Application Specific Large Scale Sensor Networks

Architecture, Energy Efficient Protocols, and Signal Processing

Lang Tong

Adaptive Communications and Signal Processing Group
School of Electrical and Computer Engineering
Cornell University, Ithaca, NY 14853

http://people.ece.cornell.edu/ltong

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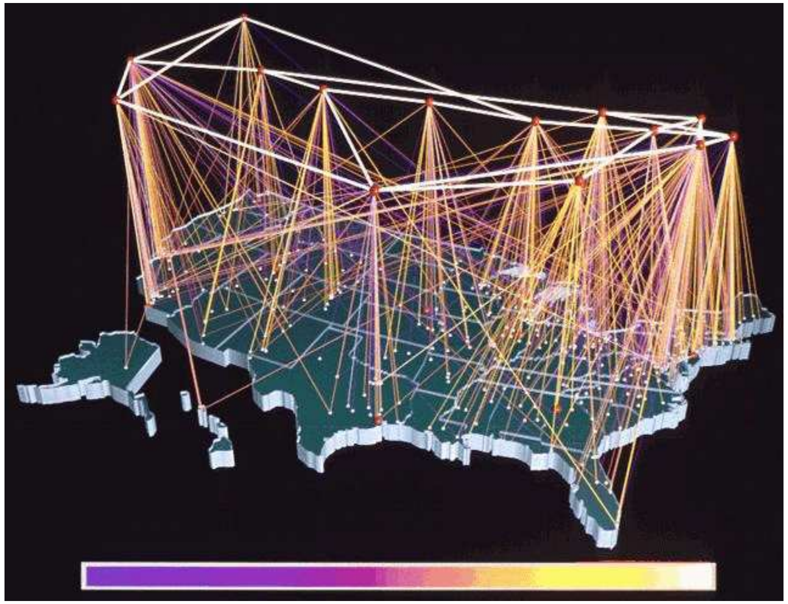
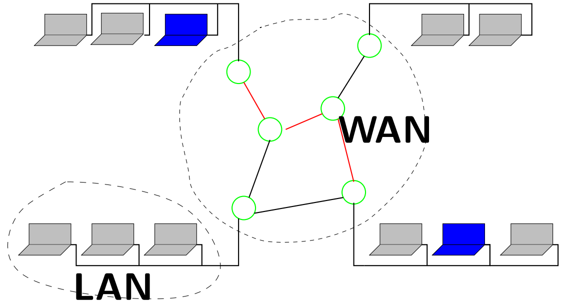
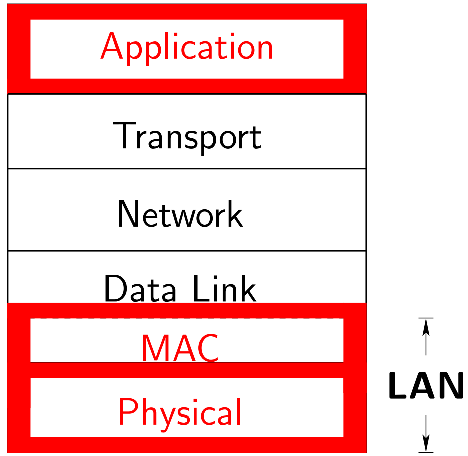
The Internet and Layered Architecture







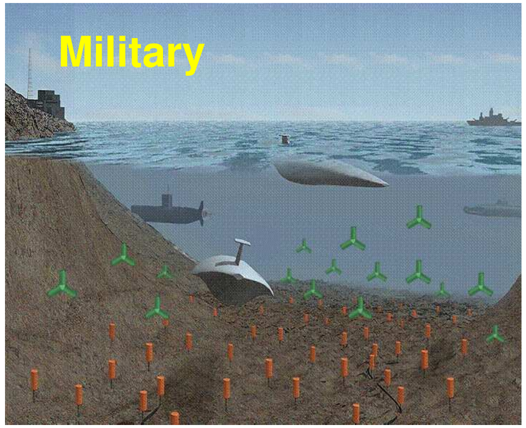
Objectives

- Millions of users
- Thousands of applications
- A growing variety of devices.

The need of layered approaches:

- Partition network functions into layers
- Design each layer separately

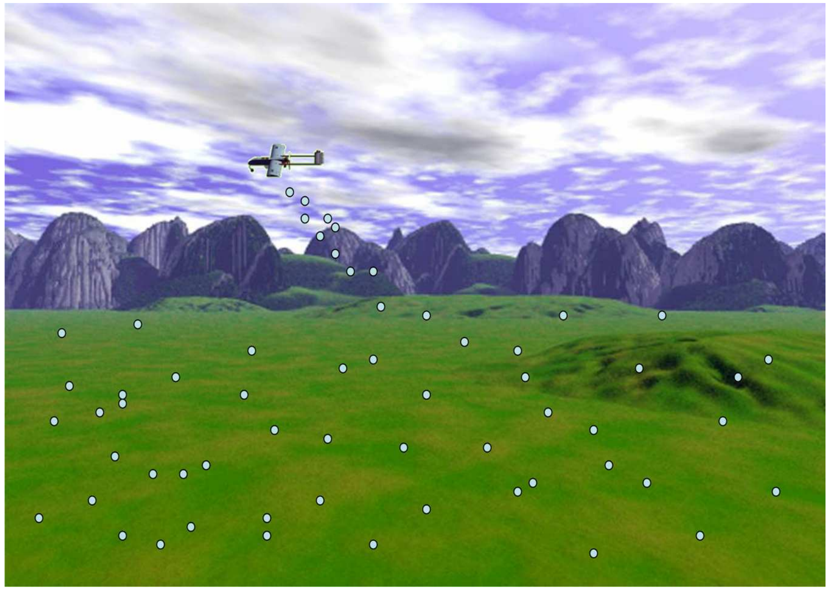
Sensor Networks are Application Specific



- Network with purposes.
- "Unconventional" design metrics
- Harsh design constraints

What should be the appropriate design paradigm?

Large Scale Sensor Networks



- Low-power low-cost sensors
- Random deployment
- Large number of nodes.

Applications

- ☐ Target detection and tracking.
- ☐ Surveillance
- ☐ Environmental monitoring
- ☐ ......

