Sensor Networks: An Overview

Philippe Bonnet

Datalogisk Institut Københavns Universitet

bonnet@diku.dk

http://www.distlab.dk/

What is a Sensor Network?

Sensor nodes

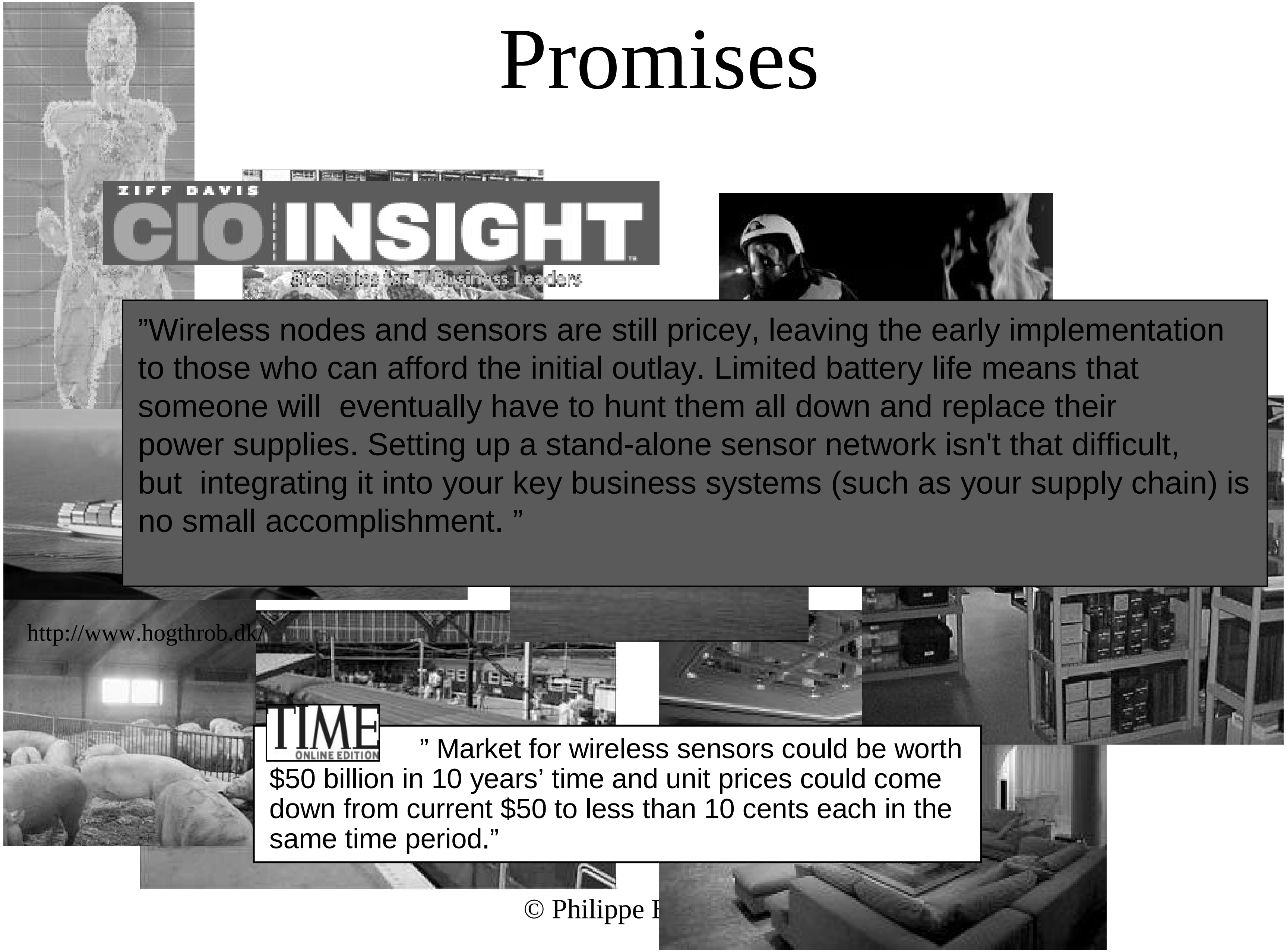
- Sensor(s)
- Wireless transceiver
  - Short range
- Processor
- Energy source
  - Active/passive
- Packaging
  - Sma

Sensor network

- Many sensor nodes
  - High density deployment
- A few gateways (readers)
- Back-end infrastructure

Online digital representation of actual physical phenomena

Promises



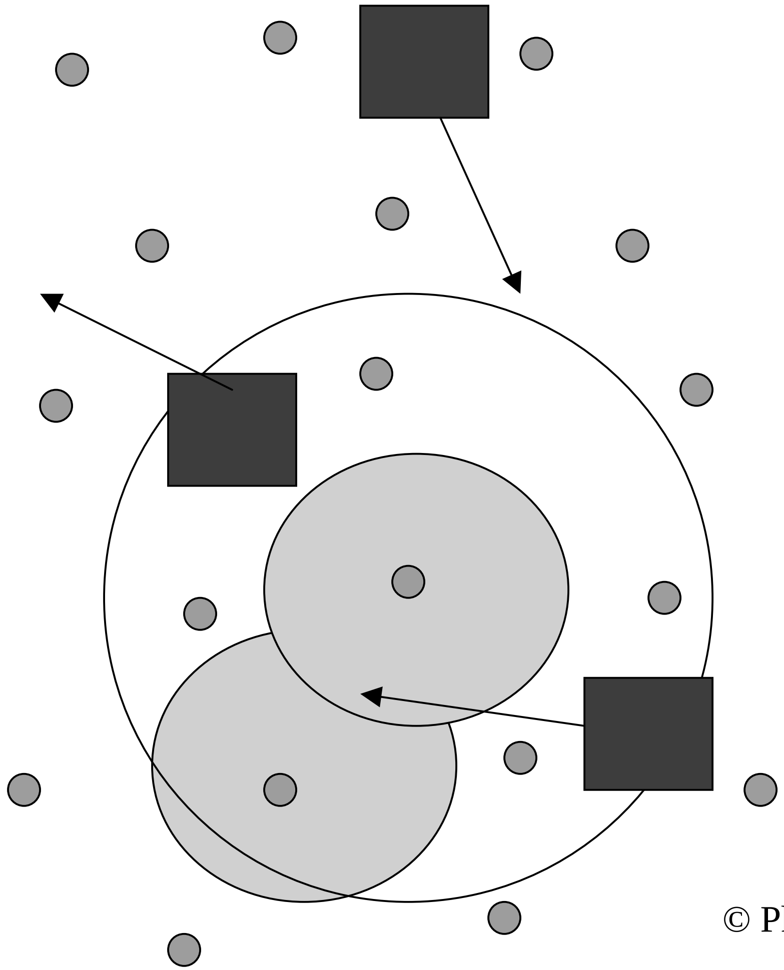
ZIFF DAVIS CIO INSIGHT

"Wireless nodes and sensors are still pricey, leaving the early implementation to those who can afford the initial outlay. Limited battery life means that someone will eventually have to hunt them all down and replace their power supplies. Setting up a stand-alone sensor network isn't that difficult, but integrating it into your key business systems (such as your supply chain) is no small accomplishment. "

TIME ONLINE EDITION

" Market for wireless sensors could be worth $50 billion in 10 years' time and unit prices could come down from current $50 to less than 10 cents each in the same time period."

