Research Directions in Sensor Networks

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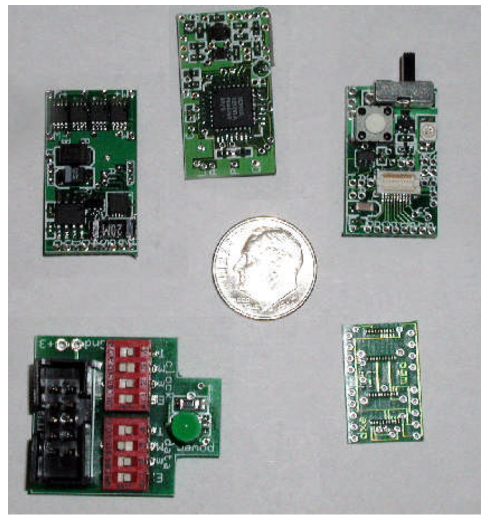
Outline and Problem Categories

- Sensors and Sensor Networks
- Coverage and Sensor Distribution
- Hierarchies and Clustering
- Mobile Sensors
- Sensor Failures and Self-Healing
- Sensor Scheduling
- Routing
- Security and Encryption

Sensors, Sensor Nodes, Mobile Sensors

Crossbow
Mica mote

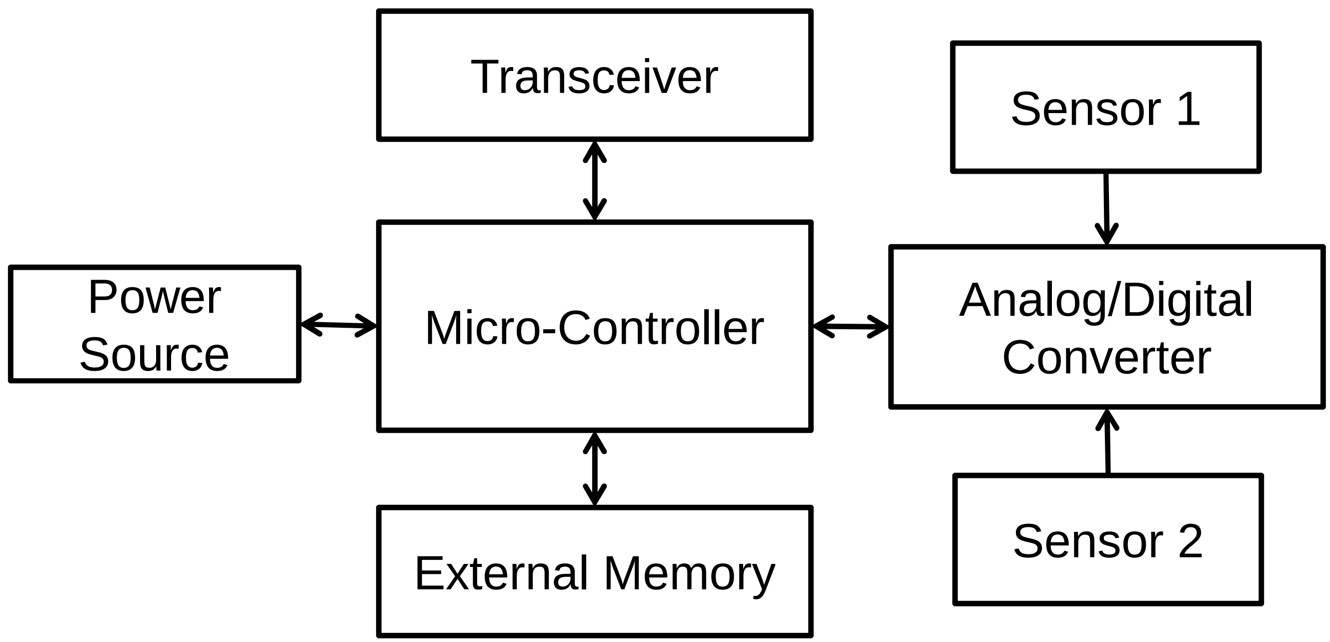
Crossbow
Stargate



NASA – Mobile Platform

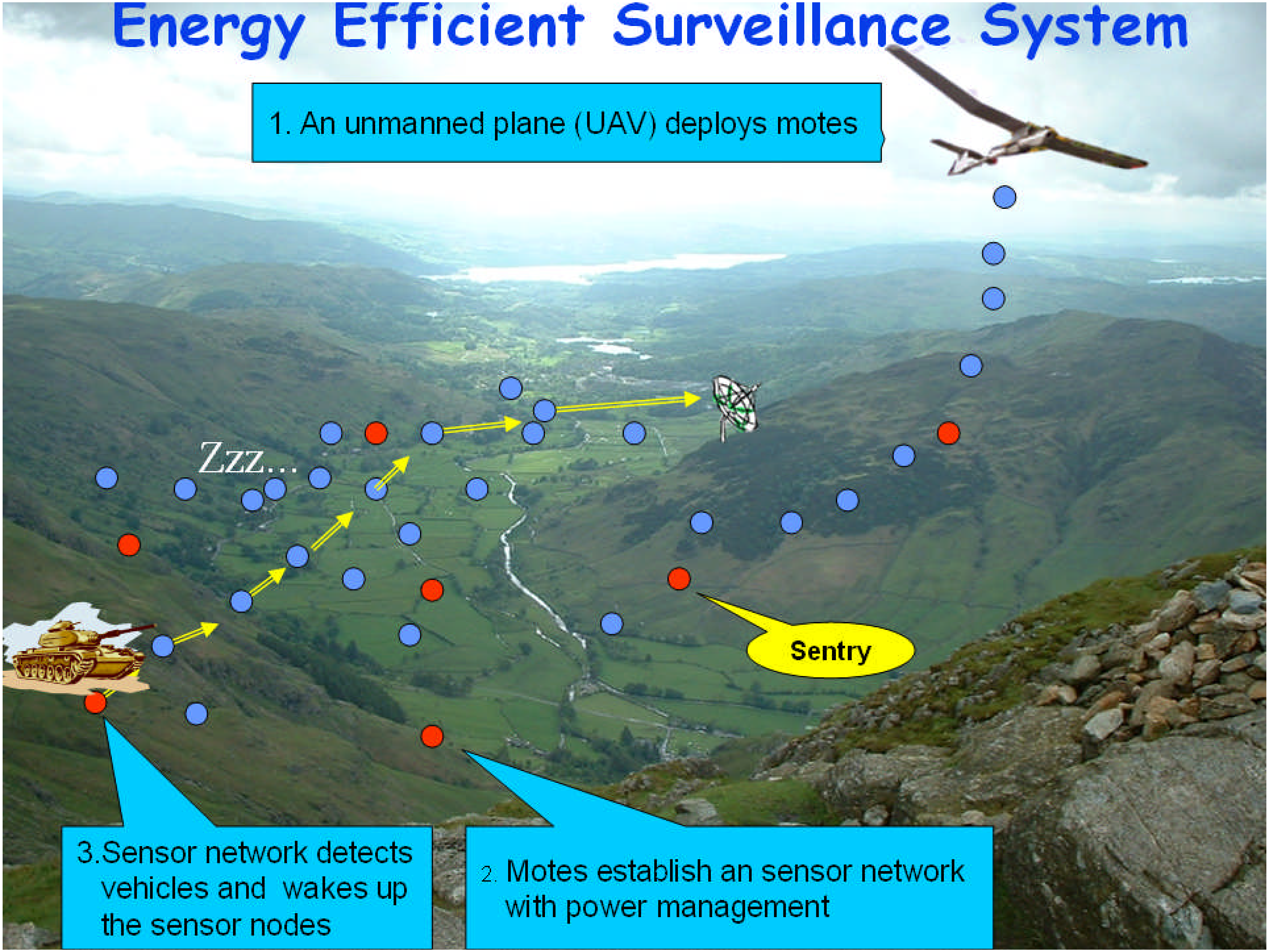
SmartPhone

Sensor Node Architecture

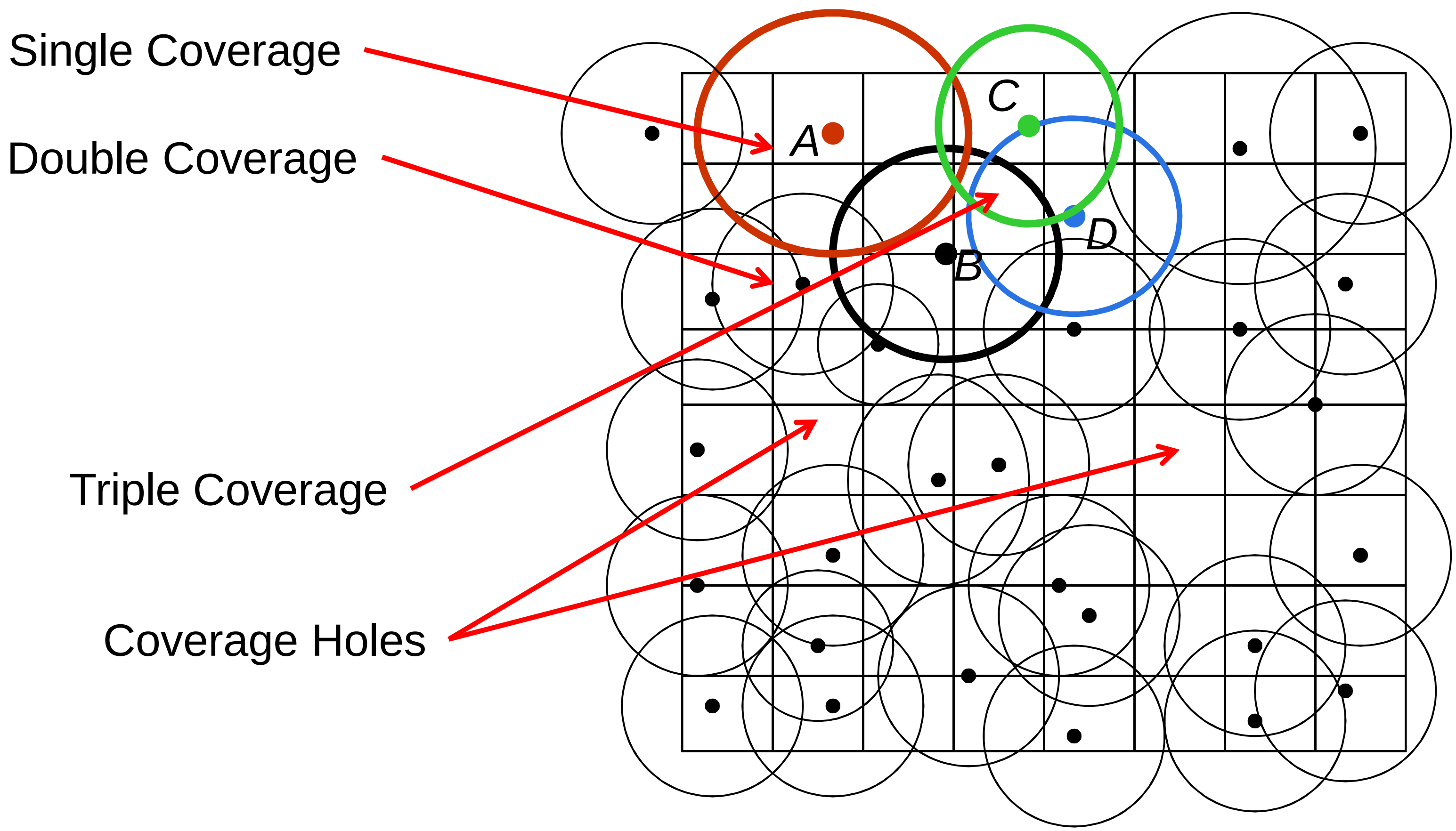


Sensor Node Characteristics

- Small
- Battery power or harvested power
- Limited power → Limited lifetime
- Limited RF communication radius
- Environmental conditions can be harsh
- Low reliability → node failures
- Static in many applications, but can be mobile
- Network topology is can be dynamic as nodes fail or others join
- Homogeneous or heterogeneous networks
- Unattended operation


Energy Efficient Surveillance System
1. An unmanned plane (UAV) deploys motes
Zzz...
Sentry
3.Sensor network detects vehicles and wakes up the sensor nodes
2. Motes establish an sensor network with power management