Design Challenges

- ☐ Architecture
- ☐ Physical Layer Design
- ☐ Protocols
- ☐ Network Maintenance.
- ☐ Security and Trust.

Outline

Architecture

- Sensor Networks with Mobile Access (SENMA)
- Experimental Testbed.

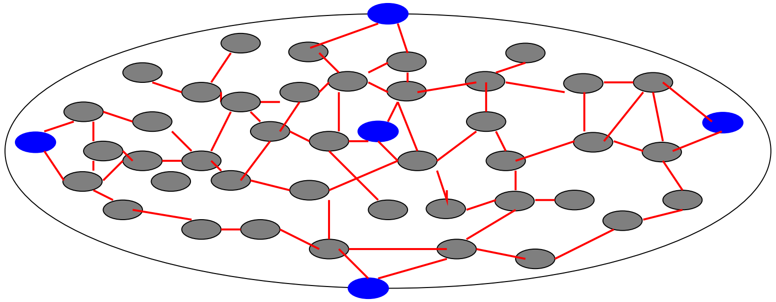
Energy Efficient Protocols

- Opportunistic Random Access
- Energy Efficient Adaptive Routing

Communication and Signal Processing

- How many sensors are alive and for how long?
- Cooperative network with misinformed nodes
- Nonparametric event change detection and localization.
- Target detection and tracking in SENMA.

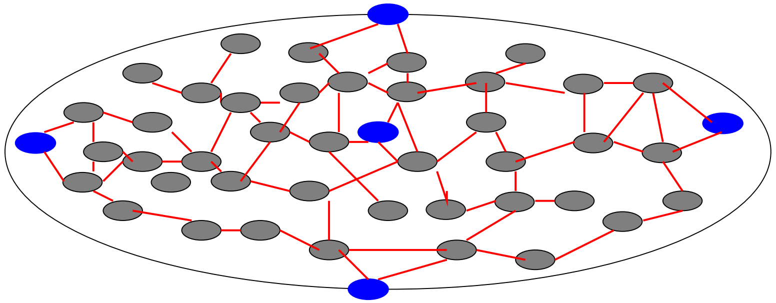
Sensor Network Architectures



Multi-hop Sensor Network

- Stationary sensors and gateway nodes.
- Multi-hop to/from gateway nodes.
- Sensors talk to sensors.
- Asymmetric and correlated traffic.

Sensor Network Architectures



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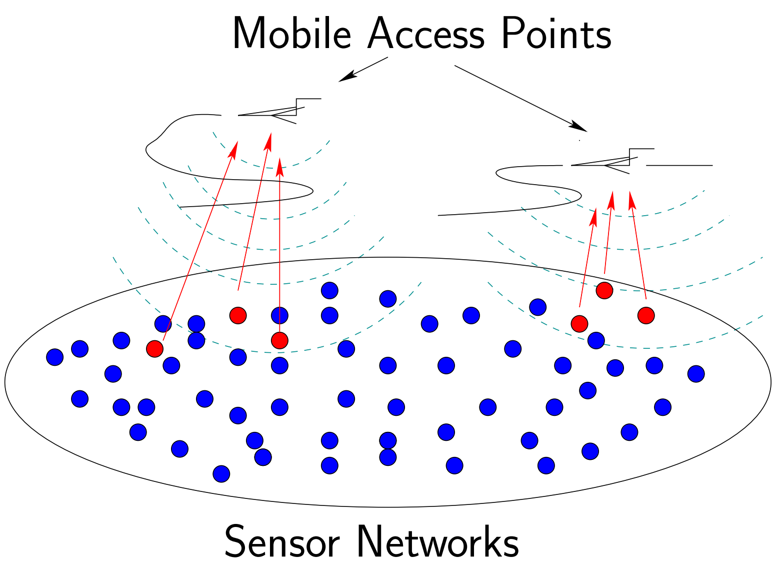
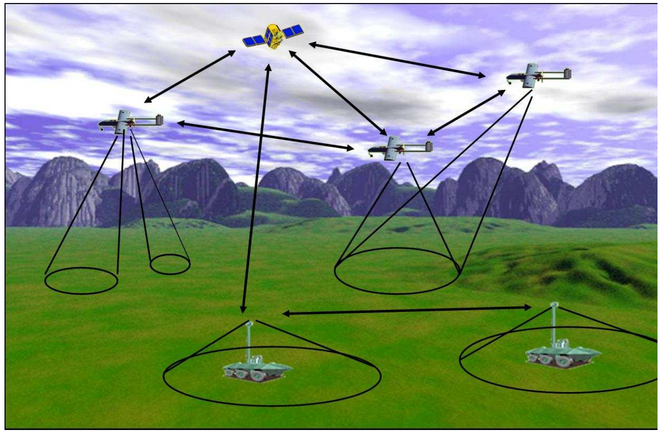
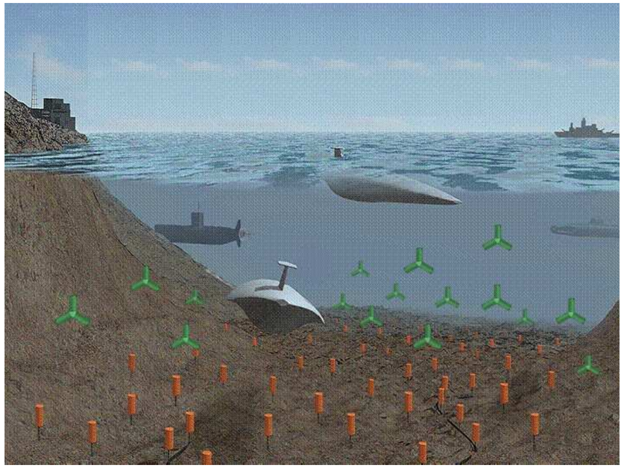


Sensor Network with Mobile Access

- ☐ Mobile APs + stationary nodes.
- ☐ Sensors talk directly to APs.
- ☐ Stationary sensors driven by mobile APs.
- ☐ Asymmetric resources.

