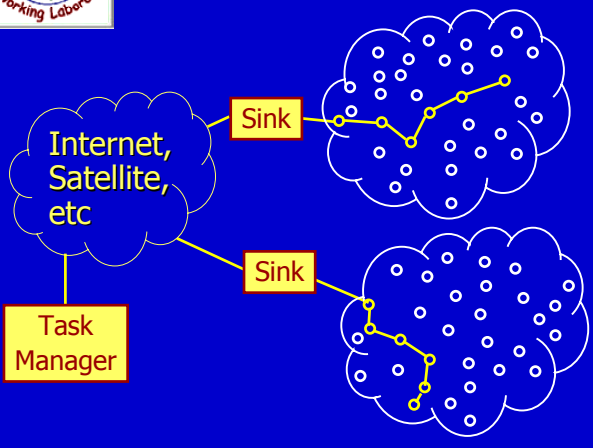
STATE-OF-THE-ART IN SENSOR NETWORKS RESEARCH

Ian F. Akyildiz

Broadband & Wireless Networking Laboratory
School of Electrical and Computer Engineering
Georgia Institute of Technology
Tel: 404-894-5141; Fax: 404-894-7883
Email: ian@ece.gatech.edu
Web: http://www.ece.gatech.edu/research/labs/bwn

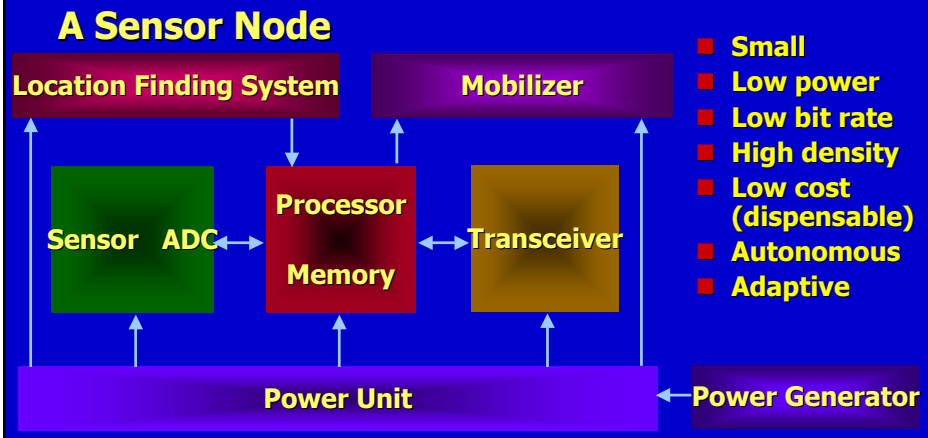
SENSOR NETWORKS



- **Several thousand nodes**
- **Nodes are tens of feet of each other**
- **Densities as high as 20 nodes/m3**

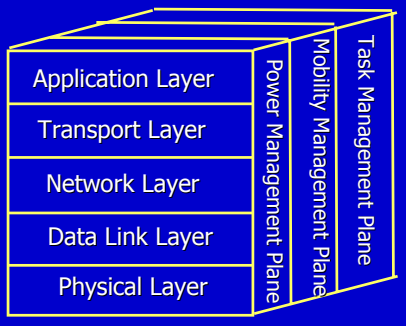
I.F.Akyildiz, W.Su, Y. Sankarasubramaniam, E. Cayirci,
"Wireless Sensor Networks: A Survey", *Computer Networks (Elsevier) Journal*, March 2002.

SENSOR NODE HARDWARE



- Small
- Low power
- Low bit rate
- High density
- Low cost (dispensable)
- Autonomous
- Adaptive

Sensor Networks Communication Architecture



- Used by sink and all sensor nodes
- Combines power and routing awareness
- Integrates data with networking protocols
- Communicates power efficiently through wireless medium and
- Promotes cooperative efforts

WHY CAN'T AD-HOC NETWORK PROTOCOLS BE USED HERE?

- Number of sensor nodes can be several *orders of magnitude higher*
- Sensor nodes are *densely deployed* and are *prone to failures*
- The topology of a sensor network changes very frequently due to *node mobility and node failure*
- Sensor nodes are limited in *power, computational capacities, and memory*
- May not have global ID like IP address.
- Need tight integration with sensing tasks.

