Wireless Sensor Network (WSN)

CS526 Advanced Internet and Web Systems

C. Edward Chow

Wireless Sensors

Low-power microscopic sensors with wireless communication capability

- Miniaturization of computer hardware
  → Intelligence
- Micro Electro-Mechanical Structures (MEMS)
  → Sensing
- Low-cost CMOS-based RF Radios
  →Wireless Communications

Wireless Sensor Networks(WSN)

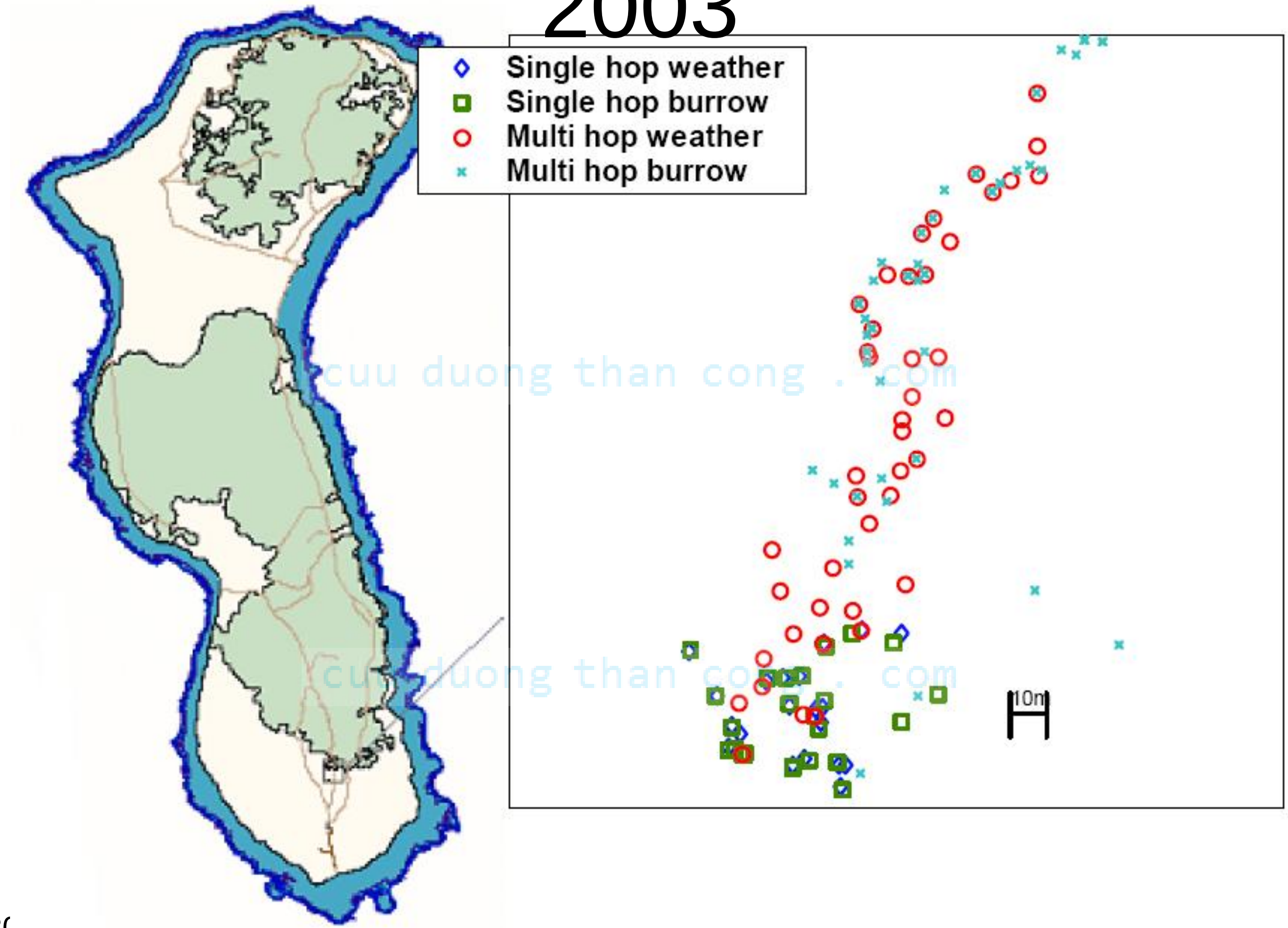
- Even though wireless sensors has limited resources in memory, computation power, bandwidth, and energy.
- With small physical size→Can be embedded in the physical environment.
- Support powerful service in aggregated form (interacting/collaborating among nodes)
- *Self-organizing multi-hop ad-doc networks*
- Pervasive computing/sensoring