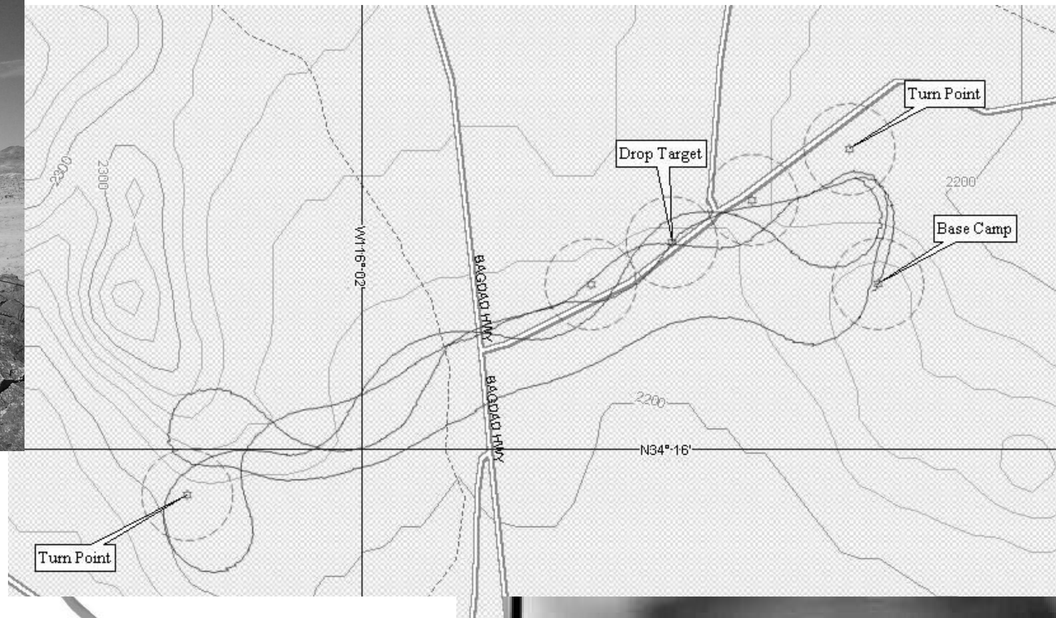
DARPA Vision

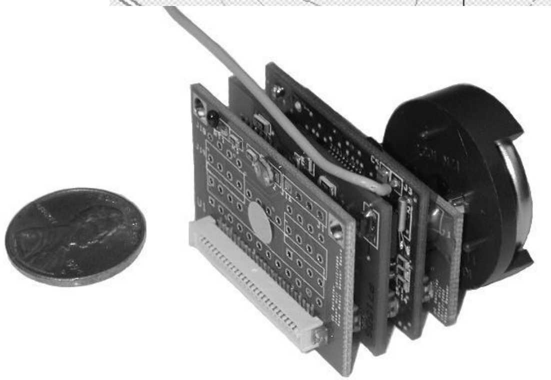


- Multiple target tracking
- Dense deployment of sensor nodes on the ground
- Flexible sensor tasking
- Multi-modal sensor nodes
  - Seismic sensor, motion detector, microphone

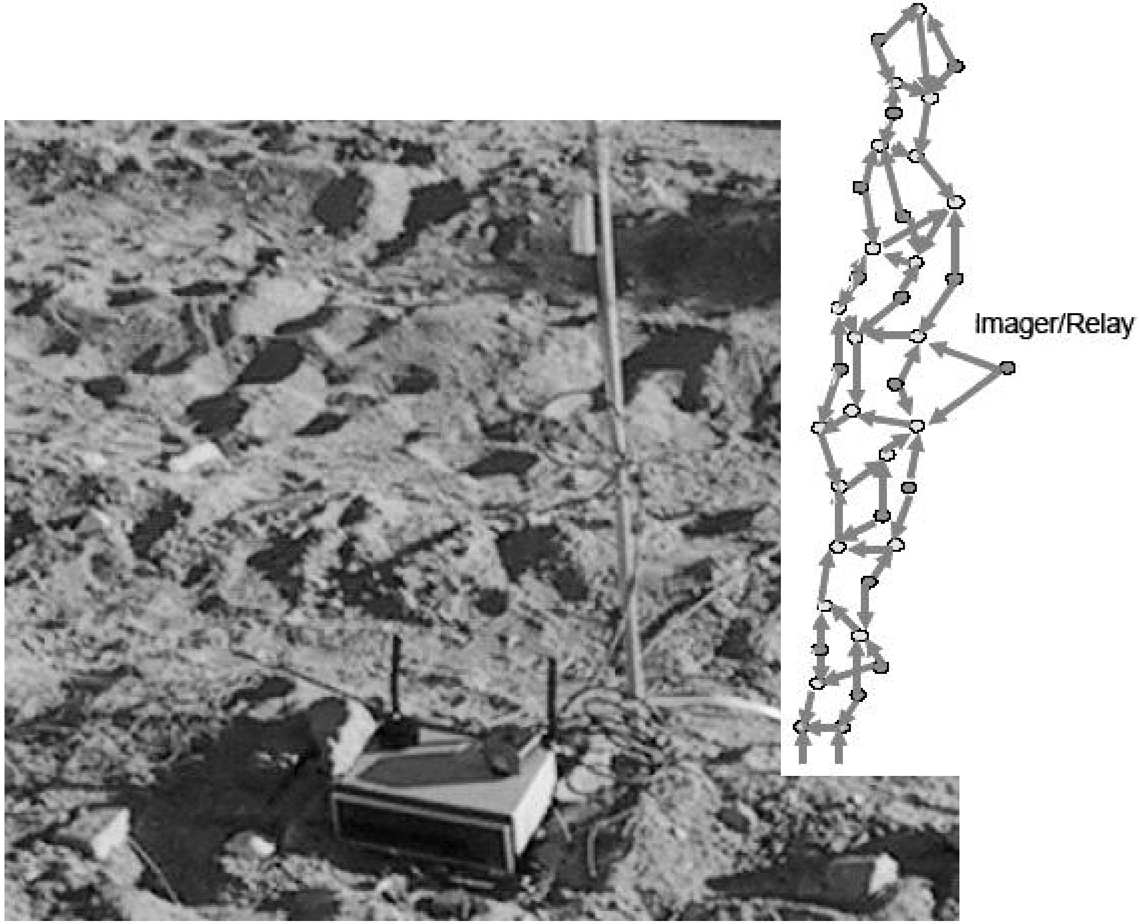
www.eecs.berkeley.edu/~pister/29Palms0103/

