CS263: Wireless Communications and Sensor Networks

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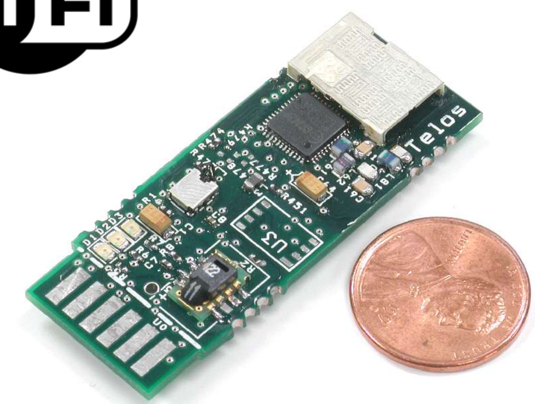
Lecture 1: Course Introduction
September 20, 2005

Welcome to CS263!

Wireless networks are everywhere ...

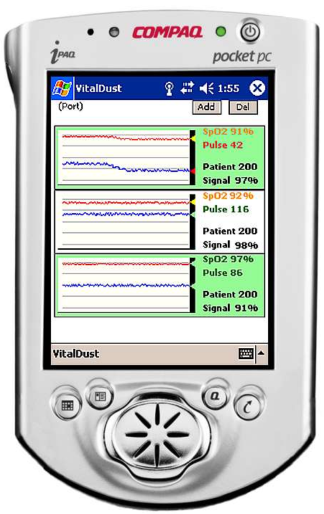
This course is all about wireless communications

- Basics of radio communication
- The deep guts of how wireless LANs work
- Specific standards: 802.11, Bluetooth, 802.15.4



With a focus on *wireless sensor networks*

- Exciting new technology: small, low-power, wireless devices with sensors
- You will develop sensor net applications and test them on a real network



Course Overview

Course is roughly divided into three parts:

Part 1: Survey of wireless network technologies

- Radio communication fundamentals, antennas, and propagation
- Coding schemes, broadband, medium access control
- Wireless networking standards: 802.11, Bluetooth, and 802.15.4

Part 2: Research papers on wireless networks

- Ad-hoc routing, TCP/IP in mobile environments
- Community wireless networks

Part 3: Sensor networks (about ½ of the course)

- Exciting new technology: small, low-power, wireless devices with sensors
- Applications, operating systems, power management
- Programming models, querying, network storage, distributed algorithms
- Localization, time synchronization, and security

Goals of this class

Learn about wireless networks and sensor networks

Read research papers on exciting new topics

Experiment with a real sensor network

Do a research project on your favorite topic

Hopefully, publish a paper on your work

Wireless Networking Overview

Wireless Local Area Networks (WLANs)

- Wide range of technologies for local, high-data-rate, wireless communications
- Very different than wide area networking, e.g., cellular, GSM, CDPD, etc.

Physical Layer (PHY)

- How devices transmit binary data over the airwaves
- Determined by frequency range, transmit power, modulation scheme, etc.

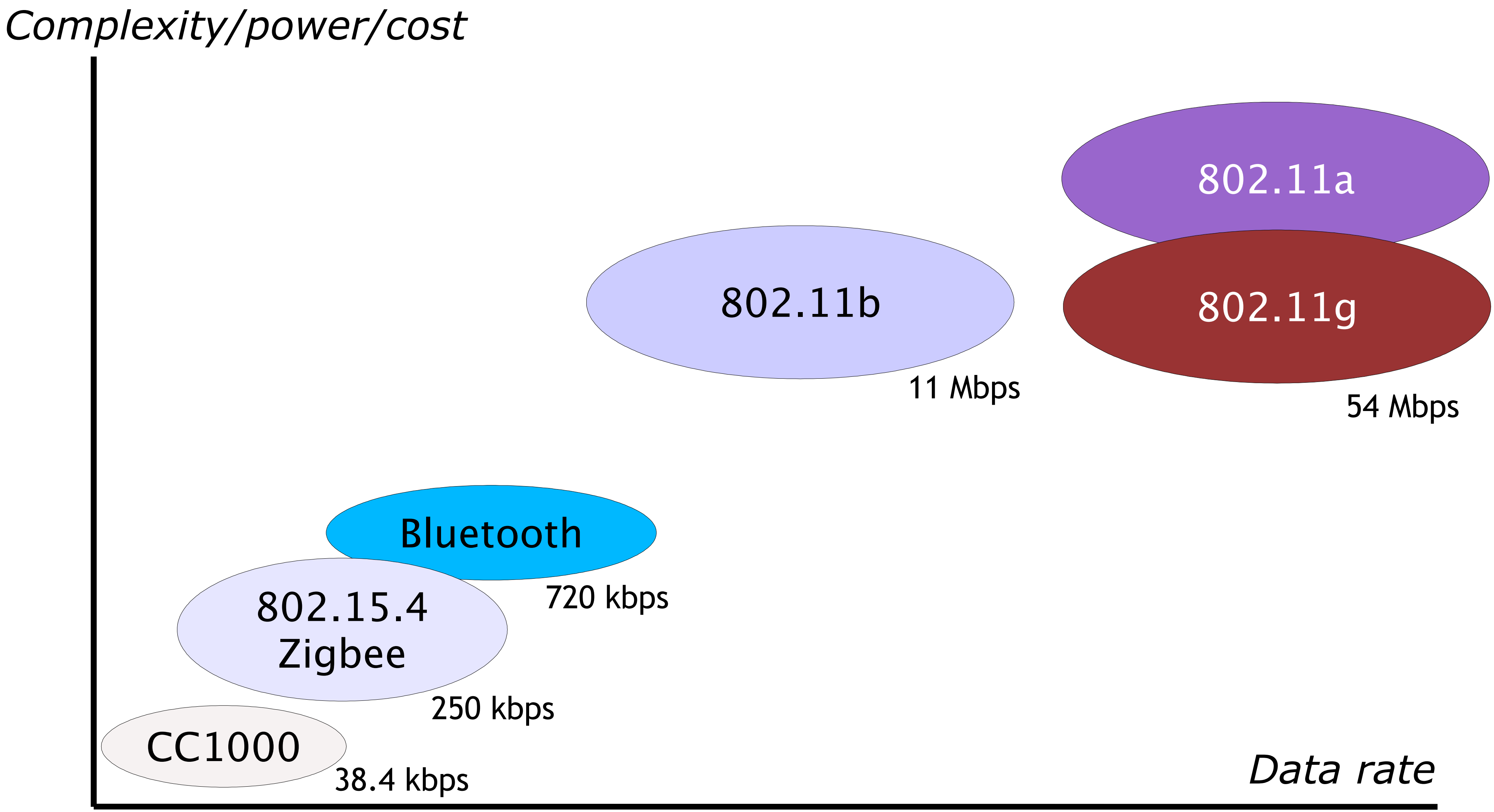
Medium Access Control (MAC)

- How devices share the radio channel and avoid interfering with one another
- “Listen before you speak” or “Only speak at certain predetermined times”

Network Layer

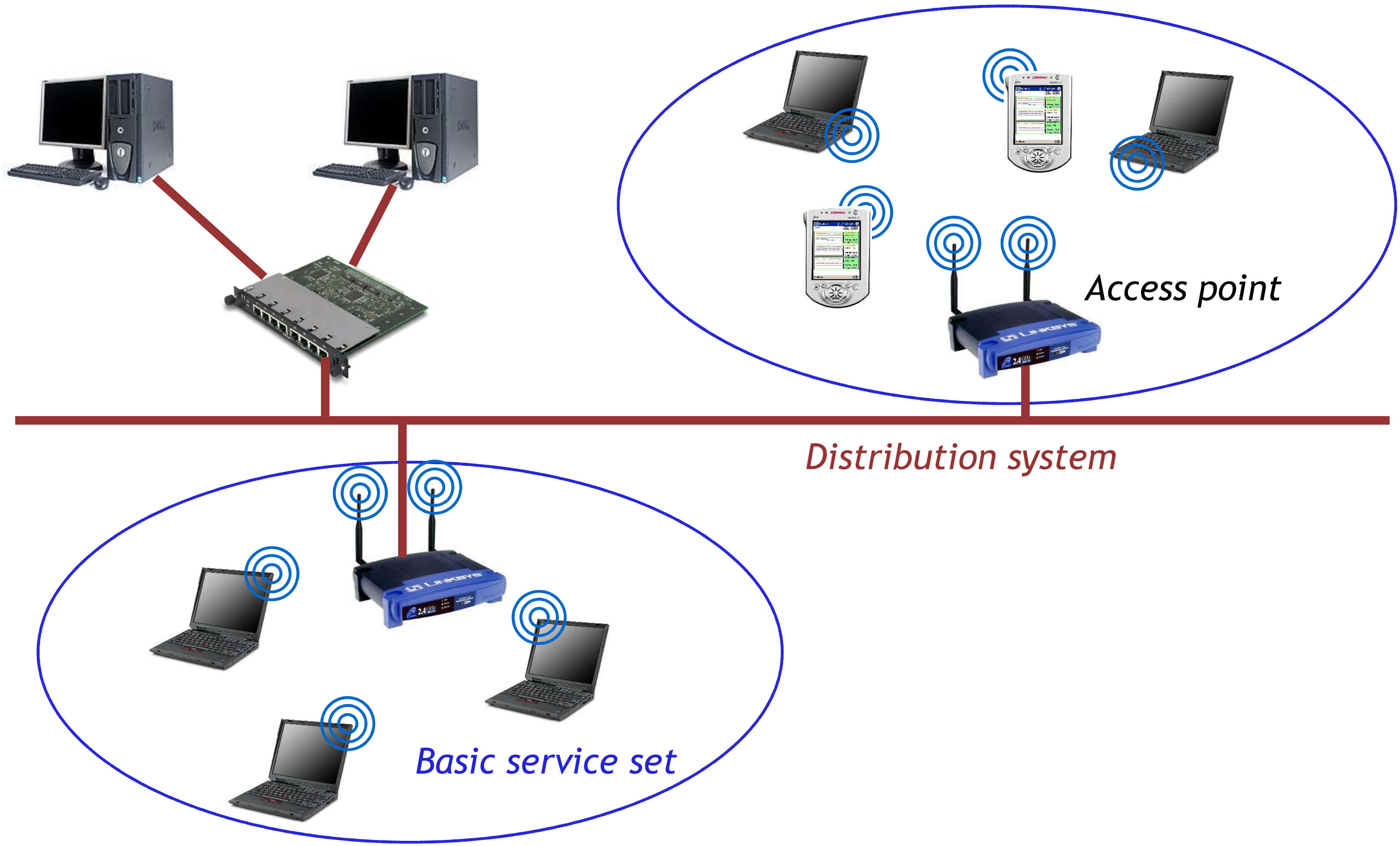
- How multiple devices in a wireless network talk to each other
- May involve devices relaying messages to each other (*multihop routing*)