SENMA: SEnsor Network with Mobile Access

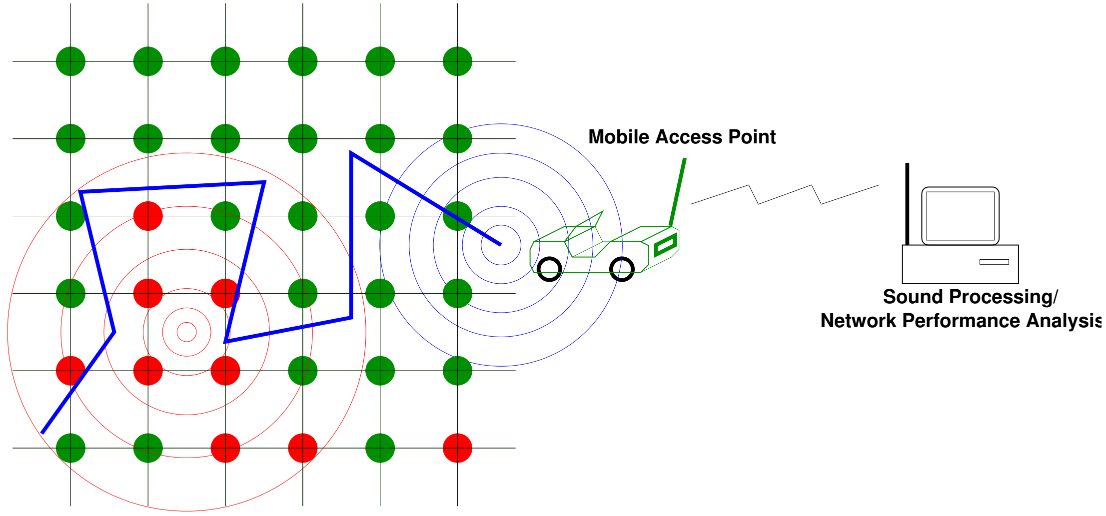


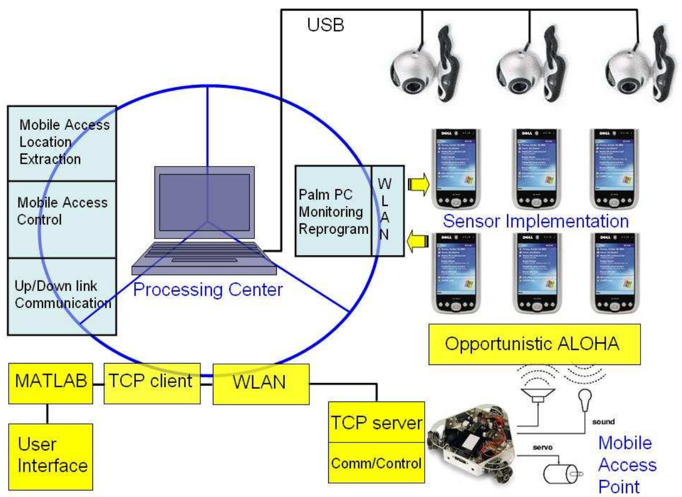


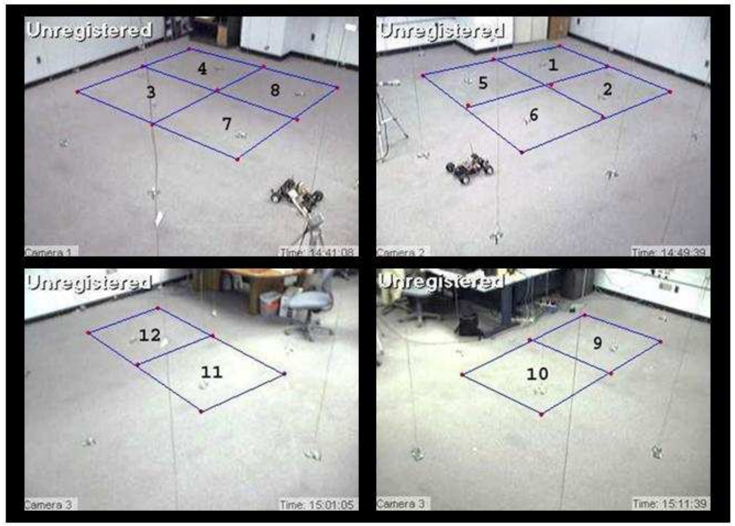
- Mobile access points can be UAV, UGV, submarine, doves, dogs...
- Mobile access points are not energy constrained.
- Suitable for clock-driven and query-driven applications.

L. Tong, Q. Zhao, and S. Adireddy, "Sensor Networks with Mobile Agents (SENMA)," Proc. IEEE MILCOM, Oct., 2003.

Acoustic SENMA: System Configuration







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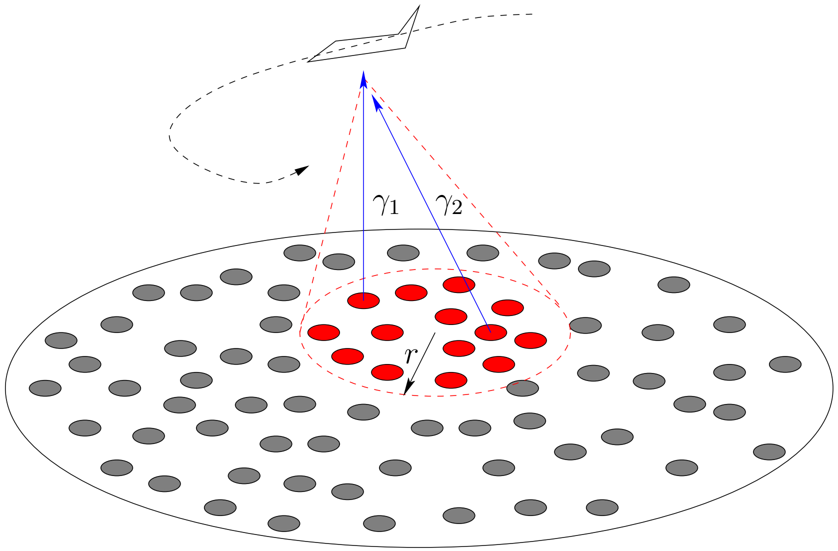
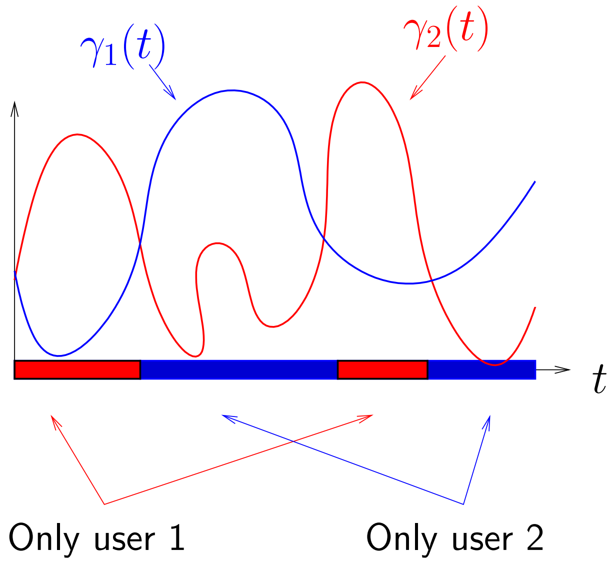
Opportunistic Communications and Networking