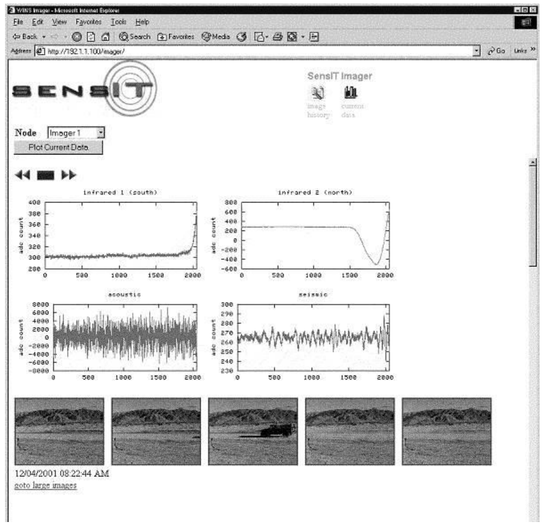
A First DARPA Demo





A Second DARPA Demo

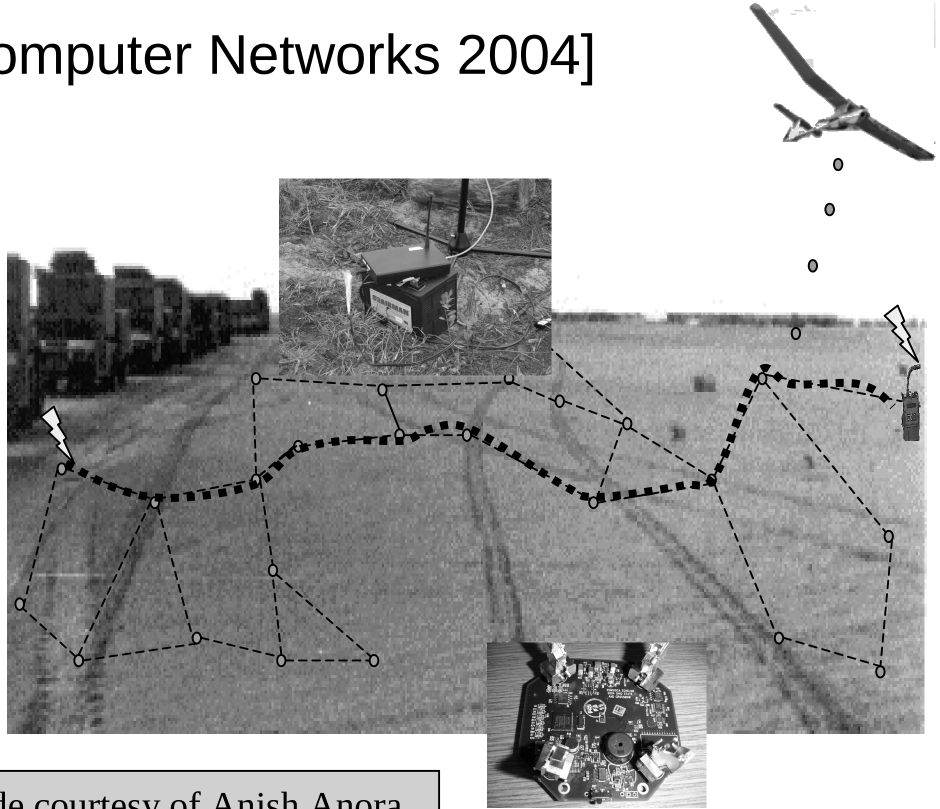




www.cast.cse.ohio-state.edu/exscal/

ExScal

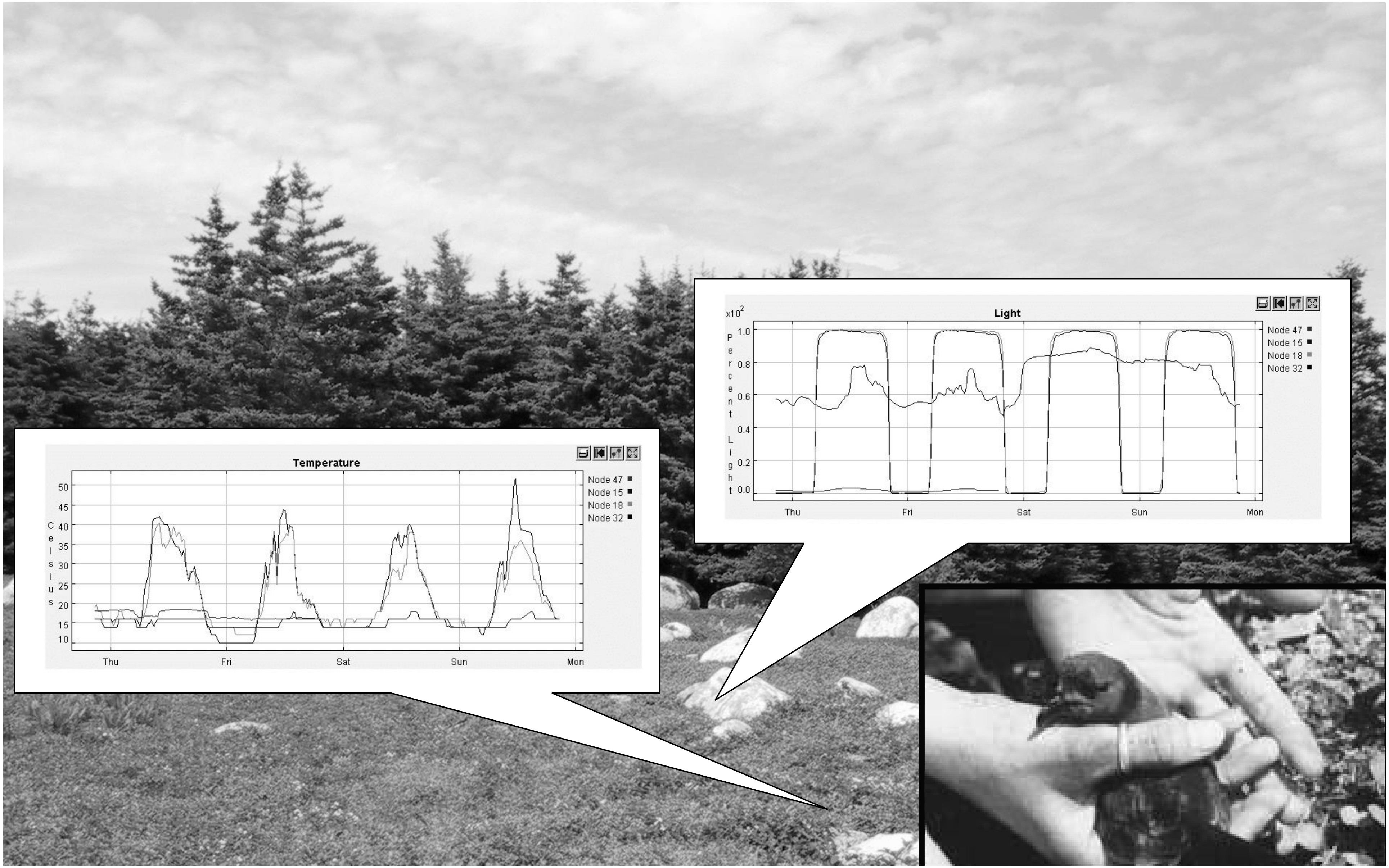
Put tripwires anywhere—in deserts, other areas where physical terrain does not constrain troop or vehicle movement—to detect, classify & track intruders [Computer Networks 2004]