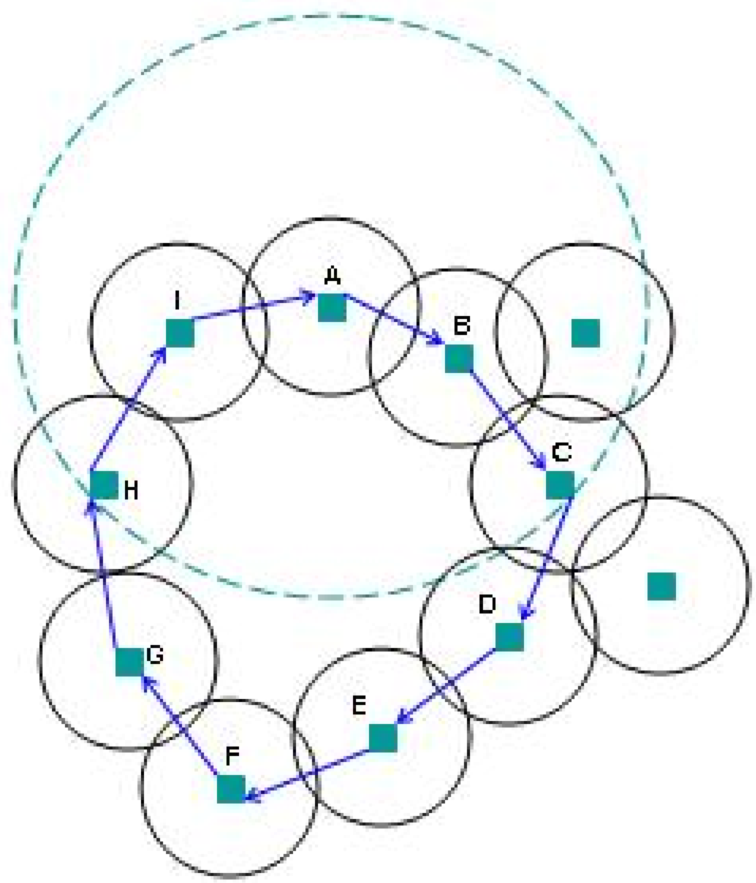
Geographical Coverage and Distribution



Research Problems in Coverage and the Distribution of Sensors

Problem	Solution Approach
Numbers of sensors to achieve a minimum coverage level	statistical analysis
Self-location	Protocols and calculations using signal strength, reference nodes,and triangulation

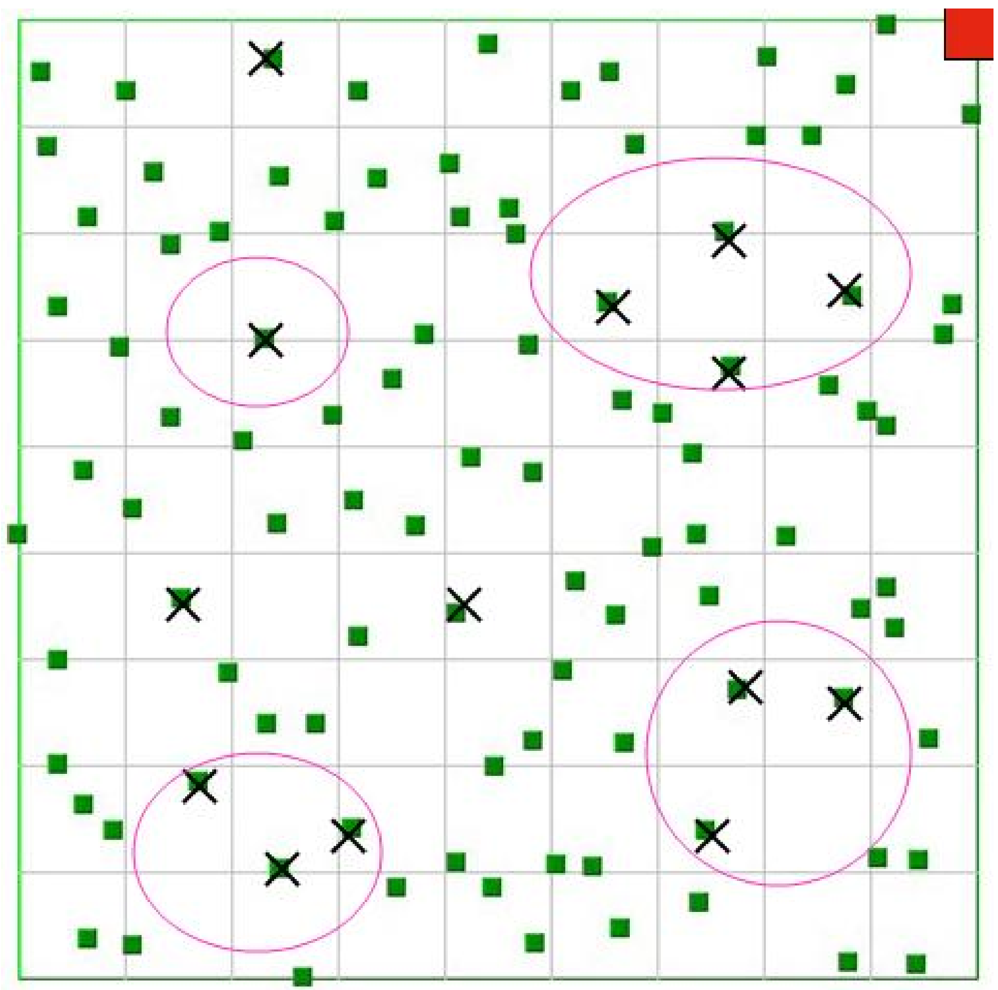
Research Problem: Coverage Hole Discovery and Boundary Calculations



