Wireless Sensor Networks

Presented by: Hung Le Xuan
Real-time and Multimedia Laboratory
Email: lxhung@oslab.khu.ac.kr
Date: October 5th 2004

Outline

- Wireless Sensor Networks Overview
  - Why Wireless Sensor Networks ?
  - What is WSN ?
- Application Overview
  - Scientist, commercial application
- System Components and Issues
  - Layers, issues at each layer
- Research Challenges

Outline

- Wireless Sensor Networks Overview
  - Why Wireless Sensor Networks ?
  - What is WSN ?
- Application Overview
  - Scientist, commercial application
- System Components and Issues
  - Layers, issues at each layer
- Research Challenges

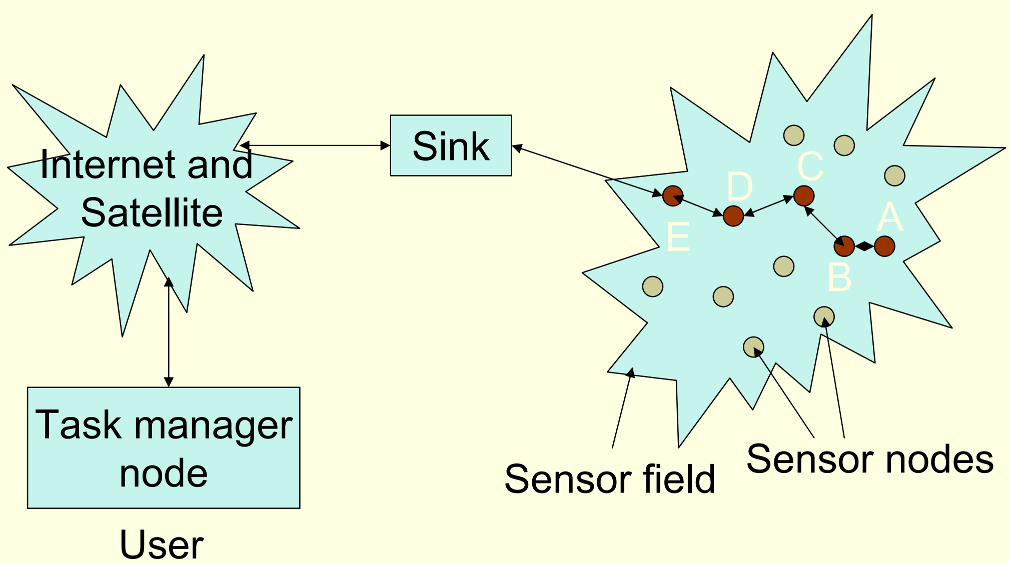
Wireless Sensor Networks

- Wireless Sensor Networks is one of the top **10 Technologies** that will change the World in 21st Century
  - According to MIT Technology Review
- Researchers at USC and ISI Pioneered the field of Sensor Information Technology
- DARPA and NSF have Programs and Initiatives in Sensor Networks

Sensor Network Projects/Platforms

- Some large-scale projects on wireless microsensor networks
  - µAMPS
    - MIT: LEACH (Low-Energy Adaptive Clustering Hierarchy)
  - AWAIRS
    - UCLA, Rockwell Science Center: SMACS, EAR, SAR, SWE, and MEW
  - SCADDS
    - USC / ISI: Directed diffusion
- Platforms
  - Smart Dust (UC Berkeley)
  - Berkeley Motes
  - iBadge (UCLA)
  - WINS (UCLA)
- Many more platforms/projects than those listed here