WSN Applications

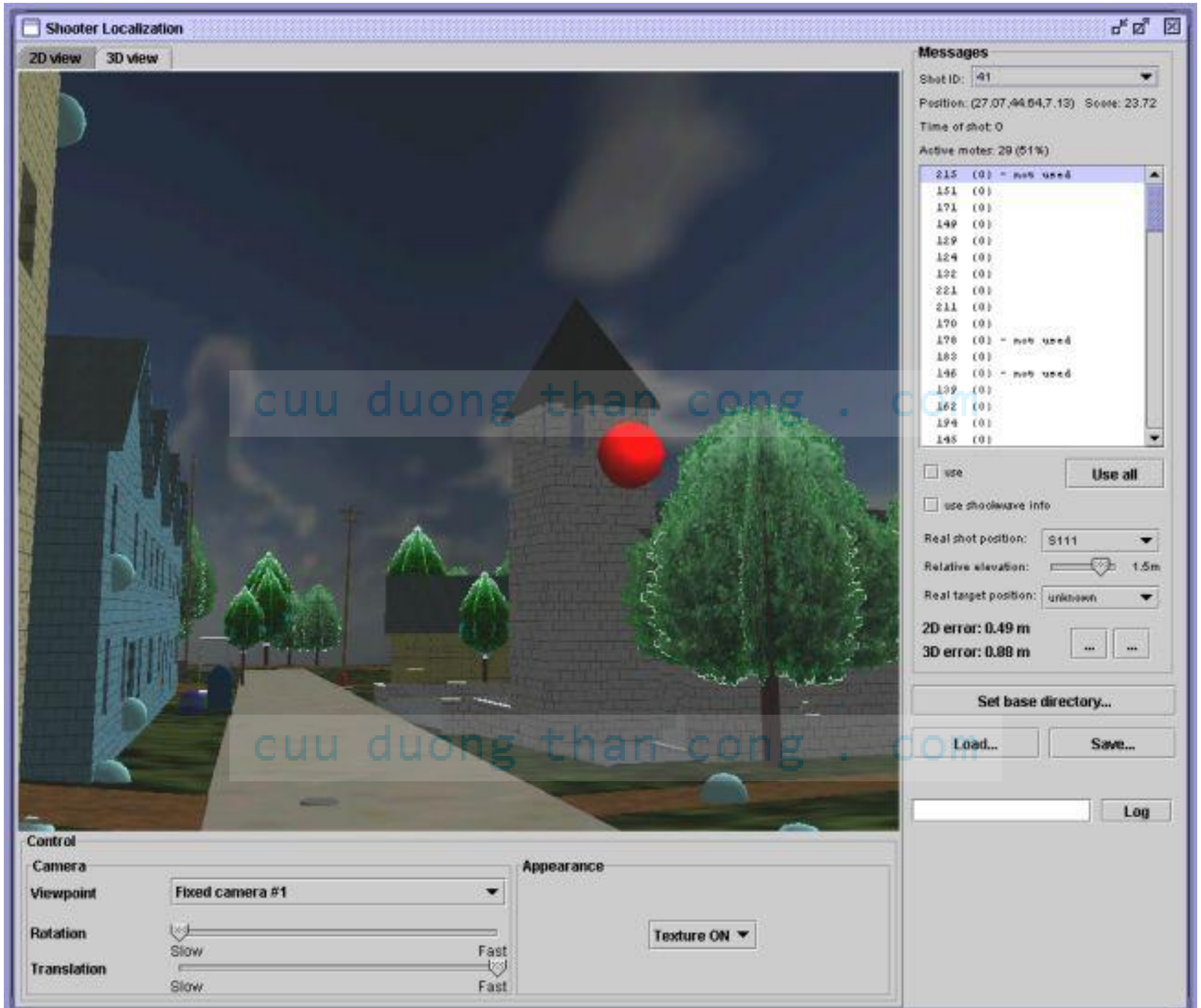
- Wide area monitoring tools supporting Scientific Research
  - Wild life Habitat monitoring projects Great Duck Island (UCB), James Reserve (UCLA), ZebraNet (Princeton.
  - Building/Infrastructure structure study (Earthquake impact)
- Military Applications
  - Shooter Localization
  - Perimeter Defense (Oil pipeline protection)
  - Insurgent Activity Monitoring (MicroRadar)

- Commercial Applications
  - Light/temperature control
  - Precision agriculture (optimize watering schedule)
  - Asset management (tracking freight movement/storage)

Senor Network/Great Duck Island 2003



Vanderbuilt's Shooter Localization



Related Info

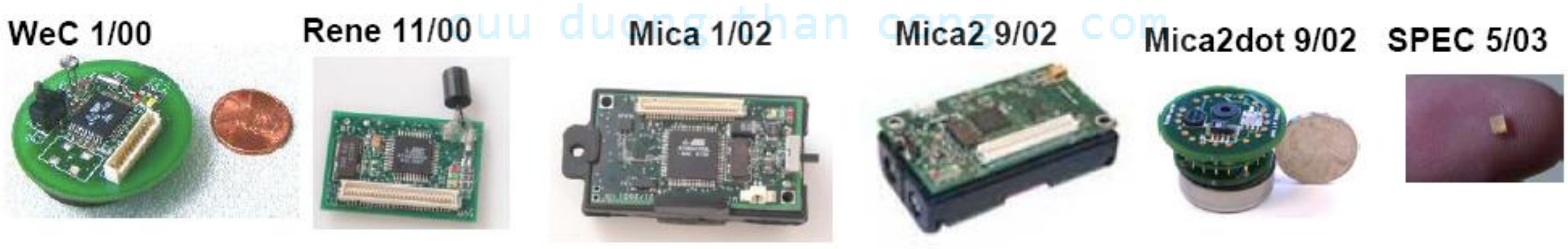
- Alec Woo's dissertation (Chapters 1-2) http://www.cs.berkeley.edu/~awoo/thesis.pdf
- Networking of Sensor System (NOSS) workshop presentations
- CACM WSN special issue, Vol. 47, Issue 6, June 2004. (this url required uccs vpn access)
  – The platforms enabling wireless sensor networks, by Jason Hill et al.

What is a mote?