Slide courtesy of Anish Anora
(Ohio State University

www.greatduckisland.net

Great Duck Island



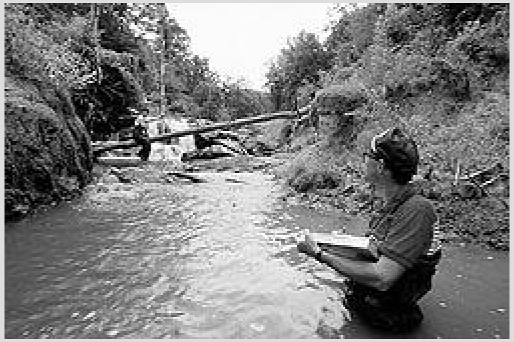
www.ee.princeton.edu/~mrm/zebranet.html

Zebranet

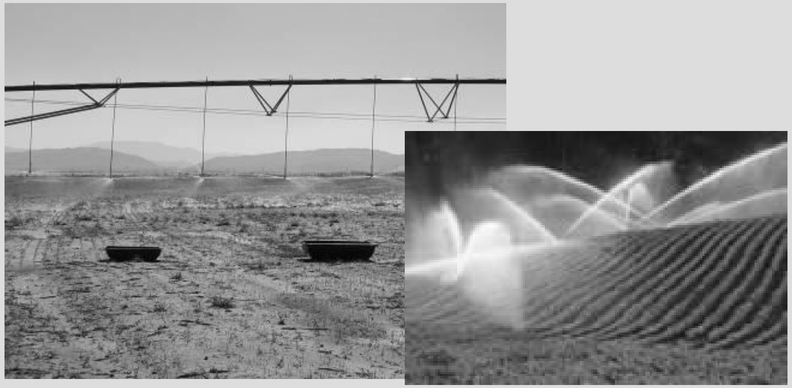
- Modelling long-range animal migrations
  - Sparse connections
- Observing inter-species predator-prey interactions
- Analyzing the impact of human development on animal behavior

cens.ucla.edu

Environmental monitoring applications exhibit high spatial variations and heterogeneity

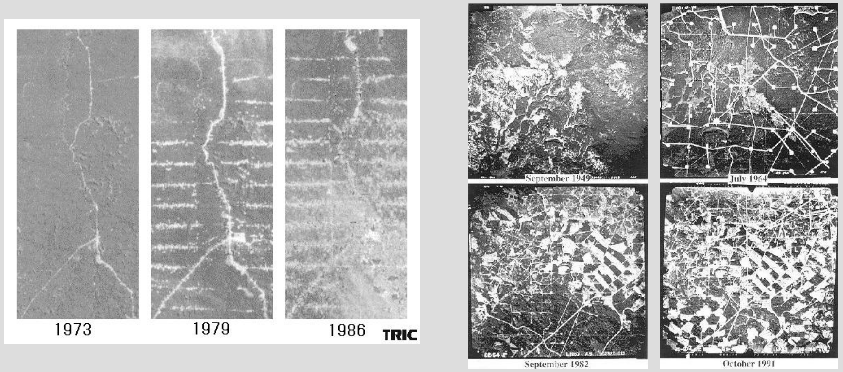


Overflow of embankment



Precision Agriculture, Water quality management

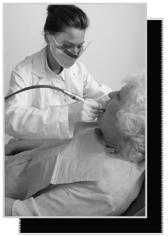
Algal growth as a result of eutrophication



Impact of fragmentation on species diversity

Slide courtesy of Deborah Estrin

Impacts Key Segments of Society & Economy



Health / Life Sciences

Agriculture

Environment

Manufacturing

Distribution

Retail

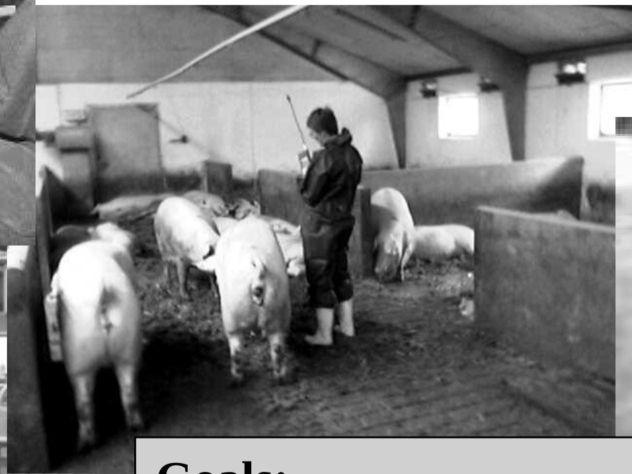
Images Courtesy of Ralph Kling (Intel Research)

Commercial developments driven by

- Automotive, logistics and business intelligence, production automation, health and well being, entertainment, environment industries
- Regulatory constraints: food safety, homeland security

