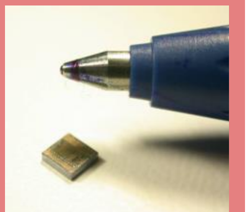


Infrastructureless Wireless Networks

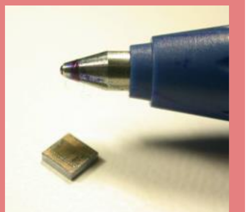
Wireless Sensor Networks

Rolland Vida

Budapest University of Technology and Economics
Department of Telecommunications and Media Informatics

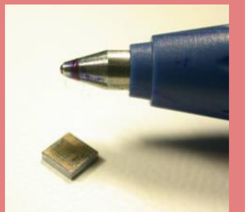
vida@tmit.bme.hu

What does „infrastructure” mean?



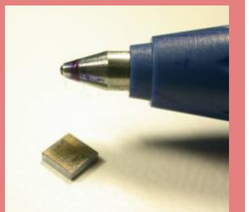
- **For wired networks**
  - On one hand, the „wire” itself
    - Cables, poles, trenches, etc.
  - On other hand, dedicated networking devices
    - Routers
    - DHCP server
    - AAA (Authentication, Authorization, Accounting) server
    - Firewall/NAT
    - SIP server
    - Etc.
- **For wireless networks**
  - Access points (AP) or base stations (BTS)
  - Internal networking devices (MSC, HLR, SGSN, GGSN, DHCP, AAA, etc.)
  - Optical or wireless backbone network

Wireless Networks



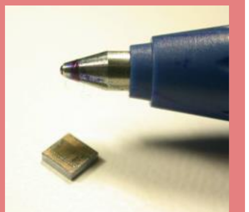
- **Infrastructure-based Networks**
  - WLAN – IEEE 802.11x
  - WMAN – IEEE 802.16x (WiMax)
  - Mobile/cellular networks
    - GSM, GPRS, EDGE, UMTS, HSDPA, HSUPA, LTE
- **Infrastructureless Networks**
  - WPAN – Bluetooth, Zigbee
  - Mobile ad hoc networks (MANET)
  - Moving networks – Network mobility (NEMO)
  - Vehicular ad hoc networks (VANET)
  - Sensor networks
    - WBAN – Wireless Body Area Network
- **Convergent hybrid networks**
  - Some connection points to the infrastructure
  - The operation of the network is „mostly independent" from the infrastructure

Really important and interesting?



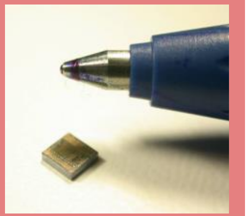
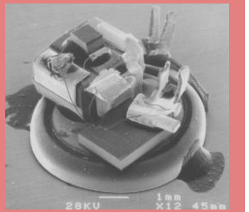
- Wireless sensor networks (WSN) are a hot topic today
  - Many research teams all over the world
- IEEE Infocom 2005, Miami, USA
  - One of the largest and strongest conferences in the field of infocommunications and networking
  - Very broad range of topics
    - Optical networks, cellular networks, P2P, multimedia protocols, traffic analysis, networking architectures, security, etc.
    - ... and sensor networks
  - 1600 submitted papers
    - More than 400 related to WSNs

Conference dumping



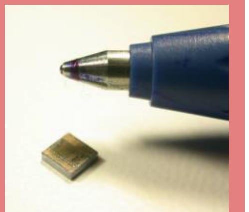

- ASTSA 2012, Third International Workshop on Advances in Sensor Technologies, Systems and Applications, November 2012, Victoria, Canada
- IEEE SenseApp 2012, Seventh IEEE International Workshop on Practical Issues in Building Sensor Network Applications, October 2012, Florida, USA
- IWSSN 2012, The 1st International Workshop on Smart Sensor Networks, October 2012, China
- SN 2012, The Fifth International Workshop on Sensor Networks , july 2012, Munich, Germany
- CAC-WSN 2012, The 2012 International Workshop on Context-Aware Computing Applications and Services via Wireless Sensor Network, Sept. 2012, Korea
- PWSN 2012, 4th International Workshop on Performance Control in Wireless Sensor Networks, May 2012, China
- SESP 2012, 1st ACM International Workshop on Sensor-Enhanced Safety and Security in Public Spaces, June 2012, South Carolina, USA
- MOBISENSOR 2012, 3nd International Workshop on Mobility in Wireless Sensor Networks, May 2012, China
- IWSN 2012, Interconnections of Wireless Sensor Networks, May 2012, China
- DMPS 2012, The First International Workshop on Data Management in Participatory Sensing, July 201, Bangalore, India
- RoboSense 2012, The International Workshop on Cooperative Robots and Sensor Networks, August 2012, Ontario, Canada
- SNIGM 2012, The Second International Workshop on Sensor Networks for Intelligence Gathering and Monitoring, August 2012, Niagara Falls
- ...and many more

Journal dumping


- Dedicated journals
  - ACM Transactions on Sensor Networks
  - Ad Hoc and Sensor Wireless Networks, an International Journal
  - IEEE Communications Magazine Ad hoc and Sensor Networks Series
  - Inderscience International Journal of Sensor Networks IJSNet
  - International Journal of Distributed Sensor Networks
- Special issues in journals targeting a broader range of topics
  - Special Issue of Elsevier Ad Hoc Networks Journal on Bio inspired Computing and Communication in Wireless Ad Hoc and Sensor Networks
  - Special Issue of IEEE Wireless Communications on Wireless Sensor Networking
  - Special Issue of Elsevier Computer Networks Journal on Wireless Multimedia Sensor Networks
- ... and many more

