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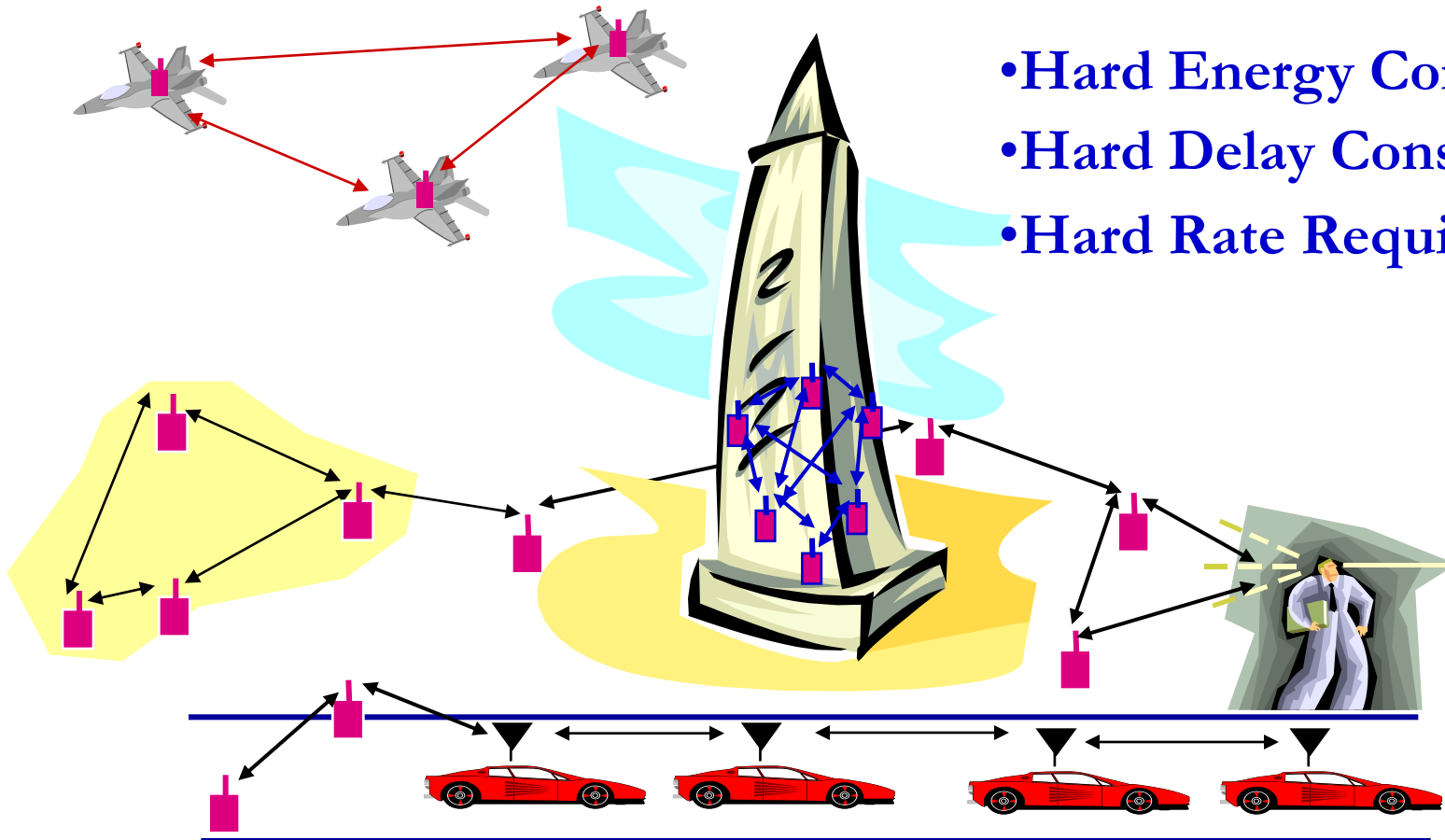
- **Hard Energy Constraints**
- **Hard Delay Constraints**
- **Hard Rate Requirements**

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

Analog Circuits
- Ultra low power
- On-chip sensor
- Efficient On/Off
- MEMS
- Miniaturized size
- Packaging tech.
- Low-cost imaging

System-on-Chip
- Integration of sensing, data processing, and communication in a single, portable, disposable device

Wireless
- Multi-hop routing
- Energy-efficiency
- Very low duty cycle
- Efficient MAC
- Cooperative Comm.

Networking
- Self-configuration
- Scalable
- Multi-network comm.
- Distributed routing and scheduling

Data Processing
- Distributed
- Sensor array proc.
- Collaborative detection/accuracy improvement
- Data fusion