Wireless Sensor Networks



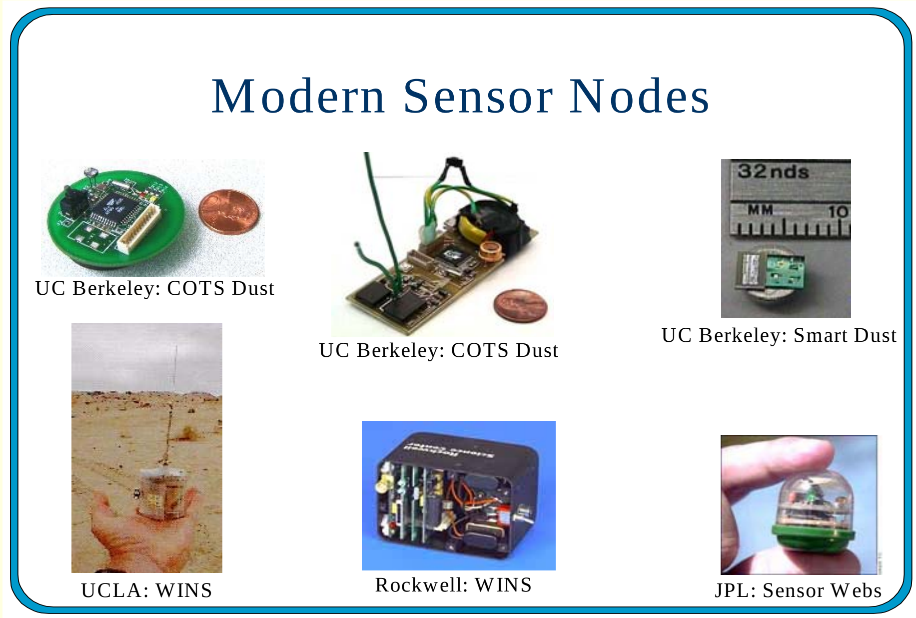
Wireless Microsensor Networks

- Microsensors
  - **Low power**, cheap sensors
  - Sensor module (e.g., acoustic, seismic, image)
  - A digital processor for signal processing and network protocol functions
  - Radio for communication
  - Battery-operated
- Sensors monitor environment
  - Cameras, microphones, physiological sensors, etc.
  - **Gather data for some purpose**
- Microsensor data limited in range and accuracy
  - Each node can only gather data from a limited physical area of the environment
  - Data may be noisy
  - Data aggregation enables higher quality (less noisy) data to be obtained that gives information about a larger physical area than any individual data signal

Microsensor Networks (cont.)

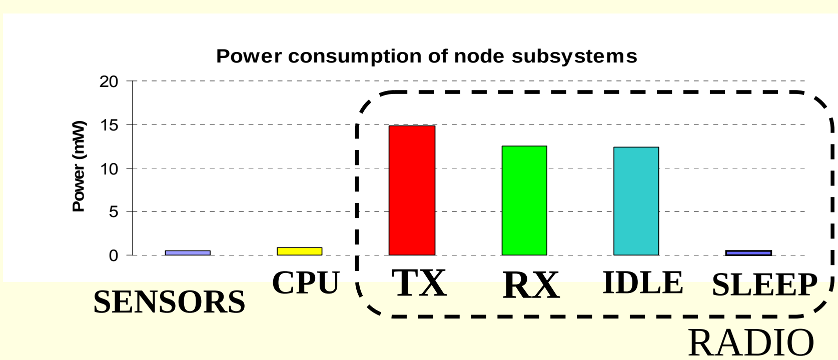
- Hundreds or thousands of nodes scattered throughout an environment
- New wireless networking paradigm
  - Requires **autonomous operation**
  - Highly **dynamic** environments
    - Sensor nodes added/fail
    - Events in the environment
  - **Distributed** computation and communication protocols required

Some Sensor Nodes



Sensor Network Limitations

- Sensor energy
  - Each sensor node has **limited energy supply**
  - Nodes **may not be rechargeable**
  - Eventually nodes may be self-powered
  - Energy consumption in sensing, data processing, and communication
    - Communication the most energy-intensive
    - Must use energy-conserving communication



Sensor Network Limitations

- Communication
  - The bandwidth is **limited** and must be **shared** among all the nodes in the sensor network
  - Spatial reuse essential
  - Efficient local use of bandwidth needed

