EEC173B Lecture:

Introduction to Wireless Sensor Networks

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Image credit: www.dho.edu.tr/enstitunet/snetsim

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Motivation

- The standard networking problem:
  How to move data from point A to point B
  - Typically over the Internet, or a wireless link
  - Usually what changes is the routing algorithm, MAC, maybe QoS
  - Typically push or pull
    - end-to-end
- What if the data is everywhere?
- What if the network is totally autonomous?

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Office Building Fire

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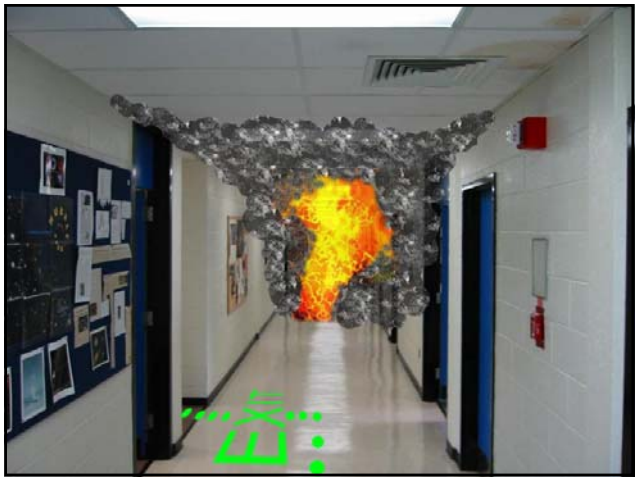
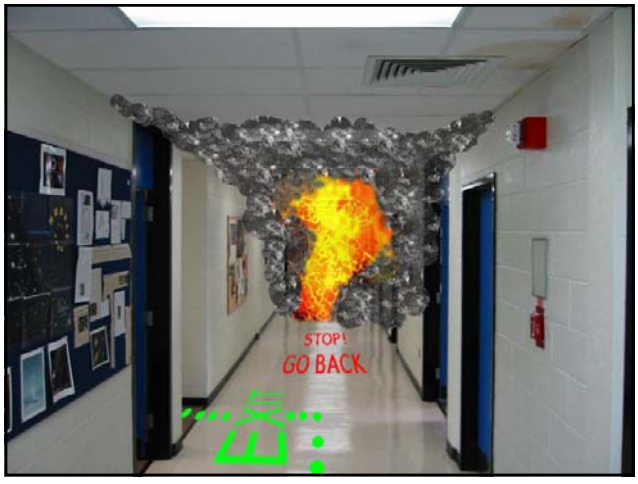
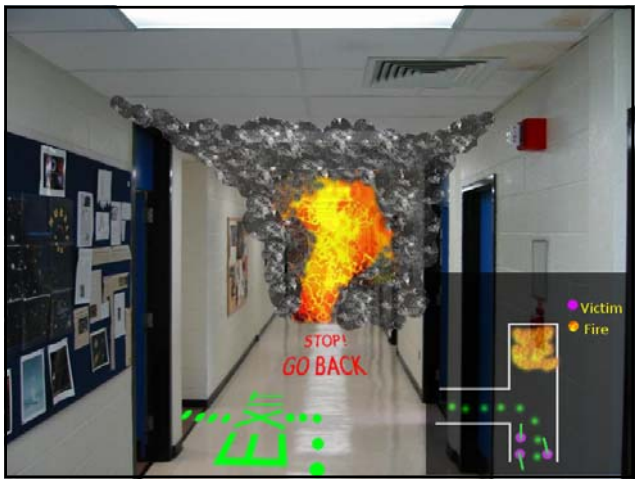



STOP!
GO BACK



Smart Paint Example

- Network senses & reacts to the fire
  - Detects {temperature, smoke, O2, CO2, people}
  - Determines {fire region(s), safe region(s), exit path}
  - Action {display path w/ warnings, notify authorities}
- Challenges?
  - Zillions of nodes!
    - Sensing & collaborating, Networking, Reliability, ...
- [http://robotics.eecs.berkeley.edu/~pister/SmartDust/in2010] easier: google "pister 2010"

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What is a Sensor Network?