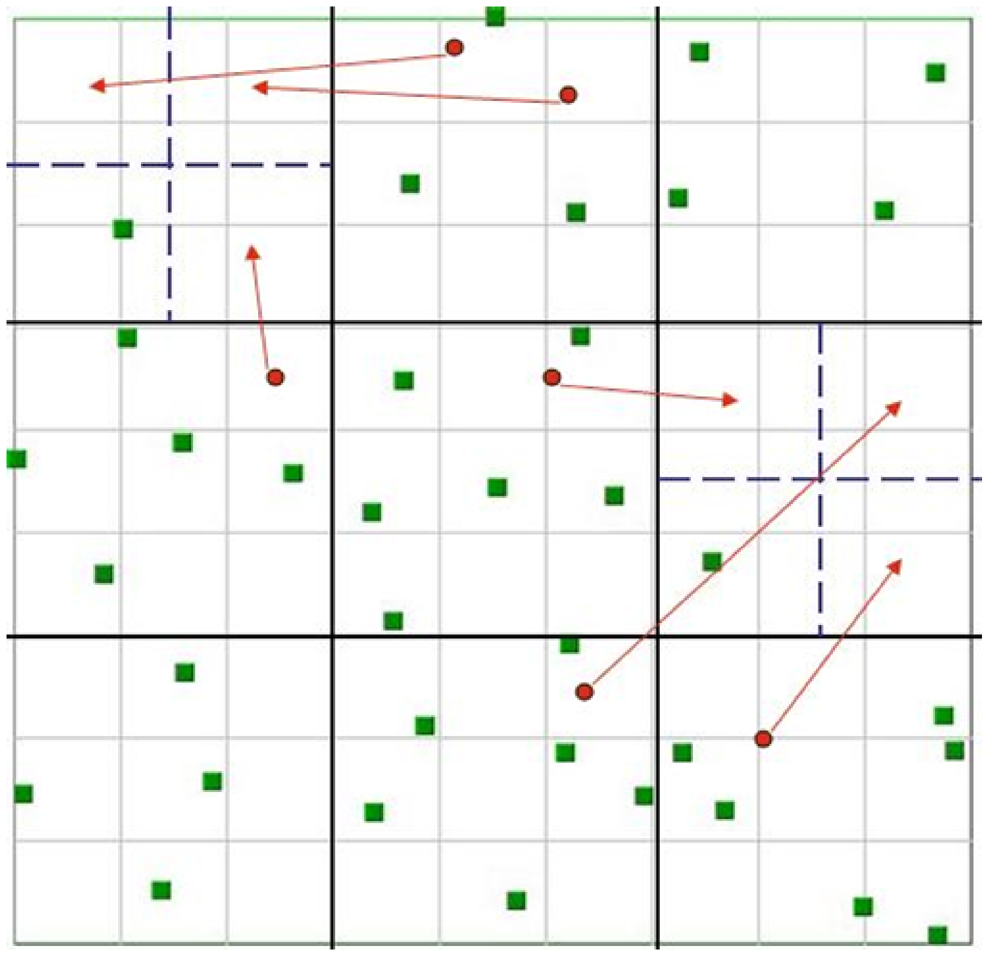
Research Problems using Mobile Sensors

Problem	Goal of Algorithmic Approaches to Direct Movements
Cover holes in sensing coverage.	Cover Holes
Improve network connectivity and topology	Reduce connectivity gaps and increase redundant communication paths
Dynamically respond to new sensing tasks	Establish or increase coverage where needed
Compensate for node failures	Cover gaps caused by the failures
Reconfigure when new nodes are added	Optimize the new topology

