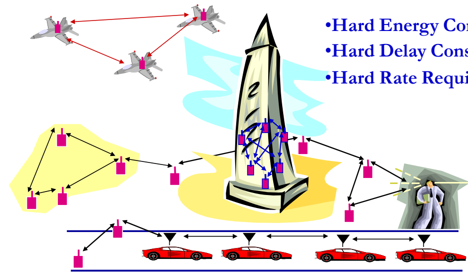
EE360: Lecture 16 Outline
Sensor Network Applications and In-Network Processing

- Announcements
  - 2nd summary due today 12am (1 day extension possible)
  - Project poster session March 15 5:30pm (3rd floor Packard)
  - Next HW posted by tonight, due March 16
  - Will extend final project deadline
- Overview of sensor network applications
- Technology thrusts
- Cross-layer design of sensor network protocols
- Cooperative compression
- Distributed sensing, communications, and control

Wireless Sensor Networks
Data Collection and Distributed Control



- Hard Energy Constraints
- Hard Delay Constraints
- Hard Rate Requirements

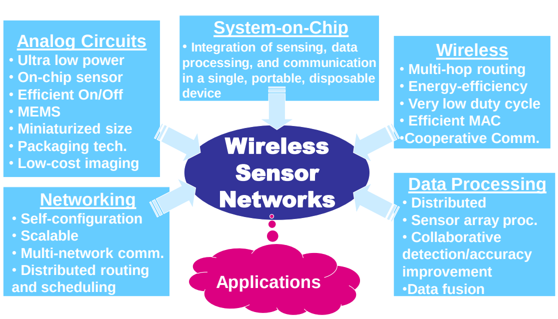
Application Domains

- **Home networking:** Smart appliances, home security, smart floors, smart buildings
- **Automotive:** Diagnostics, occupant safety, collision avoidance
- **Industrial automation:** Factory automation, hazardous material control
- **Traffic management:** Flow monitoring, collision avoidance
- **Security:** Building/office security, equipment tagging, homeland security
- **Environmental monitoring:** Habitat monitoring, seismic activity, local/global environmental trends, agricultural

Wireless Sensor Networks

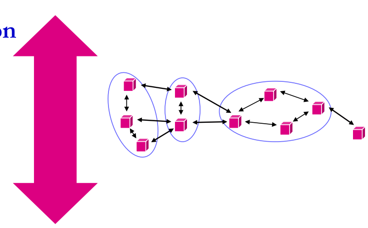
- Revolutionary technology.
- Hard energy, rate, or delay constraints change fundamental design principles
- Breakthroughs in devices, circuits, communications, networking, signal processing and crosslayer design needed.
- Rich design space for many industrial and commercial applications.

Technology Thrusts



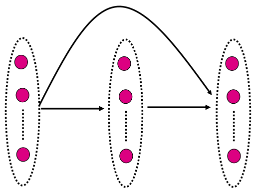
Crosslayer Protocol Design in Sensor Networks

- Application
- Network
- Access
- Link
- Hardware



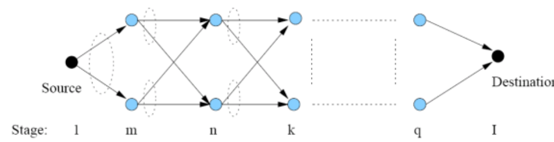
Protocols should be tailored to the application requirements and constraints of the sensor network

Cross-Layer Design with Cooperation



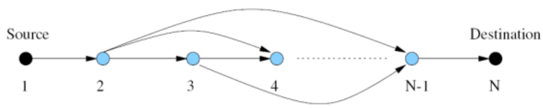
Multihop Routing among Clusters

Double String Topology with Alamouti Cooperation



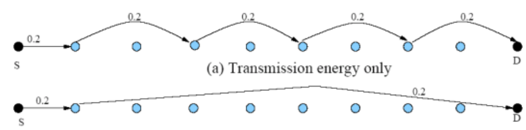
- Alamouti 2x1 diversity coding scheme
  - At layer *j*, node *i* acts as *i*th antenna
- Synchronization required
- Local information exchange not required

Equivalent Network with Super Nodes



- Each super node is a pair of cooperating nodes
- We optimize:
  - link layer design (constellation size b_{ij})
  - MAC (transmission time t_{ij})
  - Routing (which hops to use)