Wireless Sensor Networks

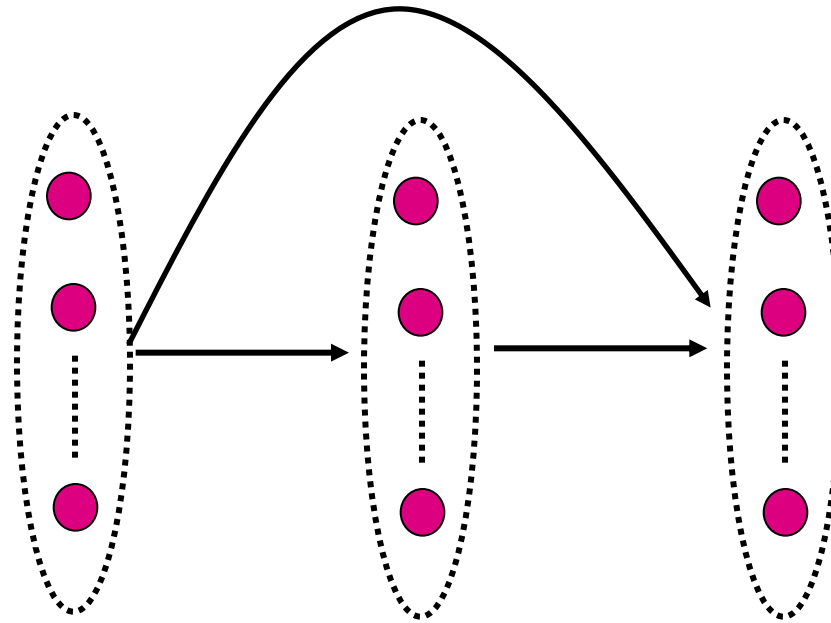**Applications**

Crosslayer Protocol Design in Sensor Networks

- **Application**

- **Network**
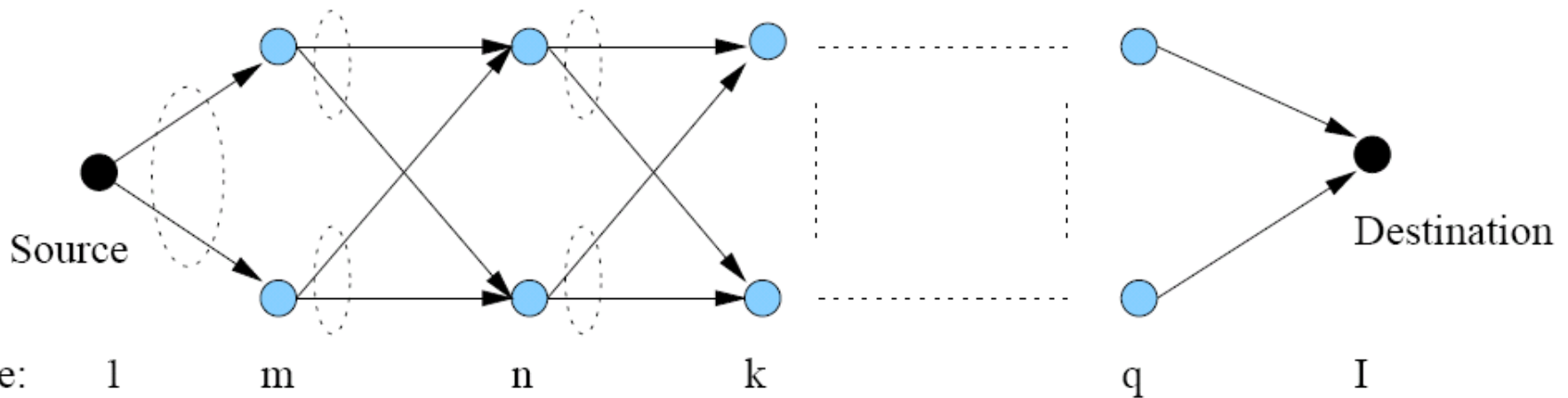
- **Access**

- **Link**

- **Hardware**
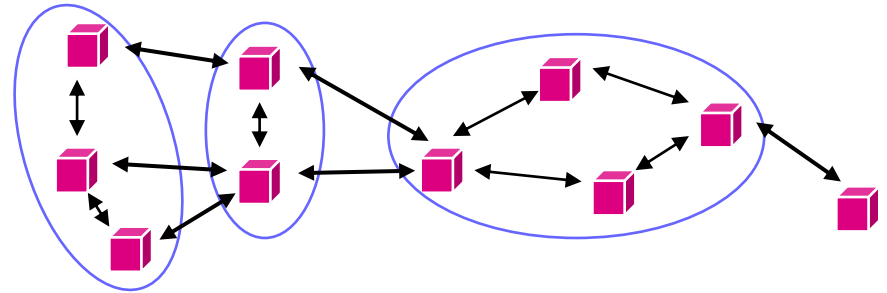
Protocols should be tailored to the application requirements and constraints of the sensor network
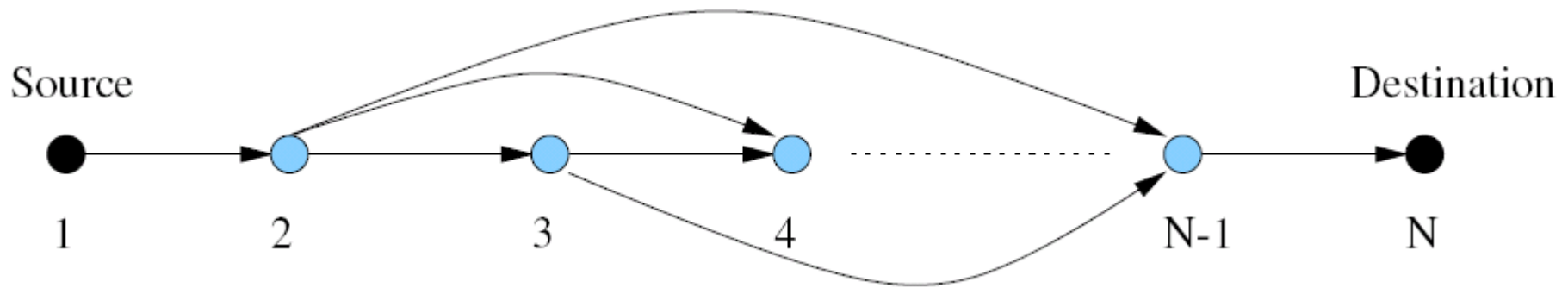
Cross-Layer Design with Cooperation

Multihop Routing among Clusters

Double String Topology with Alamouti Cooperation

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

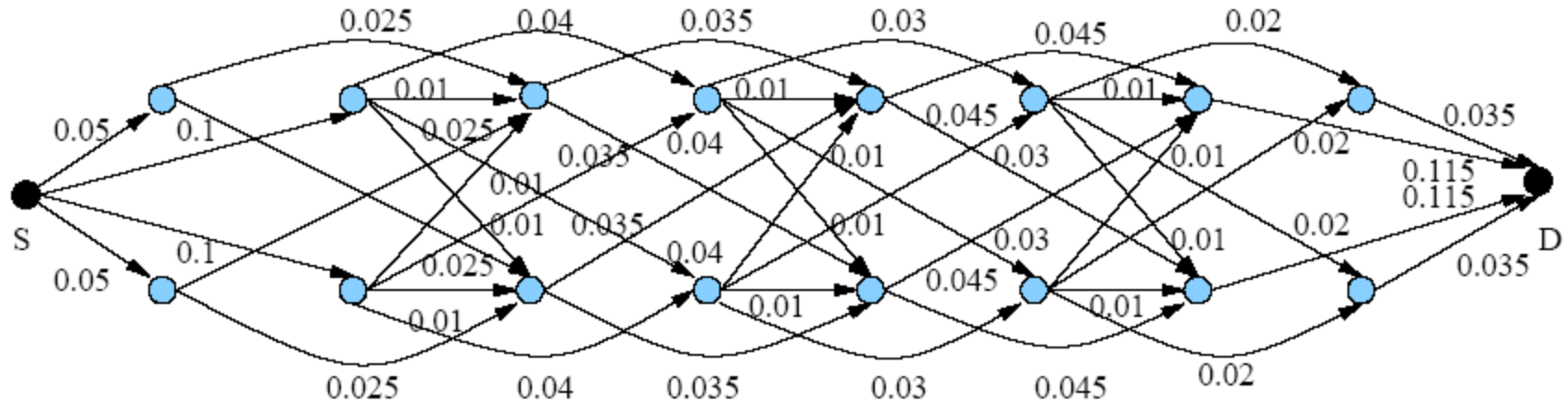# Equivalent Network with Super Nodes

- **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)
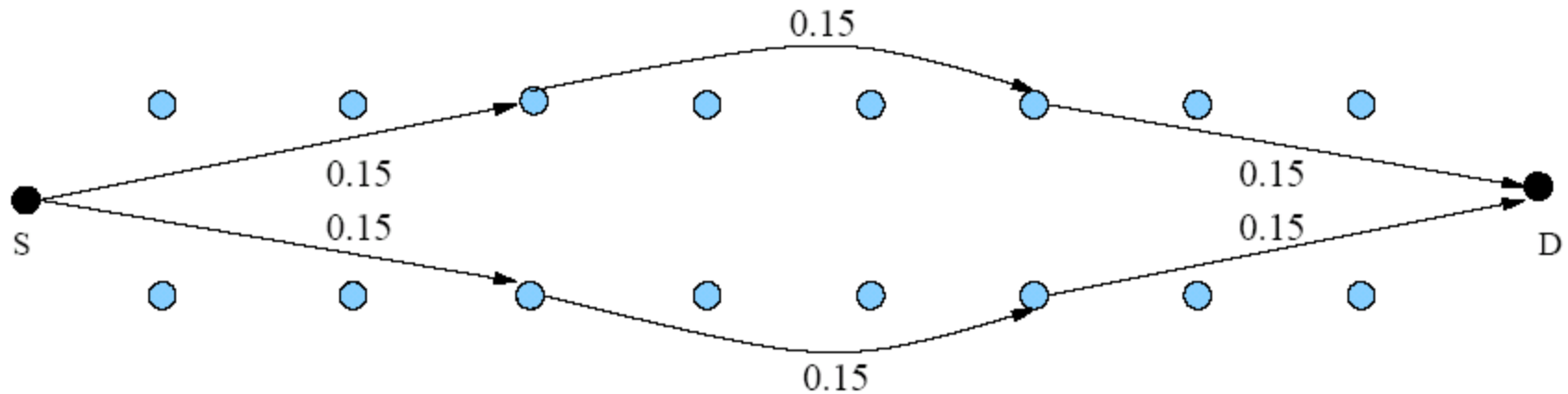