- A network nodes, connected by links
- A system rather than a mechanism
  - Data is generated inside the network ("in situ")
  - Data is (potentially) processed inside the network
- Wireless is cheaper, easier to deploy/maintain
  - Wireless Sensor Network (WSN, or ESN, ...)
  - Less disruptive to environment (or, stealthy)
- From very large (small N) to very small (large N)

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What is a WSN?

- Science
  ***1 : the state of knowing : knowledge as distinguished from ignorance or misunderstanding* [Merriam-Webster]**
  - Often, if you can't measure it, **you** can't analyze it



6 m 6 cm 6 mm

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Examples

- Motivating Applications
  - Environmental monitoring
  - Ecological studies
  - Disaster prediction, warning, response
  - Warning/Safety/Security systems
  - Military (defense, offense)
  - Tracking
  - Consumer products, home automation
    - Ubiquitous/Proactive Computing

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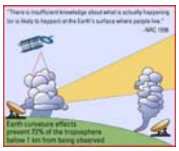
CASA (2003)

[http://www.casa.umass.edu/]

- "CASA seeks to advance fundamental knowledge and provide societal benefits by creating a new engineering paradigm for observing, detecting, and predicting weather and other atmospheric phenomena."



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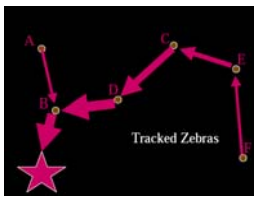
ZebraNet (2004)

[http://www.princeton.edu/~mrm/zebranet.html]



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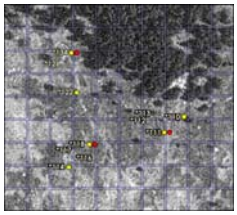
Great Duck Island (2002)

[http://www.greatduckisland.net/]

- Designed to "monitor the microclimates in and around nesting burrows used by the Leach's Storm Petrel."





- Over 200 nodes deployed
- Multi-hop, tiered

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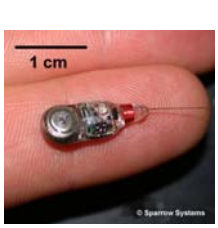
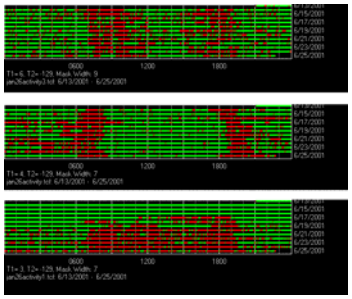
ARTS (Princeton)





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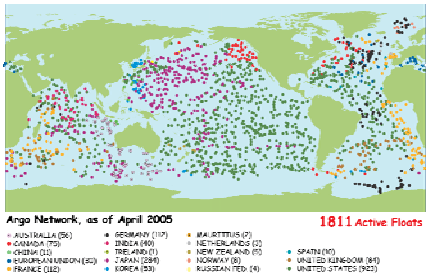
ARGO (2000)

[http://www.argo.ucsd.edu]

- Measure global salinity, temperature, pressure.



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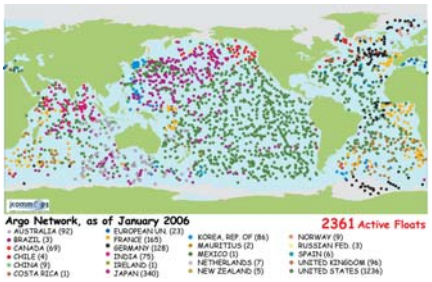
ARGO: 2006



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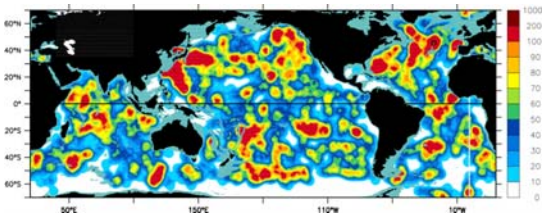
ARGO Coverage



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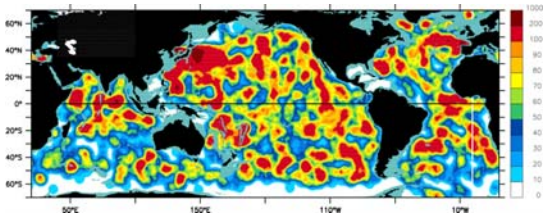
ARGO Coverage: 2006