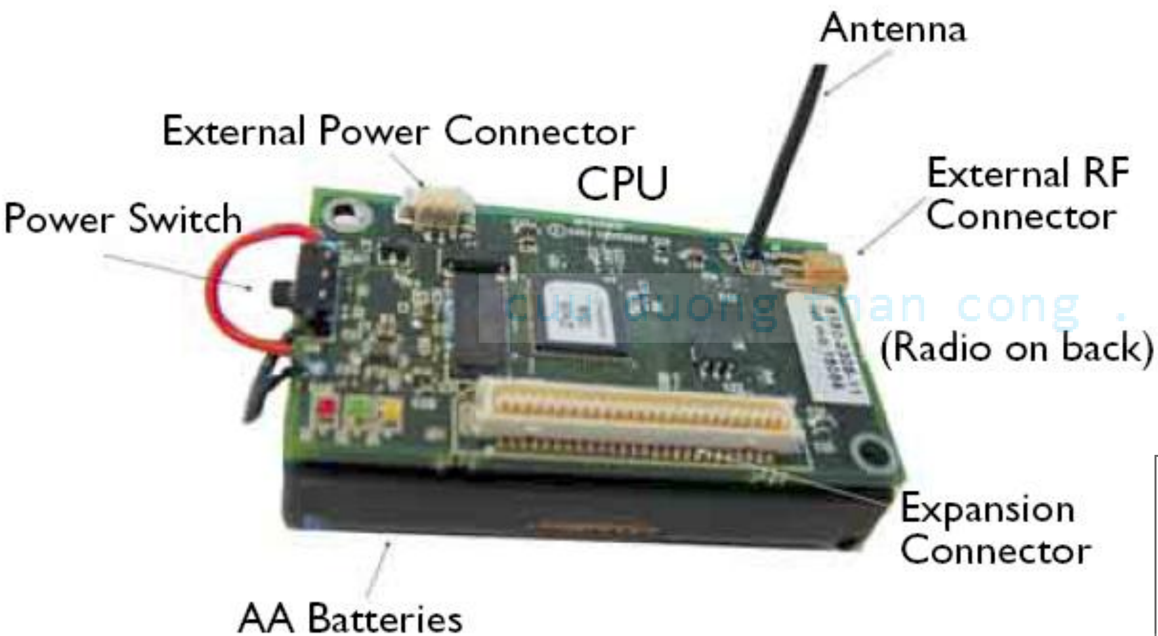
Imote2 06 with enalab camera

- **mote** noun [C] LITERARY
  something, especially a bit of dust, that is so small it is almost impossible to see
  ---Cambridge Advanced Learner’s Dictionary
  http://dictionary.cambridge.org/define.asp?key=52014&dict=CALD

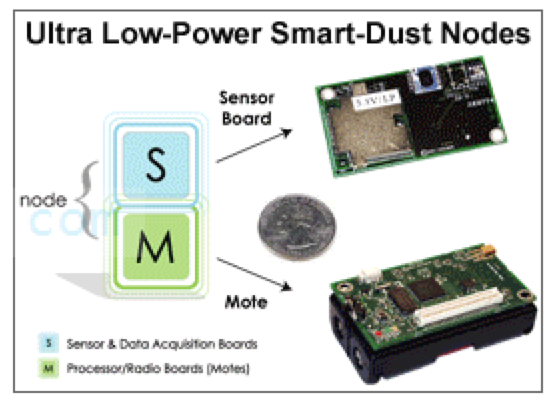
Evolution of Sensor Hardware Platform (Berkeley), [Alec Woo 2004]



Mica2 Wireless Sensors
CACM June 2004 pp. 43.



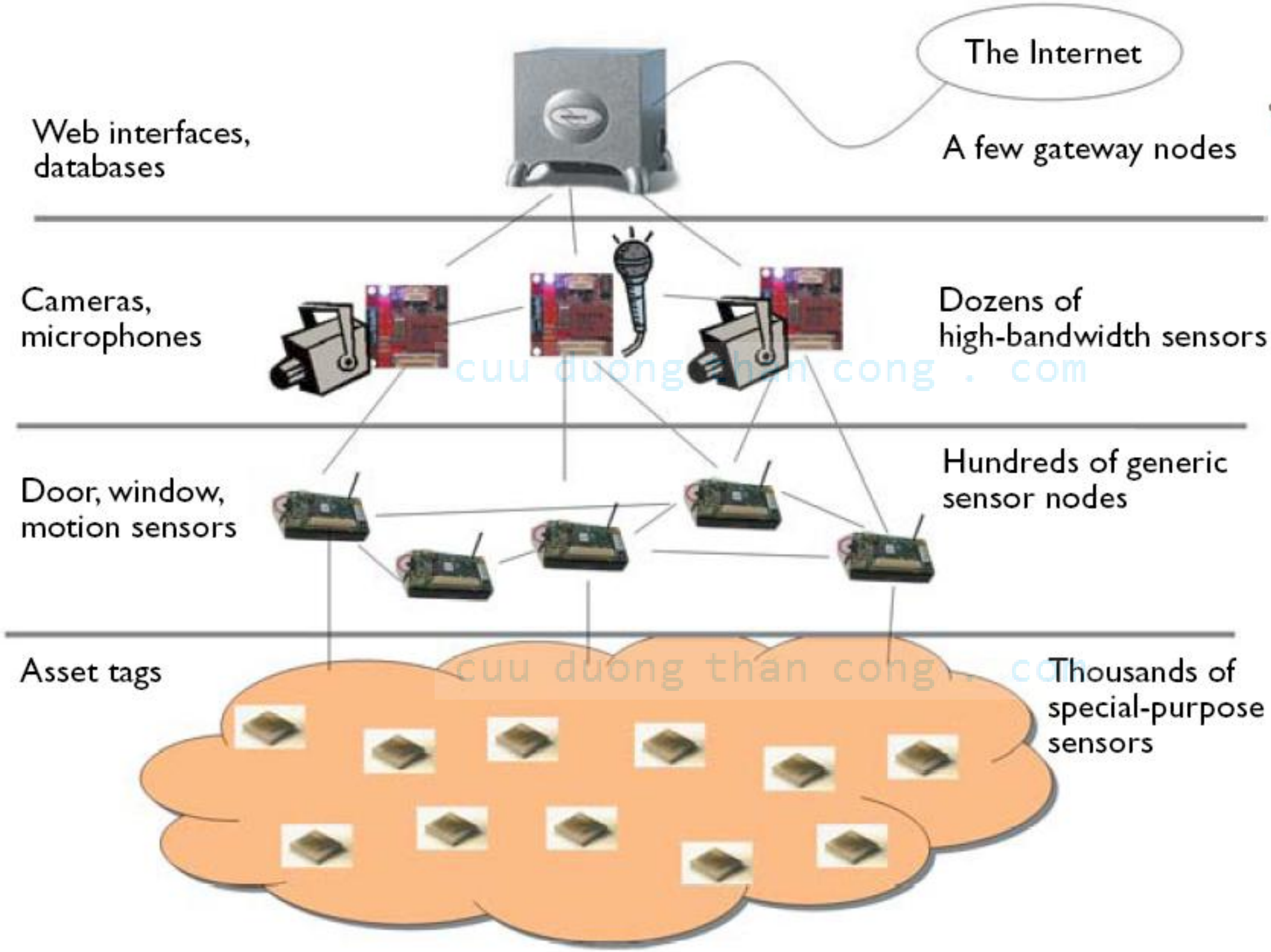
MTS310 Sensor Boards
- Acceleration,
- Magnetic,
- Light,
- Temperature,
- Acoustic,
- Sounder