(a) Transmission energy only

(b) Transmission energy + Circuit processing energy
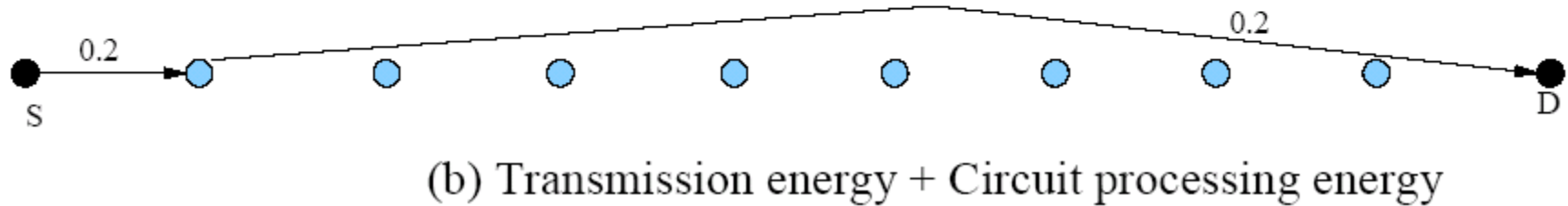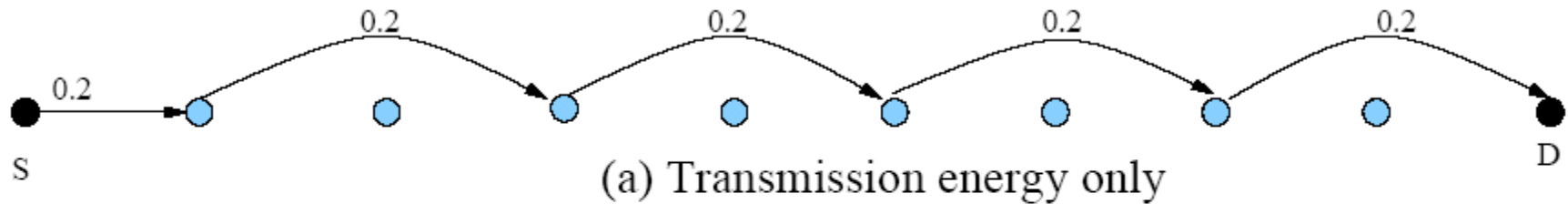
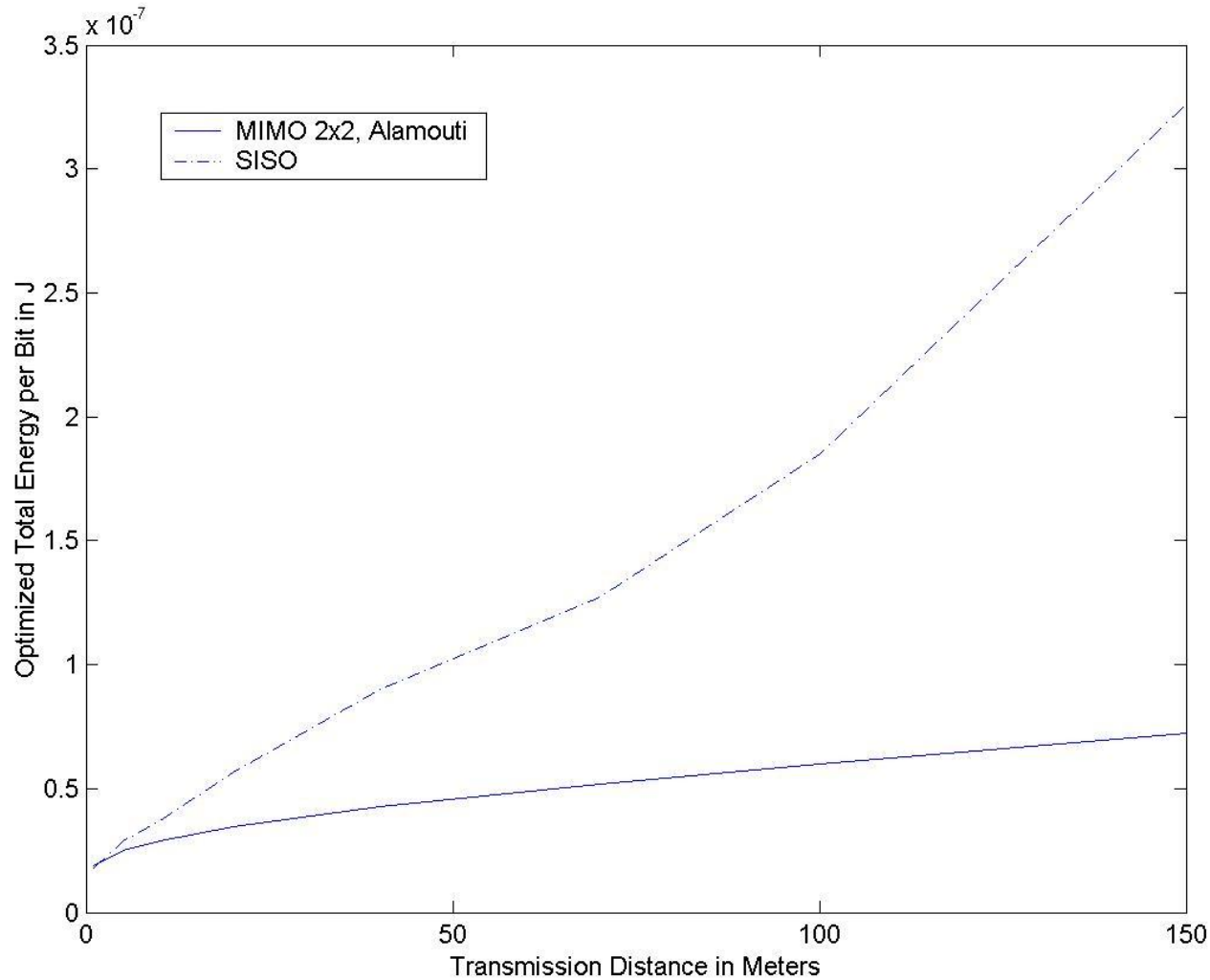# Minimum-energy Routing (non-cooperative)

(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
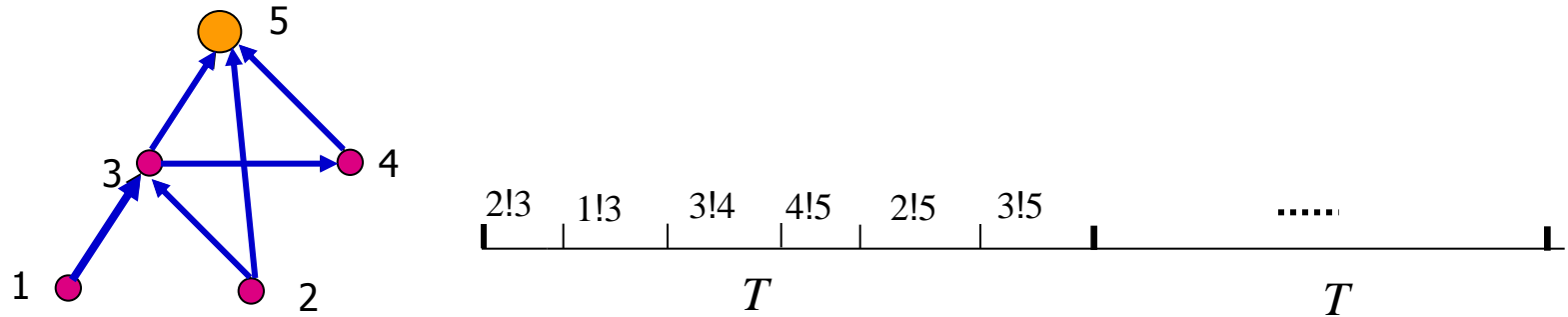
- The minimum value for scheduling delay is T **(among all the energy-minimizing schedules):** $T = \sum t_{ij}$