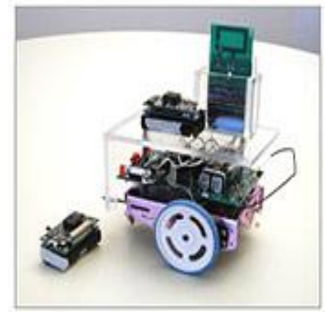
Features of sensors

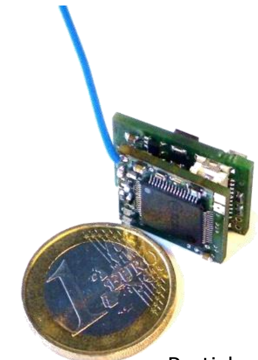


- Small devices with sensing, processing and (radio) transmitting capabilities..
- Limited resources
  - CPU: (< 10 MIPS);
  - memory: (~ 4 kbyte)
  - limited energy
    - (e.g., AAA batteries)

- Task: Collecting and forwarding data from a given territory towards the “sink” (base station)

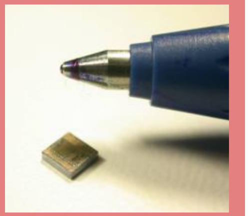
MICA

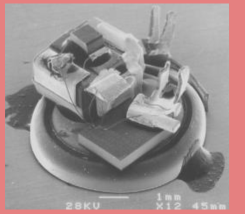




Particle-C

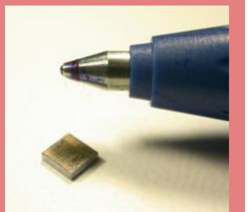
Features of sensor nets



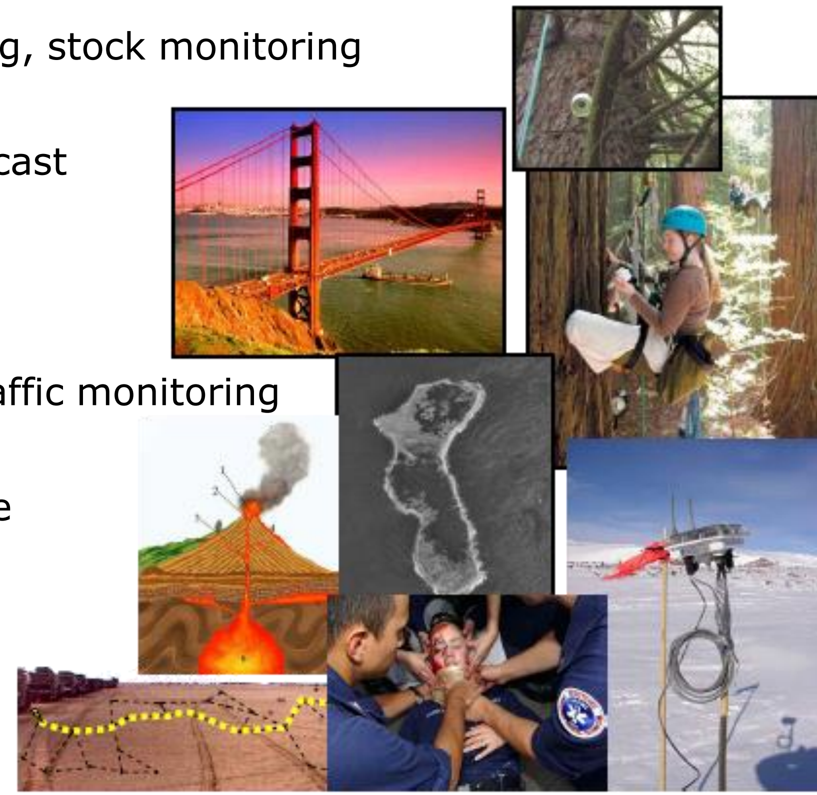


- Many, small, cheap sensors.
- Wireless communication
  - ad-hoc network formation, communication with slow bitrate (~10–100 kbps)
- Other requirements:
  - long lifetime
  - unattended operation
  - robustness

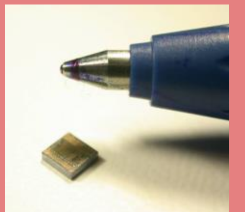
Typical areas of applications



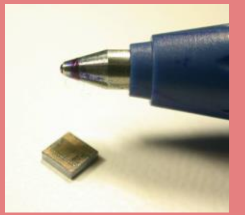
- Healthcare
  - hospital management, disaster recovery, support of elderly or disabled, home medication
- Manufacturing, storage
  - Manufacturing process monitoring, stock monitoring
- Environment
  - habitat monitoring, disaster forecast
- Agriculture
  - „precision" farming
- Engineering applications
  - static monitoring of buildings, traffic monitoring
- Intelligent buildings
  - intelligent home, intelligent office
- Defense
  - monitoring, tracking, detection, sniper localization
- Space research
  - Mars probes