Technology Space



802.11 / WiFi

The most popular Wireless LAN standard



Bluetooth

Short-range, moderate data rate wireless link for personal devices

- 720 Kbps, 10 m range

One master and up to 7 slave devices in each *Piconet*:

Master controls transmission schedule of all devices in the Piconet

- Time Division Multiple Access (*TDMA*): Only one device transmits at a time

Frequency hopping used to avoid collisions with other Piconets

- 79 physical channels of 1 MHz each, hop between channels 1600 times a sec

IEEE 802.15.4 and Zigbee

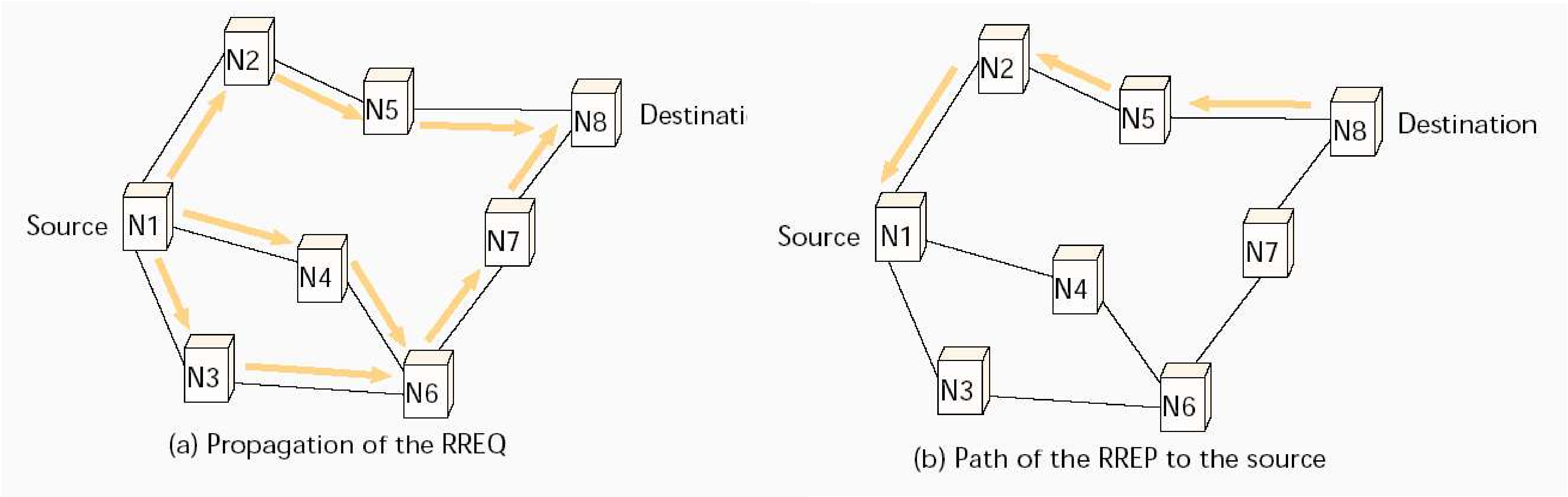
Emerging standard for low-power wireless monitoring and control

- 2.4 Ghz band, 250 kbps data rate

Chipcon/Ember CC2420: Single-chip 802.15.4 radio transceiver, $5

- 1.8V supply, consumes 19.7 mA receiving, 17.4 mA transmit
- Easy to integrate: Open source software drivers
- All PHY and encryption in hardware
- O-QPSK modulation, "plays nice" with 802.11 and Bluetooth

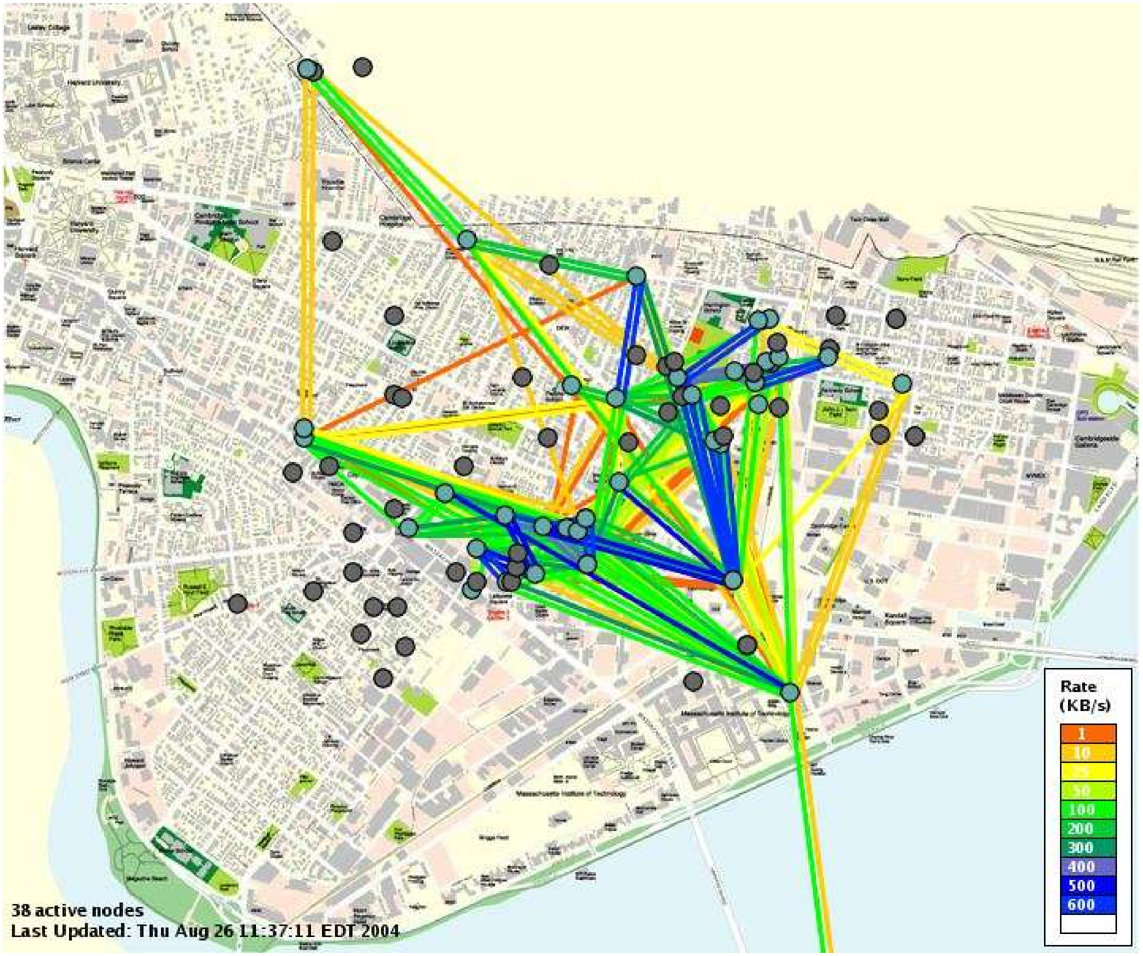
Ad Hoc Routing



How to route messages along a complex graph of moving nodes?

- Nodes are mobile wireless devices (e.g., laptops or PDAs)
- When nodes move, connectivity changes...
- Must avoid overheads such as flooding entire network to discover new routes

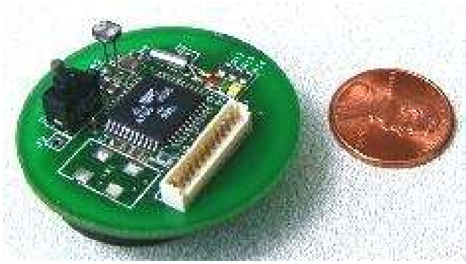
RoofNet



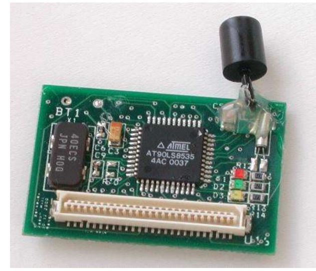
MIT community wireless network

- How to organize a network of rooftop 802.11 nodes to provide Internet connectivity to a large community?

Sensor Networks



WeC (1999)



Rene (2000)

Dot (2001)

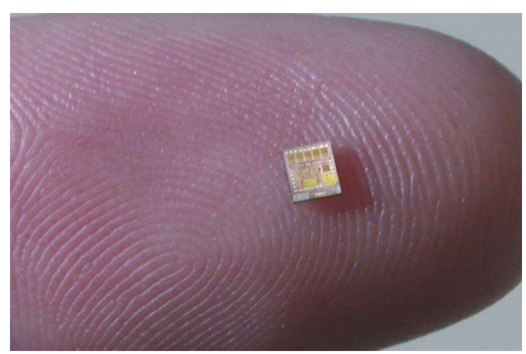
Integration of sensing, computation, and communication

- Low-power, wireless “motes” with tiny amount of CPU/memory
- Large federated networks for high-resolution sensing of environment

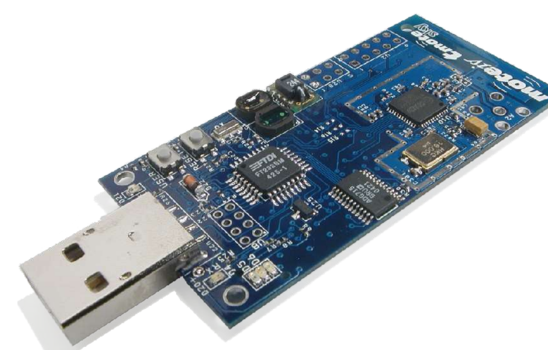
Drive towards miniaturization and low power

- Eventual goal - complete systems in 1 mm^3, MEMS sensors

MICA (2002)

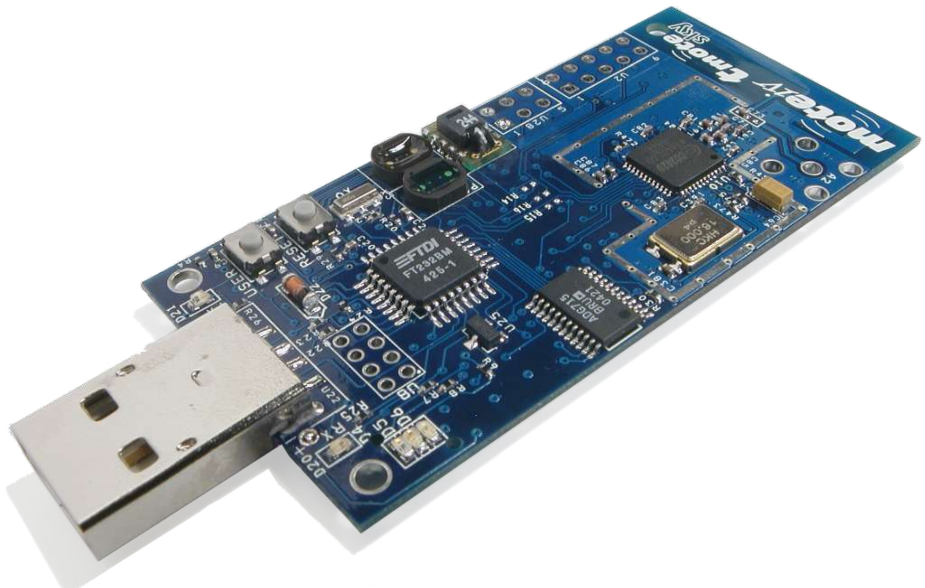


Speck (2003)



Telos (2004)

The Telos “Mote”



- TI MSP430 processor
- 128 KB code, 2 KB data SRAM
- 512 KB flash
- CC2420 radio (2.4 Ghz, 802.15.4)
- 250 kbps, 100 m range

Several thousand produced, used by 100s of research groups

Great platform for experimentation (though not particularly small)

- Easy to integrate new sensors & actuators
- 15-20 mA active (5-6 days on 2 AAs)
- 5 µA sleeping (40+ years, but limited by shelf life of battery!)