www.hogthrob.dk

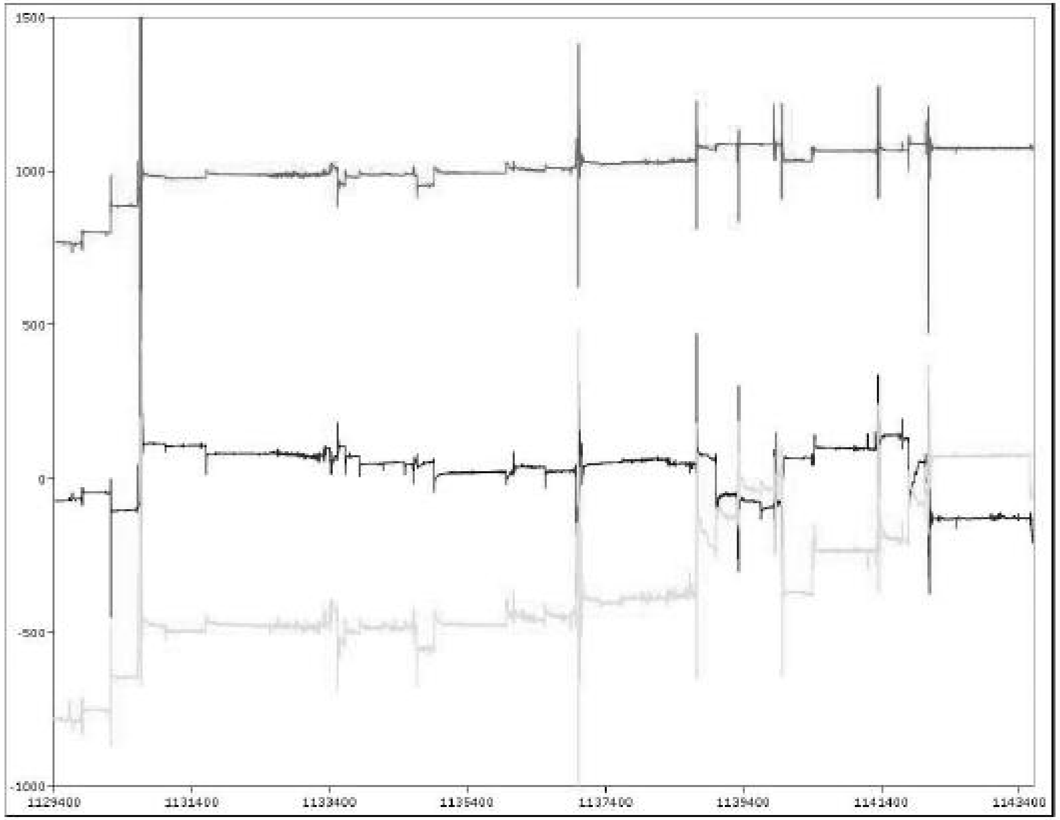
Hogthrob

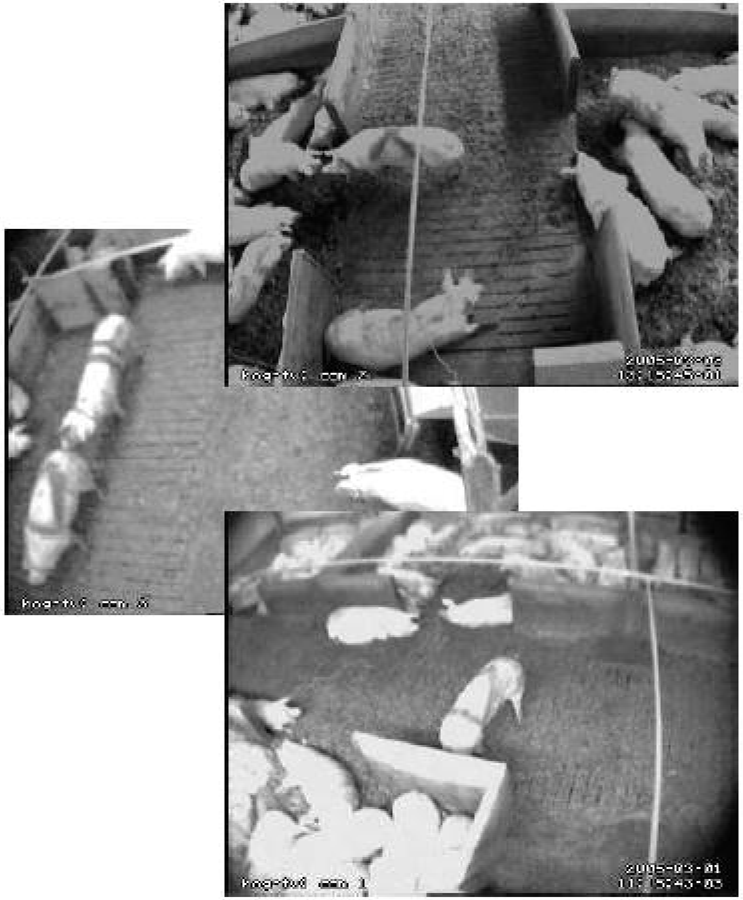


<u>Goals:</u>

- **Functionalities**
  - **Tracking**
  - **Detecting Heat Period**
  - **…**
- **Low Cost (~1 €)**
- **Low Energy (2 years)**

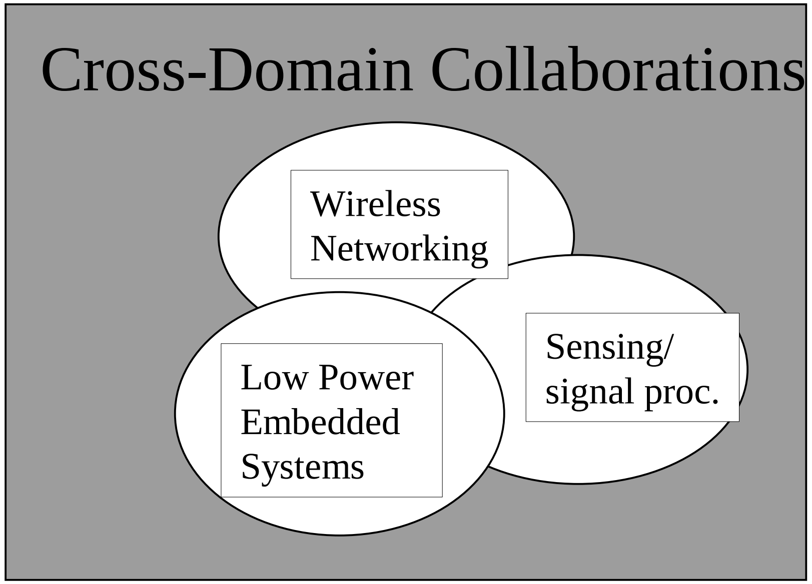
Hogthrob (Field Experiment)



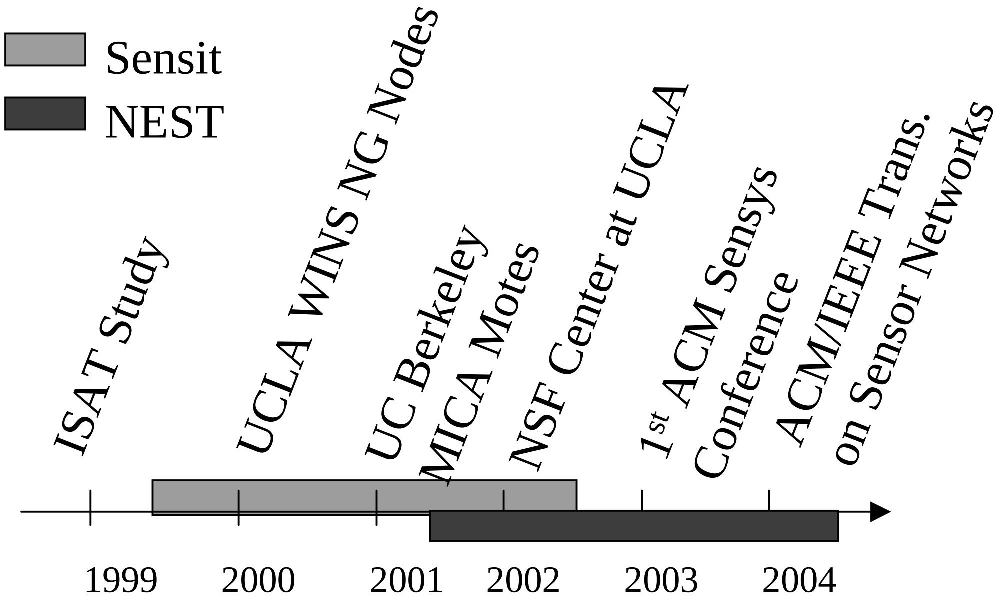


Lessons Learned

- Tens, hundreds of nodes
  - Not millions
  - Closer to ubicomp scenario (see MIT Media Lab)
- Oversampling phase is important
  - To develop model
  - To debug hardware, software and packaging
- Human in the loop
  - Deployment
  - Calibration
- The infrastructure is KEY
  - Reliability, availability
  - Throughput, storage
  - Stream processing