- 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}**
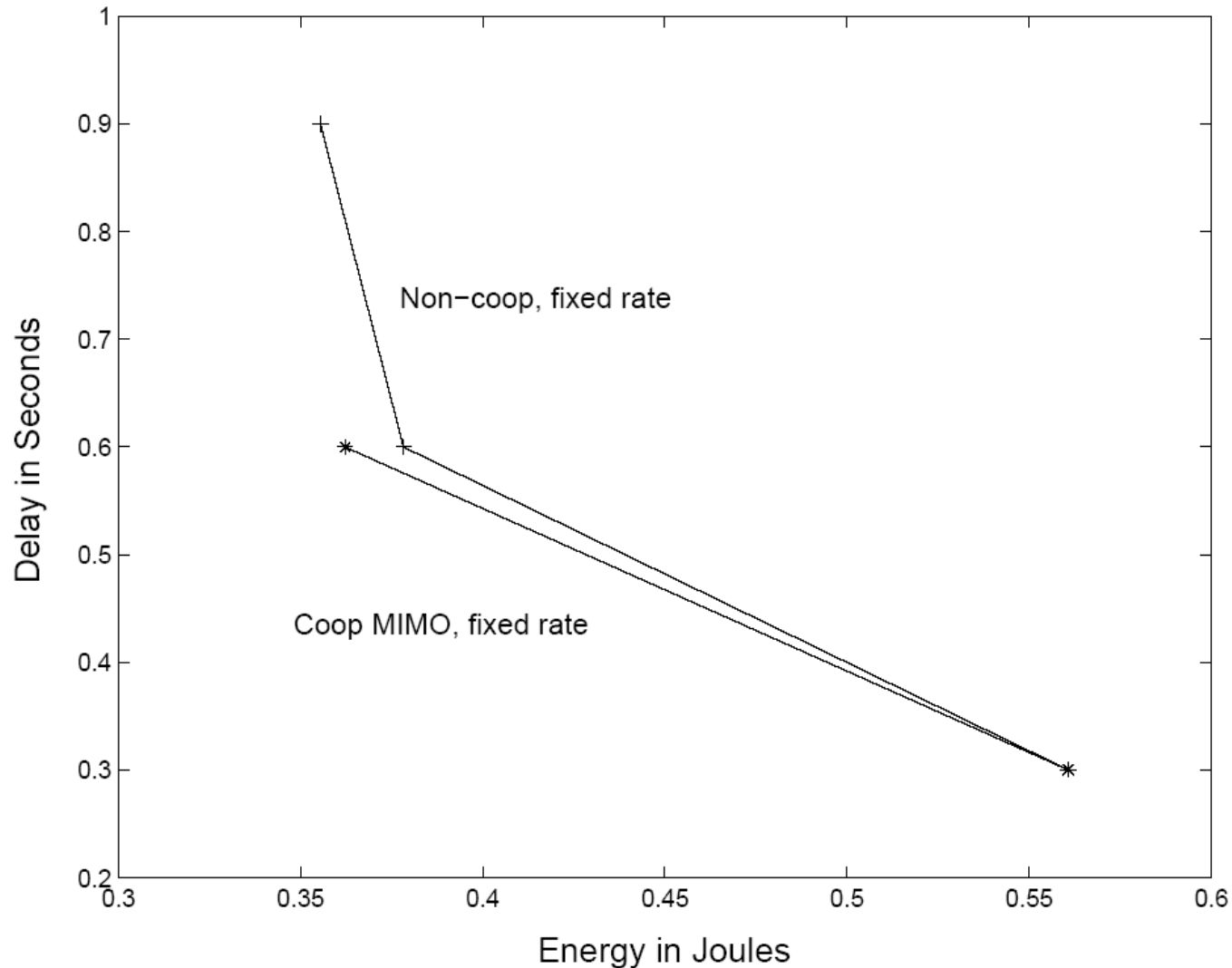
Energy-Delay Optimization