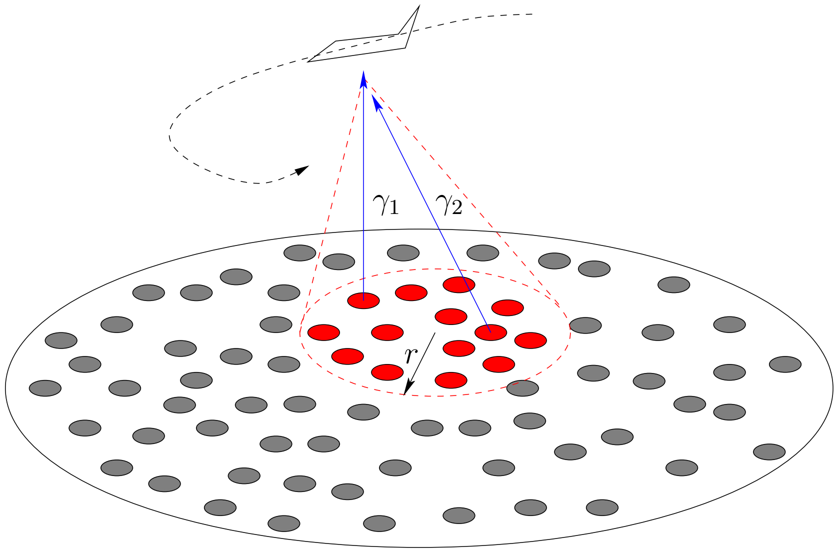


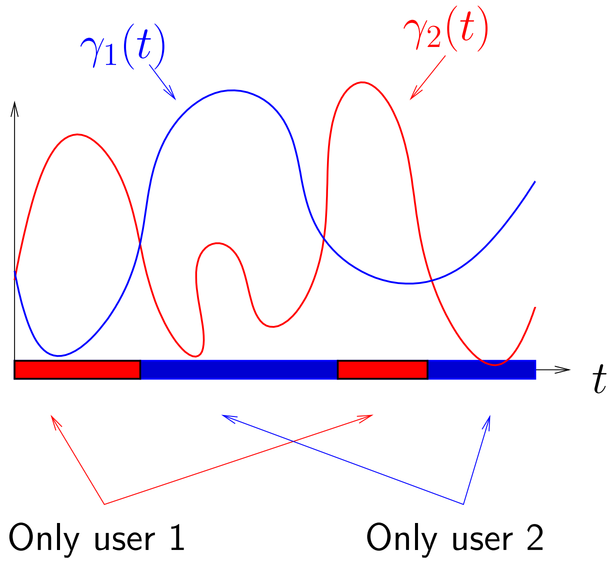


Opportunistic Communications

- □ Mobility of AP induces fading.
- □ Fading leads to channel fluctuations.

Opportunistic Communications and Networking





Opportunistic Communications

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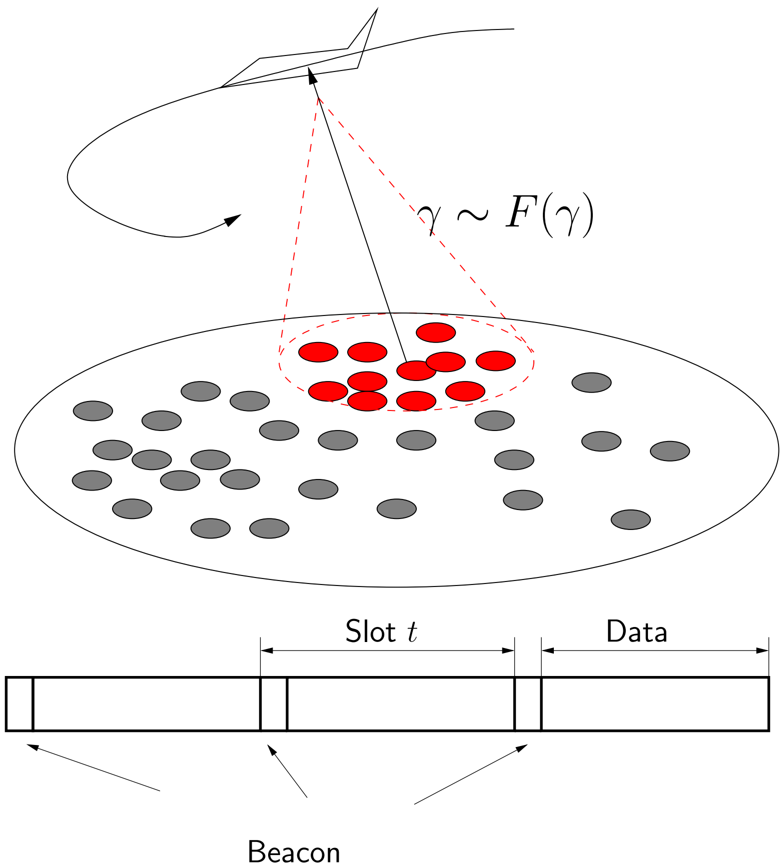
- □ Fading leads to channel fluctuations.

Design Rationale

- □ Wait for chances. Save power
  Act when opportunities arise.

Opportunistic Medium Access Control



Distributed Opportunistic MAC

- ☐ Channel Acquisition

  Estimate γ from beacon.