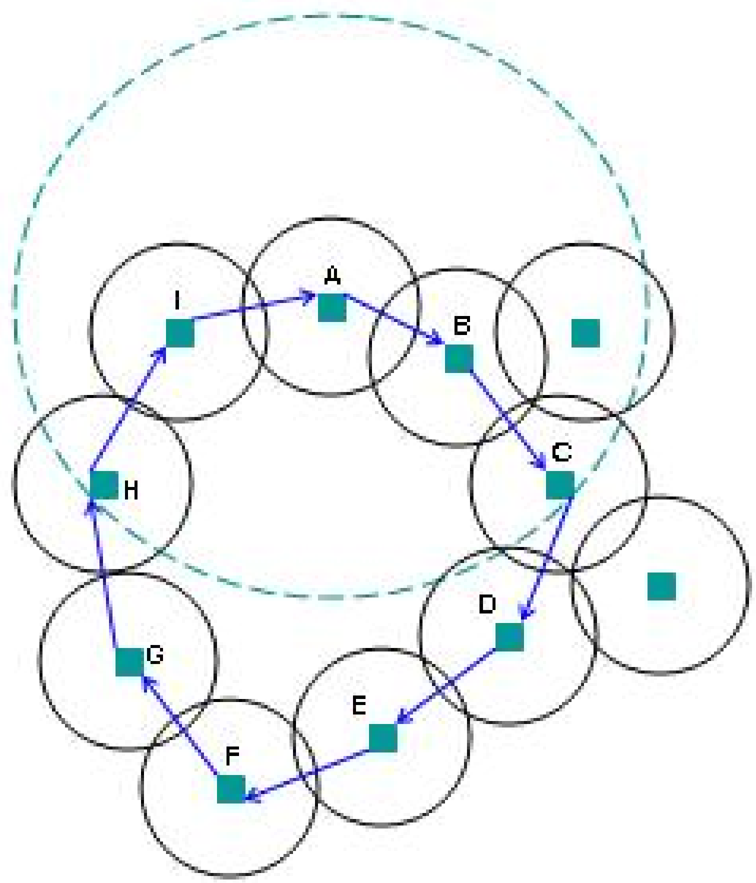
Routing Voids Caused by Sensor Failures



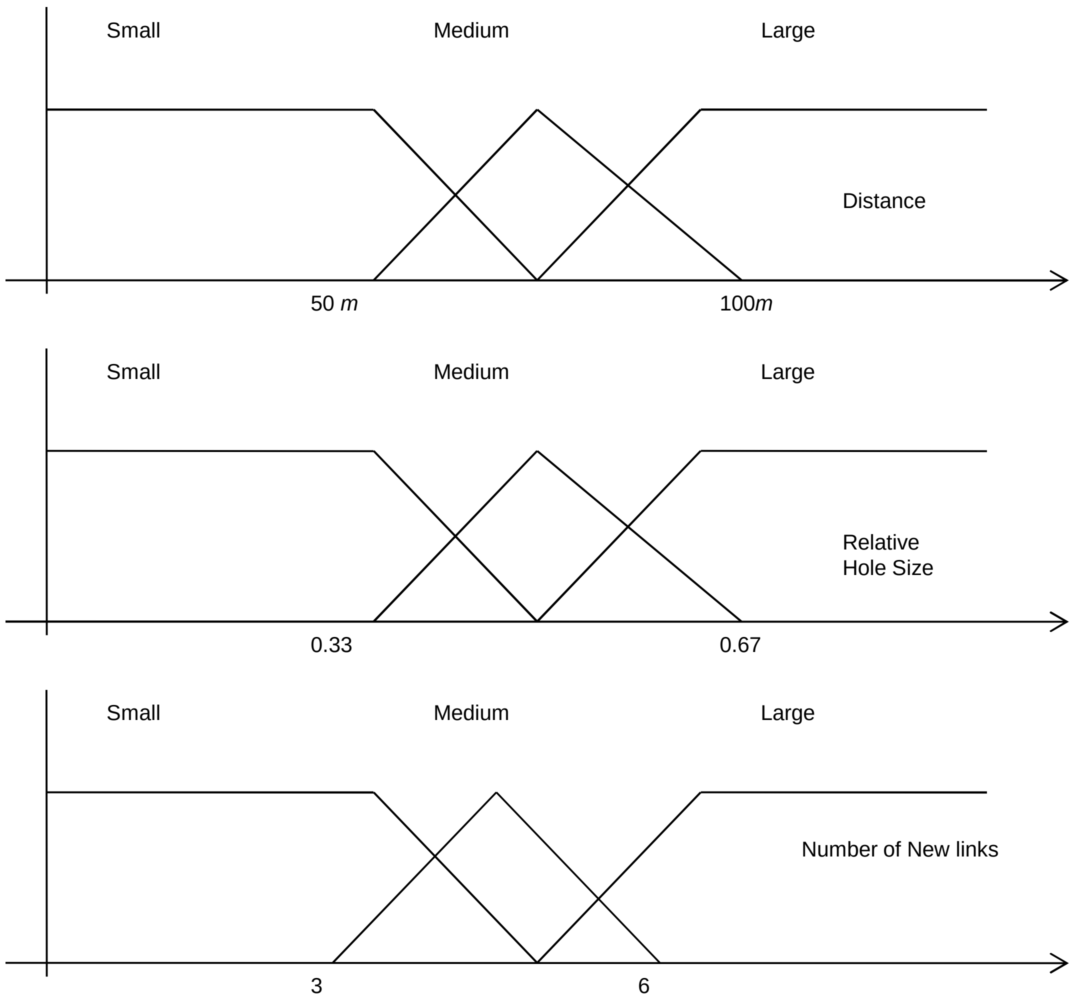
Mobile Sensors Move to Improve Coverage



Research Problem: How to Direct Mobile Sensors to Move and cover the holes?