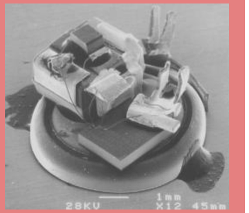


Classification of sensor networks



- Based on the nature of communication
  - Single-hop networks
    - Sensors communicate directly with the sink
    - Small size networks
    - Sink within radio range
  - Multi-hop networks
    - Sensors forward (route) each other’s packets towards the sink
    - Routing algorithm is needed
    - Larger size networks
- Based on the data reporting mode
  - Time-driven networks
    - Each sensor periodically sends its data to the sink
    - E.g., sensors embedded in the road, counting the vehicles on that road segment
  - Event-driven networks
    - Sensors alert the sink only if something unusual happens
    - E.g., temperature goes above 45 °C
  - Query-driven networks
    - A sensor sends its measurement data to the sink only when it is explicitly asked to do so
    - E.g., the sink asks for the currently highest humidity area inside the monitored region



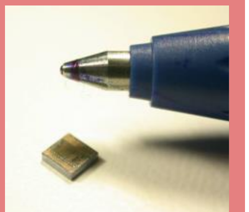


Problems to solve

- Sensor deployment
  - How many sensors to deploy, and where?
  - Ensuring (redundant) coverage
    - Monitoring the entire region
    - If a sensor(‘s battery) dies, the area should not remain uncovered
  - Ensuring (redundant) connectivity
    - From any sensor, there is at least one (or more) path(s) to the sink
  - Graph theory issues

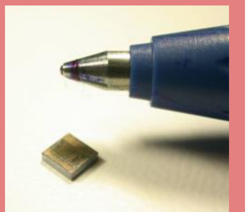
- Energy efficiency
    - One of the most important and studied areas
  - Low energy hardware design
  - Energy efficient software modules
  - Energy efficient communication

Energy efficient communication



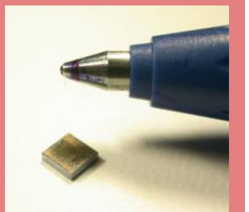
- Send the lowest amount of data
  - Data aggregation
    - Several sensors detect the same event, redundancy has no added value
    - Special data
      - Only the maximum, or the average value is interesting
    - Where to aggregate? How long should we wait for new data?
  - Clustering
    - Hierarchical structure
      - Sensors communicate with the cluster-head (CH)
      - The CH communicates with the sink
    - Dedicated CH, with more resources
    - Alternating CH role among the sensors
    - Who should be the next CH, and when? How many clusters to form? To which cluster should a given sensor belong?

Energy efficient communication



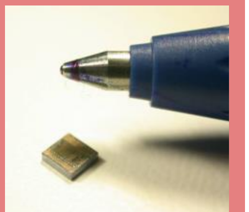
- Shorten the communication distances
  - Optimal placement of sink nodes
    - Minimizing the distance between the sensors and the closest sink
    - How many sinks are needed, in case of a given network size and specific application requirements (e.g., delay bound)?
  - Moving the sink node
    - Random mobility
      - The sink collects data from sensors it passes by
      - Used for non-real time applications
      - The sensor network does not have to be connected
    - Predictable mobility
      - The sink moves along a predefined path
      - The sensor send its data only when the sink is in the closest position
      - How long should a sink stay at a given place (sojourn time)?
    - Adaptive mobility
      - The sink moves close to the current events
      - The sink moves away, if neighboring sensors depleted their battery
      - When to move, where to go?

Increasing network lifetime



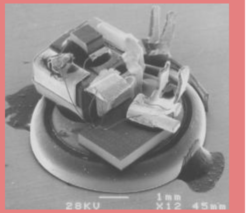
- What we mean by network lifetime depends on the application
  - Until the first sensor dies
  - Until x% of the sensors die
  - Until complete coverage is not ensured anymore
  - Until coverage drops below x%
  - Until the sink becomes unreachable, etc.
- Ensuring load balancing
  - Sensors continuously deplete their batteries
    - In a single-hop network, remote sensors die first
      - If nodes close to the sink can adjust their transmit power
    - In a multi-hop network sensors around the sink die first
      - They forward the traffic from all the other sensors towards the sink
    - In an event-driven network, nodes in „busy areas”, and nodes along the paths linking those areas to the sink die first

Increasing network lifetime



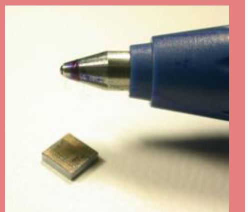
- Ensuring load balancing
  - Intelligent routing algorithms
    - It is worth choosing a longer path, if there is more energy available along that path
    - It is worth sending the data to a more distant sink, if there is more energy available at that sink
- Sleep scheduling solutions
  - Redundant deployment, sensors near to each other will measure similar values
    - Depends much on the measured parameter
    - Light or noise level has much higher variance than temperature
    - Some of the sensors might go to sleep
  - Static sleep scheduling
    - sensors take turns in a deterministic fashion
  - Dynamic, adaptive sleep scheduling
    - battery level or prediction accuracy influence the scheduling
  - Trade-off between accuracy and network lifetime

Security and reliability



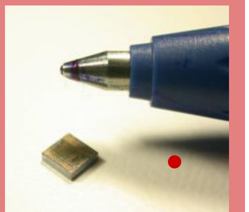
- Solutions developed for traditional networks cannot be applied here
- No resources for complex authentication and encryption schemes
- (Usually) no resources for retransmissions
  - Minimize the possibility of collisions
  - Efficient medium access control (MAC) protocols