New MicaZ follows IEEE 802.15.4 Zigbee standard with direct sequence sprad spectrum radio and 256kbps data rate

[Adapted from Crossbow web site]

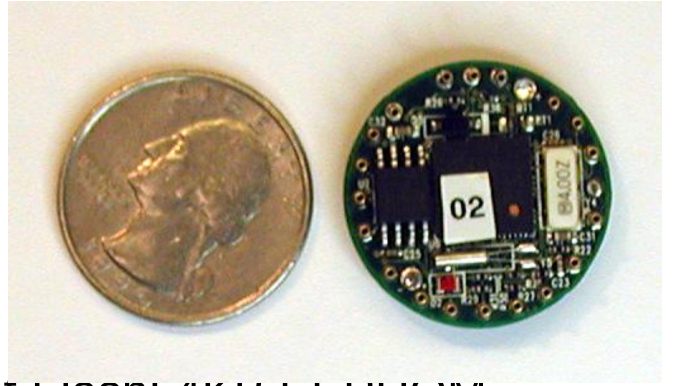
Wireless Sensor Network



Stargate

- 802.11a/b
- Ethernet
- Mica2
- PCMCIA
- Compactflash
- USB
- JTAG
- RS232

Motes and TinyOS



- **Motes** (Mica2, Mica2dot, MicaZ)
  - Worked well with existing curriculum
    - ATMega128L microcontroller
    - 128KB program flash; 512KB measurement Flash; 4KB EEPROM
  - Standard platform with built-in radio chicon1000 (433MHz, 916MHz, 2.4GHz) 38.4kb; 256kbps for MicaZ IEEE 802.15.4. (1000ft, 500ft; 90/300ft) range
  - AA battery
  - Existing TinyOS code base
  - Convenient form factor for adding sensors
- **TinyOS**
  - Event-based style helped students understand:
    - Time constraints
    - Code structure (need to write short non-blocking routines)
  - Existing modular code base saved time
    - Made a more complex project possible
    - Provided a degree of abstraction

Comparison of Energy Sources

	Power (Energy) Density	Source of Estimates
Batteries (Zinc-Air)	1050 -1560 mWh/cm^3 (1.4 V)	Published data from manufacturers
Batteries(Lithium ion)	300 mWh/cm^3 (3 - 4 V)	Published data from manufacturers
Solar (Outdoors)	15 mW/cm^2 - direct sun 0.15mW/cm^2 - cloudy day.	Published data and testing.
Solar (Indoor)	.006 mW/cm^2 - my desk 0.57 mW/cm^2 - 12 in. under a 60W bulb	Testing
Vibrations	0.001 - 0.1 mW/cm^3	Simulations and Testing
Acoustic Noise	3E-6 mW/cm^2 at 75 Db sound level 9.6E-4 mW/cm^2 at 100 Db sound level	Direct Calculations from Acoustic Theory
Passive Human Powered	1.8 mW (Shoe inserts >> 1 cm^2)	Published Study.
Thermal Conversion	0.0018 mW - 10 deg. C gradient	Published Study.
Nuclear Reaction	80 mW/cm^3 1E6 mWh/cm^3	Published Data.
Fuel Cells	300 - 500 mW/cm^3 ~4000 mWh/cm^3	Published Data.

With aggressive energy management, ENS might live off the environment.

Source: UC Berkeley

Communication/Computation Technology Projection

	1999 (Bluetooth Technology)	2004
Communication	(150nJ/bit) 1.5mW*	(5nJ/bit) 50uW
Computation		~ 190 MOPS (5pJ/OP)

Assume: 10kbit/sec. Radio, 10 m range.

Large cost of communications relative to computation continues

Source: ISI & DARPA PAC/C Program

Energy Management Issues

- Actuation energy is the highest
  - Strategy: ultra-low-power “sentinel” nodes
    - Wake-up or command movement of mobile nodes
- Communication energy is the next important issue
  - Strategy: energy-aware data communication
    - Adapt the instantaneous performance to meet the timing and error rate constraints, while minimizing energy/bit
- Processor and sensor energy usually less important

MICA mote Berkeley

Transmit	**720 nJ/bit**	Processor	**4 nJ/op**
Receive	**110 nJ/bit**	**~ 200 ops/bit**	

WINS node RSC

Transmit	**6600 nJ/bit**	Processor	**1.6 nJ/op**
Receive	**3300 nJ/bit**	**~ 6000 ops/bit**	