SENSOR NETWORK APPLICATIONS

- Military, Environmental, Health, Home, Space Exploration, Chemical Processing, Disaster Relief….
- Seismic, Low sampling rate magnetic, Thermal, Visual, Infrared, Acoustic, Radar…
- Temperature, Humidity, Vehicular Movement, Lightning Condition, Pressure, Soil Makeup, Noise Levels, Presence or Absence of Certain Types of Objects, Mechanical Stress Levels on Attached Objects, Current Characteristics Speed, Direction, Size) of an Object ….

TRANSPORT LAYER
Related Work

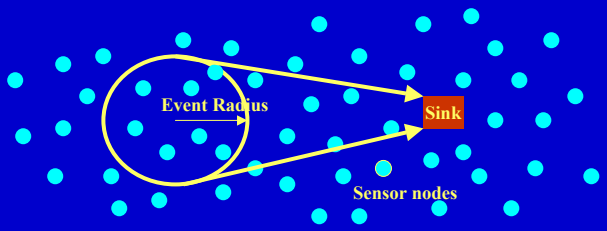
- Infrastructure Tradeoffs [1]
- RMST [2]
- PSFQ - Pump Slowly Fetch Quickly [3]
- MAC Level Reliability [4,5]

[1] S. Tilak, N. B. Abu-Ghazaleh and W. Heinzelman, "Infrastructure Tradeoffs for Sensor Networks," *In Proc. ACM WSNA'02*, September 2002.
[2] F. Stann and J. Heidemann, "RMST: Reliable Data Transport in Sensor Networks," *In Proc. IEEE SNPA'03*, May 2003.
[3] C. Y. Wan, A. T. Campbell and L. Krishnamurthy, "PSFQ: A Reliable Transport Protocol for Wireless Sensor Networks," *In Proc. ACM WSNA'02*, September 2002.
[4] A. Woo and D. Culler, "A transmission Control Scheme for Media Access in Sensor Networks", *In Proc. ACM MOBICOM'01*, July 2001.
[5] W. Ye, J. Heidemann and D. Estrin, "An Energy-Efficient MAC Protocol for Wireless Sensor Networks", *In Proc. IEEE INFOCOM'02*, June 2002.

Event-to-Sink Reliability

Y. Sankarasubramaniam, O. B. Akan, I. F. Akyildiz,

Proc. of ACM MobiHoc'03, Annapolis, Maryland, June 2003.



- Sensor networks are *event-driven*
- Multiple correlated data flows from event to sink
- Goal is to reliably detect/estimate event features from collective information
- Necessitates *event-to-sink collective reliability notion*

Open Research Issues

- Extend *ESRT* to address reliable transport of *concurrent multiple events* in the sensor field.
- Explore possible other *reliability metrics*
  - Total expected mean square distortion
  - Minimum mean squared error estimation.
- Develop unified transport layer protocols for *sink-to-sensors* and bi-directional reliable transport in WSN
- Research to *integrate WSN domain into NGWI* (Next Generation Wireless Internet)
  - Adaptive Transport Protocols for WSN-Ad Hoc environments

NETWORK LAYER Related Work

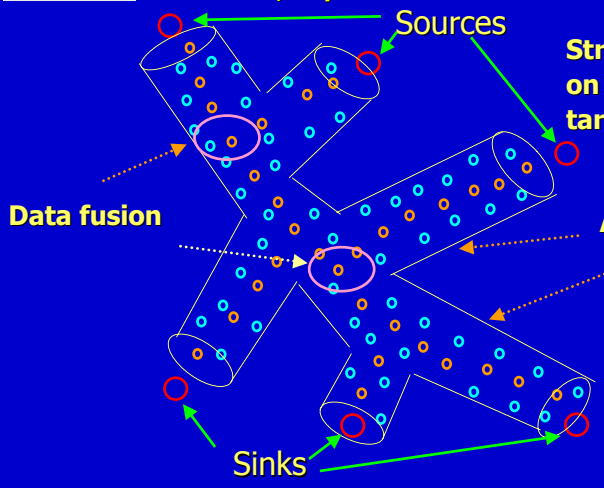
- Sensor Protocols for Information via Negotiation (SPIN) [1]
- Directed Diffusion [2]

[1] W. R. Heinzelman, J. Kulik, and H. Balakrishnan, "Adaptive Protocols for Information Dissemination in Wireless Sensor Networks," *Proc. of the ACM MobiCom'99*, pp. 174-185, Sept. 1999.