You will get a “kit” of 3 Telos motes to experiment with

Sensor Network Challenges

Low computational power

- Current mote processors run at < 10 MIPS
- Not enough horsepower to do real signal processing
  - *DSP integration may be possible*
- 4 KB of memory not enough to store significant data

Poor communication bandwidth

- Current radios achieve about 10 Kbps per mote
- Note that raw channel capacity is much greater
  - *Overhead due to CSMA backoff, noise floor detection, start symbol, etc.*
- 802.15.4 (Zigbee) radios now available at 250 Kbps
  - *But with small packets one node can only transmit around 25 kbps*

Limited energy budget

- 2 AA motes provide about 2850 mAh
- Coin-cell Li-Ion batteries provide around 800 mAh
- Solar cells can generate around 5 mA/cm^2 in direct sunlight
- Must use low duty cycle operation to extend lifetime beyond a few days

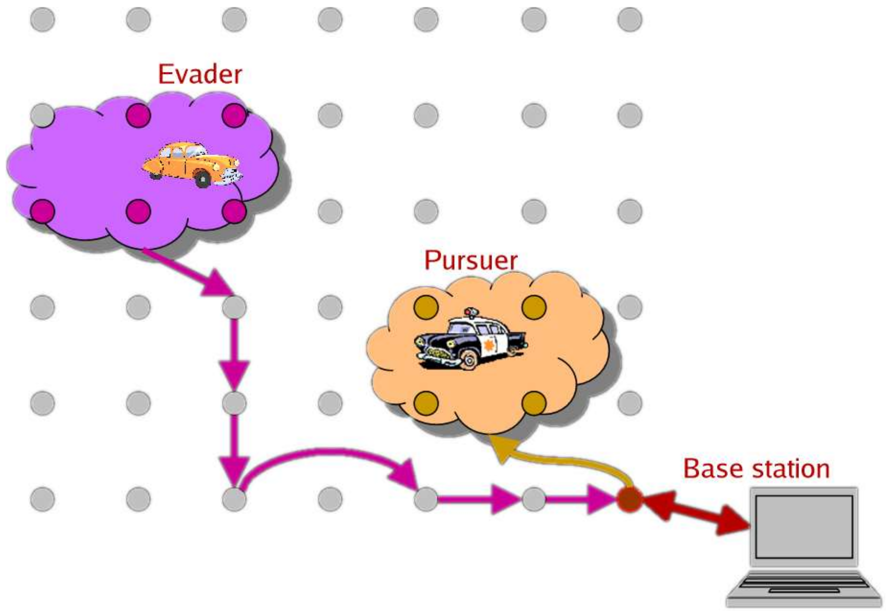
Typical Applications

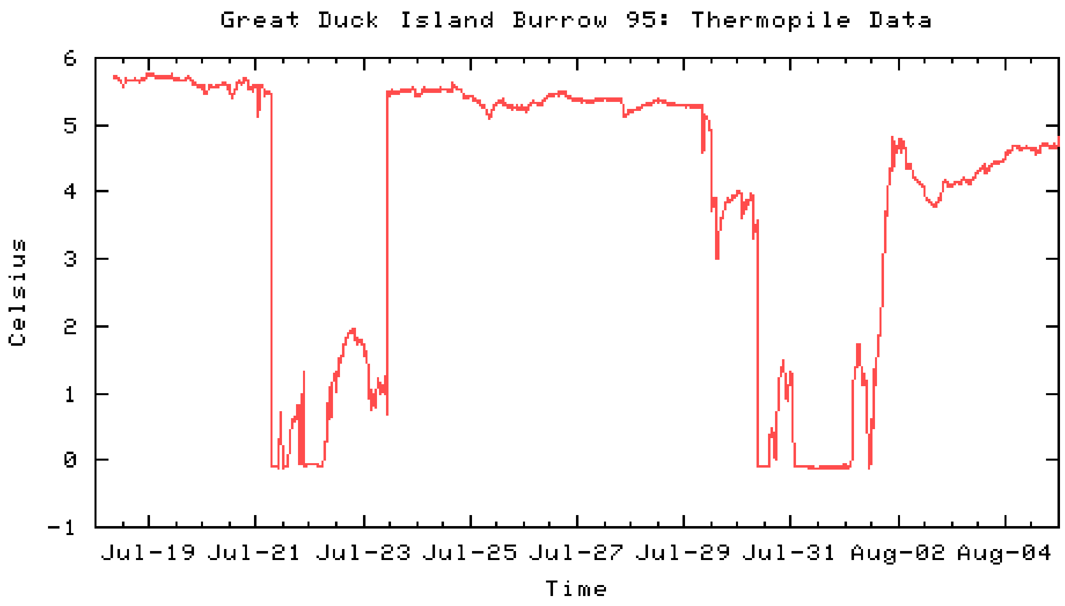
Vehicle tracking

- Sensors take magnetometer readings, localize object
- Communicate using geographic routing to base station
- Robust against node and radio link failures

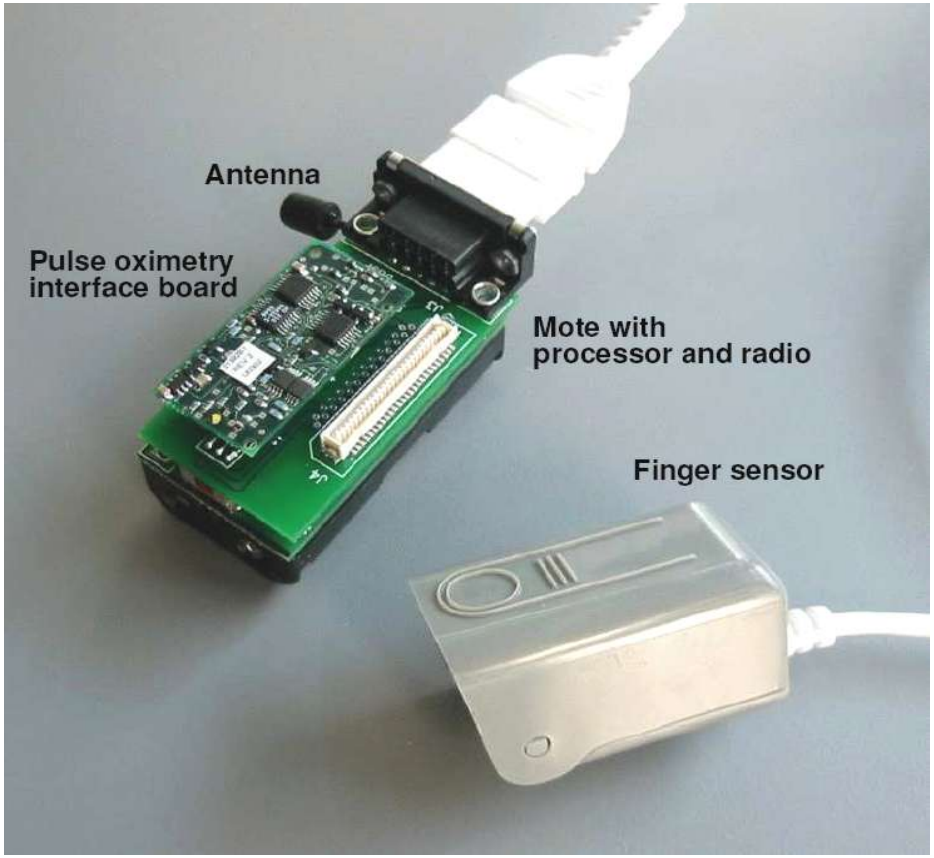
Habitat monitoring – Great Duck Island

- Gather temp, IR, humidity, and other readings from bird nests on island
- Determining occupancy of nests to understand breeding & migration behavior
- Live readings at www.greatduckisland.net

