/2)

# More Applications: Industrial Monitoring

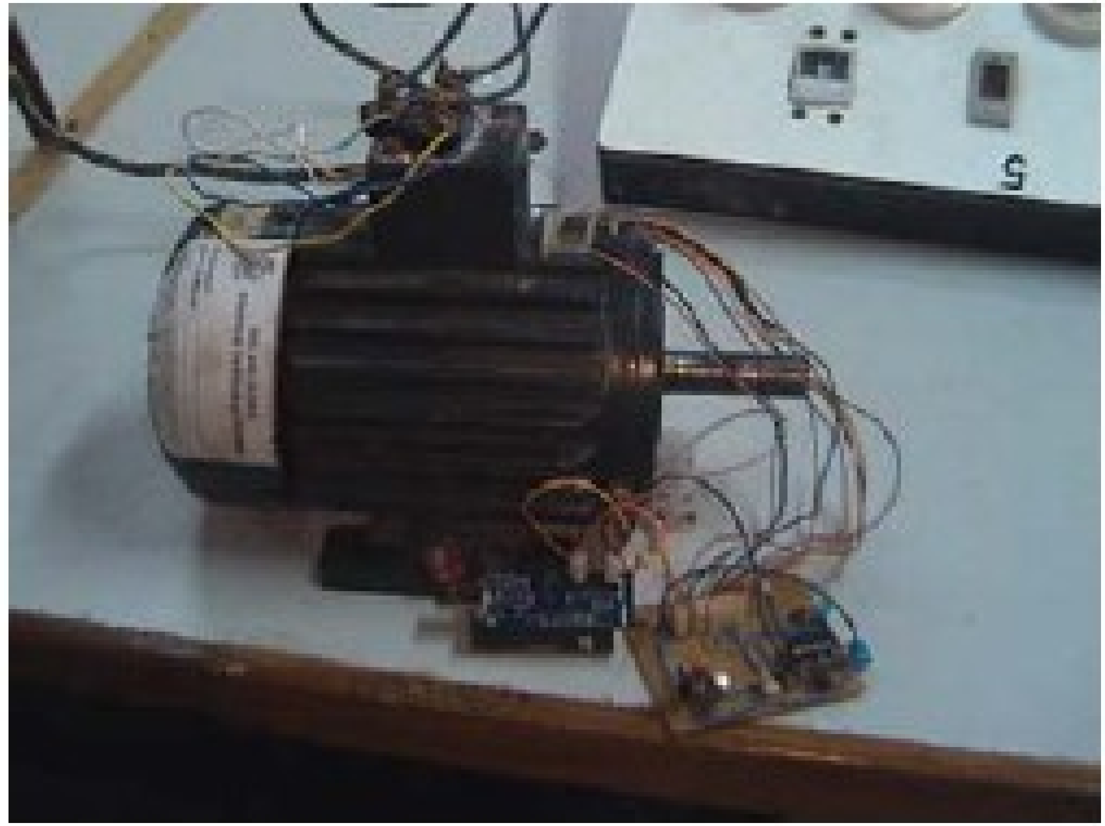


Fig. 7. Motor with sensor mounted

Source: "WiBeaM:Wireless Bearing Monitoring System", Lt Cdr VMD Jagannath, Bhaskaran Raman, WISARD 2007.

# Challenge

- Lots of sensor network literature claims: applications involving 100s or 1000s of nodes
- Think of one such application
  - Must be as well grounded as possible (preferably an extension of something which has already been built)
  - Specify what is being sensed, how often, etc.
  - Ensure that a sensor "network" is needed
  - Preferably non-military

# Summary

- Embedded Wireless Sensor Networks:
  - Possible today due to advances in several domains
  - Some interesting applications have been built