Fuzzy Logic Functions to Drive Mobile Sensor Movement



De-Fuzzification Movement Rules

Distance	Size	Number of New Connections	Decision
L	-	-	**N**
M	M/S	S	**N**
M	M/S	L	**Y-**
M	L	L	**Y**
S	L	S	**Y+**
S	M	S	**Y**
S	S	S	**N**
S	L	M	**Y+**
S	M	M	**Y+**
S	S	M	**Y**
S	L/M	L	**Y**
S	S	L	**Y-**

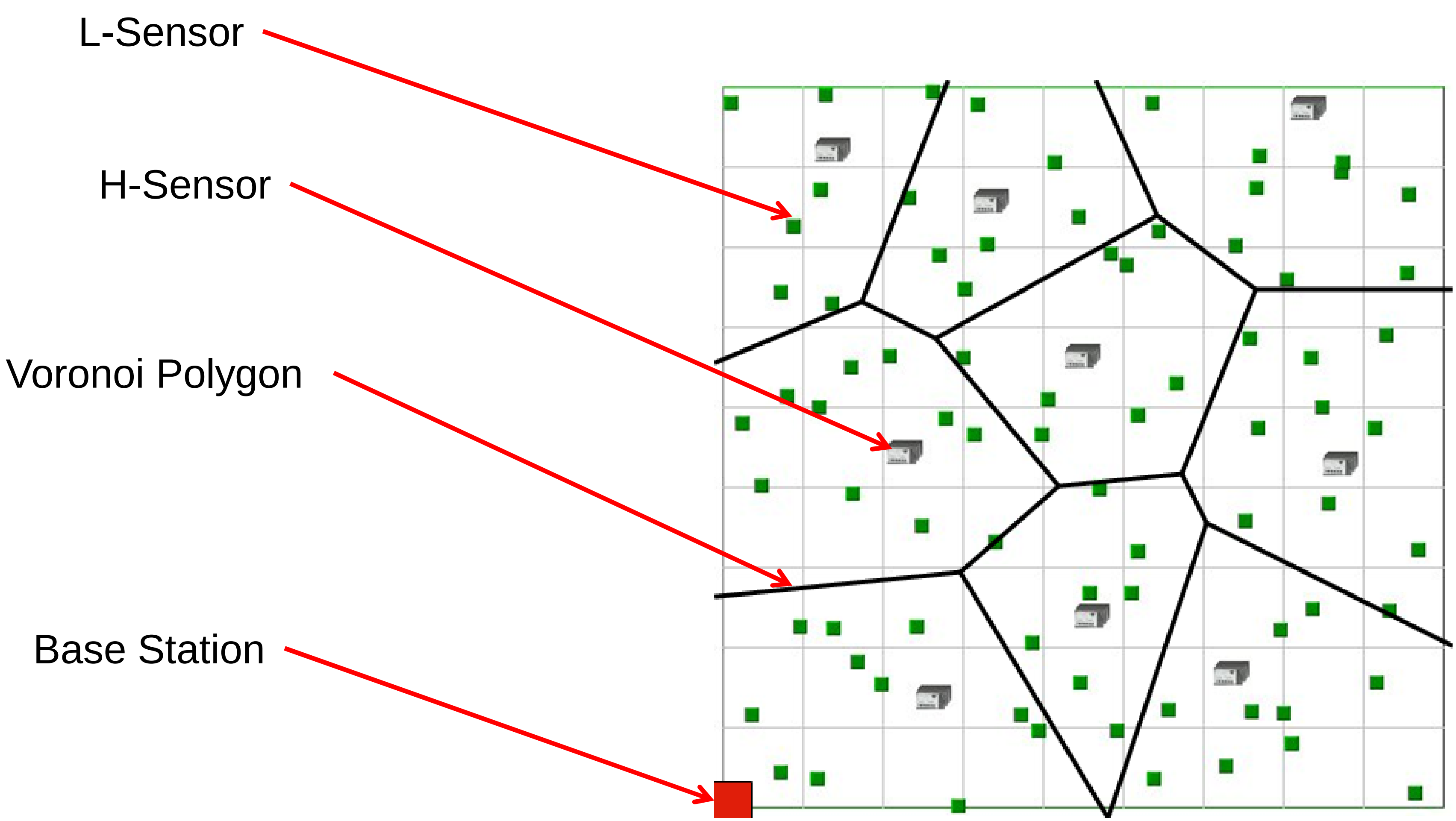
High and Low Level Sensors

- High-level sensors (like Stargate) have better capabilities than Low-level sensors (like Mica) in terms of communications, computation, memory/storage, energy supply, and reliability.
- Call them H-sensors and L-sensors respectively