P. Venkitasubramaniam, S. Adireddy and L. Tong "Sensor Networks with Mobile Access: Optimal Random Access and Coding," To appear in IEEE JSAC: Special Issue on Sensor Networks

Q. Zhao and L. Tong, "Distributed Opportunistic Information Retrieval in Sensor Networks: CSI-Based Carrier Sensing," ICASSP'04, Also submitted to IEEE Trans. Wireless Communications.

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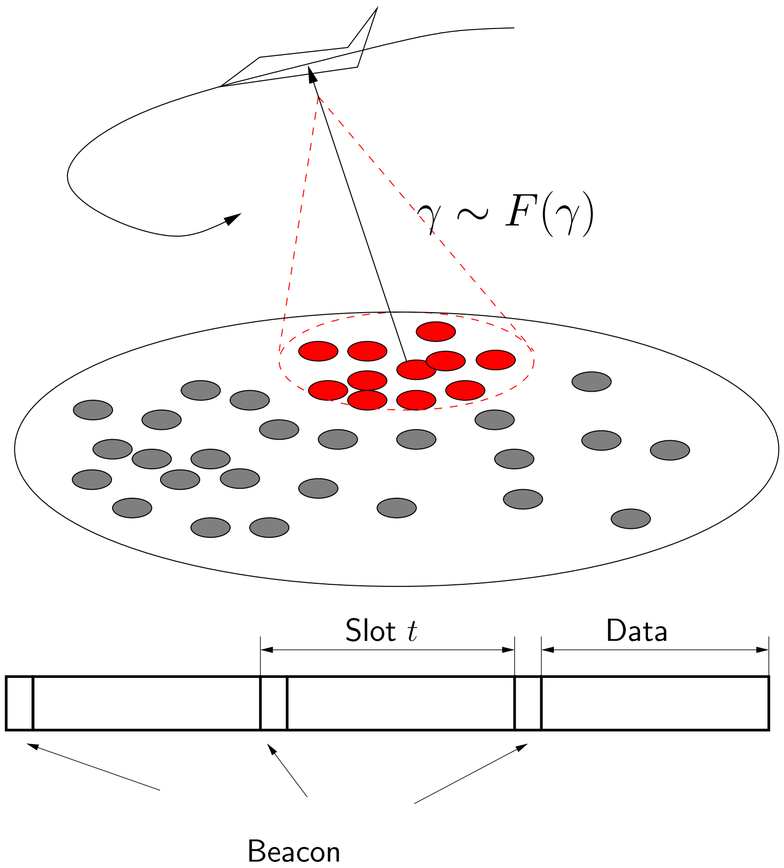

Distributed Opportunistic MAC

- □ Channel Acquisition
  Estimate γ from beacon.
- □ Opportunistic ALOHA
  Transmit with probability $s(\gamma)$.
- □ Opportunistic CSMA
  - □ Sense carrier with backoff $\tau(\gamma)$.

Advantages

- □ Simplicity. □ Scalability.
- □ Energy Efficiency.

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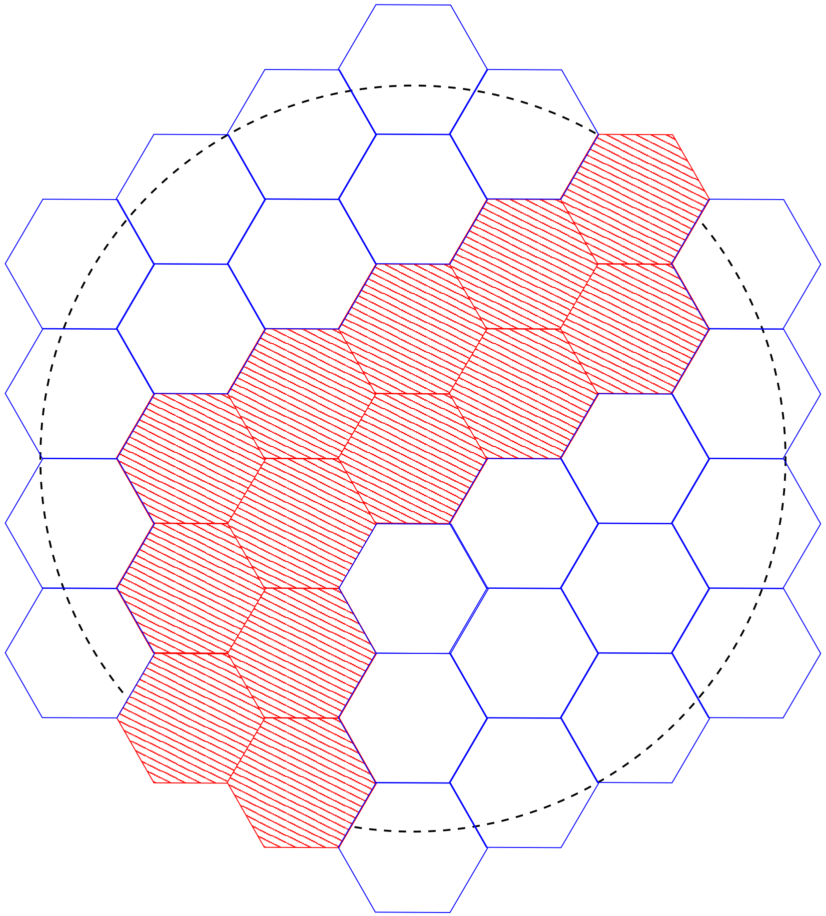
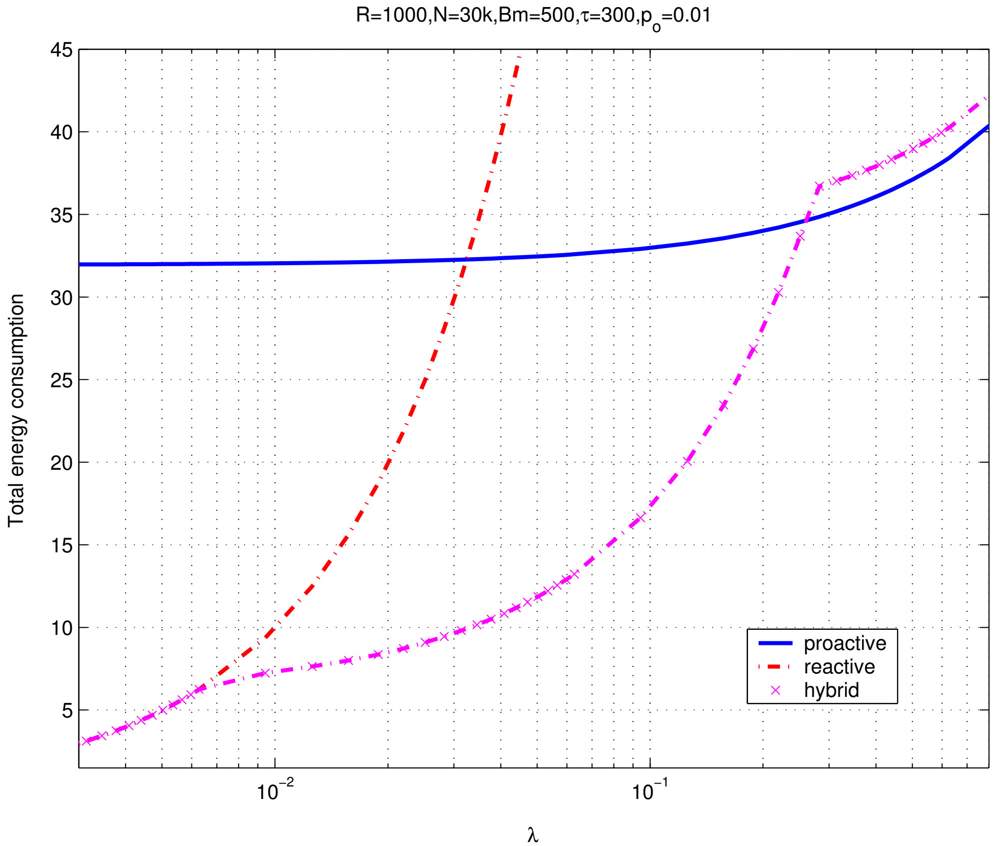
Energy Efficient Adaptive Routing