Other issues to tackle…

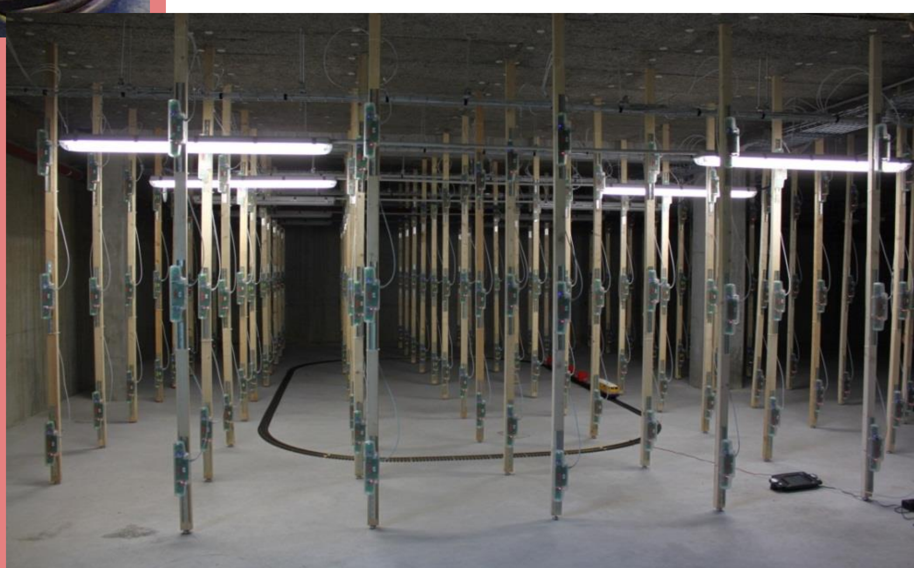


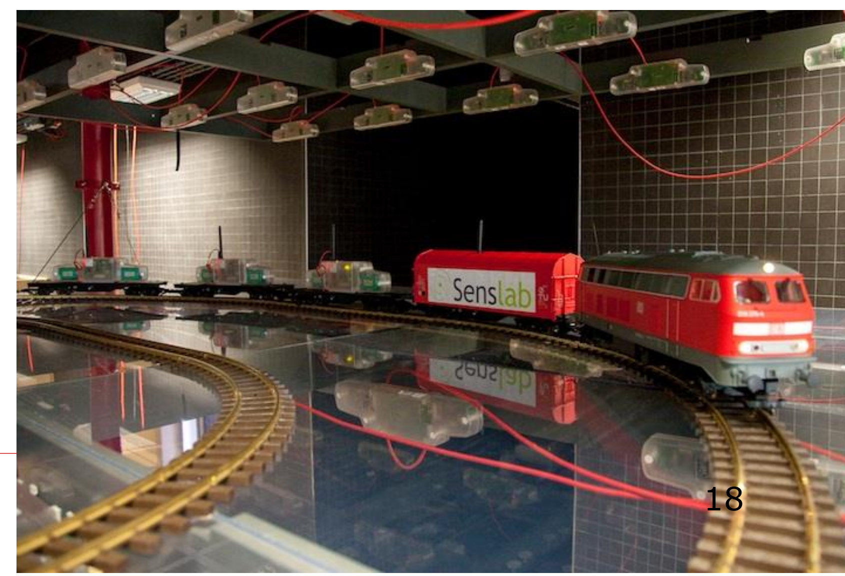
- Integration with other types of networks (wired and wireless)
- Simulation and modeling
  - Experiments should be done on large networks, but this is not trivial
- Providing Quality of Service (QoS)
- Localization and synchronization
- Sensor mobility
  - Blown by the wind, floating in the water, or sticked on people's clothes, shoes
  - Continuously changing topology, dynamic network
- Heterogeneous sensors, heterogeneous environment
- Networks operating in special conditions
  - E.g., underwater wireless sensor networks
- … and many more

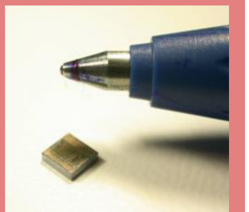
IoT-Lab (https://www.iot-lab.info/community/)