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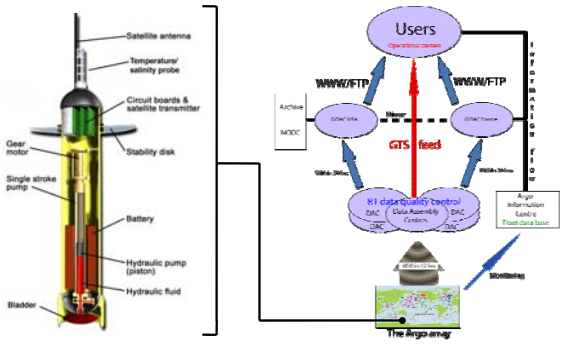
ARGO: System Architecture



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ARGO:

If we cast ARGO as a wireless sensor network, what challenges do you think the system might face?

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ARGO: Challenges

- Reliability
  - Nodes run out of energy (~4 yr)
  - SPOF: JASON-1
- Quality
  - Sensor measurements lose calibration
- Cost
  - $15k per node; double that if you count processing!
- Scalability

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Challenges

- **ENERGY**
  - Nodes are typically battery-powered (fixed energy)
- **Cost**
- **Scalability**
- **Reliability**
  - **Autonomy**
  - **Security**
- **Tasking/Programming**

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Result: Cross-Layer Optimization

- You can't just focus on the "networking part" of the problem. It's all one big problem: ENERGY.
  - Signals people have to think about communication overhead
  - Networking people have to think about processing and memory overhead
    - They probably have to work together!

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WSN Components

- Node (battery, sensors, MCU, memory, radio)
  - All low-power and with sleep modes
  - OS, routing algorithms, application(s)
- "Gateway" or ubernodes (hierarchical)
- "Base stations" and infrastructure
  - OS, routing algorithms, application(s)
  - Tasking, collection, management software

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Technology of a WSN

- The Node
  - Energy/Power sources
  - Sensors / Actuators
  - Radio
  - Processor
  - Memory
  - Enclosure
  - Operating system
- The Network
  - Management
  - Data Storage
  - Data Analysis
  - Infrastructure
  - Multi-User
  - Deployment
    - Maintenance

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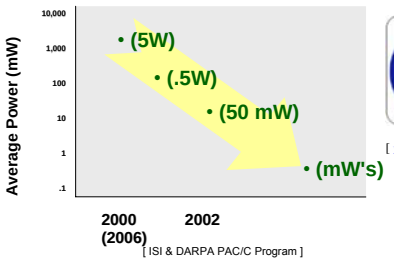
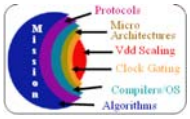
Energy



[ISI & DARPA PAC/C Program]



[www.darpa.mil/ipto/programs/pacc]

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Energy: Moore vs. Shannon

- Can continue to reduce operating power (MCU, sensors) for some time (Moore's Law)
  - Radio is less forgiving (Shannon's Theorem)
- Batteries: lithium, Zinc-air, fuel cell
  - All eventually run out
  - Ultracapacitors
- Renewables
  - solar, vibration, Piezo,
  - thermal, nuclear; e.g., solar can get 0.15-15 mW

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Sensors & Actuators

- Passives use less energy
  - Solar, seismic, acoustic, IR, salinity, temperature, humidity, strain [Estrin]
- Active Sensors:
  - Radar, sonar, ladar, radio, sounder
- Most sensors are too expensive
  - Only Solar, IR, temp. are cheap enough
  - Some sensors cost $1000's
    - MEMS is considered to be the best hope

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Radio

- Typically “free” bands (ISM)
  - 433 Mhz, 916 Mhz, 2.4 GHz, many more
- Current favorite: 802.15.4 “ZigBee” compliant
  - 2.4 GHz spread spectrum (DSSS)
  - ~20 mW to Rx/Tx
    - Listening is not free
      - Must sleep when not in use

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Processor

- Small MCU typical.
  - Atmel, TI
- Sleep when not in use
  - Leakage current and startup times are important
- Generally, we want the lowest power
  - But that usually doesn't give the lowest J/op!
  - Ex: [Srivastava]
    - 242 MIPS/W for ATMega128L @ 4 MHz (4nJ/Instruction)
    - 480 MIPS/W for ARM Thumb @ 40 MHz (2.1 nJ/Instruction)