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

$$\sum_{i=1}^{N-1} \sum_{j \in \mathcal{M}_i} t_{ij} + \alpha \sum_{i=1}^{N-1} \sum_{j \in \mathcal{M}_i} \epsilon_{ij}$$
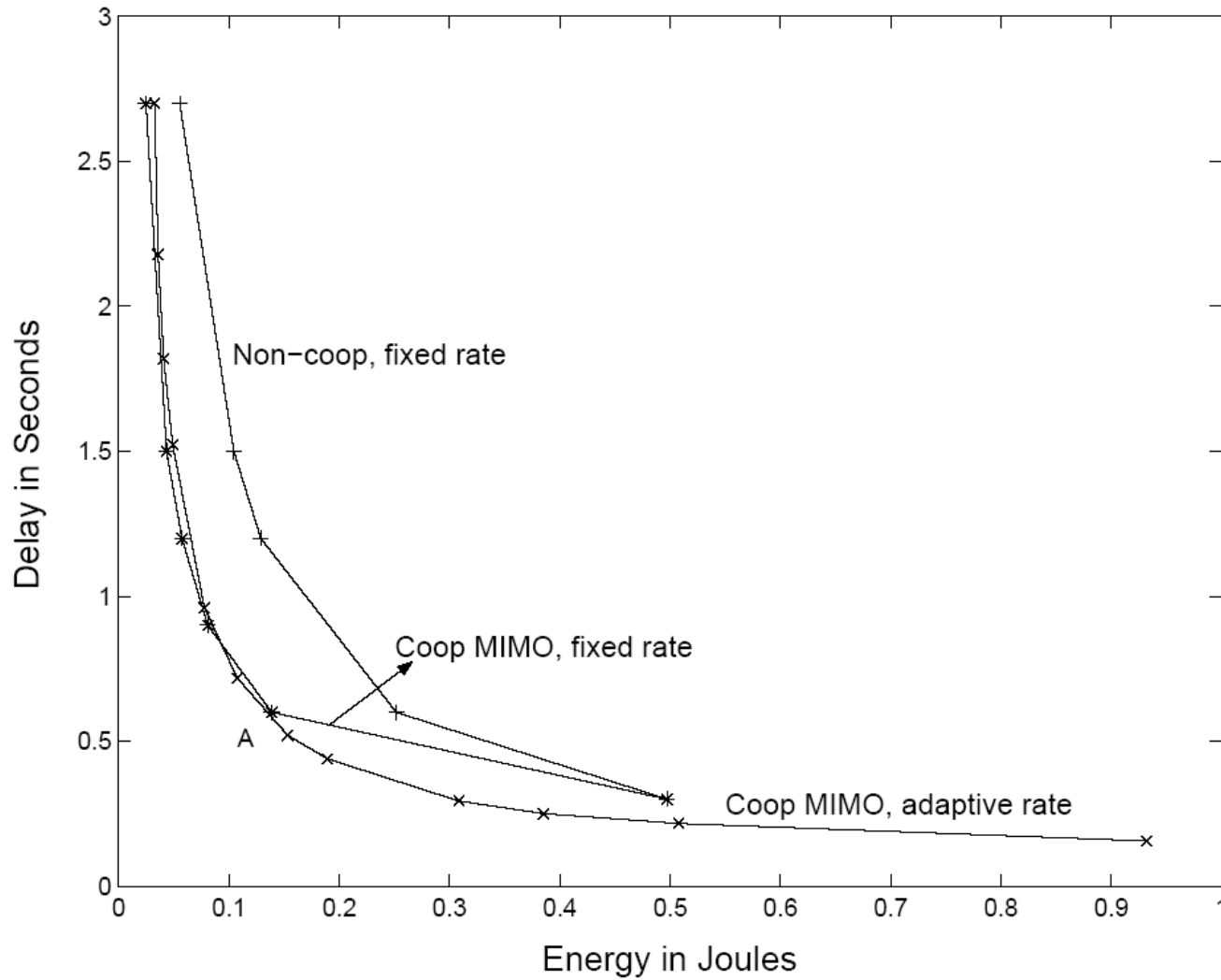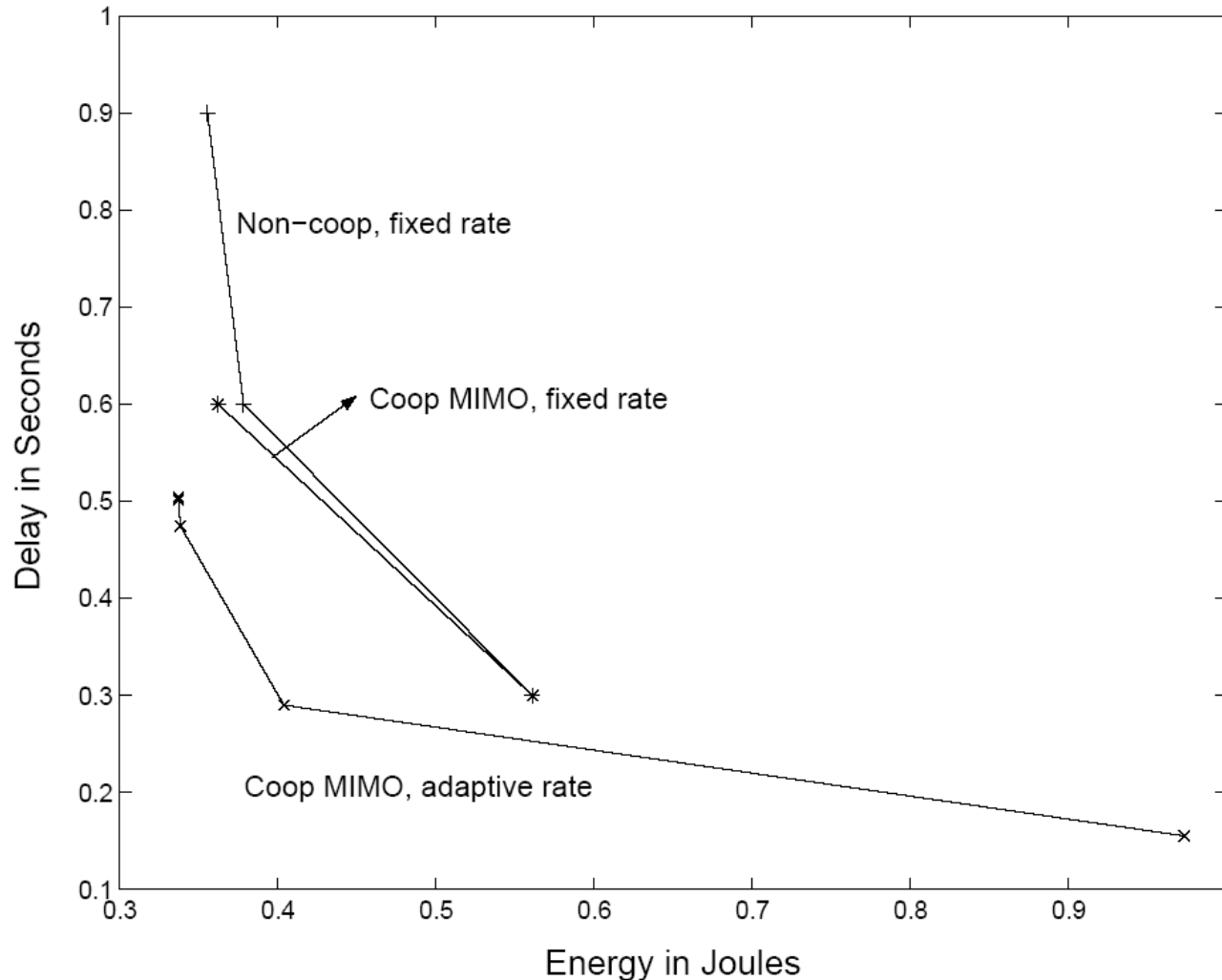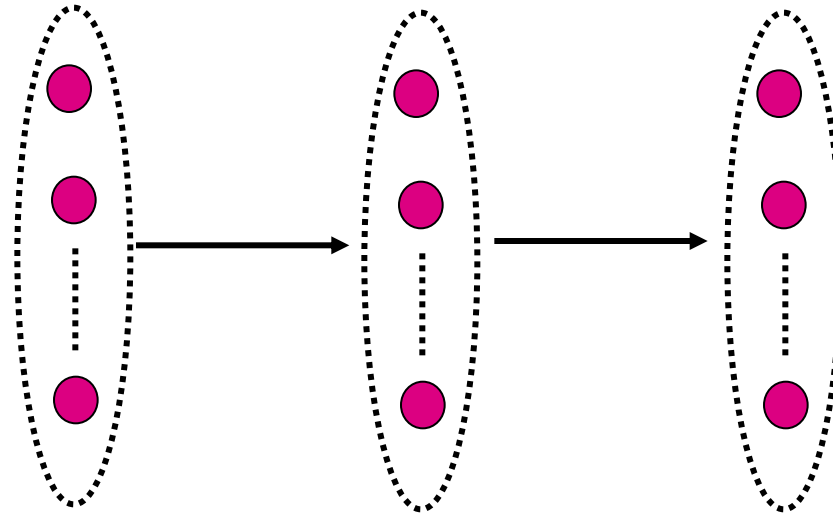
Transmission Energy vs. Delay
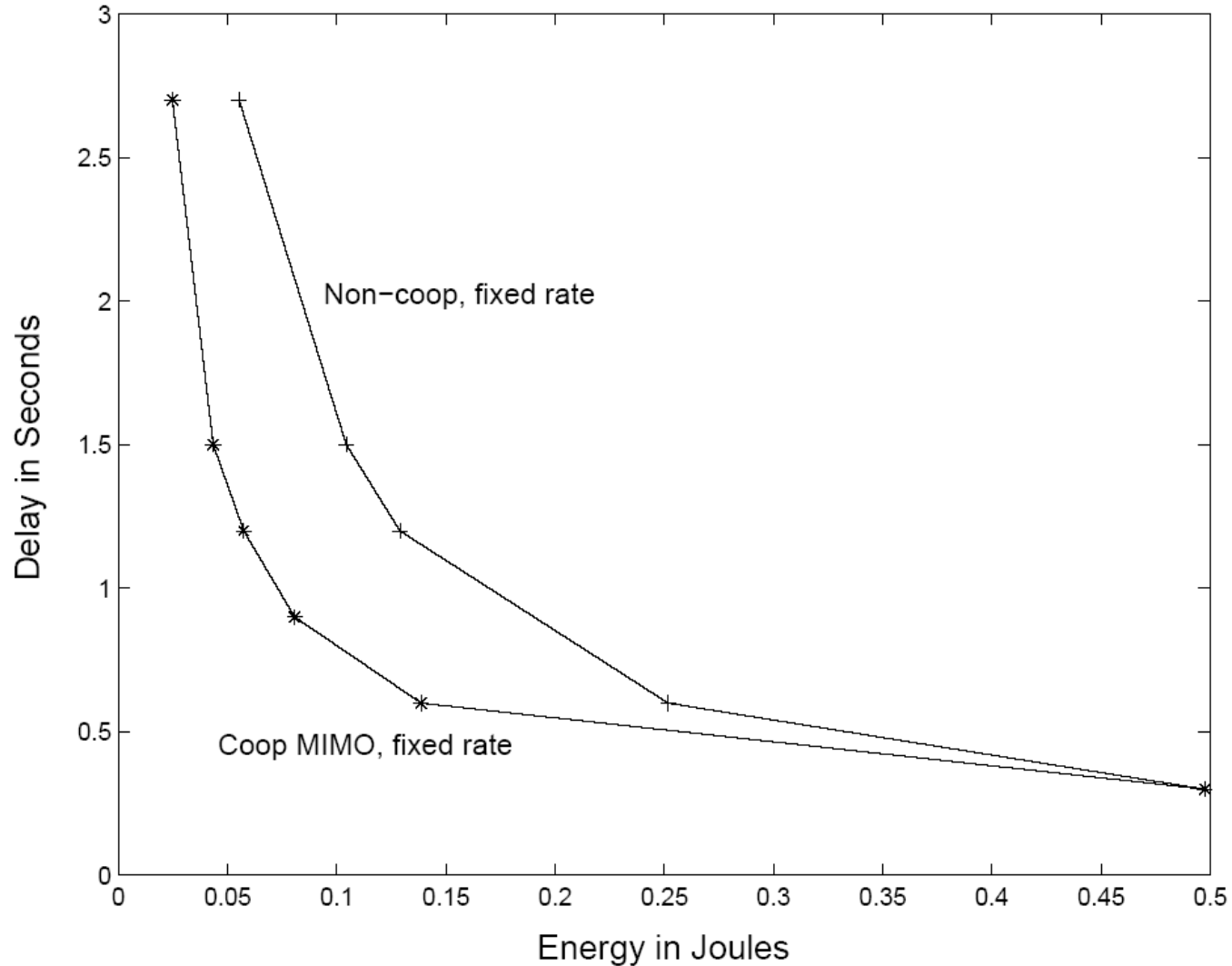
Total Energy vs. Delay