Sensor Network Differences

- Traditional wireless networks - Users can update and maintain devices (e.g., each computer maintained by a human)
- Wireless sensor networks - May be impossible to update or maintain sensor nodes, due to sheer numbers as well as deployment locations

- Traditional wireless networks - Communication between two specific end-users
- Wireless sensor networks - Communication data-centric
  - End-user does not care that the data came from node X, only what the data describes

- Traditional wireless networks - Goal: providing high QoS bandwidth efficiency
- Wireless sensor networks - Goal: prolonging lifetime of the network
  - Requires energy conservation
  - Willing to give up performance in terms of QoS or bandwidth efficiency

Sensor Network Differences

- Traditional wireless networks - Data are important
- Wireless sensor networks - End user does not require all the data
  - Data from neighboring nodes are highly correlated, making the data redundant
  - End user typically cares about a higher-level description of events occurring in the environment nodes are monitoring
  - Network quality often based on quality of aggregate data set rather than individual signals

- Traditional wireless networks - Intermediate nodes do not care what the data are
- Wireless sensor networks - Application-specific routing to improve performance

Sensor Network Differences

- Traditional wireless networks - Nodes operating (mostly) independently
- Wireless sensor networks - Sensor network application computation
  - May need to be distributed throughout network (e.g., localized algorithms that achieve desired global result)
  - May require hierarchical structure
    - Enables computation / communication tradeoff
  - Three processing levels: node, local, and global

- Traditional wireless networks - Operate in (mostly) benign environments
- Wireless sensor networks - May be deployed in hostile or dangerous territory

Outline

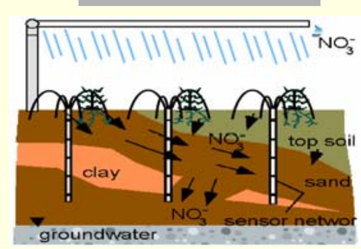
- Wireless Sensor Networks Overview
  - Why Wireless Sensor Networks ?
  - What is WSN ?
- Application Overview
  - Scientist, commercial application
- System Components and Issues
  - Layers, issues at each layer
- Research Challenges

Networked sensing for scientific applications

Ecosystems, Biocomplexity

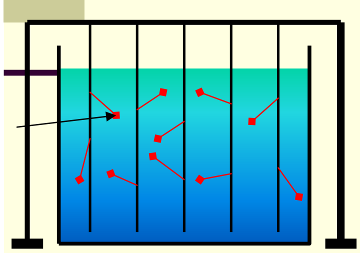
- Micro-sensors, on-board processing, wireless interfaces feasible at very small scale--can monitor phenomena “up close”
- Enables spatially and temporally dense environmental monitoring

Embedded Networked Sensing will reveal previously unobservable phenomena

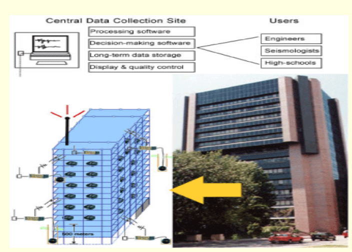


Contaminant Transport

Marine Microorganisms



Seismic Structure Response



CENS, Estrin

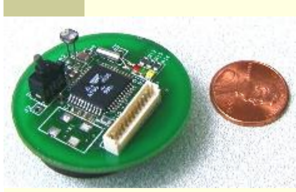
Scientific Applications of Interest - Structural Monitoring

- Seismic Sensing and Actuation
- Structural Condition Monitoring

From CENS

Habitat monitoring

- Monitoring ecosystems and species habitats



From Berkley Intel Lablet: Great Duck Island (greatduckisland.net)