[2] C. Intanagonwiwat, R. Govindan, and D. Estrin, "Directed Diffusion: A Scalable and Robust Communication Paradigm for Sensor Networks," *Proc. of the ACM MobiCom'00*, pp. 56-67, Sept. 2000.

QSR Protocol Overview

W. Su and I.F. Akyildiz, "QSR: Quality of Service Routing for Sensor Networks", May 2003.



Contributions of QSR

- Periodic update of routes not needed
- Adapt to failures
- Cope with topology changes
- No need for routing tables
- Easy incorporation of new sensor nodes
- Routes based on QoS requirements
- One-to-one, many-to-one, one-to-many, and many-to-many communications
- Works well with topology maintenance protocols, e.g., SPAN, GAF, and LEACH
- Works well with data fusion protocols

Open Research Issues

- **Store and Forward Technique**
  that combines data fusion and aggregation.
- **Routing for Mobile Sensors**
  Investigate multi-hop routing techniques for high mobility environments.
- **Priority Routing**
  Design routing techniques that allow different priority of data to be aggregated, fused, and relayed.
- **3D Routing**

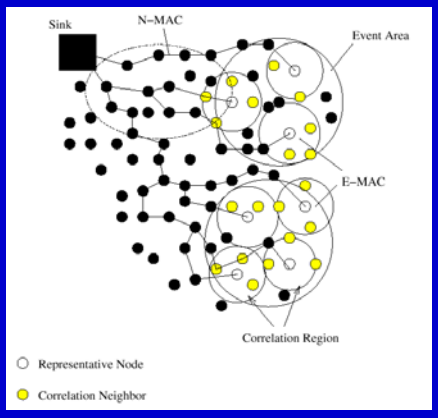
MEDIUM ACCESS CONTROL (MAC) Related Work

- IEEE 802.11
- S-MAC and EAR [1,2]
- Transmission Control Scheme [3]
- Distributed Source Coding [4,5]
- Routing and Data Compression [6]

[1] K.Sohrabi et al.,"Protocols for Self-Organization of a Wireless Sensor Network", *IEEE Personal Communications,October 2000.*
[2] W. Ye, J. Heidemann and D. Estrin, "An Energy Efficient MAC Protocol for Wireless Sensor Networks," *Proc. ACM MOBICOM '01,* pp.221 –235, July 2001.
[3] A. Woo and D. Culler, "A Transmission Control Scheme for Media Access in Sensor Networks", *Proc. ACM MOBICOM'01,* July 2001..
[4] S.S. Pradhan, K. Ramchandran, "Distributed Source Coding: Symmetric Rates and Applications in Sensor Networks," in *Proc. Data Compression Conference'00,* pp. 363 –373, 2000.
[5] S.S. Pradhan, J. Kusuma, K. Ramchandran, "Distributed Compression in a Dense Microsensor Network," *IEEE Signal Processing Magazine,* vol.19, no.2, pp.51 –60, Mar 2002.
[6] A. Scaglione, S.D. Servetto, "On the Interdependence of Routing and Data Compression in Multi-Hop Sensor Networks," *Proc. MOBICOM'02,* September 2002.

Collaborative MAC Protocol

M. C. Vuran, Y. Sankarasubramaniam, I.F. Akyildiz, "Collaborative Medium Access for Wireless Sensor Networks", March 2003.



- ***Source function:*** **Transmit event information**
- ***Router function:*** **Forward packets from other nodes in the multi-hop path to the sink**

Optimal Packet Size for Wireless Sensor Networks

Y. Sankarasubramaniam, I. F. Akyildiz, S. McLaughlin, "Optimal Packet Size for Wireless Sensor Networks", IEEE SNPA, May 2003.