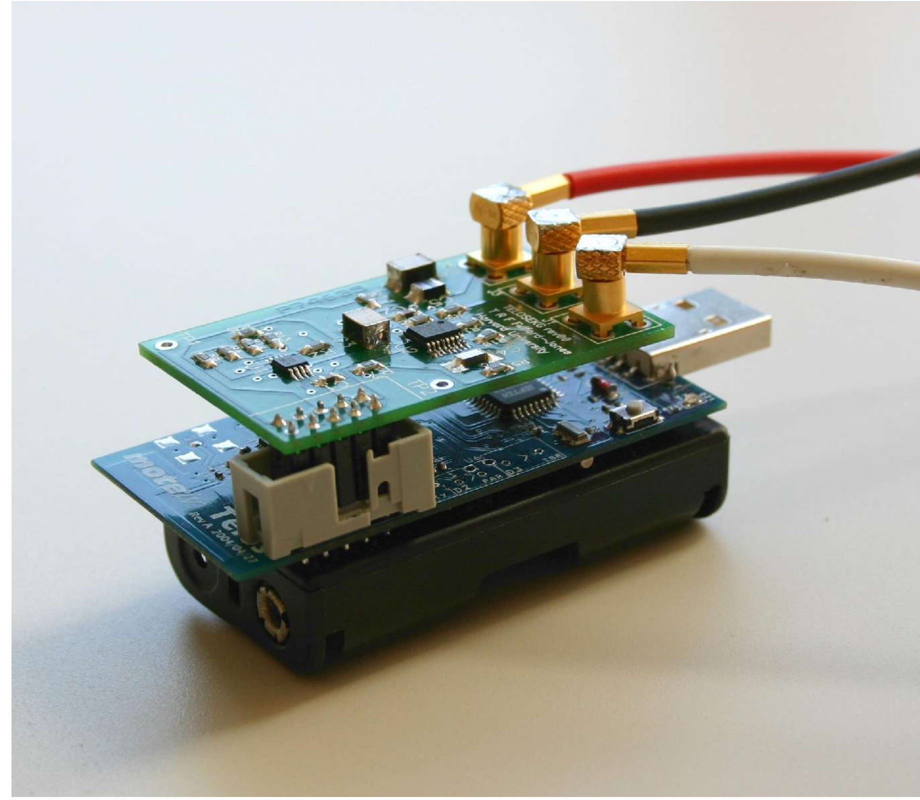




Applications: Medical Care



Pulse oximeter

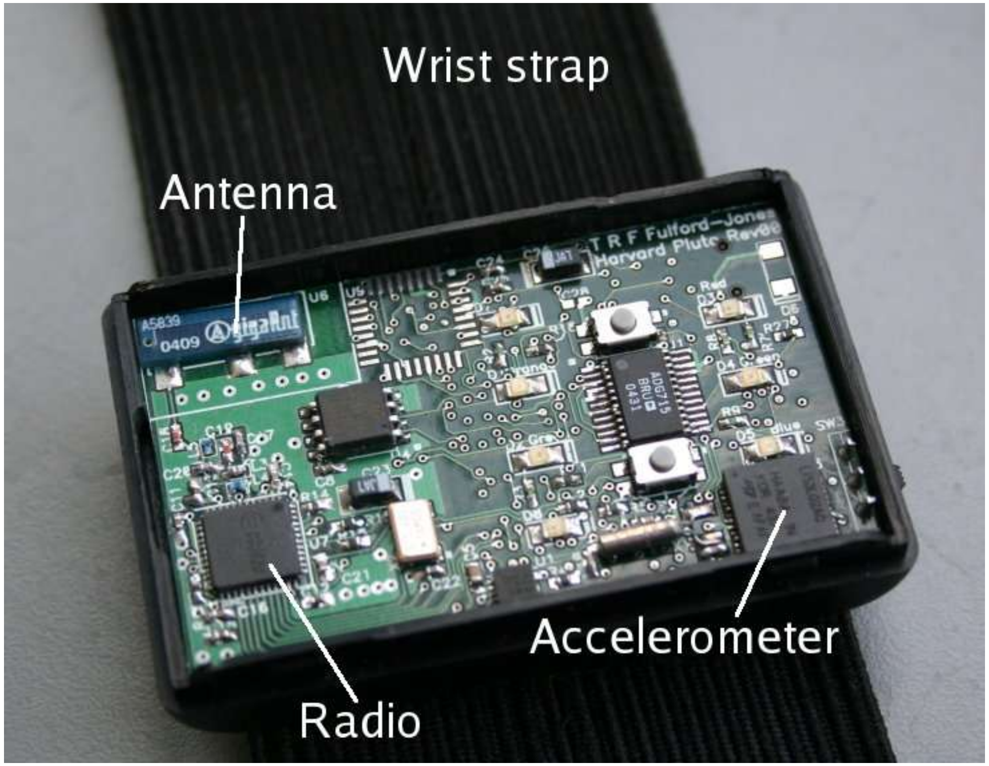


Two-lead EKG

Harvard wireless vital sign sensors

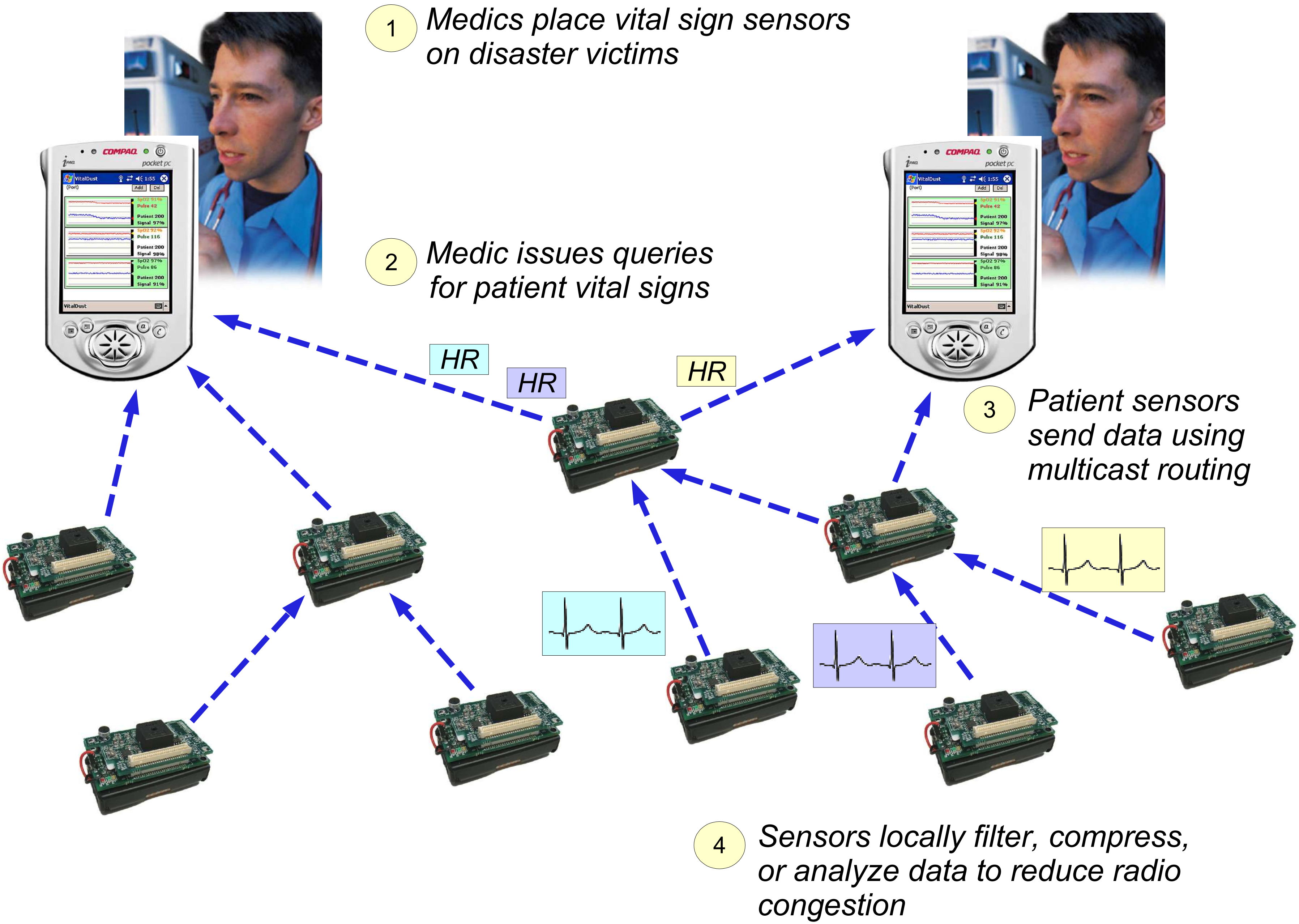
- Vital sign data encrypted over radio
- About 30mA current consumption without duty cycling optimizations

The Harvard Pluto Mote

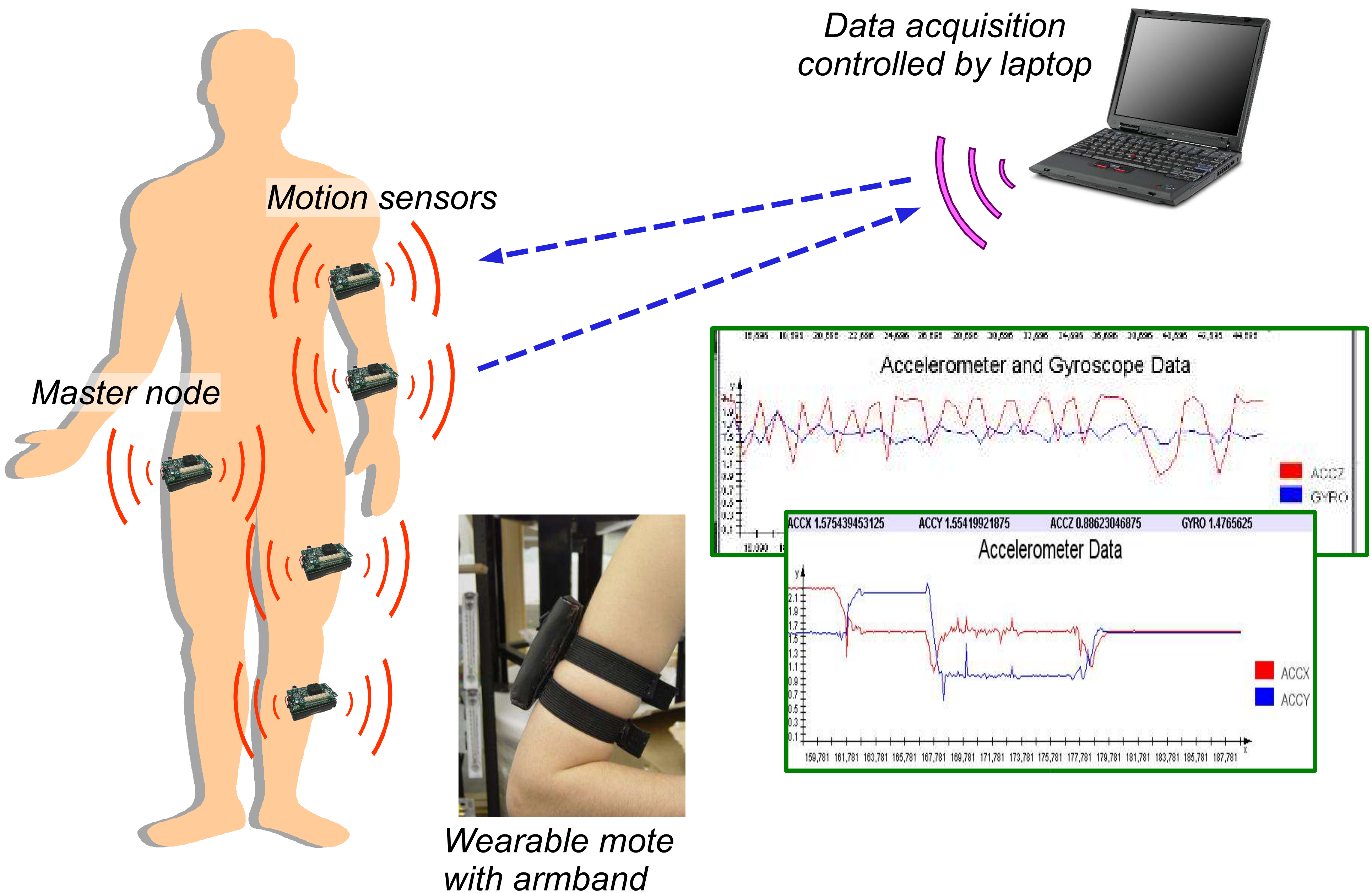


- Designed for wearable applications
  - 3-axis accelerometer
  - Tiny rechargeable battery