Battlefield detection, classification and tracking

From 29 Palms Demo, UC Berkley and others

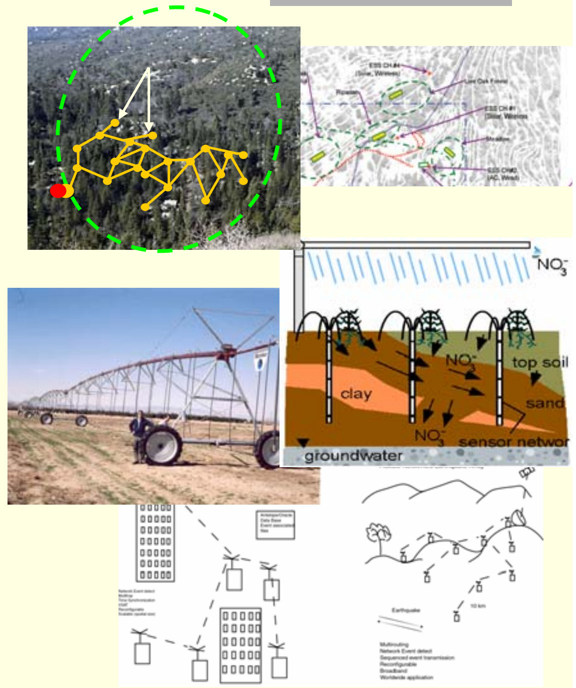
Miscellaneous

- Contaminant Flow
- Chemical Leaks
- Forest Fires
- Emergency Response

Images from Google

Example early adopter applications

- Biology/Ecosystems
  - Microclimate monitoring
  - Triggered image capture
  - Canopy-net (Wind River Canopy Crane Site)
- Contaminant Transport
  - County of Los Angeles Sanitation Districts (CLASD) wastewater recycling project, Palmdale, CA
- Seismic monitoring
  - 50 node ad hoc, wireless, multi-hop seismic network
  - Structure response in USGS-instrumented Factor Building w/ augmented wireless sensors

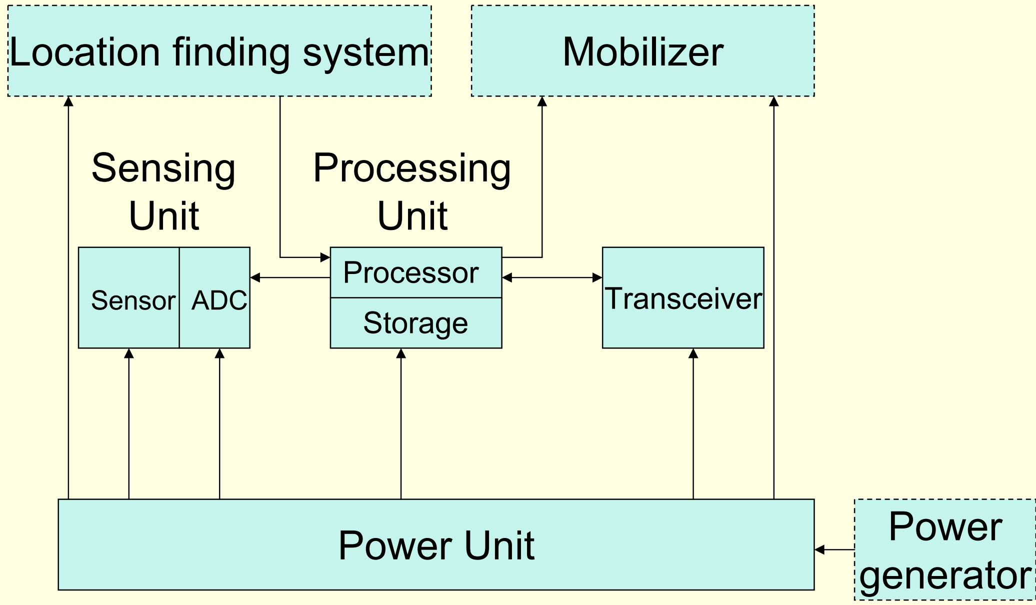


Outline

- Wireless Sensor Networks Overview
  - Why Wireless Sensor Networks ?
  - What is WSN ?
- Application Overview
  - Scientist, commercial application
- System Components and Issues
  - Layers, issues at each layer
- Research Challenges

Design Factors (cont.)