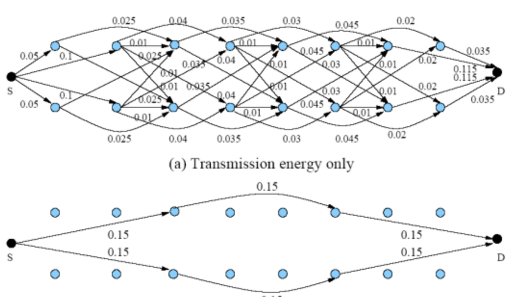
Minimum-energy Routing (cooperative)



(a) Transmission energy only

(b) Transmission energy + Circuit processing energy

Minimum-energy Routing (non-cooperative)

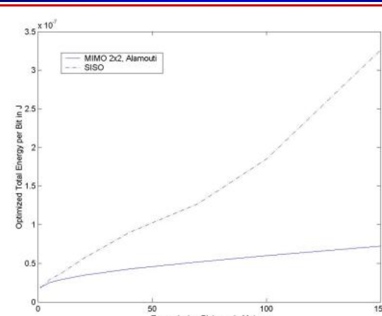


(a) Transmission energy only

(b) Transmission energy + Circuit processing energy

MIMO v.s. SISO

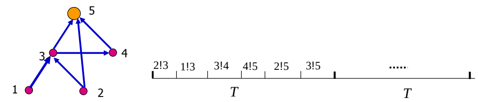
(Constellation Optimized)



Delay/Energy Tradeoff

- **Packet Delay: transmission delay + deterministic queuing delay**
- **Different ordering of t_{ij}'s results in different delay performance**
- **Define the scheduling delay as total time needed for sink node to receive packets from all nodes**
- **There is fundamental tradeoff between the scheduling delay and total energy consumption**

Minimum Delay Scheduling



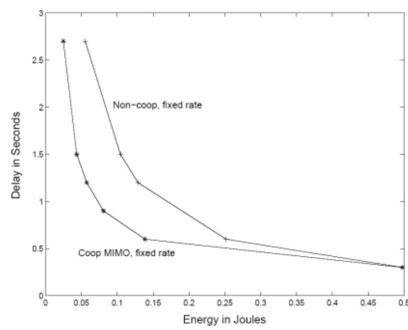
- The minimum value for scheduling delay is T **(among all the energy-minimizing schedules):** $T=\sum t_{ij}$
- Sufficient condition for minimum delay**: at each node the outgoing links are scheduled after the incoming links**
- **An algorithm to achieve the sufficient condition exists for a loop-free network with a single hub node**
- **An minimum-delay schedule for the example: {2!3, 1!3, 3!4, 4!5, 2!5, 3!5}**

Energy-Delay Optimization

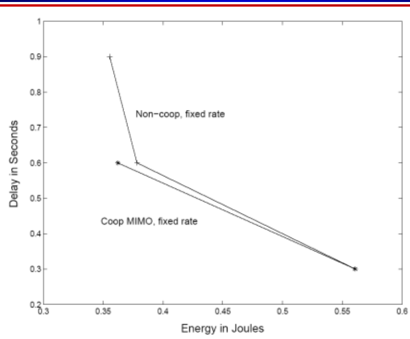
- **Minimize weighted sum of scheduling delay and energy**

$$\sum_{i=1}^{N-1}\sum_{j\in\mathcal{M}_i} t_{ij} + \alpha\sum_{i=1}^{N-1}\sum_{j\in\mathcal{M}_i}\epsilon_{ij}$$

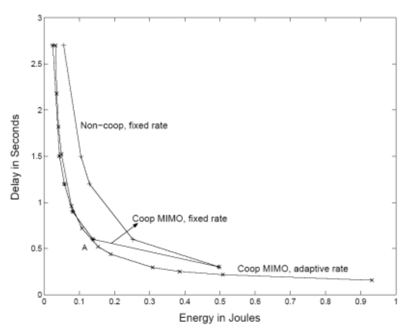
Transmission Energy vs. Delay



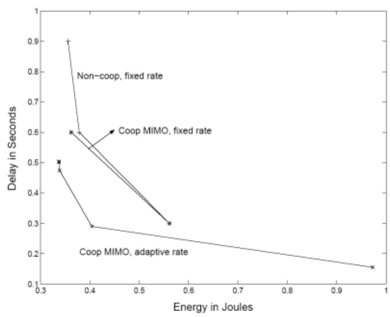
Total Energy vs. Delay



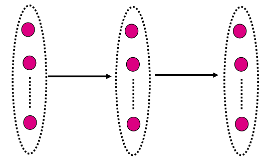
Transmission Energy vs. Delay (with rate adaptation)