Transmission Energy vs. Delay (with rate adaptation)

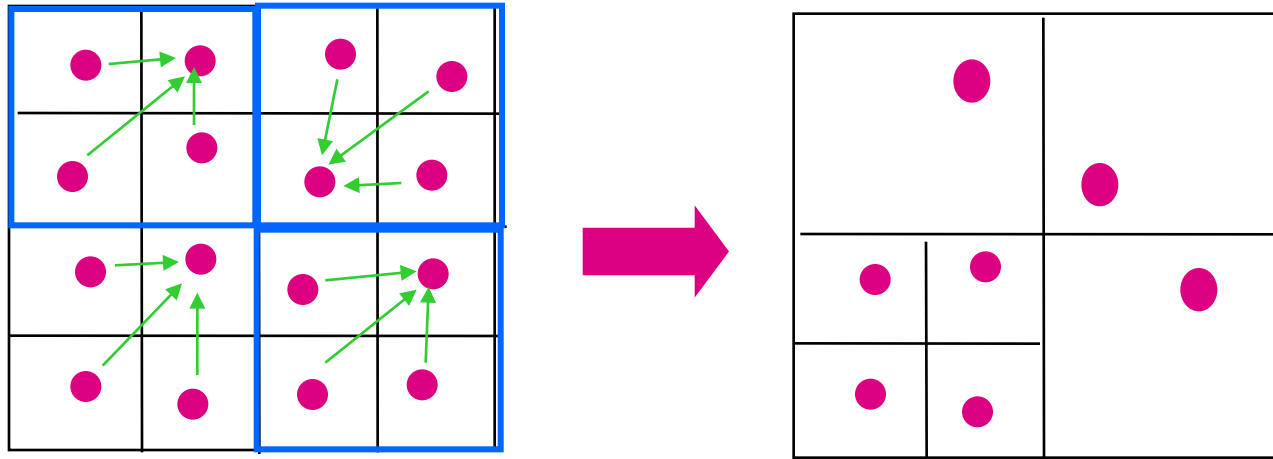# Total Energy vs. Delay (with rate adaptation)
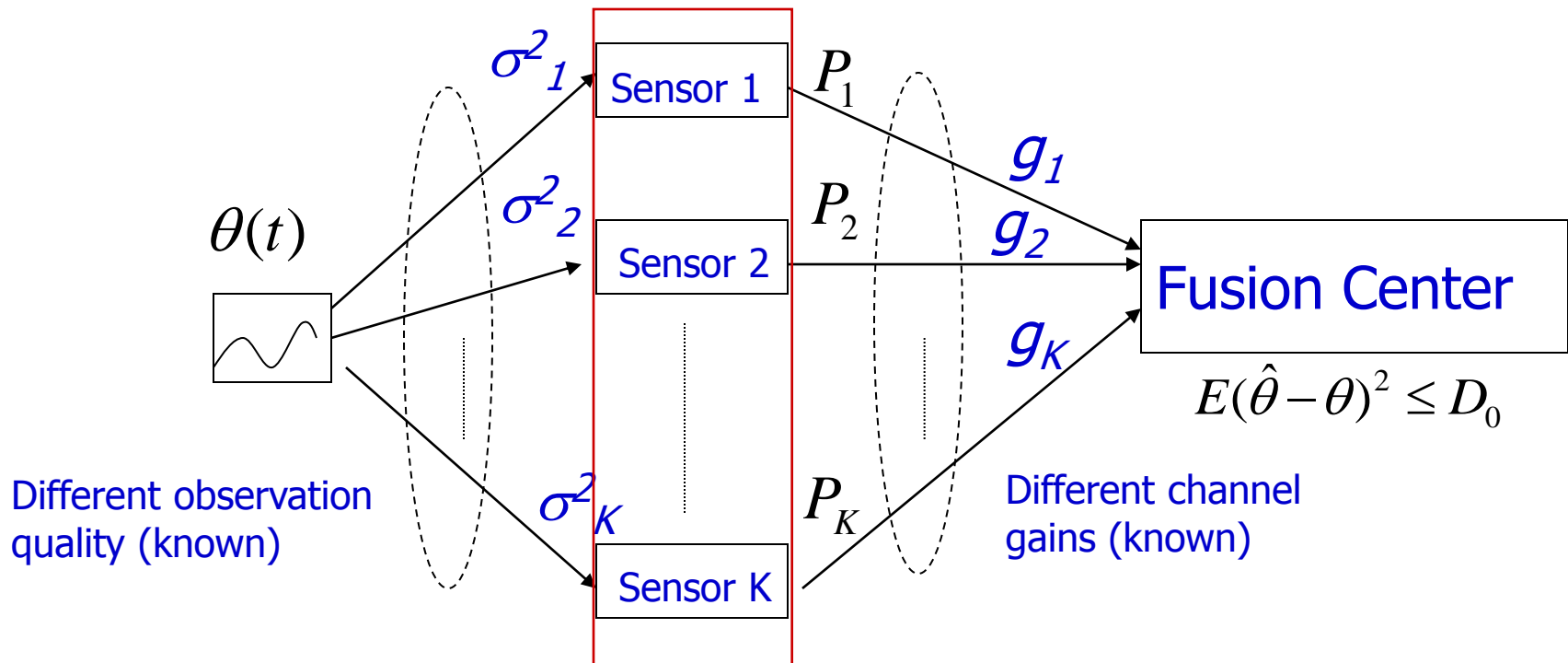
Cooperative Compression