- **Determining the optimal packet size for sensor networks is necessary to *operate at high energy efficiencies*.**
- **The *multihop wireless channel* and *energy consumption characteristics* are the two most important factors that influence choice of packet size.**

Header (*2*)	Payload (*<=73*)	Trailer (FEC) (*>=3*)

SYNCHRONIZATION Related Work

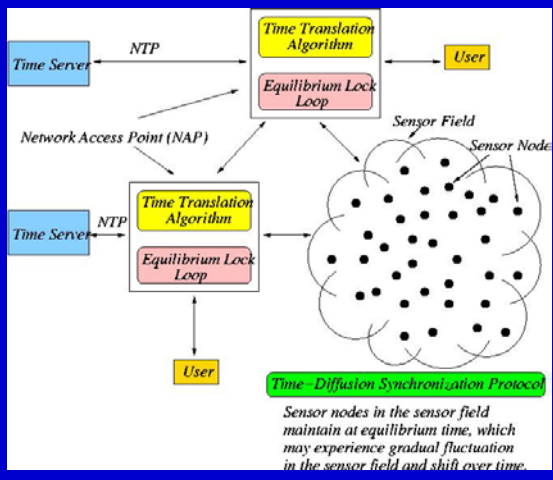
- Post-Facto Synchronization [1]
- Reference-Broadcast Synchronization (RBS) [2]

[1] J. Elson and D. Estrin, "Time Synchronization for Wireless Sensor Networks," *Proceedings of the 15th International Parallel and Distributed Processing Symposium (IPDPS-01)*, IEEE Computer Society, April 2001.

[2] J. Elson, L. Girod, and D. Estrin, "Fine-Grained Network Time Synchronization using Reference Broadcasts," *Proceedings of the Fifth Symposium on Operating Systems Design and Implementation (OSDI 2002)*, December 2002.

TDP (Time Diffusion Protocol)

W. Su and I.F. Akyildiz, "Time Diffusion Synchronizaton Protocols for Wireless Sensor Networks", Revised in June 2003



Contributions

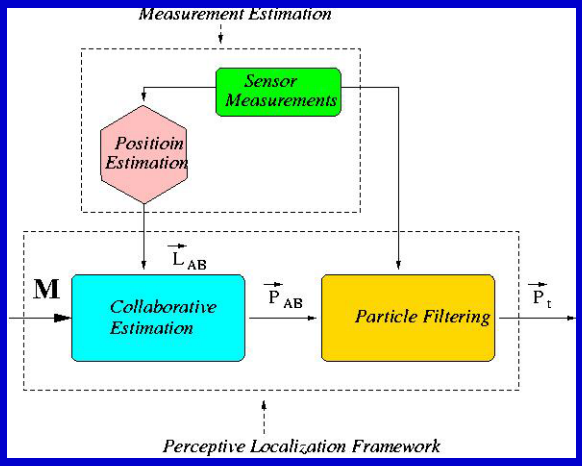
- Enables applications to coordinate sensor nodes.
- Enables users to perceive events in the same time frame.
- Enables protocols that require time-stamps.
- Maintains the time throughout the network within a certain tolerance.
- Controls the network time tolerance with system parameters.
- Enables a sink to detect time difference of events.
- Allows a sink to issue a start time to sensor nodes that are in different part of the sensor field.

PERCEPTIVE LOCALIZATION
Related Work

- N. Patwari et. al., "Relative Location Estimation in Wireless Sensor Networks," *IEEE Transactions on Signal Processing*, August 2003.
  - Mathematical analysis of sensor location accuracy based on fixed base-stations capable of peer- to-peer time-of-arrival or received signal strength measurements
- R. Moses et.al., "A Self-Localization Method for Wireless Sensor Networks," *Eurasia Journal on Applied Signal Processing*, No. 4, pp. 348-358, 2003.
  - A self-location method that uses base-stations with known positions as references
- L. Doherty et.al.,
  "Convex Position Estimation in Wireless Sensor Networks," *Infocom'01* , April 2001.
  - Solving the position estimation problem using convex optimization (assuming each node has a fixed radius)
- A. Savvides et.al., "Dynamic Fine-Grained Localization in Ad-Hoc Networks of Sensors," *Proc. Of ACM MobiCom'01*, pp. 166-179, 2001.
  - Use fixed-base stations for fine-grained location

Perceptive Localization Framework

W. Su and I.F. Akyildiz, "Perceptive Localization Framework for Sensor Networks", June 2003.



Open Research Issues

- **Proposal Distribution for Particle Filters:**
  Enable the particle filter to better estimate the movement behavior of the sensor nodes
- **Non Fixed Base-Station based Techniques:**
  Enable location of sensor nodes without the need for location beacons
- **New CE Techniques:**
  Investigate different CE techniques for different types of sensors and environment

SENSOR NETWORK TESTBED