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Memory

- Small RAM (4 kB typ.) for run-time
- Flash for code
- Flash for nonvolatile data storage (4 Mb typ.)
  - cost of storing versus transmitting
- With many nodes, that's a significant amount of storage

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OS

- Needs to be lightweight (small memory footprint)
- Allows for cross-layer optimization
  - TinyOS [UCB] is the current champ
    - nesC language
    - Restricted C syntax designed to save RAM (no malloc)
    - Modular component architecture (code reuse, save RAM)
      - Memory use is deterministic, except for stack
  - Mantis MOS [http://mantis.cs.colorado.edu]
  - UCLA SOS [http://nesl.ee.ucla.edu/projects/SOS]

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Other Challenges

- Time synchronization
- Enclosure
  - Protect the node & allow sensing
- Radio details (RF design)
  - How much work should the radio do?
    - e.g. 802.11 vs. mote
- Novel circuits and architectures
  - Energy scavenging circuits
  - Self-timed circuits

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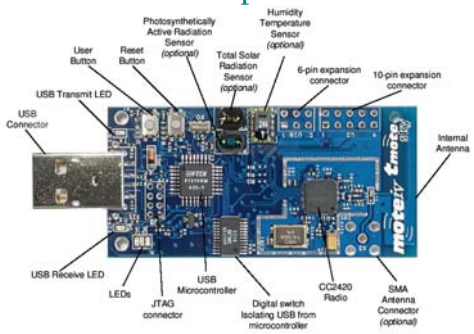
Node Example: Tmote



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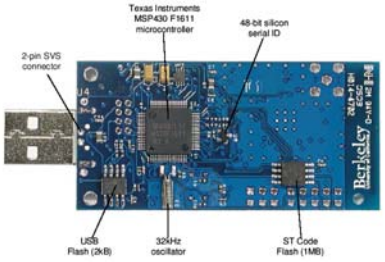
Node Example: Tmote



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Example TinyOS Program

```
Blink.nc

configuration Blink {
}
implementation {
  components Main, BlinkM, SingleTimer, LedsC;

  Main.StdControl -> BlinkM.StdControl;
  Main.StdControl -> SingleTimer.StdControl;
  BlinkM.Timer -> SingleTimer.Timer;
  BlinkM.Leds -> LedsC;
}
```

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Example (Cont'd)

```
BlinkM.nc, continued implementation {

  command result_t StdControl.init() {
    call Leds.init();
    return SUCCESS;
  }

  command result_t StdControl.start() {
    return call Timer.start(TIMER_REPEAT, 1000) ;
  }

  command result_t StdControl.stop() {
    return call Timer.stop();
  }

  event result_t Timer.fired()
  {
    call Leds.redToggle();
    return SUCCESS;
  }
}
```

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WSN in Academia

- Partial listing!
  - UCLA/CENS (SW)
  - UCLA/SOS (SW)
  - UCB/Intel/BWRC (HW, SW)
  - MIT (HW, SW)
  - JPL (HW, ?)
  - MANTIS @ UC Boulder (HW, SW)

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WSN in Industry

- Crossbow motes
- Moteiv “Telos” motes
- Millennial Net “i-Beans”
- Sensicast
- MeshDynamics
- Innovative Wireless Technologies (IWT)



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Some Research Problems

- Collaborative (in-network) Signal Processing (CSP)
- Routing
  - Broadcast
  - Rooted tree
  - Point-to-point
  - Geographic
  - Gradient (e.g. directed diffusion)
  - Random walk (e.g. rumor routing)

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Focus of Current Academic Research

- Reducing cost, power (always)
- How to program?
  - Monolithic, Reconfigurable parameters, Scripting, Macroprogramming, Agents, Communication primitives
- What should the architecture be?
  - TinyOS 2.0 (UCB)
  - Tenet (UCLA)
- How to secure the networks

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What Needs More Attention

- Heterogeneous networks
- Multiple users per network
- MEMS sensors
- How to program

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Summary

- Basic Foundations
- Motivation
- State of the Art
- Research Challenges
  - Energy
  - Cross-Layer Optimization
  - Scalability

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