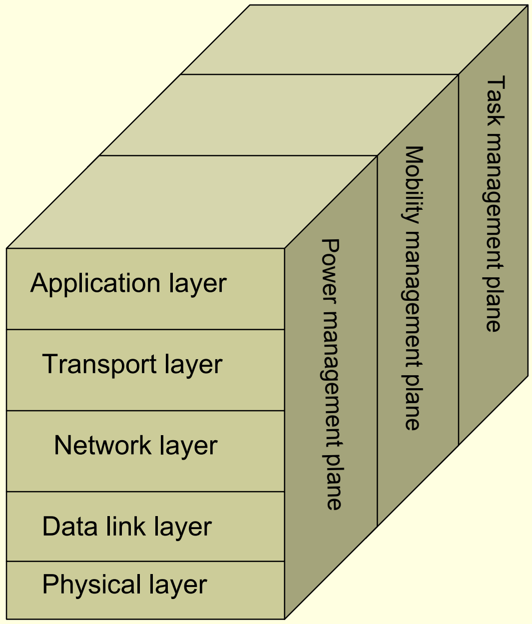
Hardware Constraints



Design Factors (cont.)

- **Sensor Network Topology**
  - Predeployment and deployment phase
  - Post-deployment phase
  - Redeployment of additional nodes phase
- **Environment**
  can work in different environments.
- **Transmission Media**
  links between nodes can be formed by radio, infrared, or optical media.
- **Power Consumption**
  battery lifetime
  design of power-aware protocols and algorithms
  Power consumption: sensing, communication, and data processing

Protocol Stack



The Physical Layer

- Frequency selection.
- Carrier frequency generation.
- Signal detection.
- Modulation
  Binary and M-ary modulation schemes
  the binary modulation scheme is more energy-efficient
- Low transmission power and simple transceiver circuitry make Ultra wideband (UWB) an attractive candidate.
- **Open research issues:**
  - **Simple and low power** modulation scheme is needed
  - Hardware design: Tiny, low-power, low-cost transceiver, sensing processing units is needed

The Data Link Layer

- Multiplexing of data streams.
- Data frame detection.
- Medium access and error control.
- Ensures reliable point-to-point and point-to-multipoint connections in a communication network.
- **Open research issues**
  - MAC for mobile sensor networks
  - Low-power self-organization
  - Error control coding schemes
  - Power saving mode operation

Continue.. The Data Link Layer

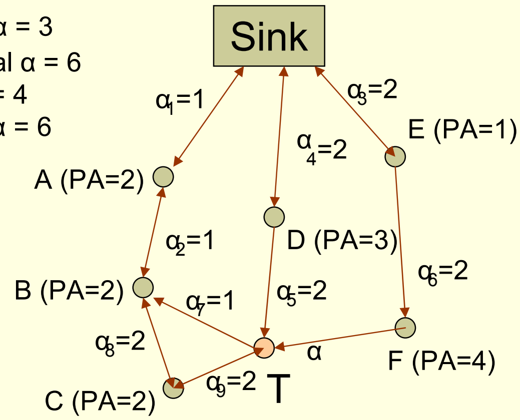
Some of the proposed MAC protocols

MAC protocol	Power conservation
SMACS and EAR	Random wakeup during setup and turning off while idle
Hybrid TDMA/FDMA	Hardware-based approach for system energy minimization
CSMA-based	Constant listening time for energy efficiency