Research Driven Developments



5 year status:

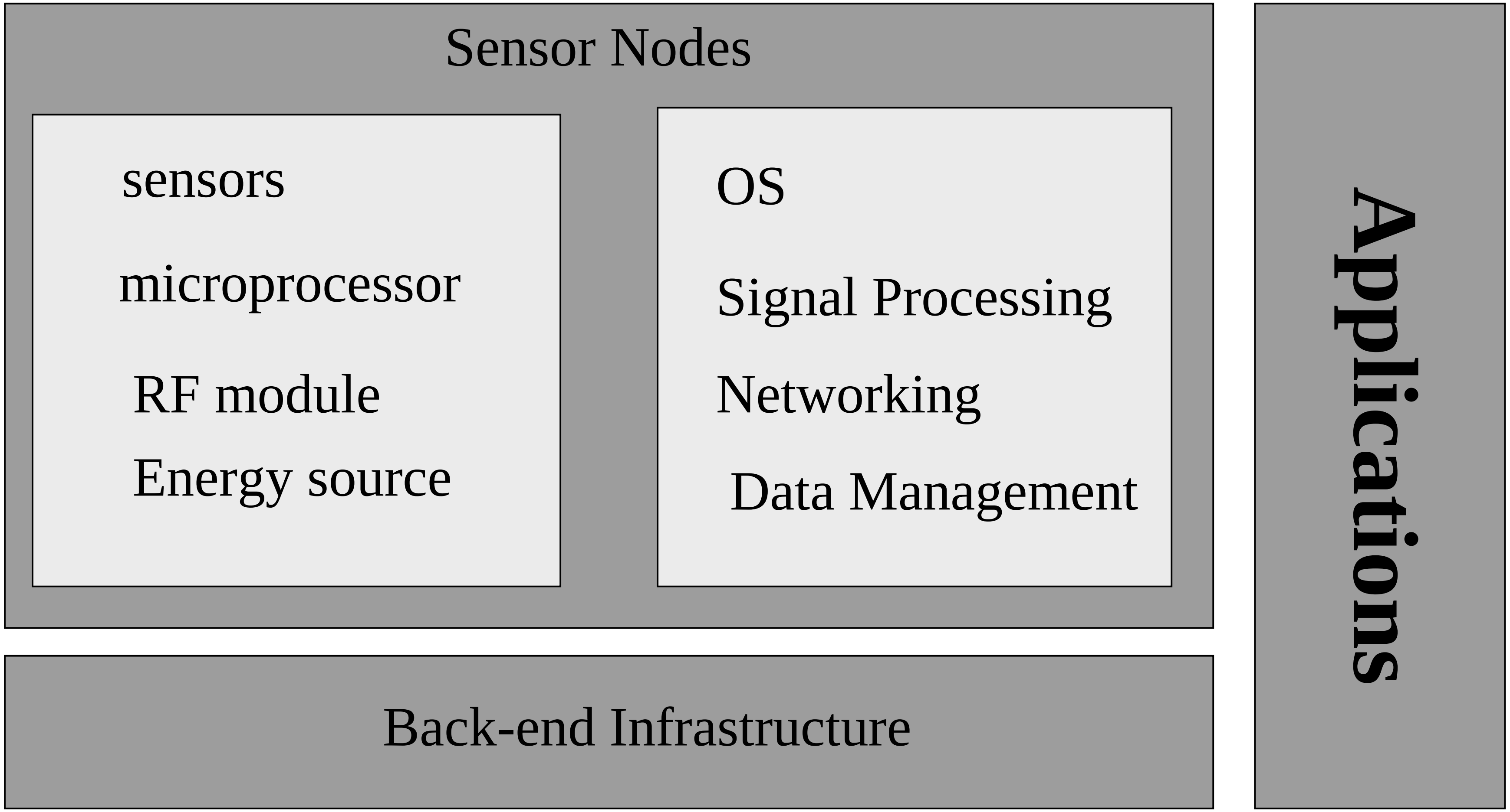
- Startups (ember, dust inc, moteiv)
- Transfer (Intel, AFRL)
- Centers (CENS, Intel lablets)
- Open Source (TinyOS)

Military, scientific and commercial applications
Similar to Internet development model

Industry Initiatives

- ZigBee (www.zigbee.org)
  - The Zigbee Alliance is an association of companies working together to enable reliable, cost-effective, low-power, wirelessly networked, monitoring and control products based on an open global standard
  - Freescale, Motorola, Honeywell, Philips, Chipcon, Ember, Mitsubishi Electric, Samsung, …
  - Zigbee (interoperability, application) + 802.15.4 (MAC/PHY)
- MIMOSA (www.mimosa-fp6.com)
  - Nokia, ST Microelectronics, Sonion, Suunto, …
  - Microsystems platform for MObile Services and Applications centered around mobile phone as gateway to environment (sensors, RFID tags)

Technology


Sensor Nodes
sensors
microprocessor
RF module
Energy source
OS
Signal Processing
Networking
Data Management
Back-end Infrastructure
Applications

Design Space

- **Detection Model**
  - Adaptation to individual sows
  - Dictates sensor modality
    - Accelerometer 2D, 3D
  - Dictates duty cycling
- **Sensor Network Infrastructure**
  - Alert at home + info inside the penn (mobile Phone)
  - Star topology
  - Wake-up: in-channel, add-on low power radio
- **Sensor Node Design**
  - Packaging
  - Energy source
    - Battery, harvesting
    - Dictates energy budget
  - Generic node vs. Custom Design
  - SW design on given HW platform vs. <u>Co-design</u>
    - COTS vs. custom components

<u>Goals</u>:

- Functionalities
  - Tracking
  - Detecting Heat Period
- Low Cost (~1 €)
- Low Energy (2 years)

Hardware impact on applications

- Lifetime
  - Depends on energy budget (batteries, energy harvesting, passive vs. active)
  - Energy consumption depends on hardware components and on interaction with software
    - Turning off components to save energy

      <u>DUTY CYCLING</u>
    - Moving boundary between hardware and software components