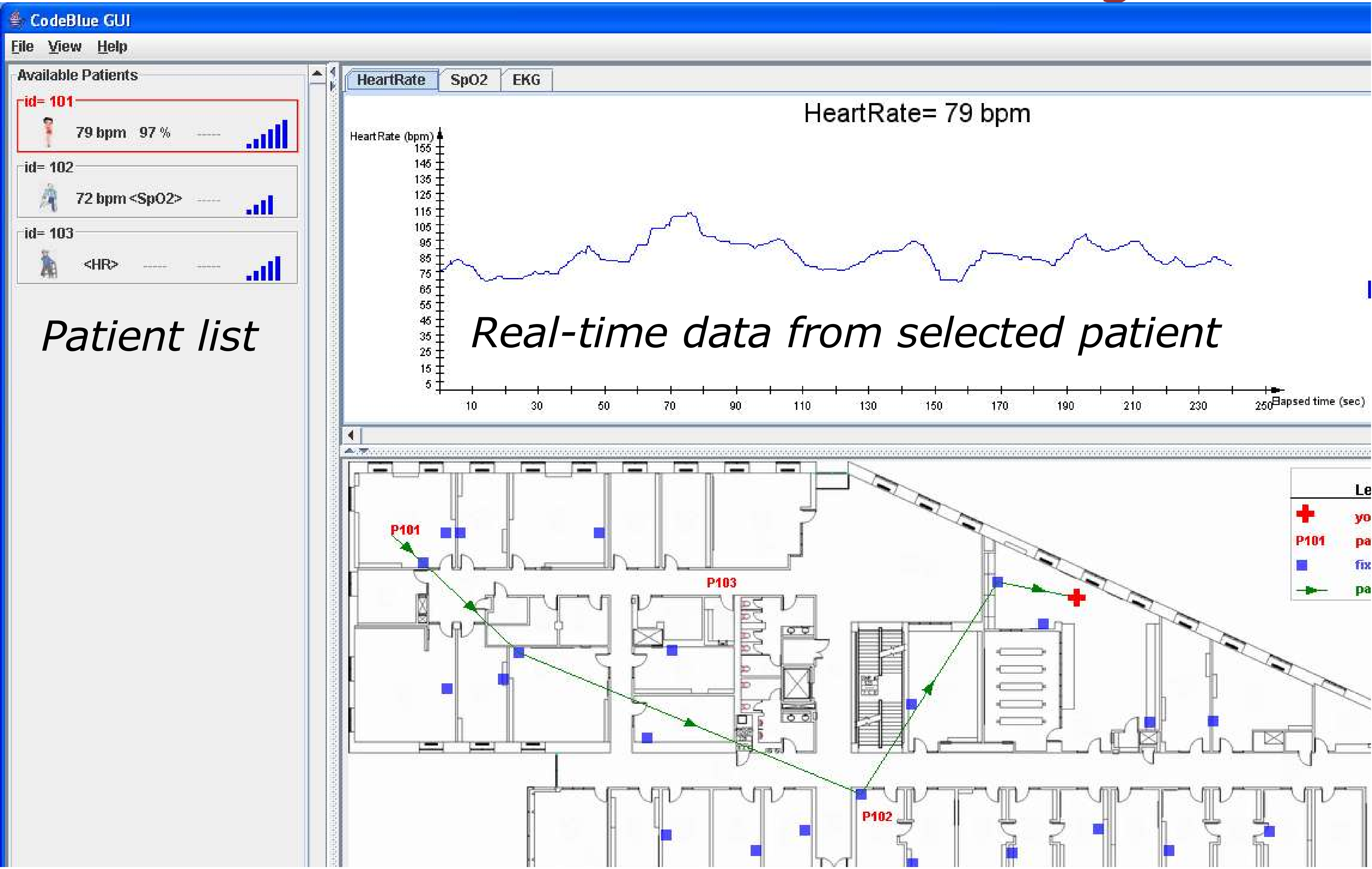
The CodeBlue Network Infrastructure



CodeBlue use in Clinical Settings



GUI for Real-Time Patient Tracking

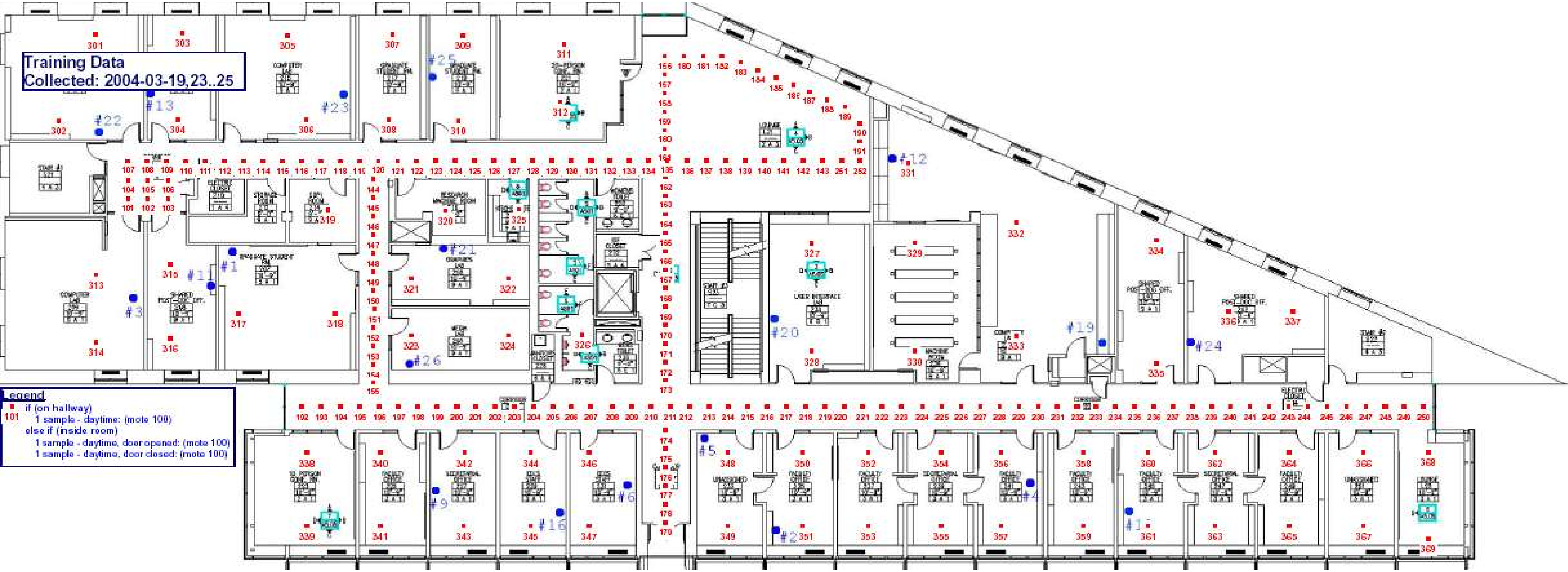


Patient list

Real-time data from selected patient

Map showing location and routing path

RF Location Detection



MoteTrack – Based on mica2 mote platform

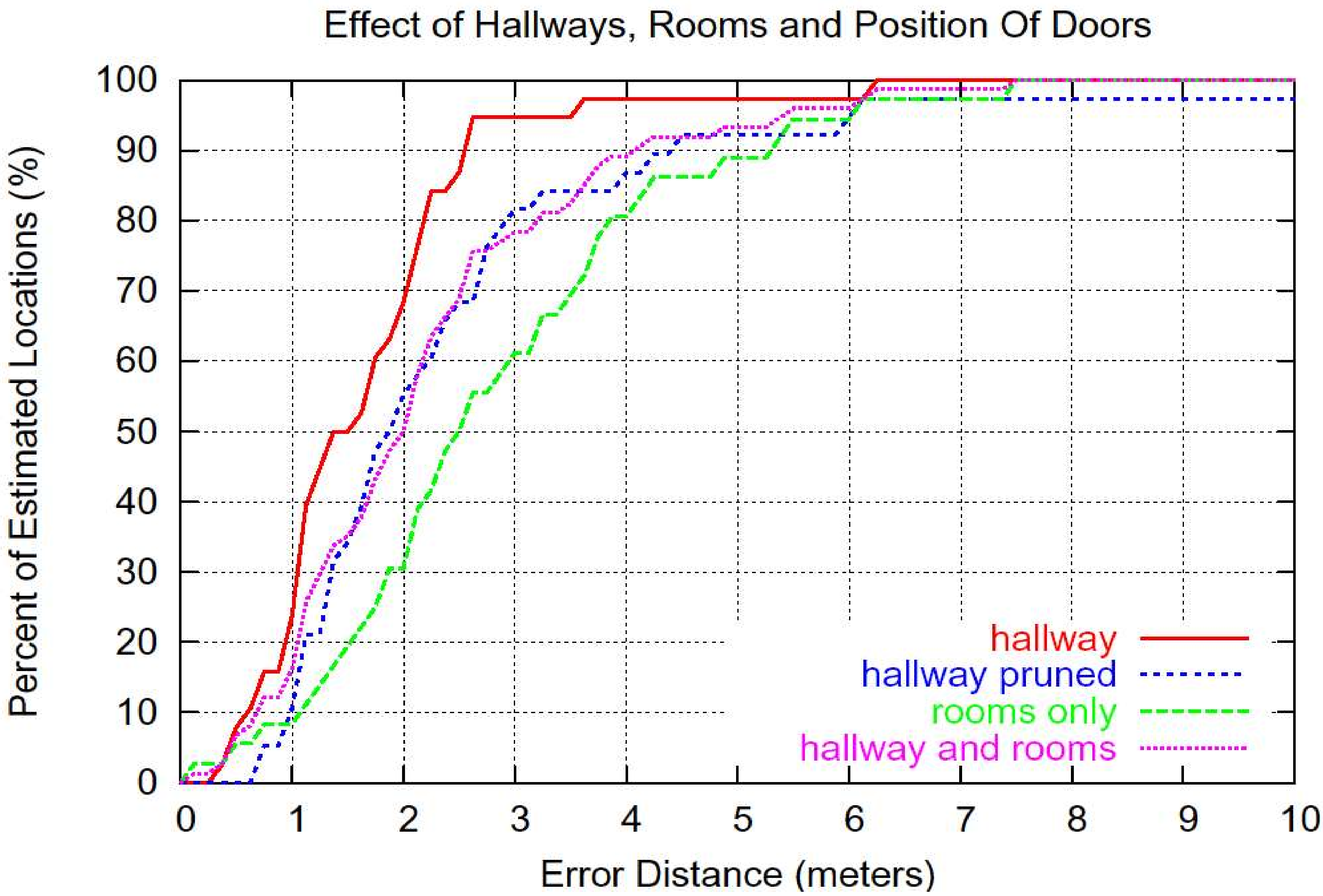
Gather RF “signatures” at known locations in the building