Network Layer

Task: energy efficient routes

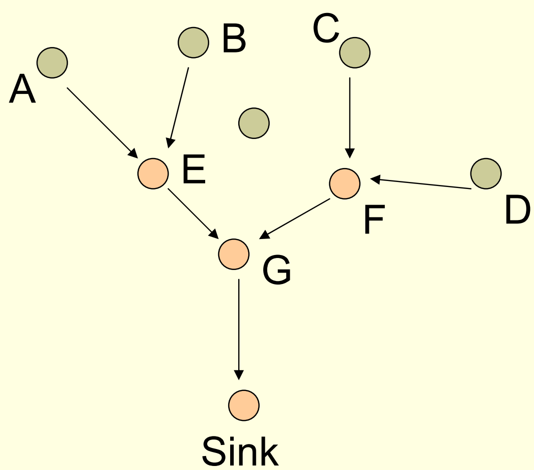
Route 1: Sink-A-B-T, total PA=4, total α = 3
Route 2: Sink-A-B-C-T, total PA=6, total α = 6
Route 3: Sink-D-T, total PA=3, total α = 4
Route 4: Sink-E-F-T, total PA=5, total α = 6



Approaches:
- Minimum PA route: route 4
- Minimum Energy (ME) route: route 1
- Minimum hop (MH) route: route 3
- Maximum minimum PA node route: route 3

Continue.. Network Layer

Data Aggregation, data fusion

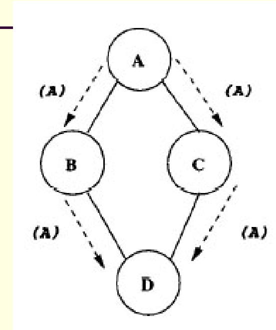


Routing techniques

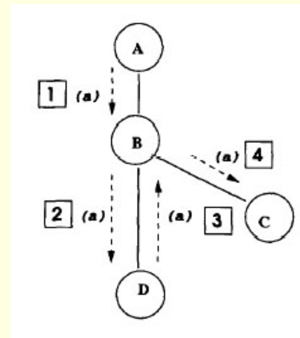
Continue.. Network Layer

- Flooding
  each node receiving a data or management packet repeats it by broadcasting.

->***Implosion****: node A starts by flooding its data to all of its neighbors. Two copies of the data eventually arrive at node D. The system wastes energy and bandwidth in one unnecessary send and receive.*

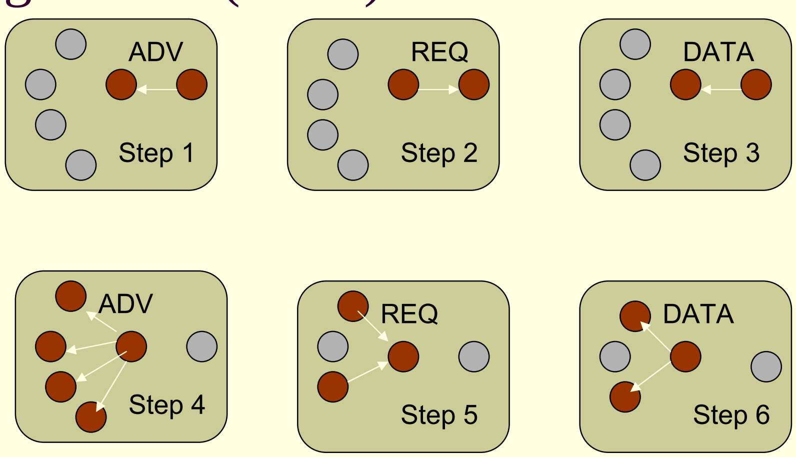


- Gossiping
  send the incoming packets to a randomly selected neighbor.
  At every step, each node only forwards data on to one neighbor, which it selects randomly. After node D receives the data, it must forward the data back to the sender (B), otherwise the data would never reach node C.



Continue.. Network Layer

Sensor Protocols for Information via Negotiation (SPIN)



Continue.. Network Layer

Sequential Assignment Routing (SAR)

Creates multiple trees where the root of each tree is a one-hop neighbor from the sink.