      <u>CO_DESIGN</u>
    - Hardware characteristics impact software design

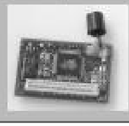
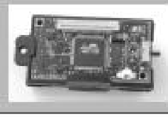
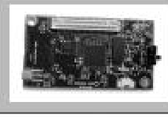
      <u>CROSS LAYER OPTIMIZATIONS</u>

Hardware impact on applications

- Cost
  - Dictates choice of hardware components, of fabrication method
- Sensed Data
  - Dictates choice of radio, of sensors, of microprocessor
- Environment
  - form factor impacts choice of hardware components, layout

http://www.tinyos.net/media.html

Berkeley Mote Evolution

Mote Type	*WeC*	*René*	*René 2*	*Dot*	*Mica*	*Mica2Dot*	*Mica 2*	*Telos*
Year	1998	1999	2000	2000	2001	2002	2002	2004
								
Microcontroller								
Type	AT90LS8535		ATmega163		ATmega128			TI MSP430
Program memory (KB)	8		16		128			60
RAM (KB)	0.5		1		4			2
Active Power (mW)	15		15		8		33	3
Sleep Power (μW)	45		45		75		75	6
Wakeup Time (μs)	1000		36		180		180	6
Nonvolatile storage								
Chip	24LC256				AT45DB041B			ST M24M01S
Connection type	I^2C				SPI			I^2C
Size (KB)	32				512			128
Communication								
Radio	TR1000				TR1000	CC1000		CC2420
Data rate (kbps)	10				40	38.4		250
Modulation type	OOK				ASK	FSK		O-QPSK
Receive Power (mW)	9				12	29		38
Transmit Power at 0dBm (mW)	36				36	42		35
Power Consumption								
Minimum Operation (V)	2.7		2.7		2.7			1.8
Total Active Power (mW)	24				27	44	89	41
Programming and Sensor Interface								
Expansion	none	51-pin	51-pin	none	51-pin	19-pin	51-pin	10-pin
Communication	IEEE 1284 (programming) and RS232 (requires additional hardware)							USB
Integrated Sensors	no	no	no	yes	no	no	no	yes

(courtesy of Joe Polastre et al.)

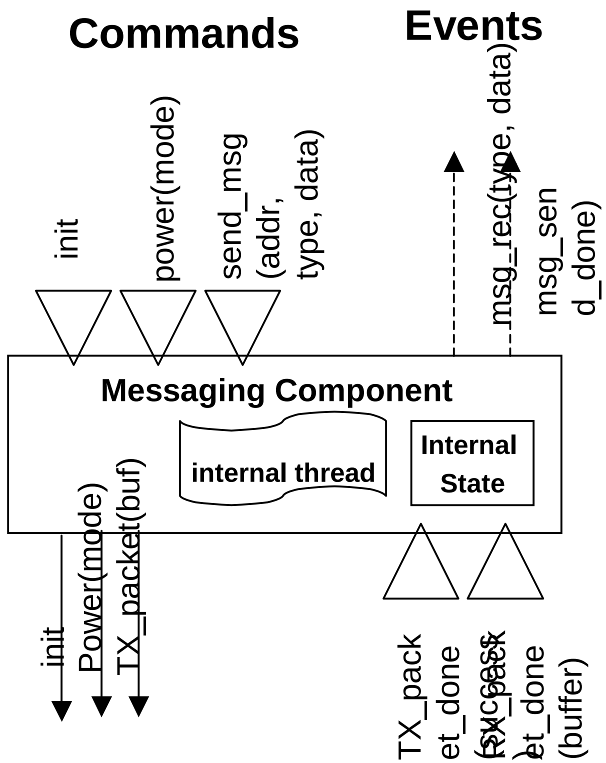
Programming a Sensor Network

- Interacting with predefined generic programs
  - SmartMesh from Smart Dust.inc (http://www.dust-inc.com)
  - Sensorscope platform (http://sensorscope.epfl.ch/)
  - Sensor databases (Cougar, TinyDB)
- Uploading application specific programs
  - Motelab platform (http://motelab.eecs.harvard.edu/)
- Composing services
  - Mate virtual machine
  - Active messages

sourceforge.net/projects/tinyos/
www.tinyos.net

Tiny OS

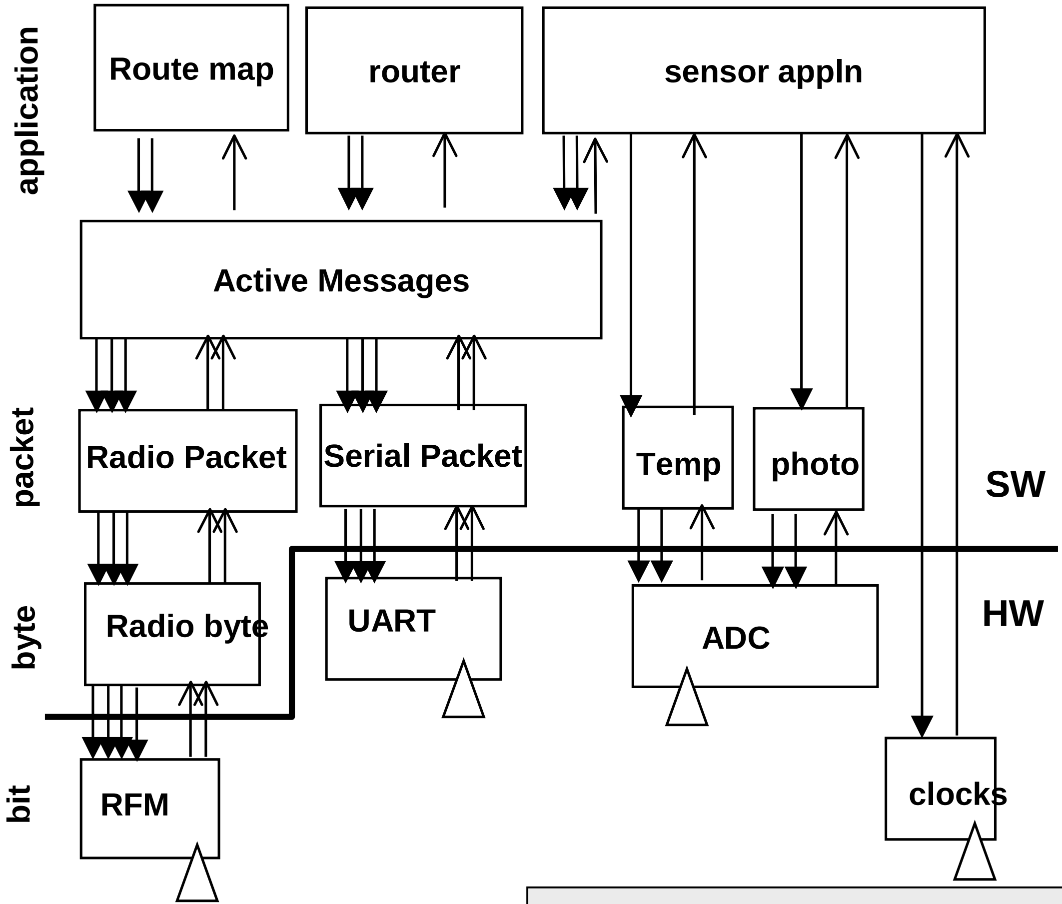
- Scheduler + Graph of Components
  - constrained two-level scheduling model: threads + events
- Component:
  - Commands,
  - Event Handlers
  - Frame (storage)
  - Tasks (concurrency)
- Constrained Storage Model
  - frame per component, shared stack, no heap
- Very lean multithreading
- Efficient Layering