- **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**
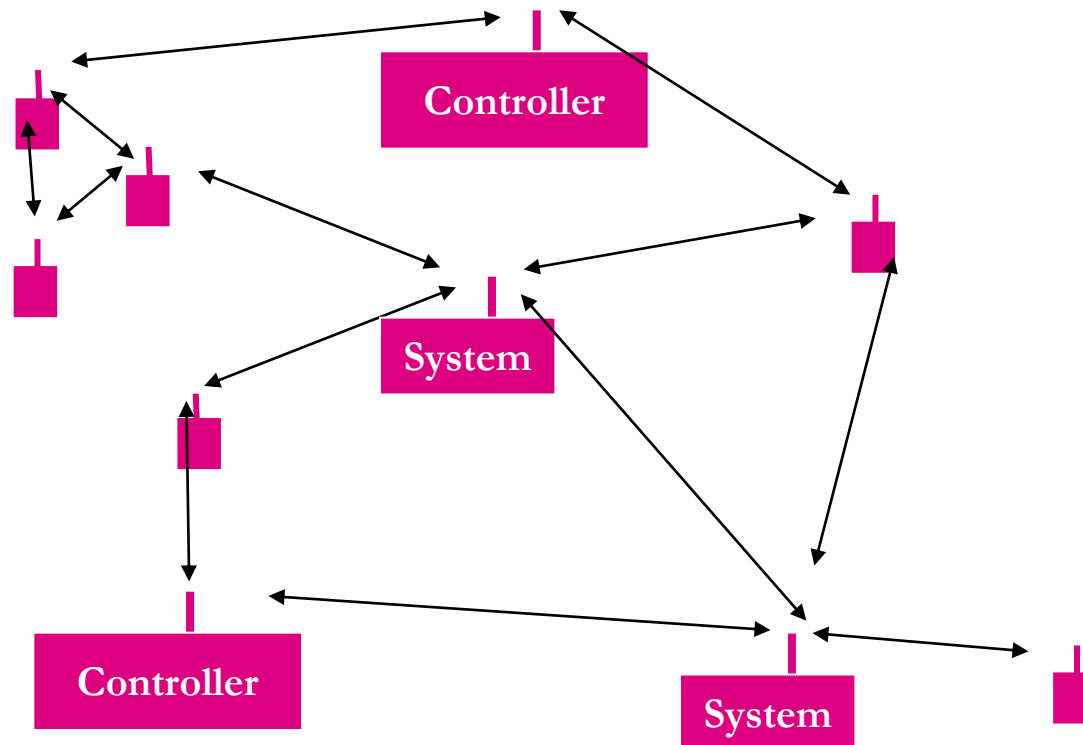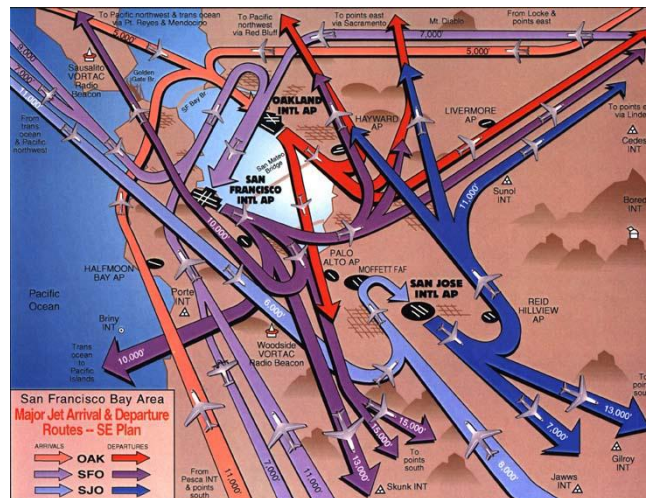
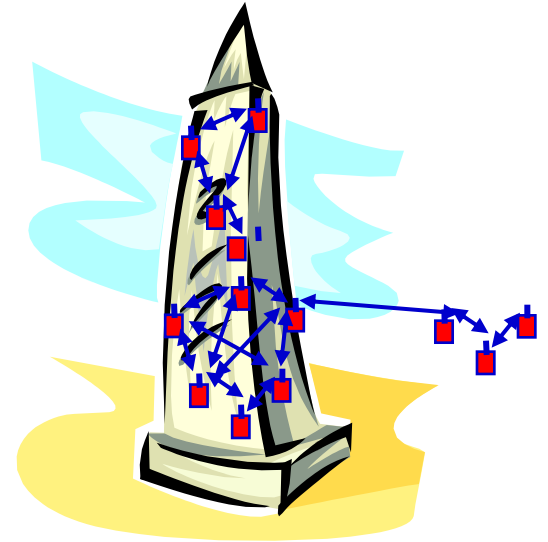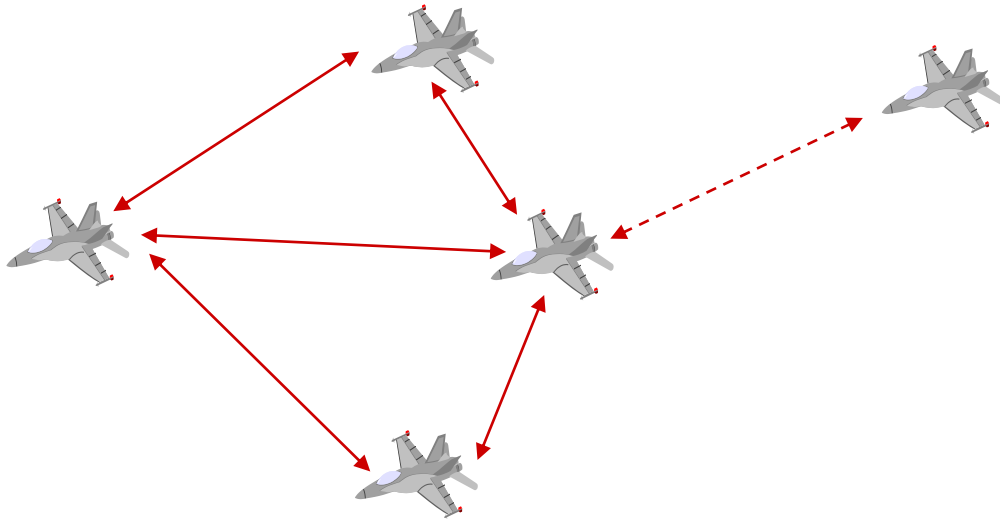# Digital vs. Analog
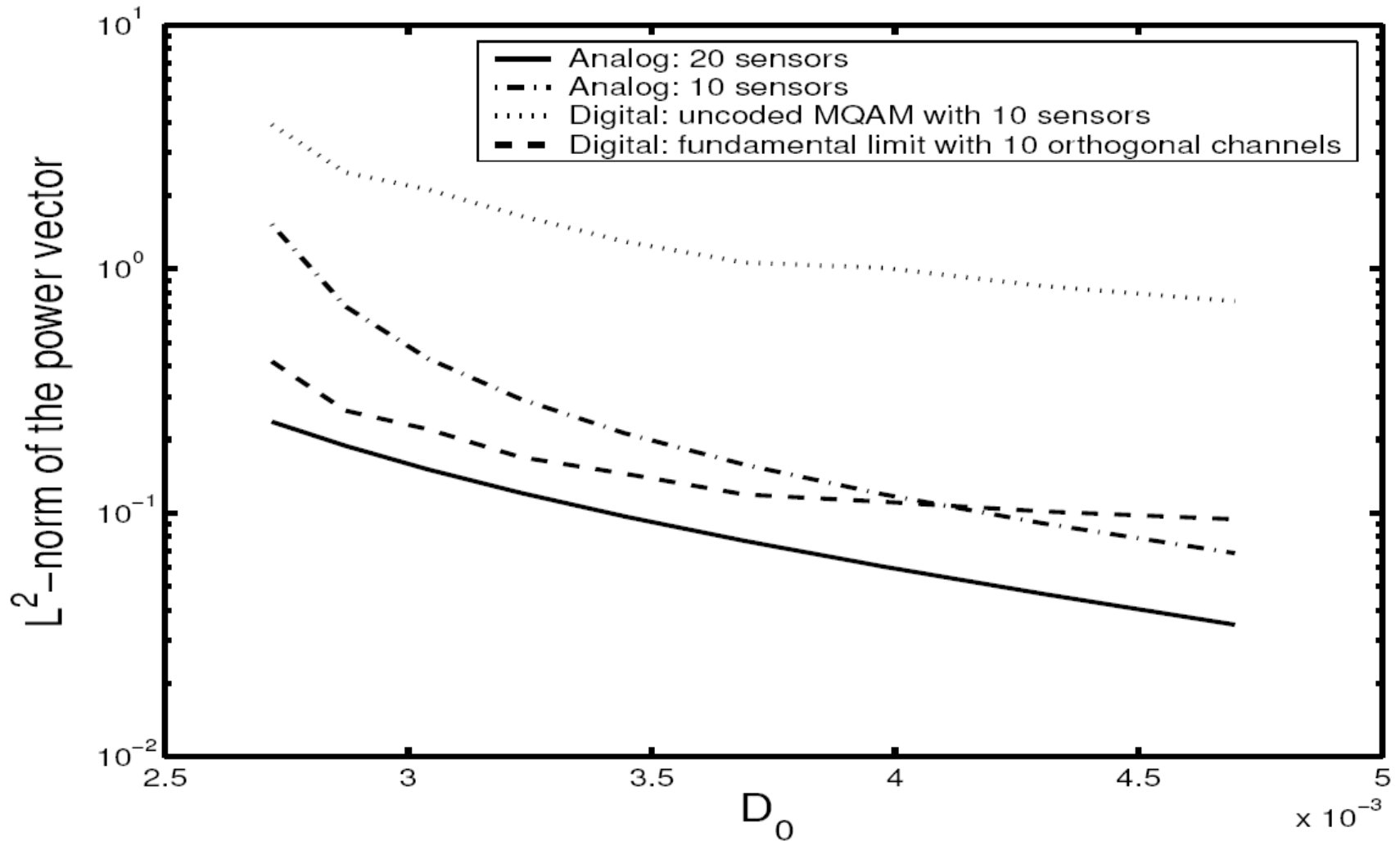
Key Message