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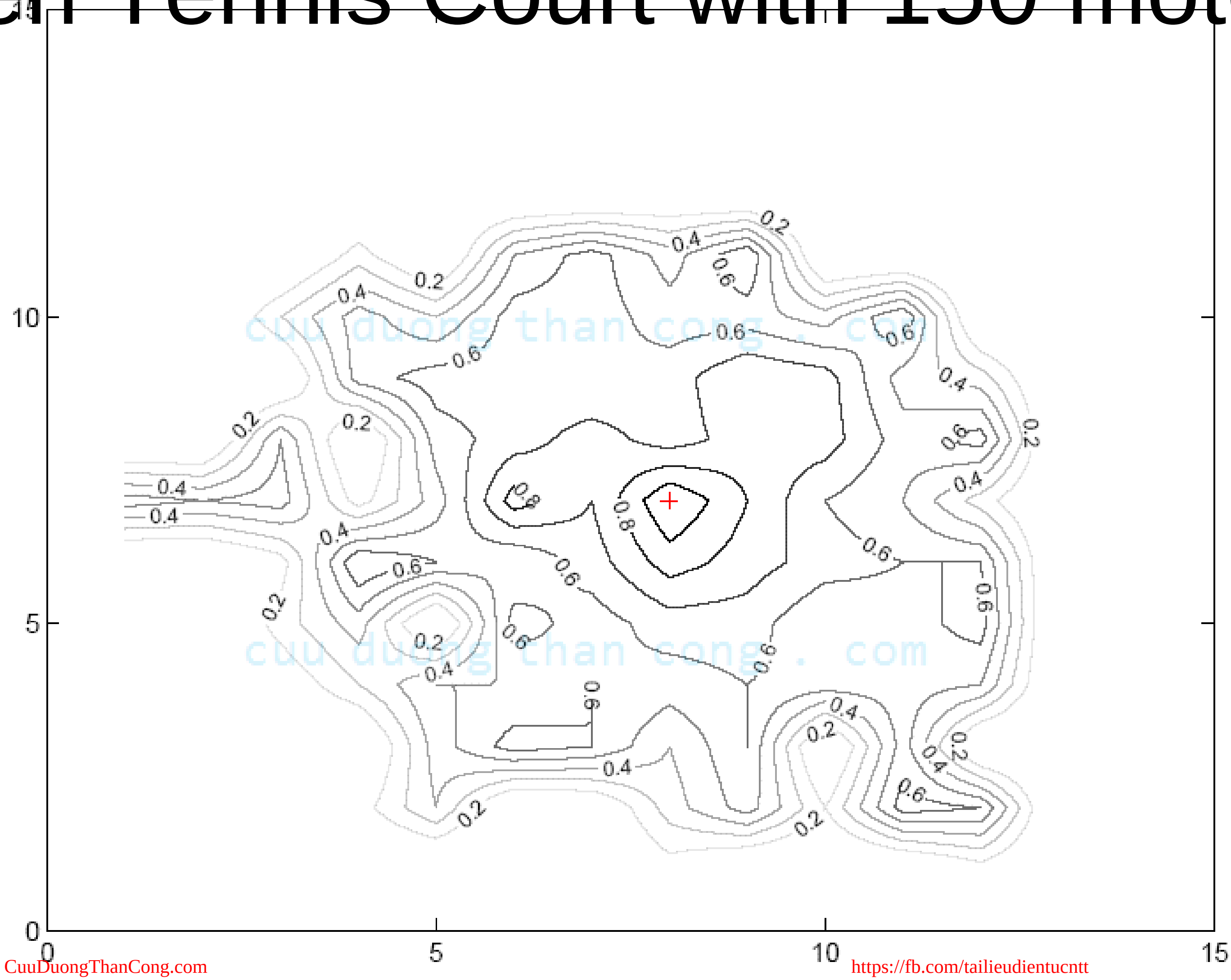
Wireless Sensor Network(WSN) vs. Mobile Ad Hoc Network (MANET)

	WSN	**MANET**
Similarity	Wireless	Multi-hop networking
Security	Symmetric Key Cryptography	Public Key Cryptography
Routing	Support specialized traffic pattern. Cannot afford to have too many node states and packet overhead	Support any node pairs Some source routing and distance vector protocol incur heavy control traffic
Resource	Tighter resources (power, processor speed, bandwidth)	Not as tight.

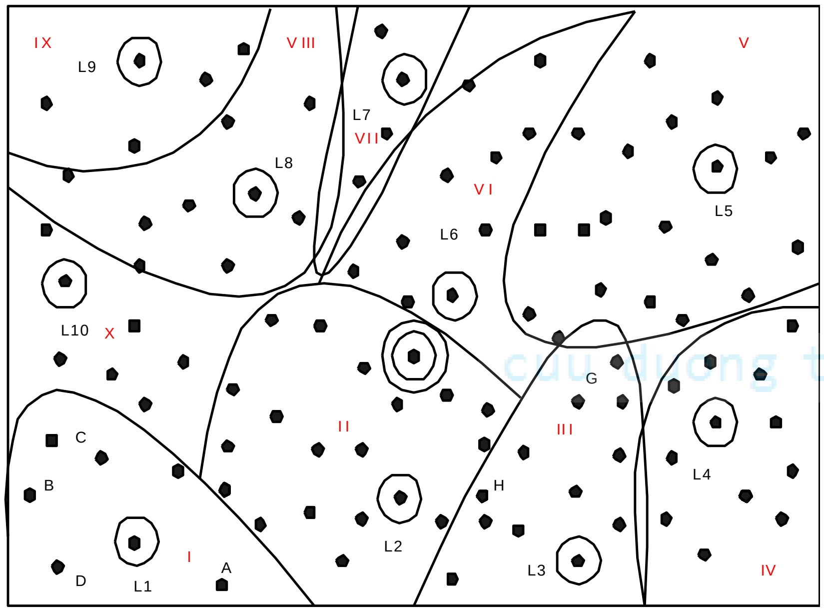
Unusual WSN Link Characteristics Packet Success Rate Contour Open Tennis Court with 150 motes