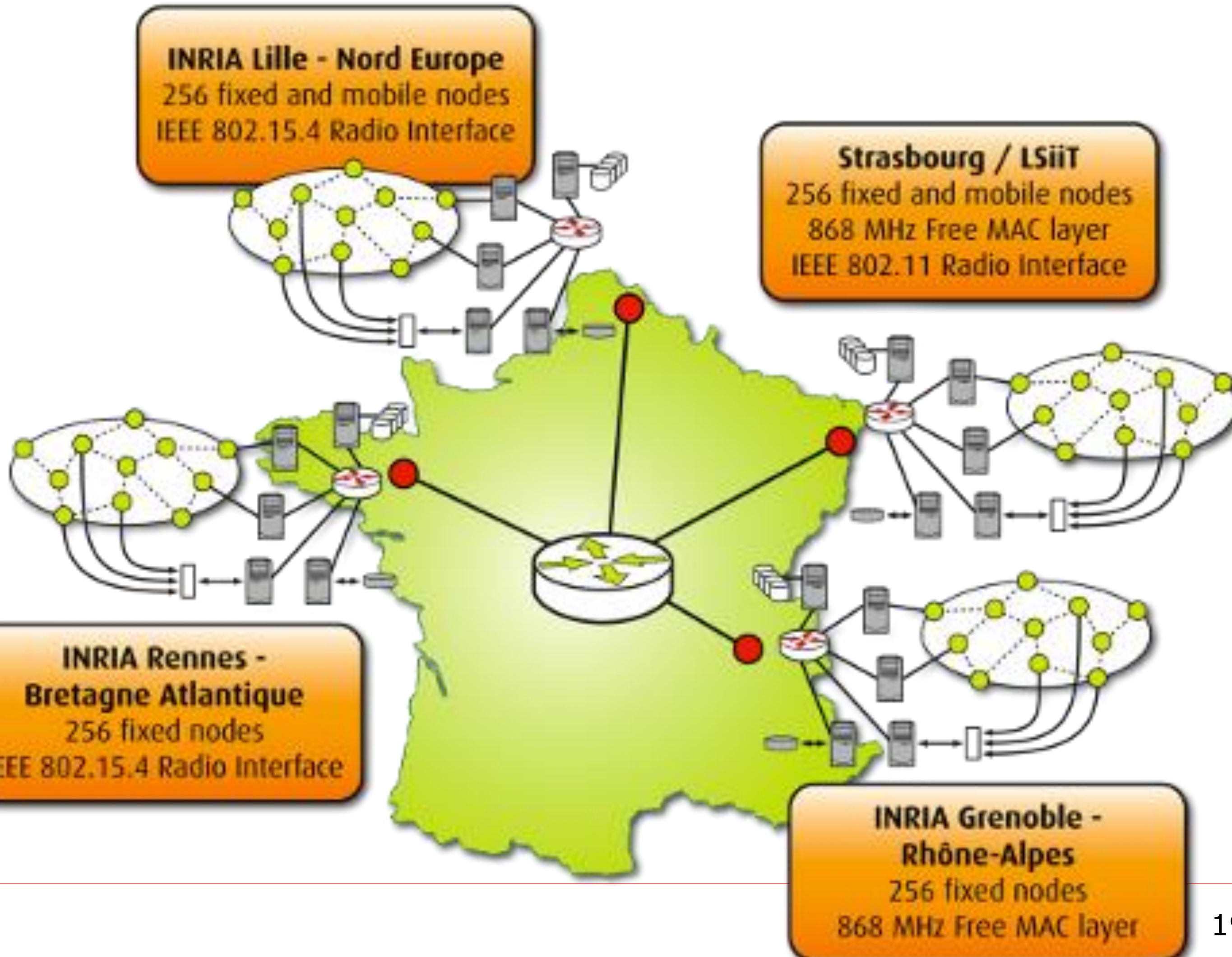


- Large-scale wireless sensor network testbed
- 6 testbeds in French cities (Grenoble, Lille, Paris, Strasbourg, etc)
- Real measurements instead of simulations
  - Routing algorithms, energy-efficient communication, data aggregation
- Fixed and mobile sensors and sink nodes

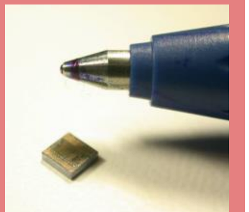
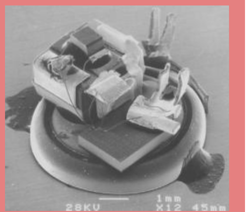







INRIA Lille - Nord Europe
256 fixed and mobile nodes
IEEE 802.15.4 Radio Interface
Strasbourg / LSiiT
256 fixed and mobile nodes
868 MHz Free MAC layer
IEEE 802.11 Radio Interface
INRIA Rennes - Bretagne Atlantique
256 fixed nodes
IEEE 802.15.4 Radio Interface
INRIA Grenoble - Rhône-Alpes
256 fixed nodes
868 MHz Free MAC layer