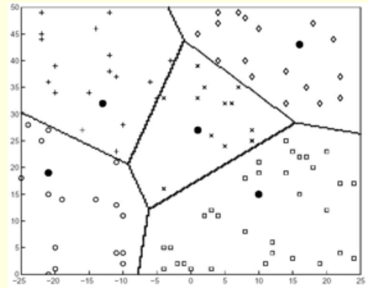
Low-Energy Adaptive

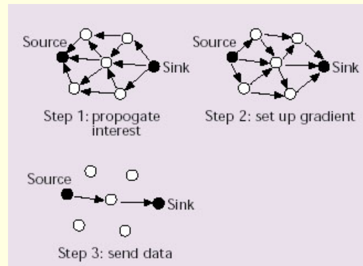
Clustering Hierarchy (LEACH)

Forms clusters to minimize energy dissipation.

Directed diffusion

Sets up gradients for data to flow from source to sink during interest dissemination.





Open Research Issues

-Energy Efficiency

-Higher changed topology

-Higher scalability

Transport Layer

Open Research Issues:

Transport layer protocols are still unexplored: they may be purely UDP-type protocols, because each sensor node has limited memory and power.

The Application Layer

- **Sensor Management Protocol (SMP)**
  makes the hardware and software of the lower layers transparent to the sensor network management applications. System administrators interact with sensor networks using SMP.
- **Task Assignment And Data Advertisement Protocol (TADAP)**
  provides the user software with efficient interfaces for interest dissemination.
- **Sensor Query and Data Dissemination Protocol (SQDDP)**
  provides user applications with interfaces to issue queries, respond to queries and collect incoming replies.
- **Open research Issues**
  - Although SQTL is proposed, other application layer protocols still need to be developed to provide a greater level of services.

Outline

- Wireless Sensor Networks Overview
  - Why Wireless Sensor Networks ?
  - What is WSN ?
- Application Overview
  - Scientist, commercial application
- System Components and Issues
  - Layers, issues at each layer
- Research Challenges

Research Challenges

- Sensor Nodes have Limited Capabilities
- Interdisciplinary Research
- Application Aware Research
- New Networking Paradigms and Protocols
- Self Organization and Localization
- Incomplete and Inaccurate Field Data
- Energy Efficient Algorithms and Protocols
- Embedded Environments and Deployment

Key Papers

- **Ian F. Akyildiz, Weilian Su, Yogesh Sankarasubramaniam, and Erdal Cayirci** @ GaTech
  A Survey on Sensor Networks ----
  IEEE Communications Magazine, 2002, 40(8):102~114.
- **D. Estrin, L. Girod, G. Pottie and M. Srivastava** @ UCLA
  Instrumenting the world with wireless sensor networks ----
  In *Proc. of the International Conference on Acoustics, Speech and Signal Processing*, (ICASSP 2001)
- **G. J. Pottie and W. J. Kaiser** @ UCLA
  Wireless Integrated Network Sensors ---
  Communications of ACM, 2000, 43(5)
- **Deborah Estrin, Ramesh Govindan, John Heidemann and Satish Kumar** @ USC/ISI
  Next Century Challenges: Scalable Coordination in Sensor Networks. ----
  In *Proc. of the fifth Annual ACM International Conference on Mobile Computing and Networking*, 1999, Seattle, Washington, USA
- **C. E. Jones, K. M. Sivalingam, P. Agrawal, and J. C. Chen**
  A survey of energy efficient network protocols for wireless networks. ----
  Wireless Networks, vol. 7, no. 4, pp. 343--358, July, 2001
- **S. Tilak, N. Abu-Ghazaleh, and W. Heinzelman** @ Binghamton & Rochester
  A Taxonomy of Wireless Micro-Sensor Network Models. ----
  ACM Mobile Computing and Communications Review (MC2R), Volume 6, Number 2, April 2002
- **Sanjay Shakkottai, Theodore S. Rappaport and Peter C. Karlsson**
  Cross-layer Design for Wireless Networks. ---
  IEEE Communications Magazine, October, 2003

Questions & Comments ?