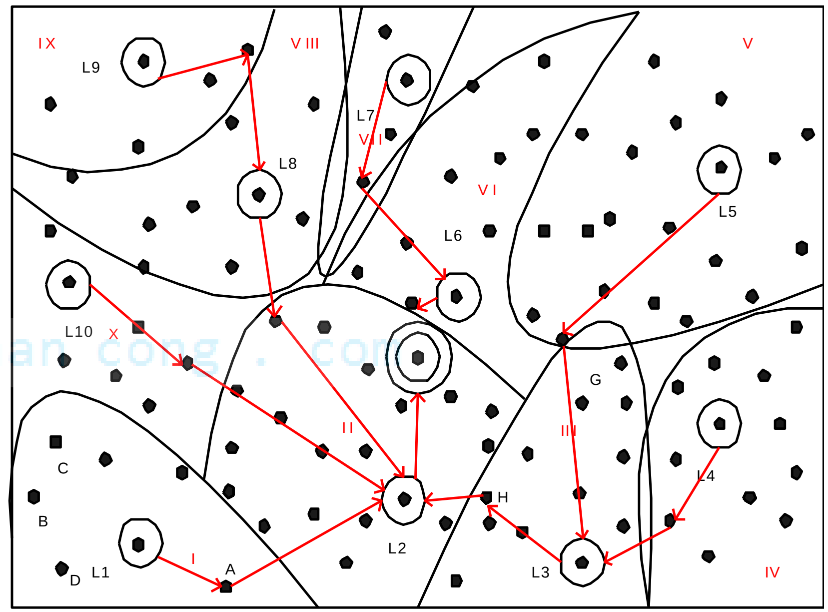


Challenges in Self-organizing Multi-hop Ad-doc Networks

- Problems has been studied in packet radio network and mobile computing.
- However in sensor networks, it is unique in:
  - Lossy short-range wireless ratio
    Need more cross-layer interaction
  - Tight resource constraints
  - Traffic pattern differences
  - In-Network Processing

Cluster /Sink Tree Formation





Cluster Formation Phase

Sink Tree Formation Phase

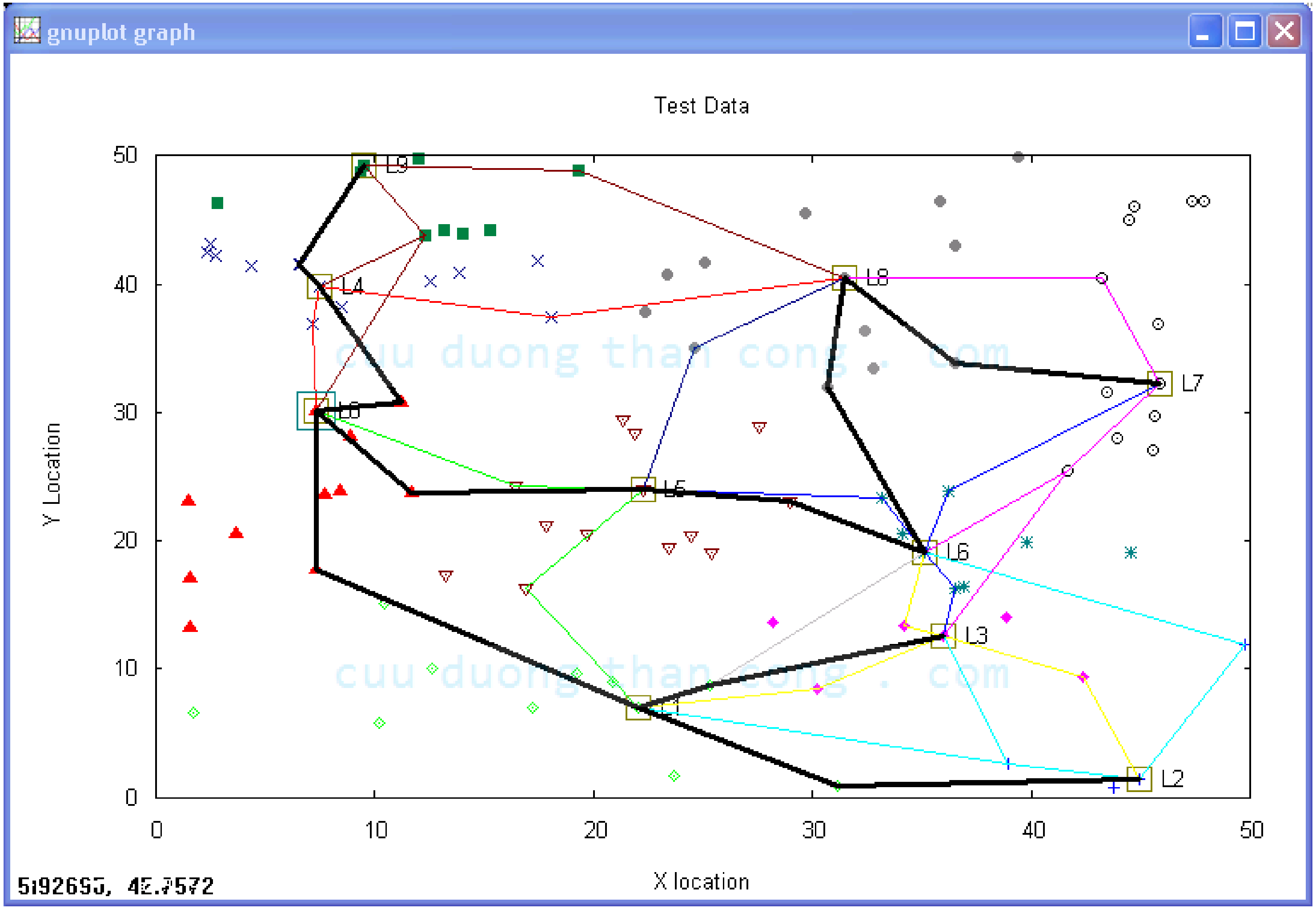
Node with Double Circle: Sink Node

Node with Single Circle: Chosen Cluster Leader

Red Arcs forms the sink tree

Should there be direct link between leaders? (Wendi Heinzelman)