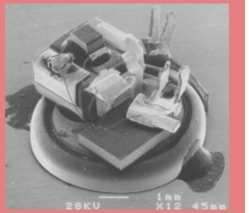
One example – Volcano monitoring

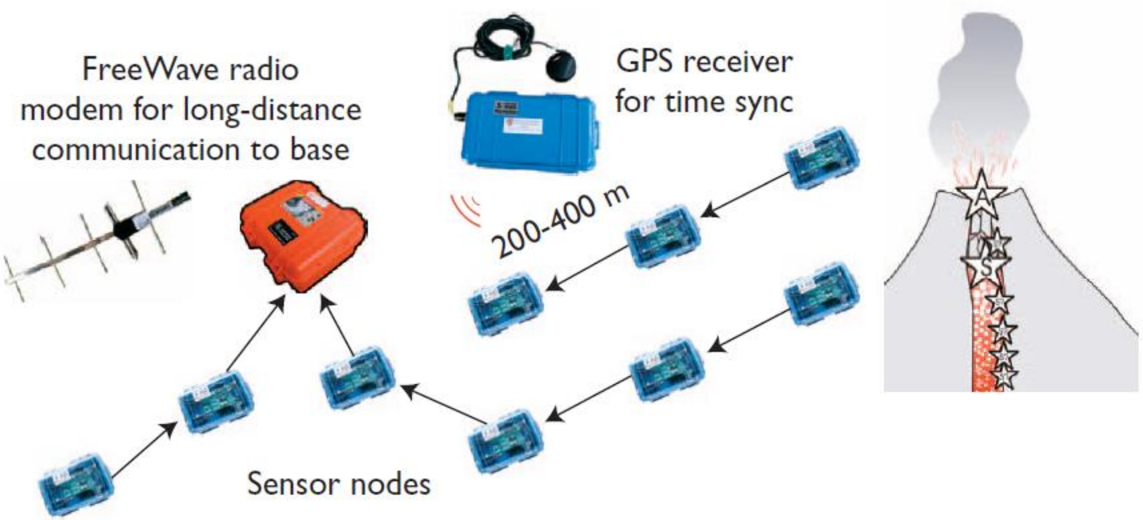

- G. Werner-Allen, K. Lorincz, M. Welsh, O. Marcillo, J. Johnson, M. Ruiz and J. Lees, **“Deploying a wireless sensor network on an active volcano”**, IEEE Internet Computing 10 (2006) (2), pp. 18–25.
- Participants
  - Harvard University
  - University of North Carolina
  - University of New Hampshire
  - Instituto Geofisico, Ecuador

- Test networks
  - Tungurahua volcano (5023 m), Ecuador, 2004
    - 3 sensors gather data for 3 days
  - Reventador volcano (3562 m), Ecuador, 2005
    - 16 seismo-accoustic sensors, 3 km area, multi-hop
    - noticed 230 volcanic events during 3 weeks

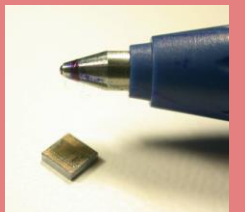
Volcano monitoring

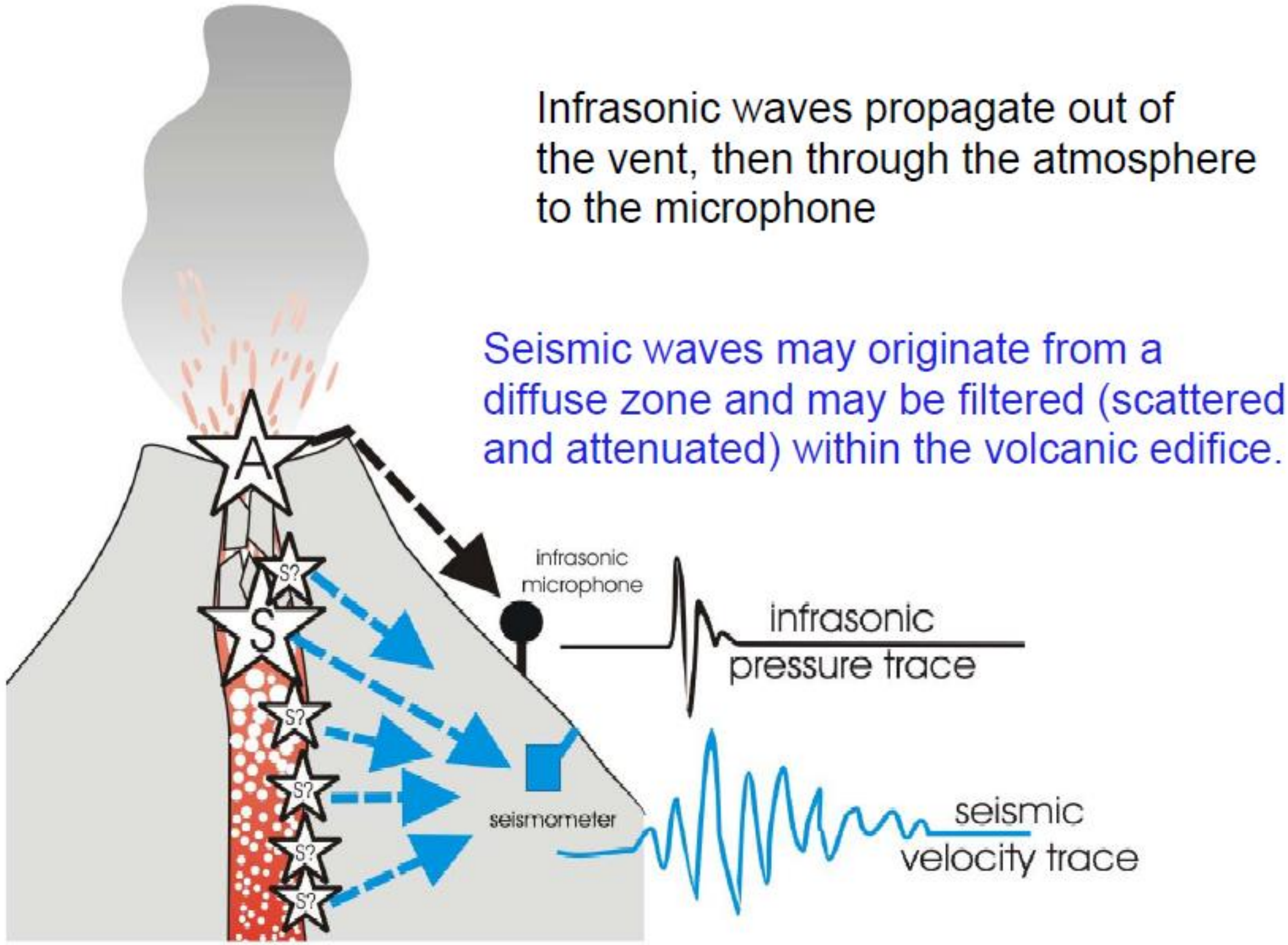


- Sensors
  - Seismic movements
  - Infrasound microphones
    - Sounds not perceived by humans
      - Below 16-20 Hz frequency
    - Whales, elephants emit such sounds, can be heard for hundreds of kilometers
  - Monitor larger areas, observe the propagation of seismic and infrasound signals
    - Sparse network, long but narrow branches in the topology