Total Energy vs. Delay (with rate adaptation)

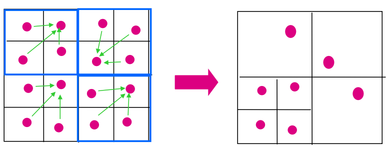


Cooperative Compression



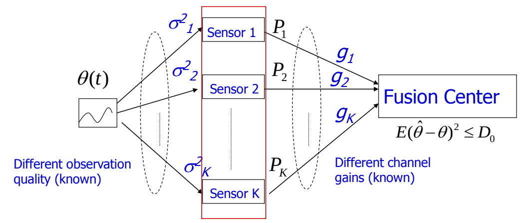
- Source data correlated in space and time
- Nodes should cooperate in compression as well as communication and routing
  - Joint source/channel/network coding

Cooperative Compression and Cross-Layer Design



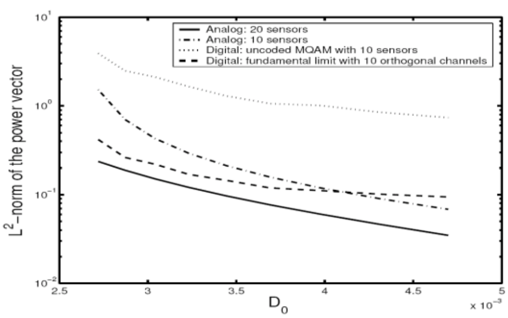
- Intelligent local processing can save power and improve centralized processing
- Local processing also affects MAC and routing protocols

Energy-efficient estimation



- We know little about optimizing this system
  - Analog versus digital
  - Analog techniques (compression, multiple access)
  - Should sensors cooperate in compression/transmission
  - Transmit power optimization

Digital vs. Analog

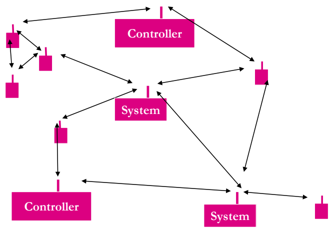


Key Message

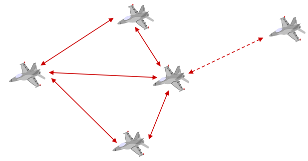
Cross-layer design imposes tradeoffs between rate, power/energy, and delay

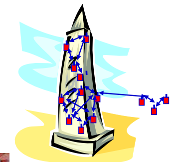
The tradeoff implications for sensor networks and distributed control is poorly understood

Distributed Sensing, Communications, and Control



Applications

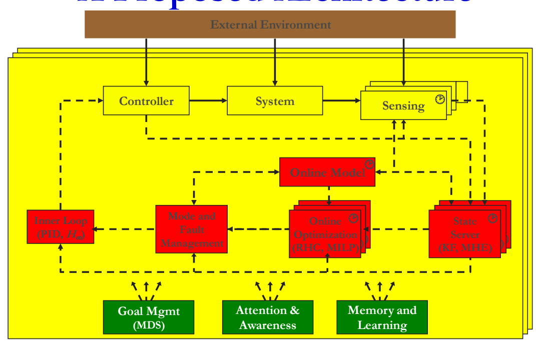




Joint Design of Control and Communications

- Generally apply different design principles
  - Control requires fast, accurate, and reliable feedback.
  - Networks introduce delay and loss for a given rate.
- Sensors must collect data quickly and efficiently
- The controllers must be robust and adaptive to random delays and packet losses.
  - Control design today is highly sensitive to loss and delay
- The networks must be designed with control performance as the design objective.
  - Network design tradeoffs (throughput, delay, loss) become implicit in the control performance index
  - This complicates network optimization

A Proposed Architecture



Potential Pieces of the Puzzle

- Local autonomy
  - Subsystems can operate in absence of global data
- Estimation, prediction, and planning
  - Exploit rich set of existing tools
- Command buffering and prefetching
  - Increases tolerance to data latency and loss
- Time stamps and delay-adaptive control
- Modular design
  - Supervisory control via models, cost functions, modes

Summary

- Cross layer design especially effective in sensor networks.
- Node cooperation can include cooperative compression
  - Cooperative gains depend on network topology and application.
- Cross layer design must optimize for application
  - Requires interdisciplinary understanding, e.g. for control

Presentation

- **An application-specific protocol architecture for wireless microsensor networks**
- **By W. Heinzelman, A. P. Chandrakasan and H. Balakrishnan**
- **Presented by Mainak Chowdhury**