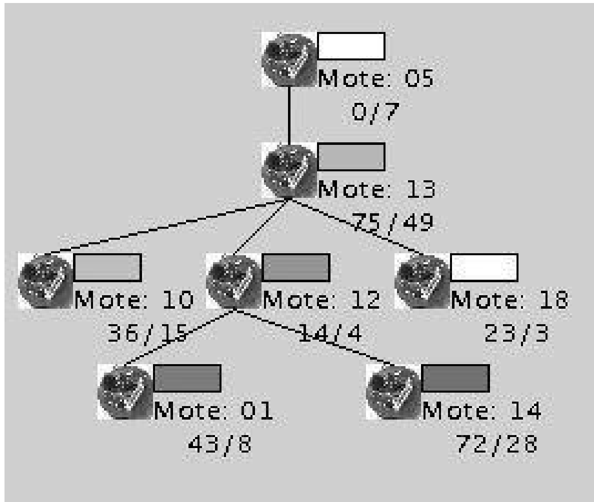


Slide Courtesy of David Culler

www.tinyos.net

NesC Application = Graph of Components





Example: ad hoc, multi-hop routing of photo sensor readings

3450 B code
226 B data

Slide Courtesy of David Culler

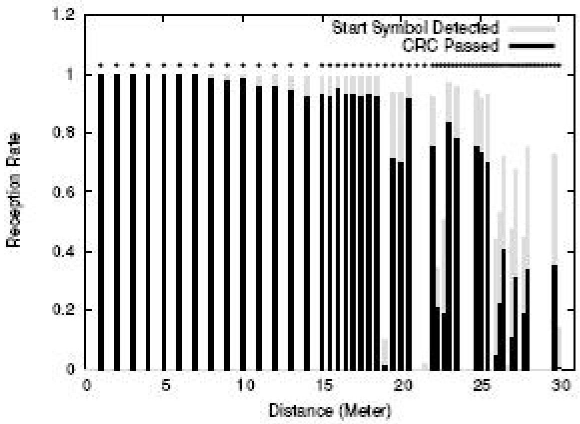
Networking Issues

- Single vs. Multiple channels
- Coding
  - Trade-off between error tolerance and overhead
  - Leverage temporal, spatial correlations
- MAC Layer
  - Not fairness, latency, throughput, bandwidth utilization
  - Energy efficiency
    - Limit idle listening
    - Reduce packet size
    - Reduce retransmissions
    - Leverage overhearing (in a broadcast medium)
  - Scalability
    - Density
    - Topology
- Adressing
  - ID based vs. logical attribute
- Routing
  - Link state, distance vector, source routing considered static and expensive
  - Routing Tree, Geographic, Gradient considered appropriate
  - Single vs. multiple path
- Duty Cycling
  - Requires discovery and connection

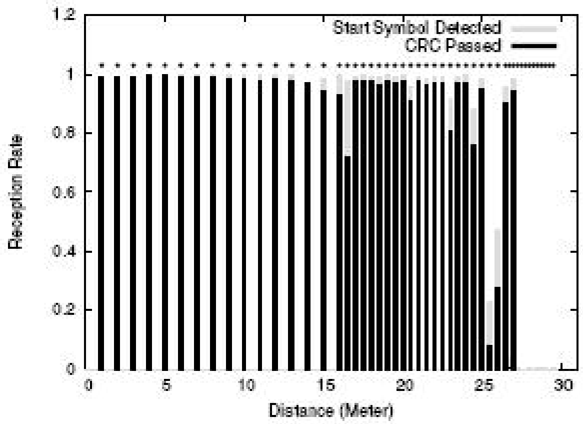
Packet Delivery Performance

[Zhao et al Sensys'03]

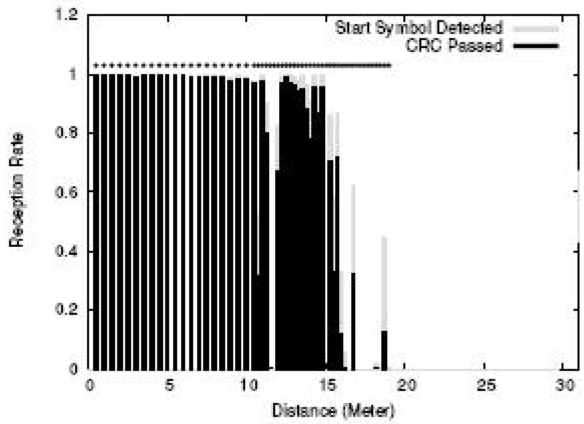
Indoor



Outdoor



Habitat



World State

- From physical phenomena
  - Mechanics, heat, energy, sound, light, magnetism, electricity, optics, atoms.
  - Fields evolving in time across a region of space
- To a model of the physical world

Signal Processing + Data Management

Model of the Physical World

- Models
  - Finite State Machine
  - Rule-based
  - *Relational* (Sensor Database)
  - Probabilistic
- Data Access
  - Data retrieval vs. data dissemination
    - 1 tier vs. 2 tier data retrieval
  - Snapshot vs. long running
  - Acquisition-based vs. event-based
  - User-based vs. model-based

Data Management Systems

- Implements data access
  - Sensor tasking
  - Data processing
  - Data routing
  - Possibly support for data model and query language (for relational and probabilistic models)
- Goals:
  - Adaptive
    - Network conditions
    - Variing/unplanned stimuli
  - Energy efficient
    - In-network Processing
    - Flexible tasking
    - Duty cycling

Trends

- Applications
  - Towards context aware applications, responsive systems
- Hardware
  - Sensor node on a chip
    - FPGA based prototypin
  - 8/16/32 bits nodes
- Networking
  - Multi-tier architecture
  - Routing based on link quality (based on packet delivery measurements – not distance, signal strenght or transmission power)
- Data Management
  - Model-based data acquisition
  - Approximate aggregates along multiple paths using synopsis

Challenges

- Develop Technology based on Application needs
  - Passive sensors
  - Packaging
  - Sensor node on-a-chip
  - Energy efficient co-design
  - Ease of programming
  - Large scale deployment
  - Integration with back-end data processing
- Focus on Barriers to Adoption
  - Privacy
  - Cost