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
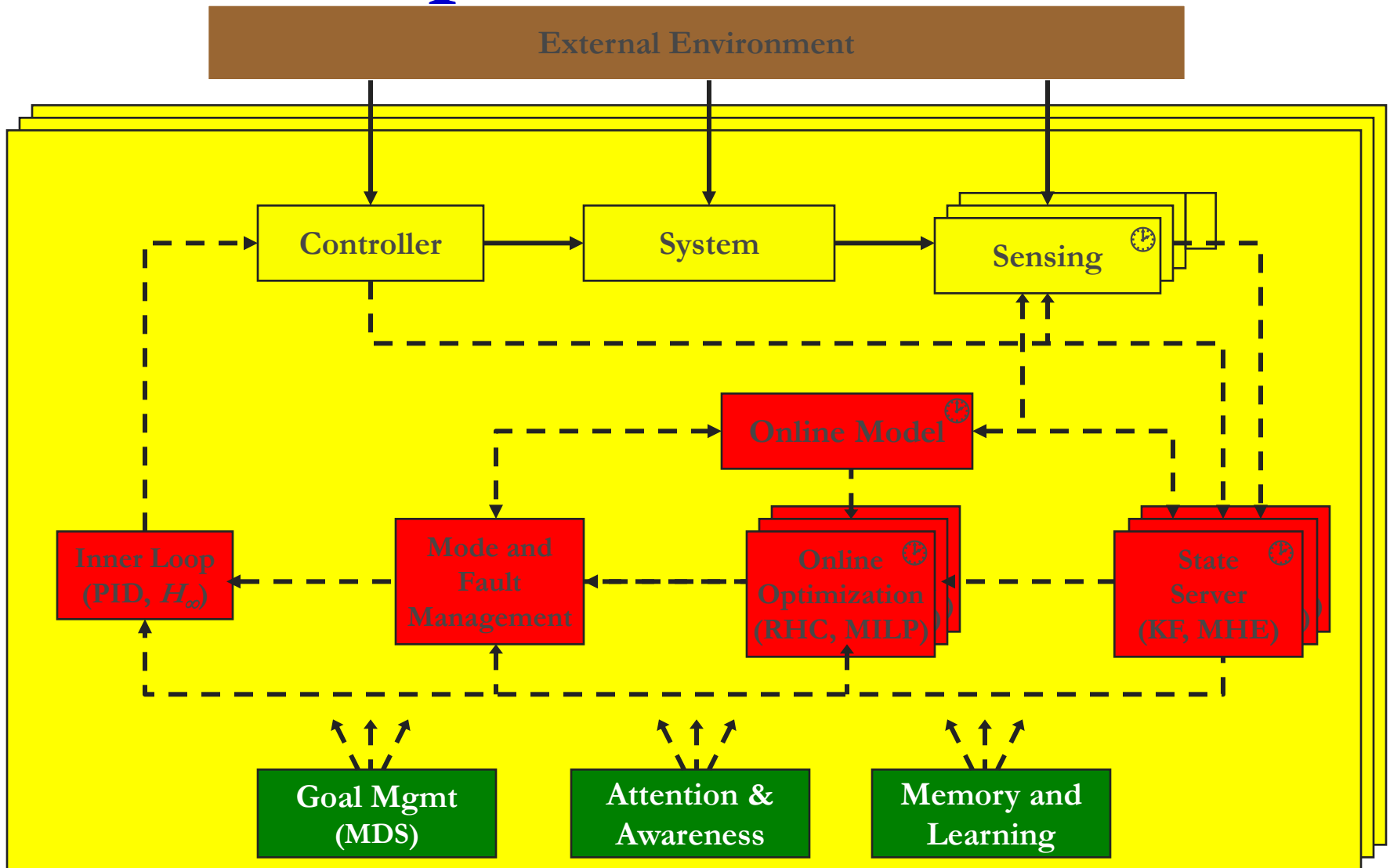
Potential Pieces of the Puzzle

- **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