- Multiple beacon nodes transmitting at varying power levels

Determine location by comparing to signature database

- Database replicated across beacon nodes for failure resilience

Location tracking results

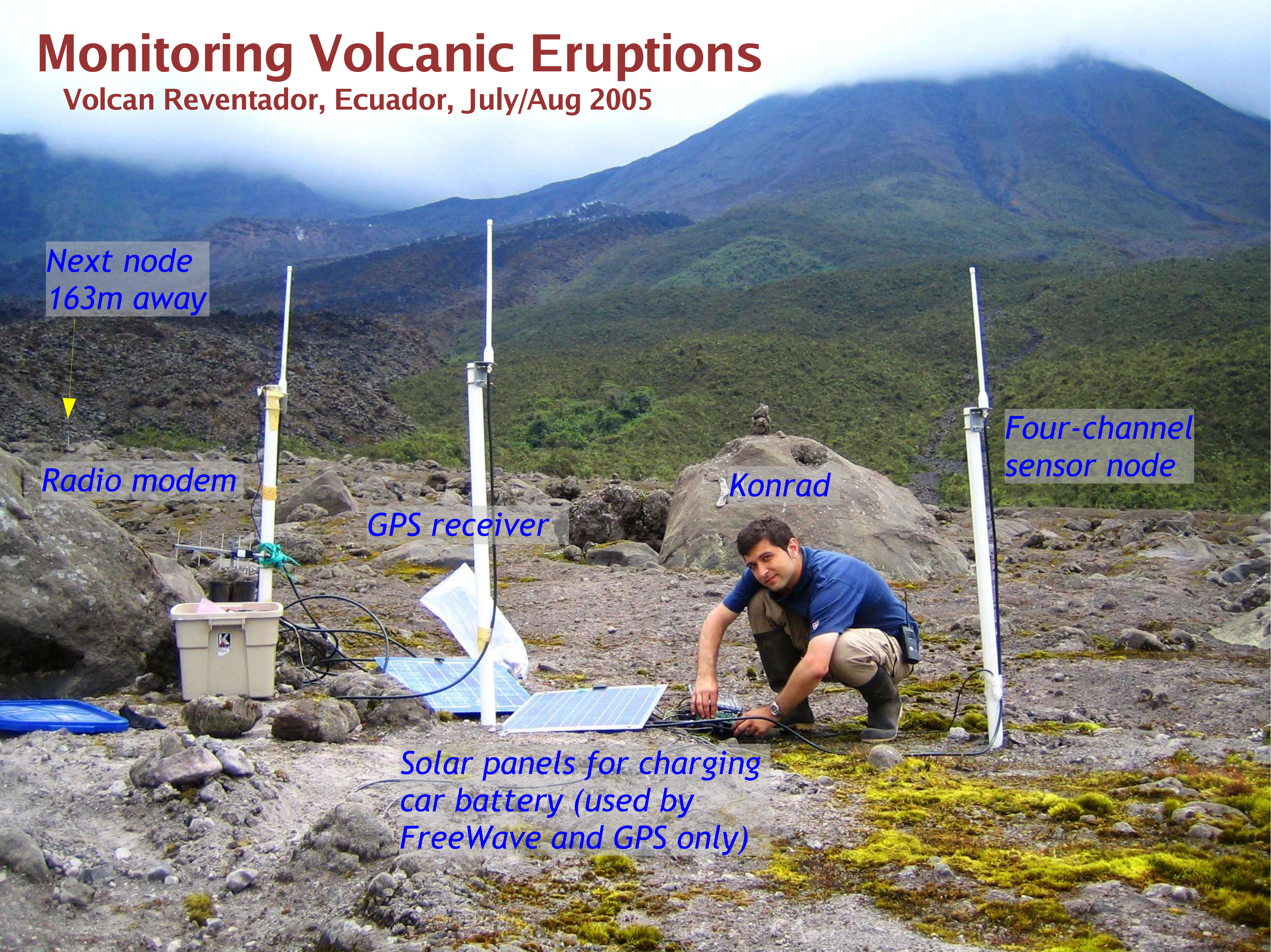


80th percentile position error of 3 m

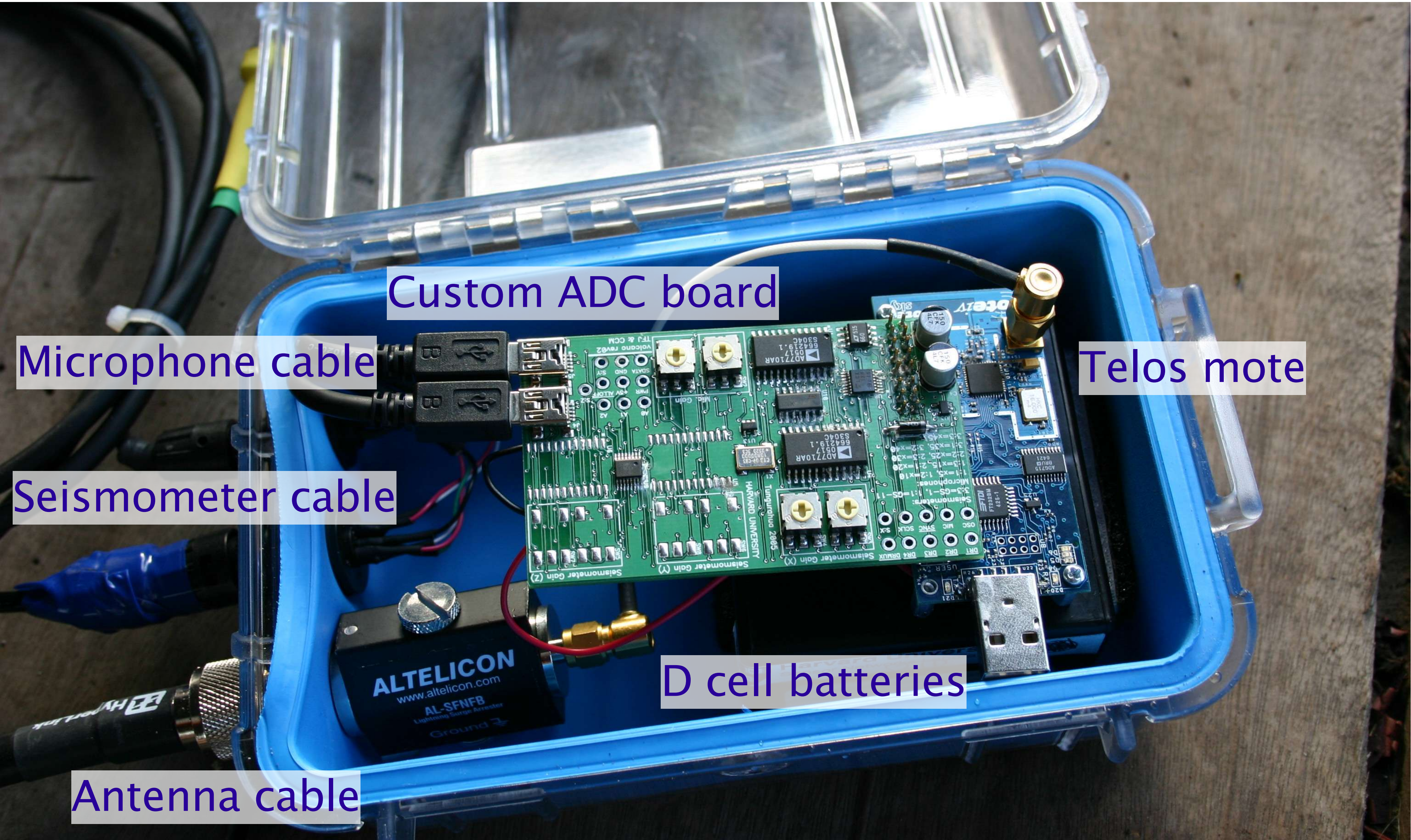
- Can be improved with better filtering techniques

Monitoring Volcanic Eruptions

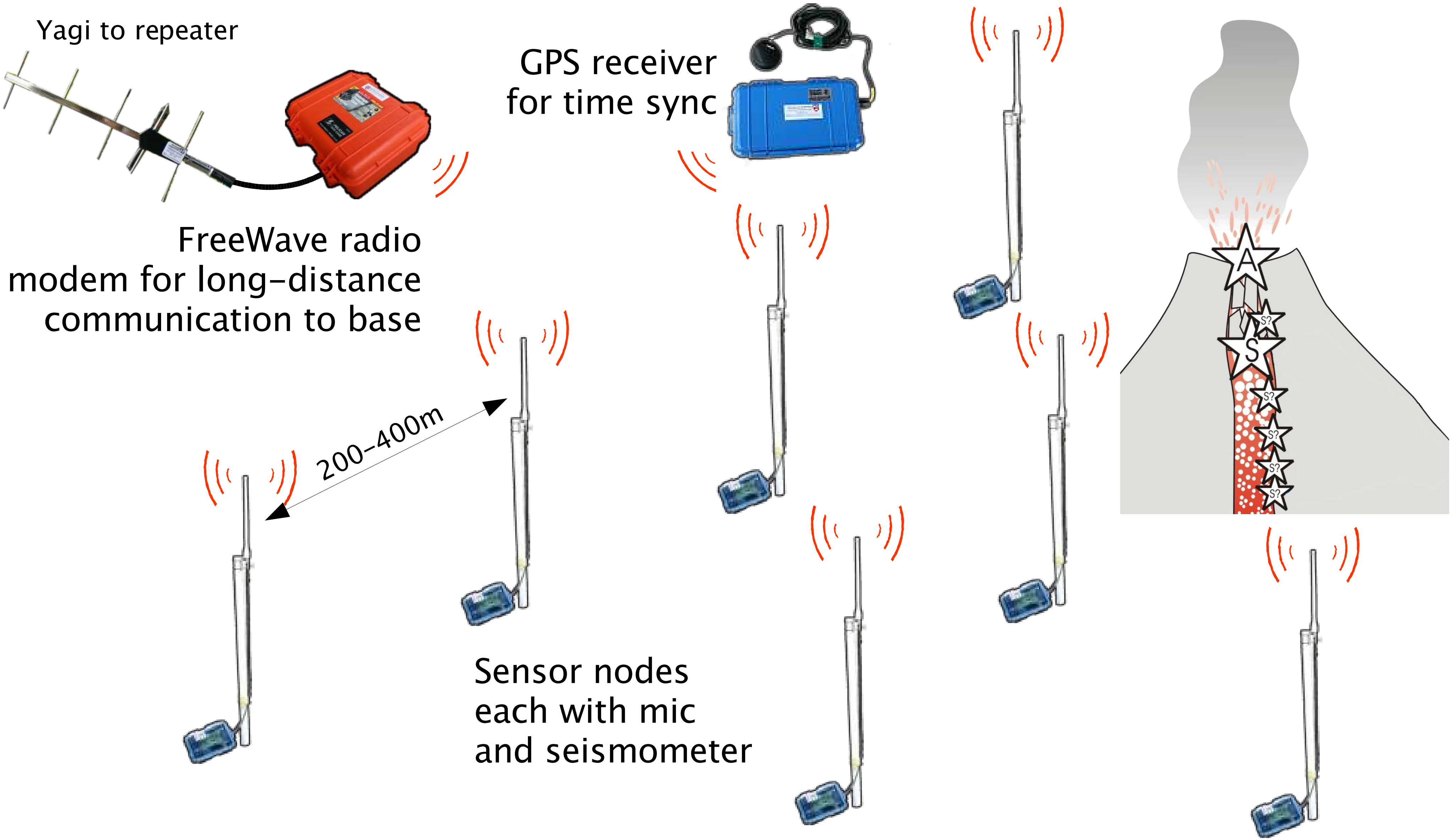
Volcan Reventador, Ecuador, July/Aug 2005