Q. Zhao and L. Tong, "Energy Efficiency of Ad Hoc Networks: An Analysis of Proactive, Reactive, and Hybrid Networking Strategies," submitted to IEEE INFOCOM, July, 2004.

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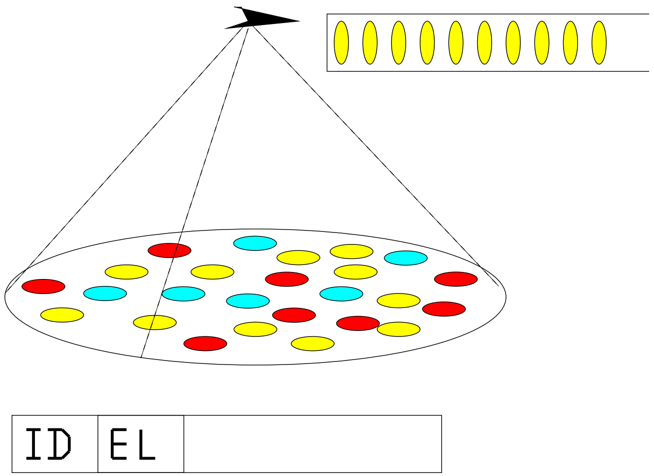
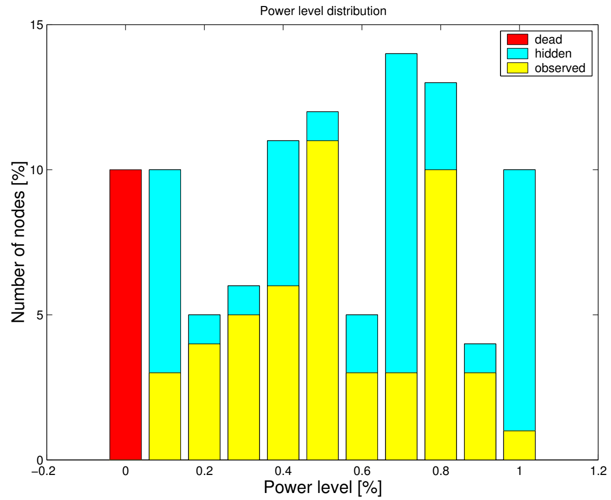
Operating Sensors and Energy Distribution





Problem : Estimate the number of operating sensors and the histogram of the energy distribution using the information in the received packets.

Two Approaches in Monitoring Wireless Sensor Networks

Counting via Scheduled Interrogation

Ask each sensor transmit and count the number of successes

- Central scheduling is needed. Mobile AP must address sensors individually.
- Requiring at least $O(N)$ and more if channel has fading and interferences.

Counting via Random Collection

Collect packets randomly and count the number of successes.

- Distributed transmission with simple medium access.
- For such a method to be effective, it requires $N \log N + O(N)$ successfully received transmissions.
- Example: $N = 1000$, on the order of $10,000$ successful receptions are needed.