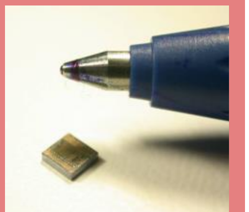


Volcano monitoring

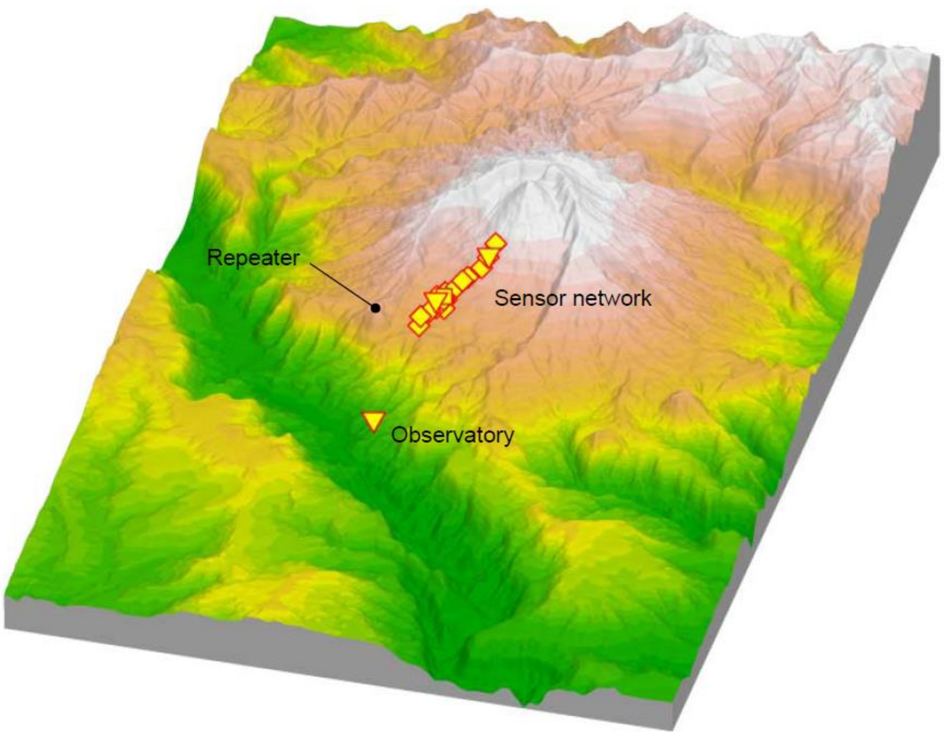


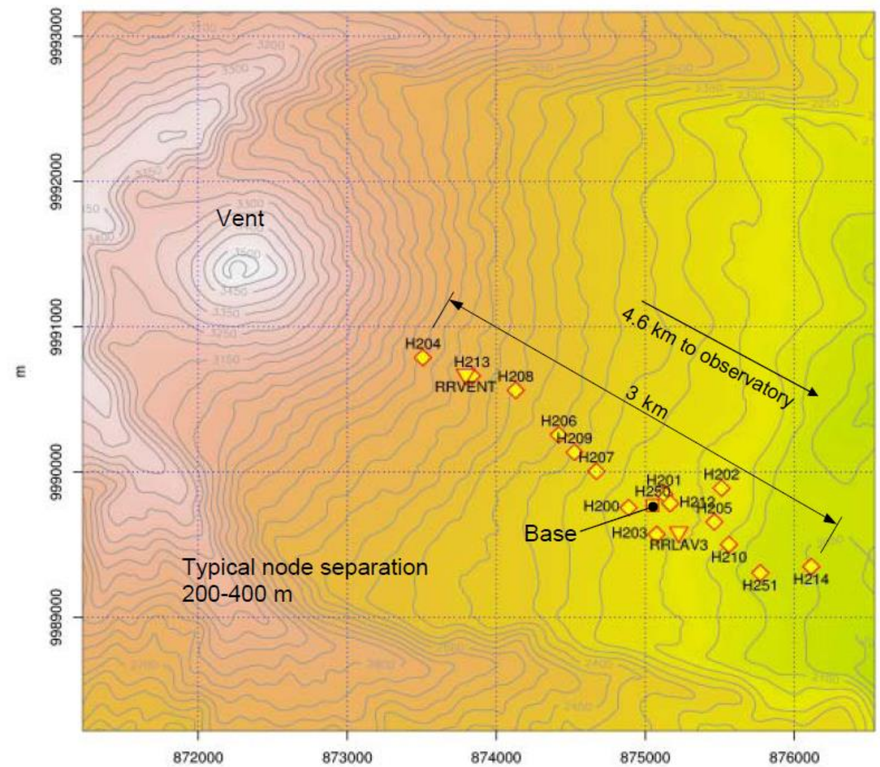


Volcano monitoring (2005)