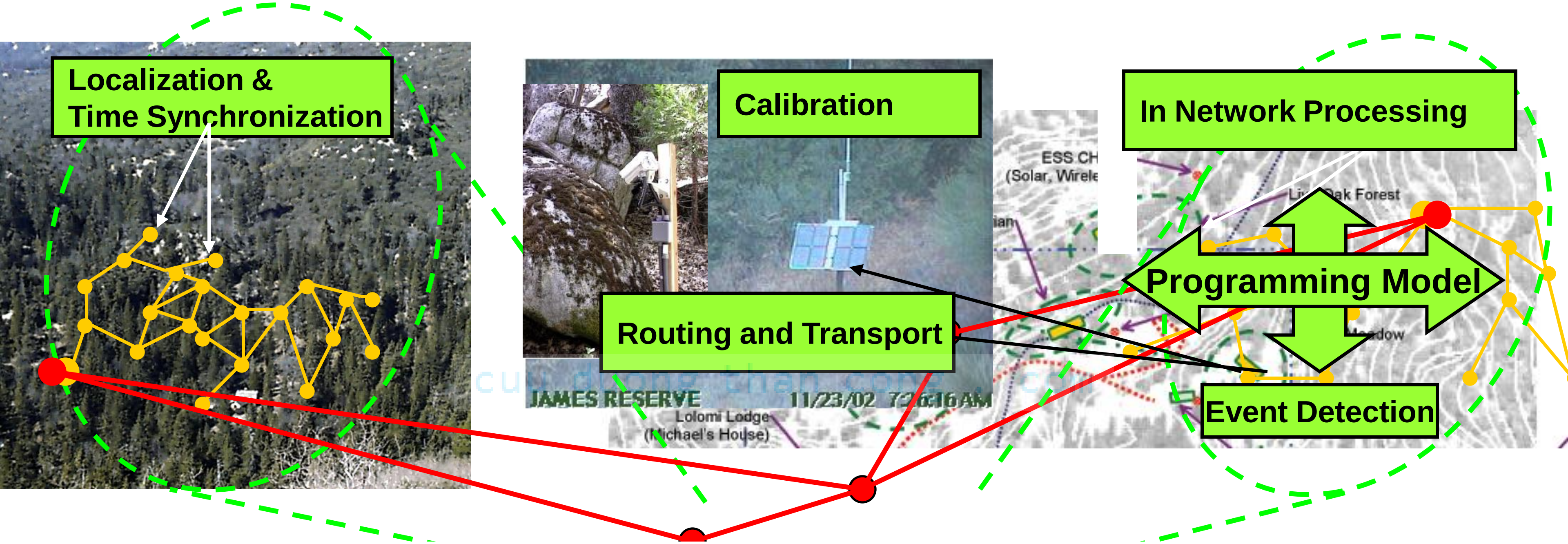
SNATool: Sensor Network Analysis Tool



Cluster/Sink Tree Formation Problems

- How to make cluster size more even? →All leaders will consume power evenly.
- How to form a sink tree with smallest link distance? →shorter link less radio power
- How to avoid frequent cluster/sink tree formation? →avoid disrupt normal data collection traffic
- How to perform tracking responsively?
- How to extend the life time of WSN?
- These are conflict requirements.
  How to resolve it?

Common system services



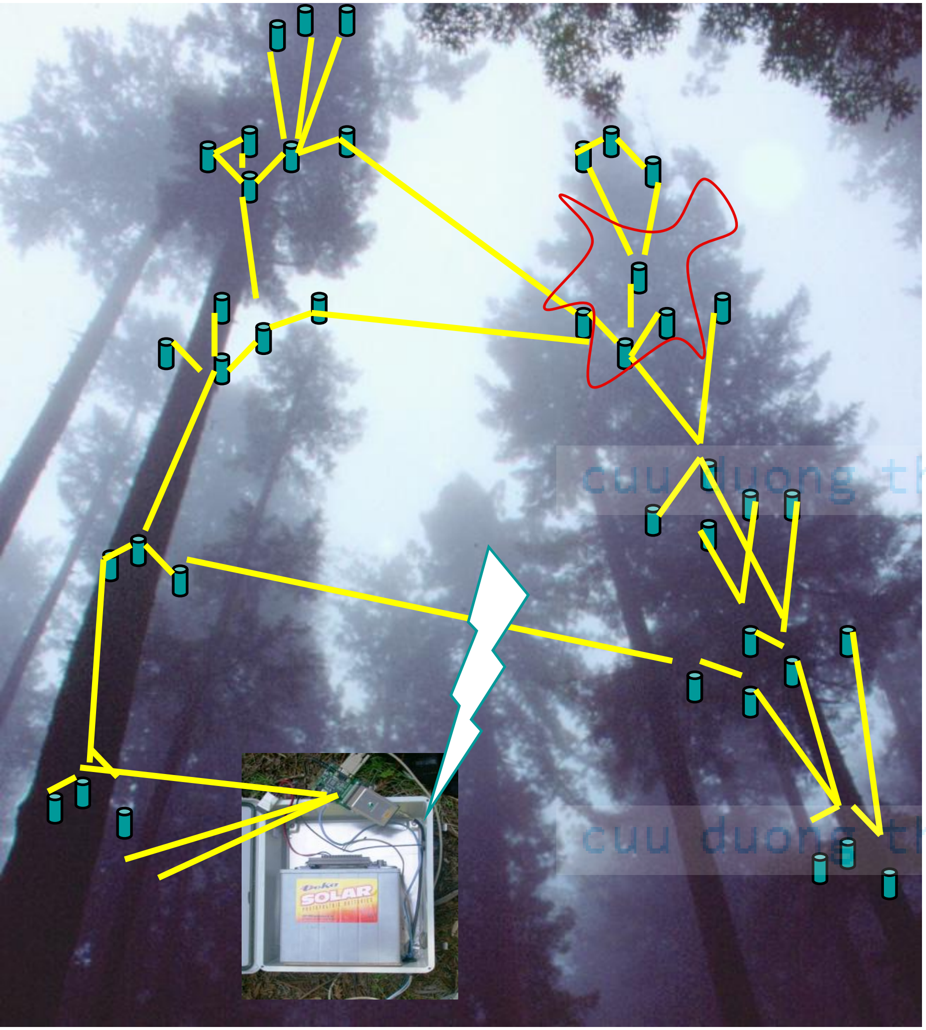
Needed: Reusable, Modular, Flexible, Well-characterized Services/Tools