Two Approaches in Monitoring Wireless Sensor Networks

The Estimation Approach

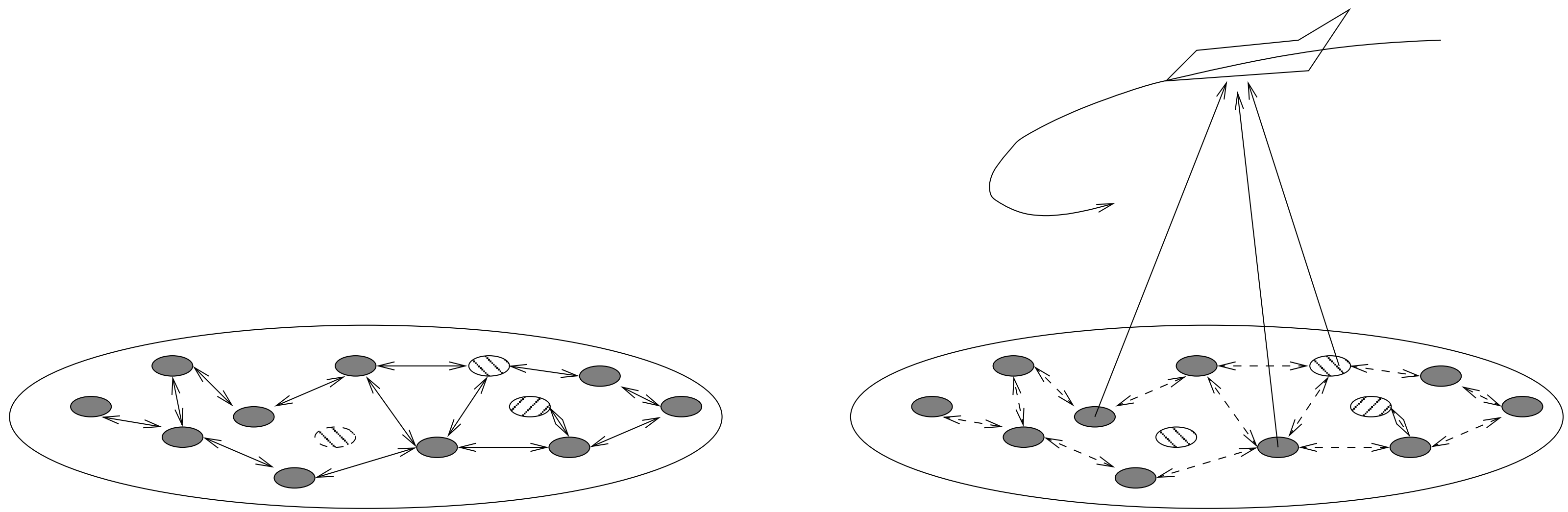
- In network monitoring, the exact values of the network parameters are not required.
- Estimate the number of operating sensors using the statistical properties of the received samples.

Question:

Can we estimate accurately using less than $N \log N + O(N)$ samples ?

- C. Budianu, S. Ben-David and L. Tong, "Estimation of the Number of Operating Sensors in Large Scale Sensor Networks", ICASSP 2004, also submitted to IEEE Trans. Signal Proc., June, 2004.

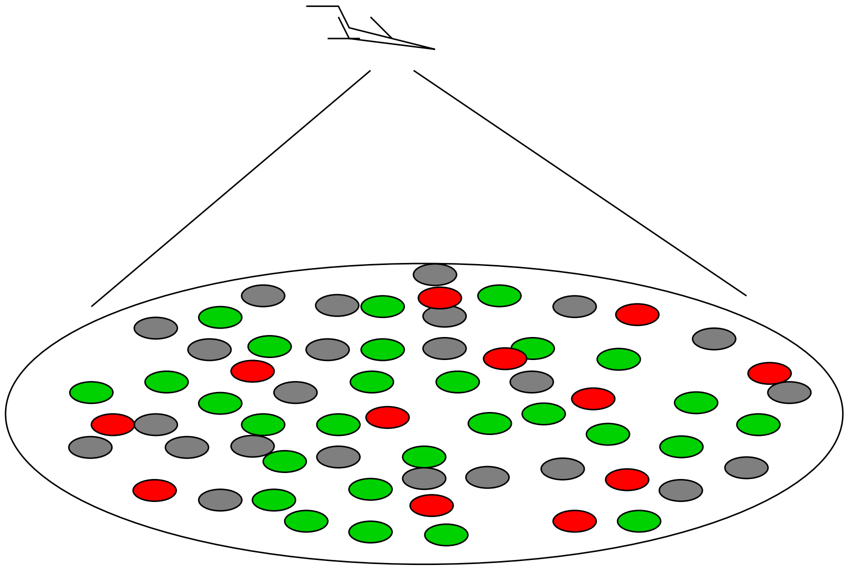
Cooperative SENMA with Misinformed Sensors



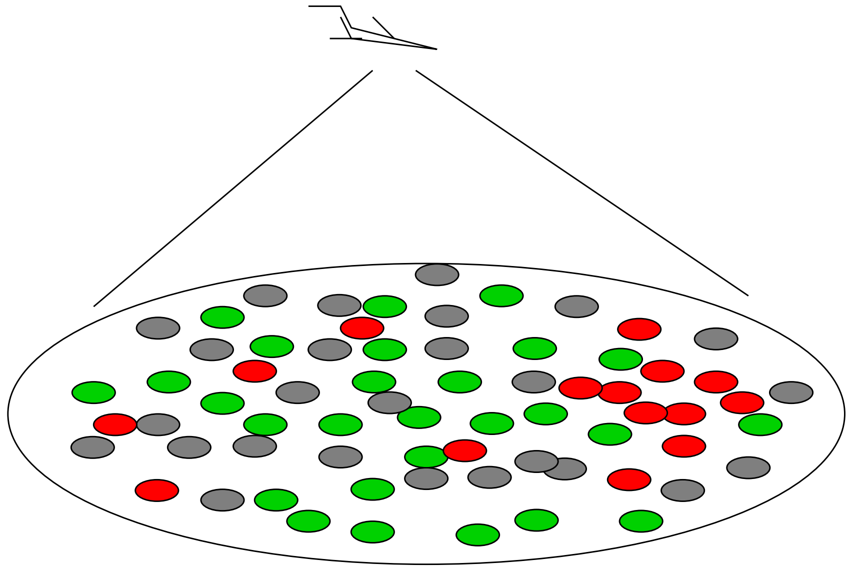
- In cooperative sensor networks, sensors may not agree with each other.
- What is the maximum rate of information retrieval with the presence of misinformed sensors?

- Z. Yang and L. Tong, "Coopative Sensor Networks with Misinformed Sensors," Proc. of the 38th Annual Conference on Information Sciences and Systems (CISS'04), Princeton, NJ, March 2004. To be submitted to IEEE Trans. Information Theory, July, 2004.
- Z. Yang and L. Tong, "The effect of fading on the achievable rate of cooperative sensor networks with misinfomred sensors," to appear in IEEE 2004 GLOBECOM,

Nonparametric Event Change Detection and Localization



First data collection

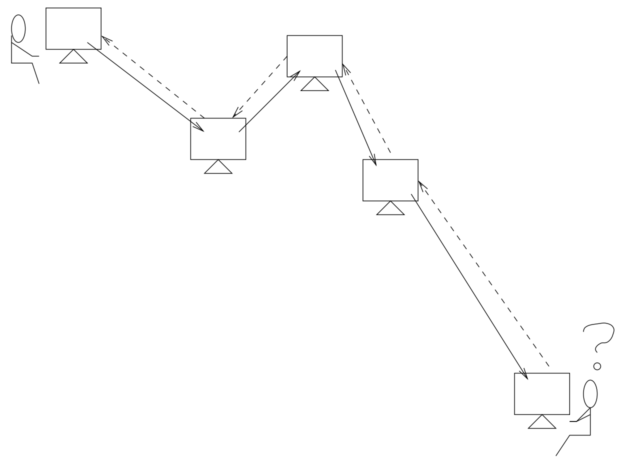


Second data collection

- Is there a change in the distributions of "red" and "green"? where?
- Can we guarantee detection precision? What is the computation complexity?