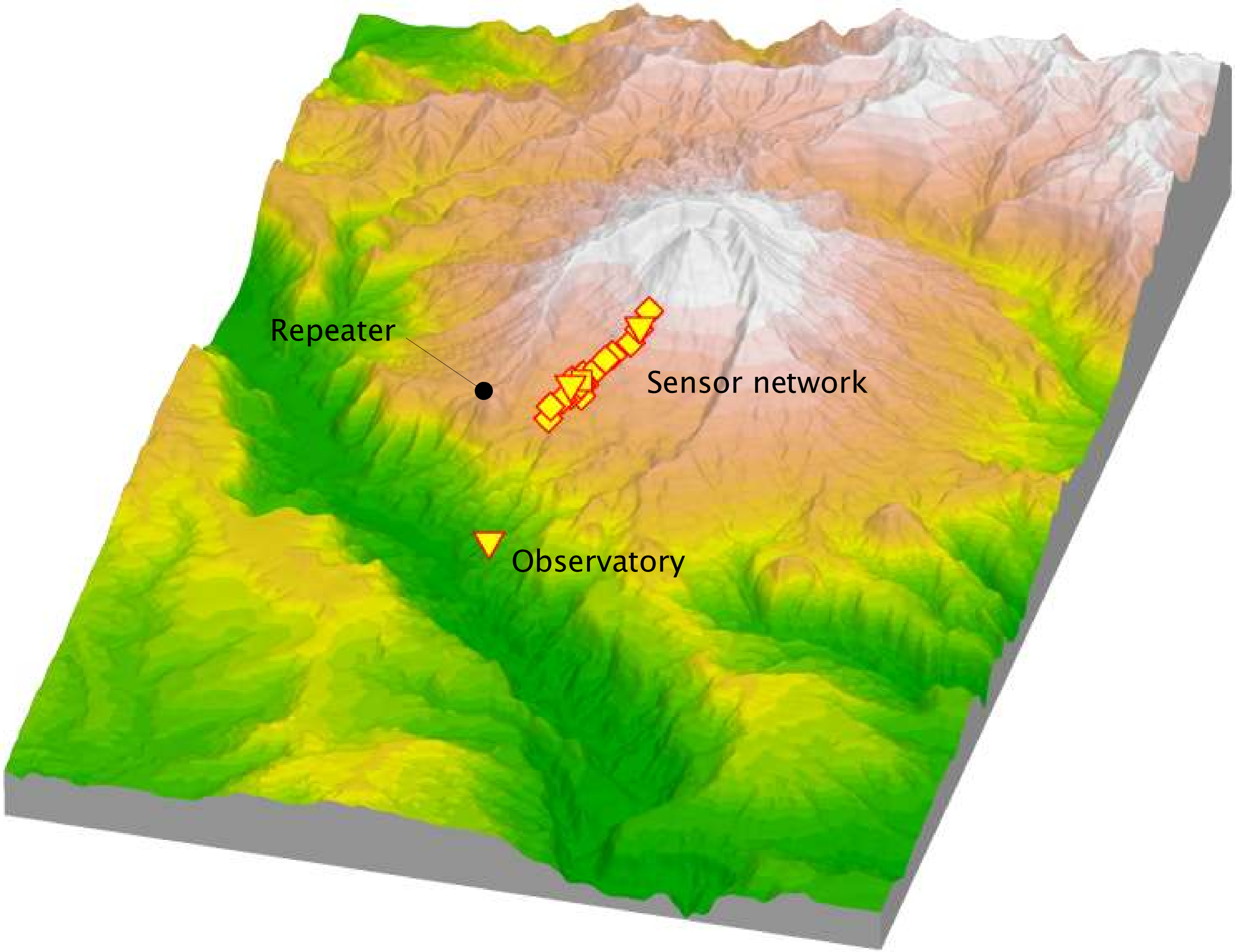
Harvard Wireless Volcano Monitoring Sensor Node



Sensor Network Architecture

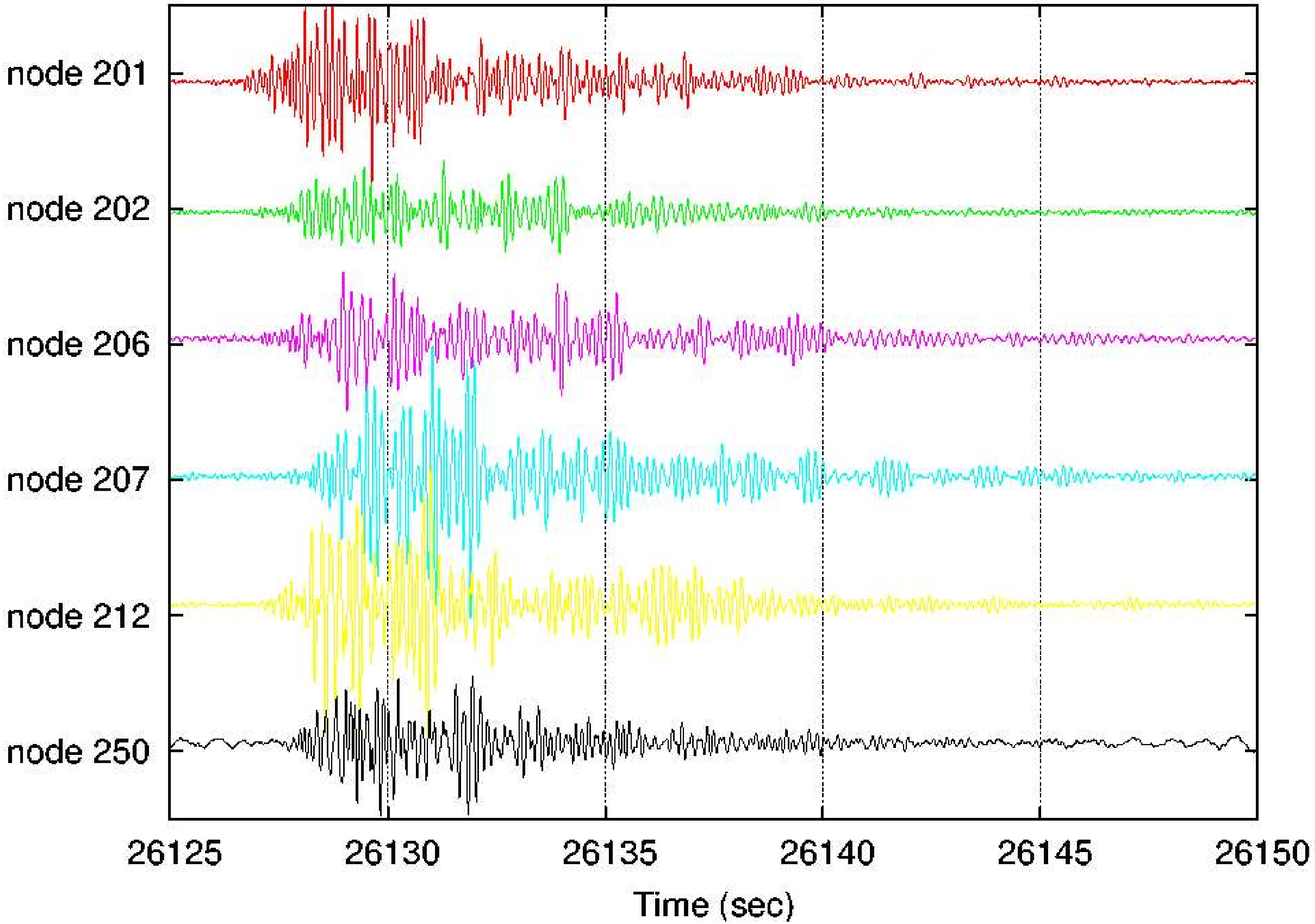


Sensor Deployment Map



Some Representative Events

Volcano-Tectonic (VT) earthquake



Course Requirements

This is a graduate level Computer Science course.

- All Computer Science and EE grad students are eligible
- Undergrads welcome ...
- As are grad students from other fields.
- But, you must have taken undergraduate *operating systems* or *networking*

What will you do in this class?

- You will read and comment on advanced technical papers
- One significant programming project (in C)
- Design and carry out an independent research project

Visitor and audit policy

- Talk to me first!

Course staff and administrivia

Instructor: Matt Welsh (`mdw@eecs`)

- Office: Maxwell Dworkin 233
- Office hours: Thursdays, 10am – 12pm

TF: Bor-rong Chen (`brchen@eecs`)

- Office: Maxwell Dworkin 238
- Office hours: TBD
- General course consulting and help with programming assignment

All papers, due dates, etc. on course web page:

- `http://www.eecs.harvard.edu/~mdw/course/cs263/`

Readings and Reviews

You are responsible for completing assigned readings *before* lecture

- Textbook readings for first few lectures
- 1-2 papers for subsequent lectures

Email a short review of the reading to cs263-reviews@eecs

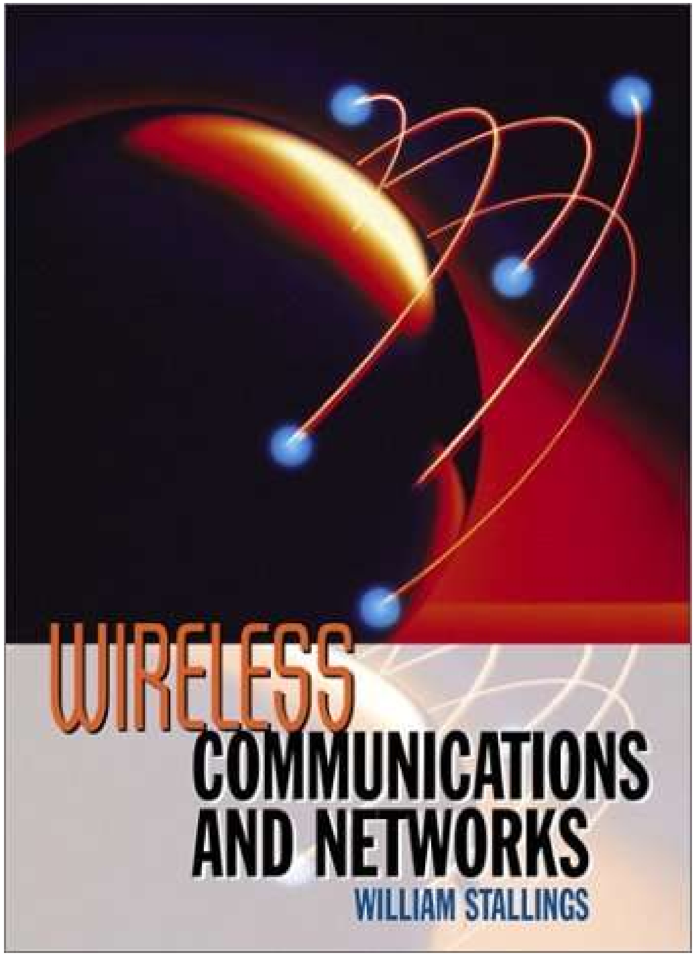
- Review is due before beginning of lecture
- A couple of paragraphs or “bullets” about the reading
- Highlight the main “take away” point of the reading
- For research papers, include a short critique of the work as well
  - *Be concise, critical, and thoughtful*

Required Textbook

Wireless Communications and Networks, 1st Ed., William Stallings

First 4 weeks of course will use this text

Available at Harvard Co-op, also see link on course web page



Programming Assignment

There is one programming assignment for the course

- Main goal: Learn the ropes of programming wireless sensor nets
- You will use this experience for your course project

You will implement a simple wireless multihop routing protocol

- Each pair of students will get a kit of 3 Telos motes for development and testing
- Learn to program in the TinyOS operating system for sensor nodes
- Run your protocol on MoteLab, a network of 30 sensor nodes installed in Maxwell Dworkin

You should be comfortable writing low level code in C.

MoteLab: Harvard Sensor Net Testbed

30 nodes deployed in Maxwell Dworkin
Web-based interface for programming and debugging
    http://motelab.eecs.harvard.edu

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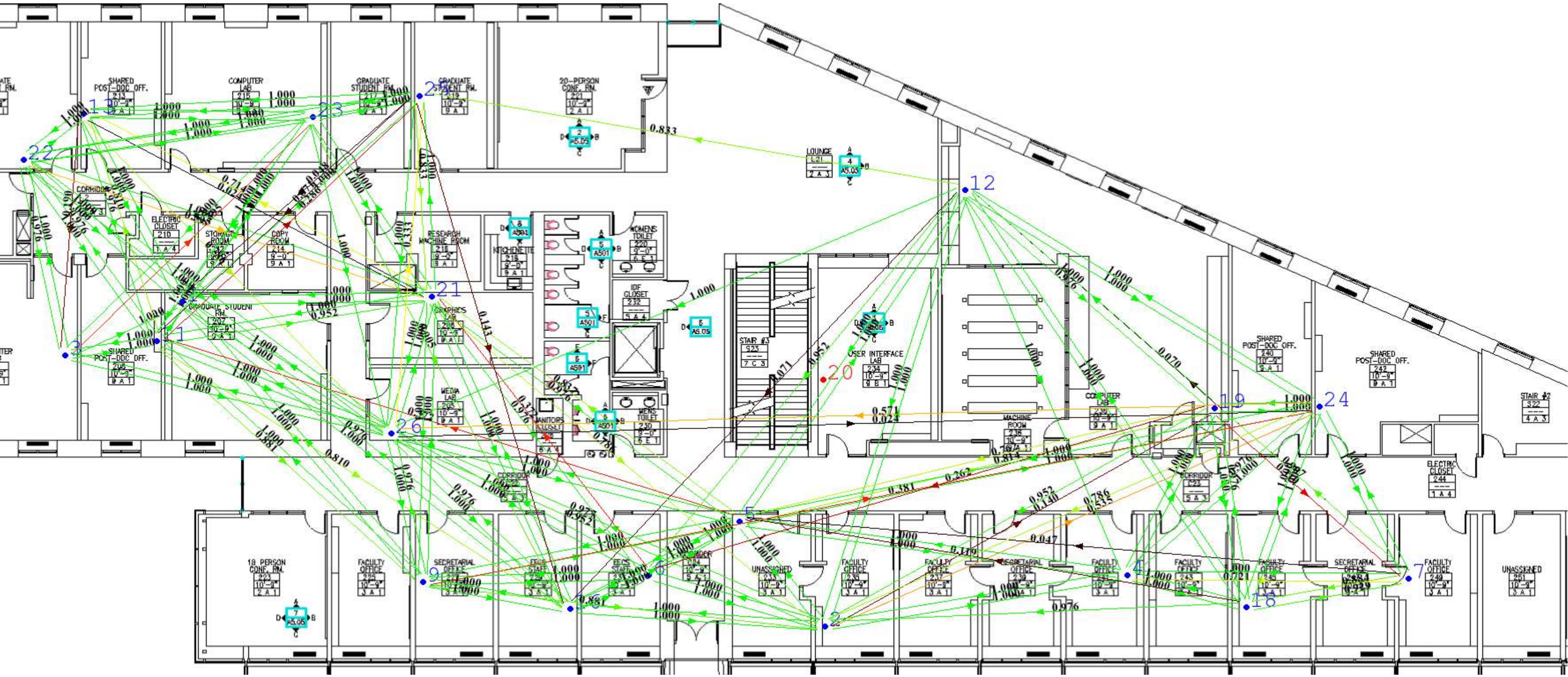

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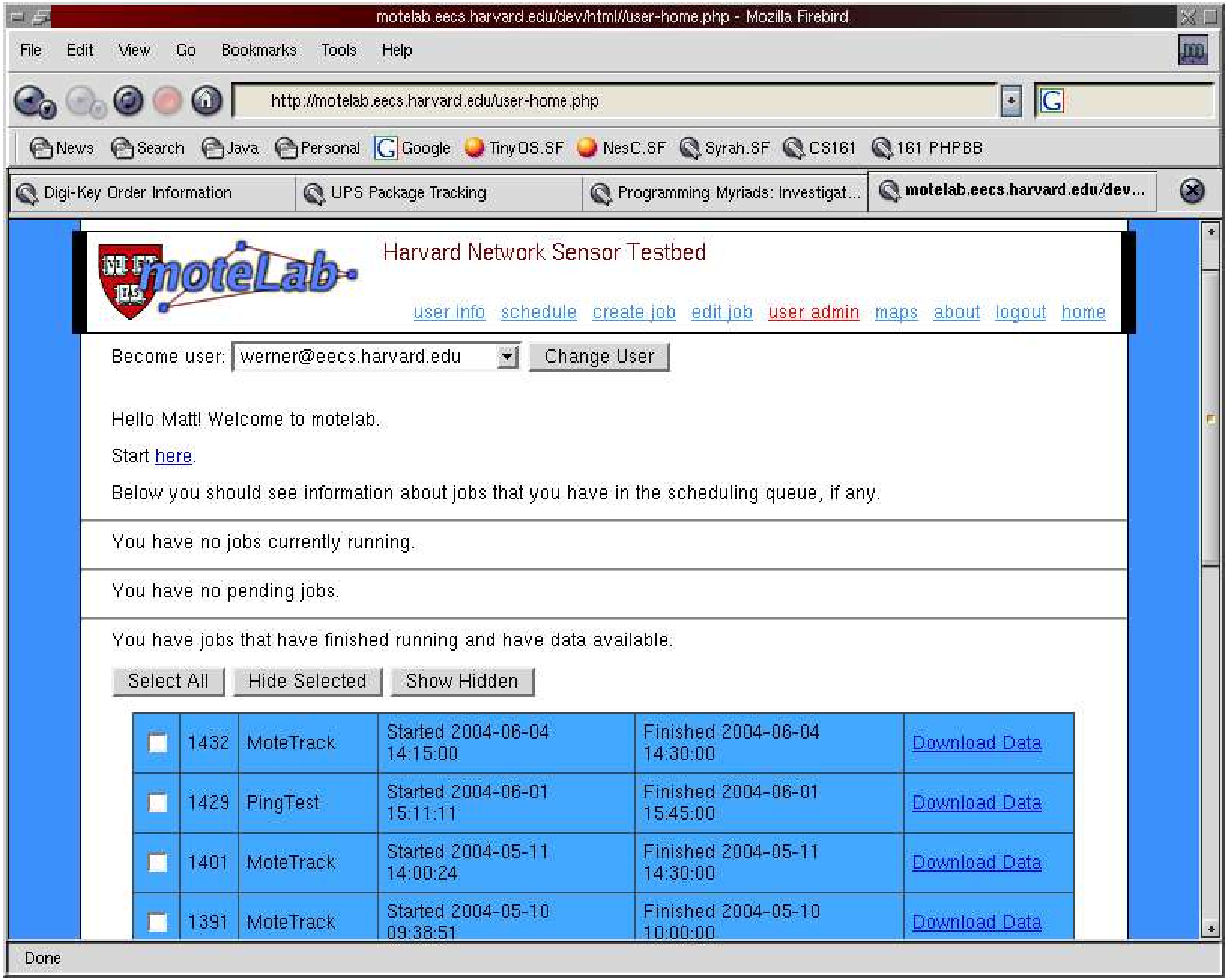

Research Project

Main goal of this course: Do some research

- Work individually or in pairs (pairs preferred)
- Select a juicy research problem that fits the theme of this course
- May be able to share the project with other courses (e.g., CS266)

Use the project to further your own research goals

- Ideal project is one that fits in with your own thesis topic in some way
- Focus of project need not be on “systems” and “networks”
  - *e.g., theory, AI, hardware design, etc. are all valid*
  - *As long as it ties into the course topic in some way*

Project Proposals (due 10/27)

- Short (2 pages max) on what you propose to do, why the project is interesting, and how you plan to get started
- Should include rough schedule of project milestones
- Short project update due 11/22 – short email on where you are and how you plan to finish up your project

Research Projects, cont'd

Research presentations (last day of class)

- Give a short, fun talk telling us what you did
- Learn from each other's experiences

Research papers

- Conference-style research paper (10 pages max) detailing your project
- Goal is to get used to writing these things – it's important
- I can work with you afterwards to to turn it into a conference/journal submission

Project Ideas

Study effects of packet loss on ad hoc routing protocols (e.g., AODV, DSDV, etc.)

Develop a novel energy management scheme for sensor networks

Build a medical paging system using the Telos motes and MoteLab "backbone" network

Design a security protocol for sharing information among groups of sensor nodes

Develop a distributed volcanic eruption back-projection algorithm

Design an adaptive congestion control scheme for high-data-rate wireless transmissions