- Routing and Reliable transport
- Time synchronization, Localization, Calibration, Energy Harvesting
- In Network Storage, Processing (compression, triggering), Tasking
- Programming abstractions, tools
- Development, simulation, testing, debugging

WSN Architecture

- David Culler, Scott Shenker, Ion Stoica, UC Berkely. Creating an Architecture for Wireless Sensor Networks –in a nutshell.

Key Properties



- Networks meaningfully distributed over physical space
- Large numbers of nodes
- Long duration
- Irregular, varying connectivity
- Variations in density
- Loss & interference
- Constrained resources & Energy
- Connected to deeper infrastructure

So how do we go about it?

Wirelss Sensor Network and Pervasive Computing

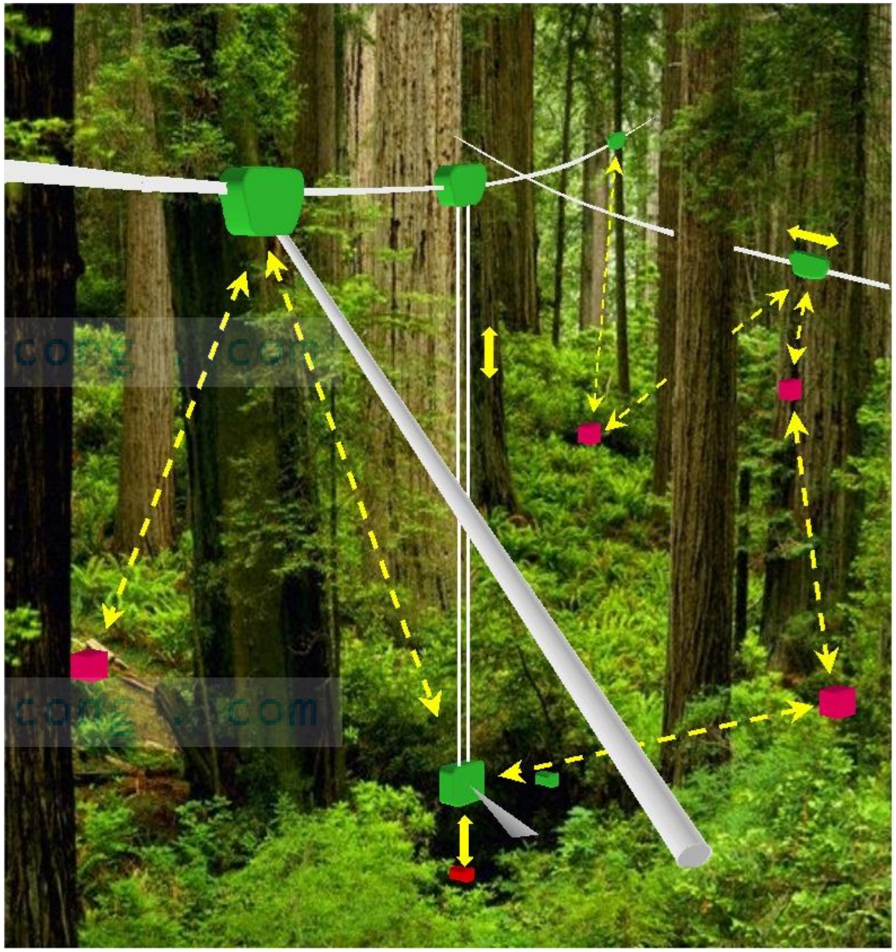
- D.Raychaudhuri, Rutgers WINLAB. Research Challenges in Sensor Nets and Pervasive Systems. Including a presentation on writing effective grant proposals.

Mobile Sensor Networks

- William J Kaiser, UCLA CENS. On Constrained Actuation for Sensor Networks.
- Challenges
  - Sustainability
- Solutions in Constrained Actuation and Infrastructure
  - Limited dimension, limited range mobility
  - Infrastructure-supported mobility
- New Research Area
  - Adaptive sampling and deployment
  - Coordinated mobile embedded sensors
  - Adaptation of network resources
  - Active Fusion

Networked Infomechanical Systems (NIMS)

- **Networked mobile nodes**
  - Sensing
  - Sampling
  - Energy logistics
  - Communication
- **Infrastructure**
  - Deterministic and precise motion
  - 3-D volume access
  - Mass transport at low energy
- ***System Ecology for Sustainability***
  - Fixed nodes
  - Mobile nodes
  - Infrastructure



System Ecology : Introduces New Design Rules

Tiers	Sensing Accuracy	Energy Efficiency	Spatial Coverage	Temporal Coverage
Mobile Nodes	Adaptive Topology and Perspective	Low Energy Transport/ Comm	Both Sensing and Sampling in 3-D	Enable Long Term Sustainability
Connected Fixed Nodes	Optimal, Precise Deployment	Energy Production and Delivery	Optimized Location in 3-D	Continuous, In Situ Sensing-Sampling
Untethered Fixed Nodes	Localized Sensing and Sampling	Alert and Guide Mobile Assets	Access to Non-Navigable Areas	Continuous Low Energy Vigilance

Security and Privacy in Sensor Networks: Research Challenges

- Radha Poovendran, U. Washington.
- Resource constrains on WSN devices. Energy, computation, memory

WSN Education

- Waylon Brunette, U. Washington. The Flock project.