- S. Ben-David, T. He and L. Tong, "Non-Parametric Approach to Change Detection and Estimation in Large Scale Sensor Networks," Proc. of the 38th Annual Conference on Information Sciences and Systems (CISS'04), Princeton, NJ, March 2004.

Detection of Stepping Stone Attack



Stepping Stone Attack

The attacker uses a chain of compromised hosts to construct a sequence of interactive attacks

Quickest Attack Detection

Detect possible stepping-stone attack pairs based on statistical properties of incoming and outgoing traffic.

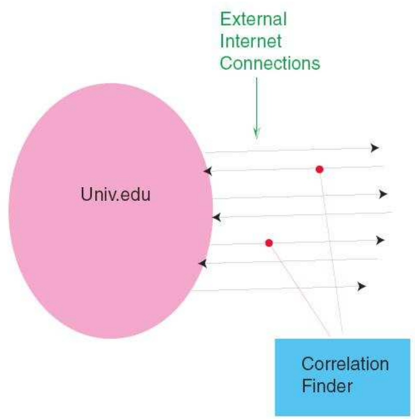
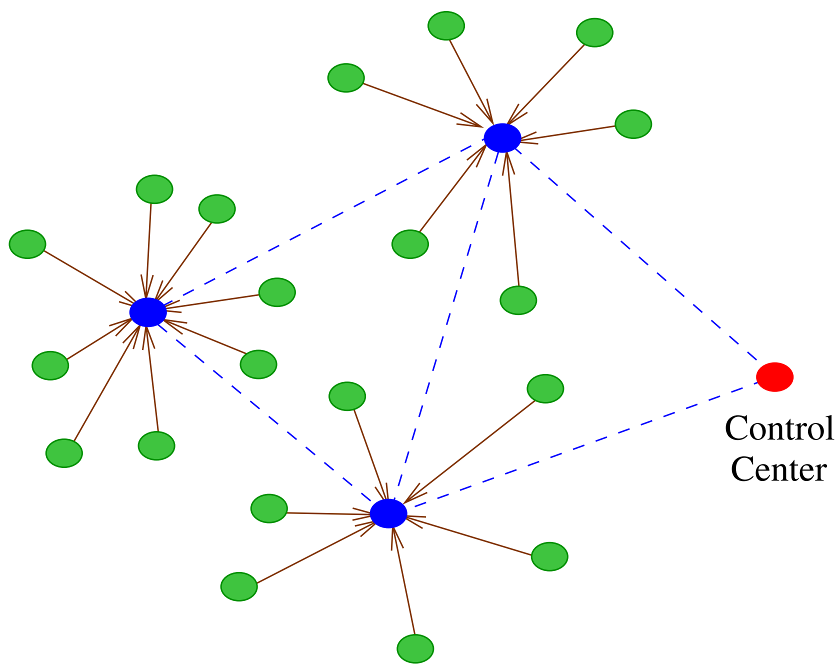
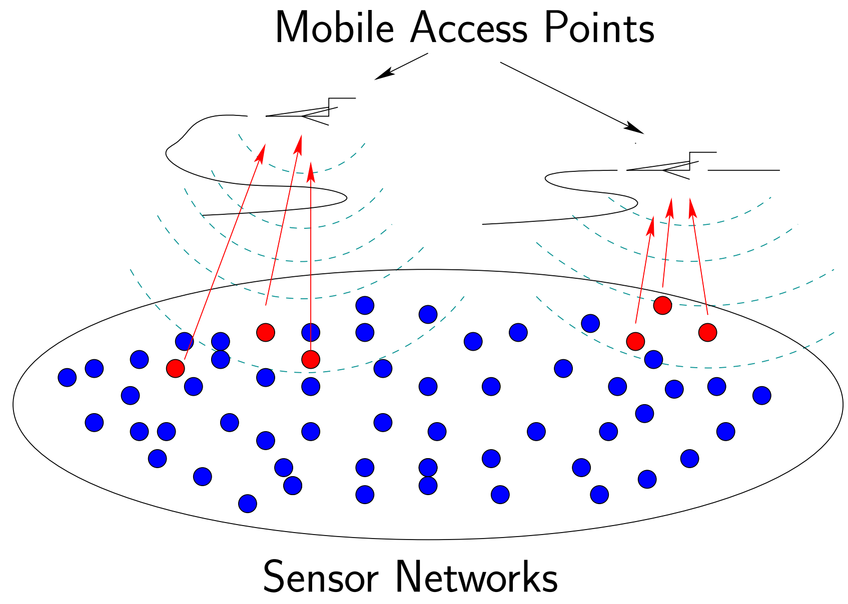


Fig. 1. Stepping-Stone Monitor

- T. He and L. Tong, "Detection of Encrypted Interactive Stepping Stone Attack: Algorithms and Performance," to be submitted to IEEE Trans. Signal Processing.

Target Detection and Tracking





- Sensors perform low quality DoA estimation and target classification.
- The fusion center estimates the field parameters.
- Develop optimal detection, estimation, and fusion algorithms.

Related Projects

National Science Foundation

- Signal Processing for Random Access: A Cross Layer Approach.
- SENSORS: The Reachback Channel in Wireless Sensor Networks. (Servetto (PI))
- NET-NOSS: Ultra Low-Power Self-Configuring Wireless. (Wicker (PI))
- TRUST: Team for Research in Ubiquitous Secure Technology (Wicker (PI))

Office of Naval Research

Channel and QoS Adaptive Multimedia Wireless Ad-Hoc Networks (with Haas, Hemami, Manohar, Wicker, Proakis, Nahrstedt).

DARPA Connectionless Networking.

Army Research Laboratory

Signal Processing for Sensor Networks. Cross Layer Design for Wireless Networks. Direction of Arrival Estimation with Networked Sensors.