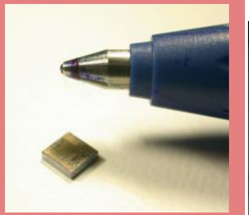


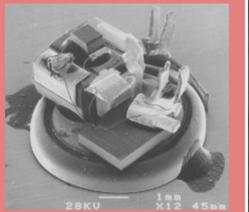
- Sensor placement

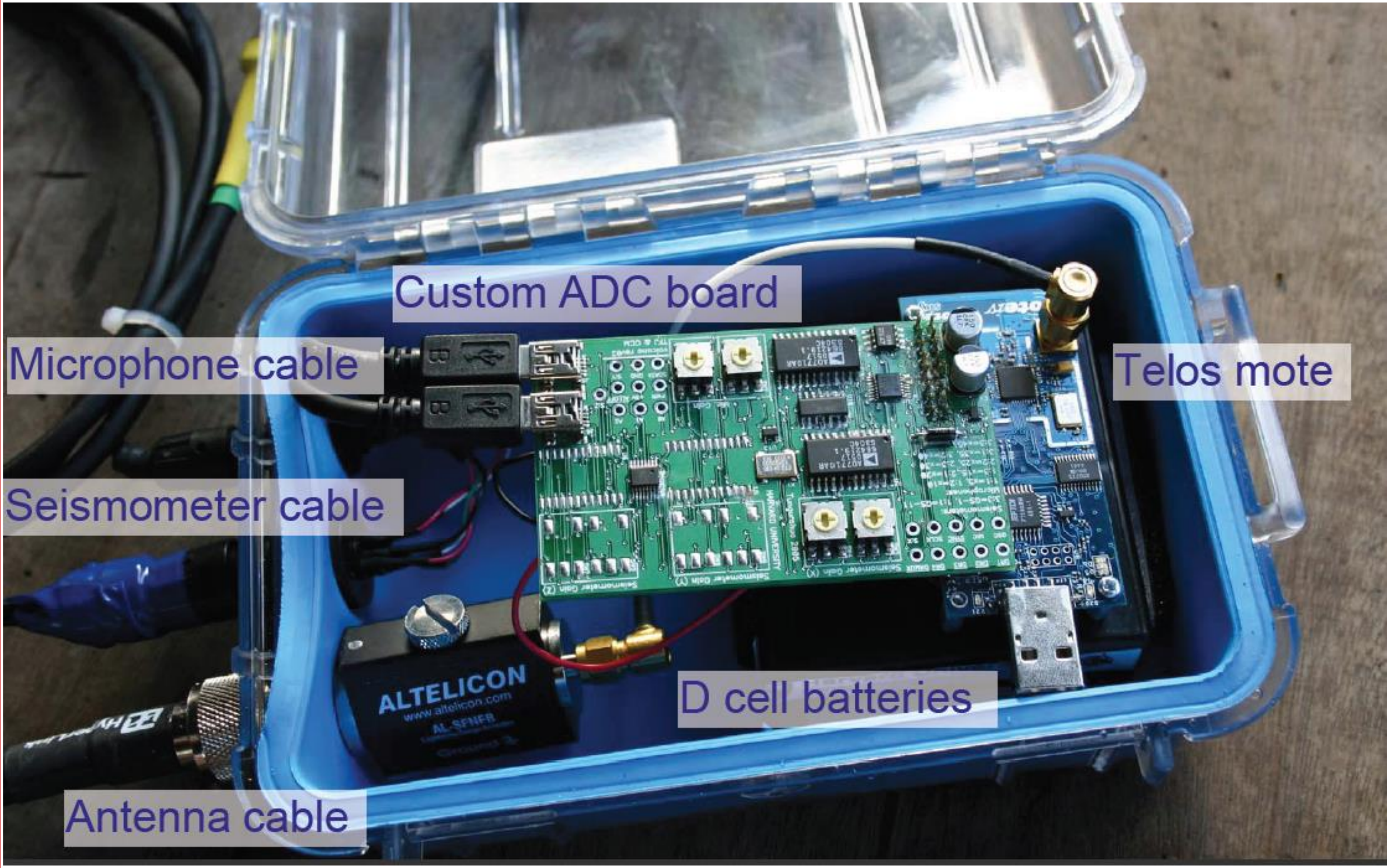


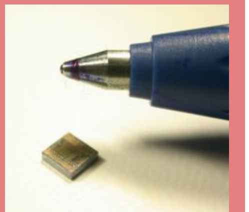


Volcano monitoring (2005)





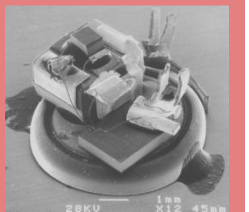




Volcano monitoring (2005)

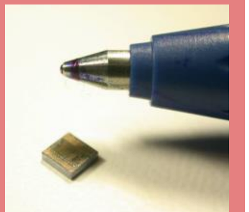
- Sensors
  - Geospace Industrial GS-11 geophone
    - cheap (below 80 USD)
  - Geospace Industrial GS-1
    - Expensive, but more precise, only on two nodes
  - Panasonic infrasound microphone

Volcano monitoring (2005)



- Antenna
  - 8,5 dbi omnidirectional
  - 400m+ range
  - On a 1,5 m PVC tube
    - To avoid ground reflections
- Microphone on the tube
- Seismometer buried in the ground

Volcano monitoring (2005)



- The deployed network is far from the research center (4 km)
  - No direct line of sight, no direct radio communication
- Connectivity ensured through three FreeWave radio modems
  - One in the observatory, one at the deployment site, and one on a high hill, serving as relay
  - Each one uses a car battery that is recharged with solar panels

Volcano monitoring (2005)