Research Problems regarding Architectures with Low and High Level Sensors (Hierarchies)

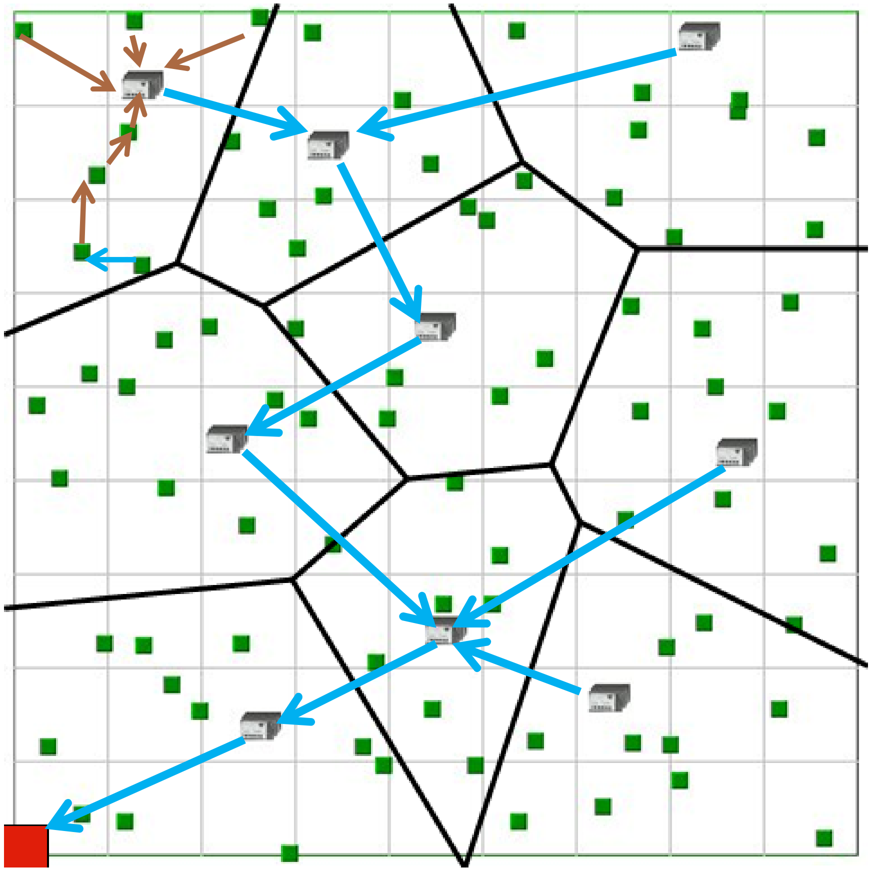
Problem	Goal of Algorithmic Approaches to Utilize the H-Sensors
Design 2-level topology to support energy-efficiency and high data rates to a base station	Cluster the L-sensors around each H-sensor which serve as relay heads, and establish intra and inter cluster routing
Manage H-sensors to support privacy, authenticity, and integrity	Establish secure routing protocols at the 2 levels
Coordinate sensing tasks over time and track mobile objects.	Build secure and efficient time synchronization schemes
Build intelligence into the sensor network	Build Neyman-Pearson and/or Bayesain Models
Build self-healing into the sensor network	Reconfigure routing tables when sensors fail

Hierarchies and Clustering



Intra and Inter Cluster Routing

- Shortest path trees intra and Inter cluster
- L-sensors can have small transmission radius
- Backbone H-sensors have longer transmission range and higher bandwidth
- H-sensors can carry out data fusion and other intelligent operations



Tabu Search to Improve Clusters

Step 1: Create Voroni clusters as an initial solution solution i. Set i* = i and k=0.

Step 2: Set k=k+1 and generate candidate neighborhood clusters by carrying out non-Tabu boundary node exchanges between clusters.

Step 3: Generate candidate neighborhood clusters by carrying out non-Tabu cyclic transfers among clusters.

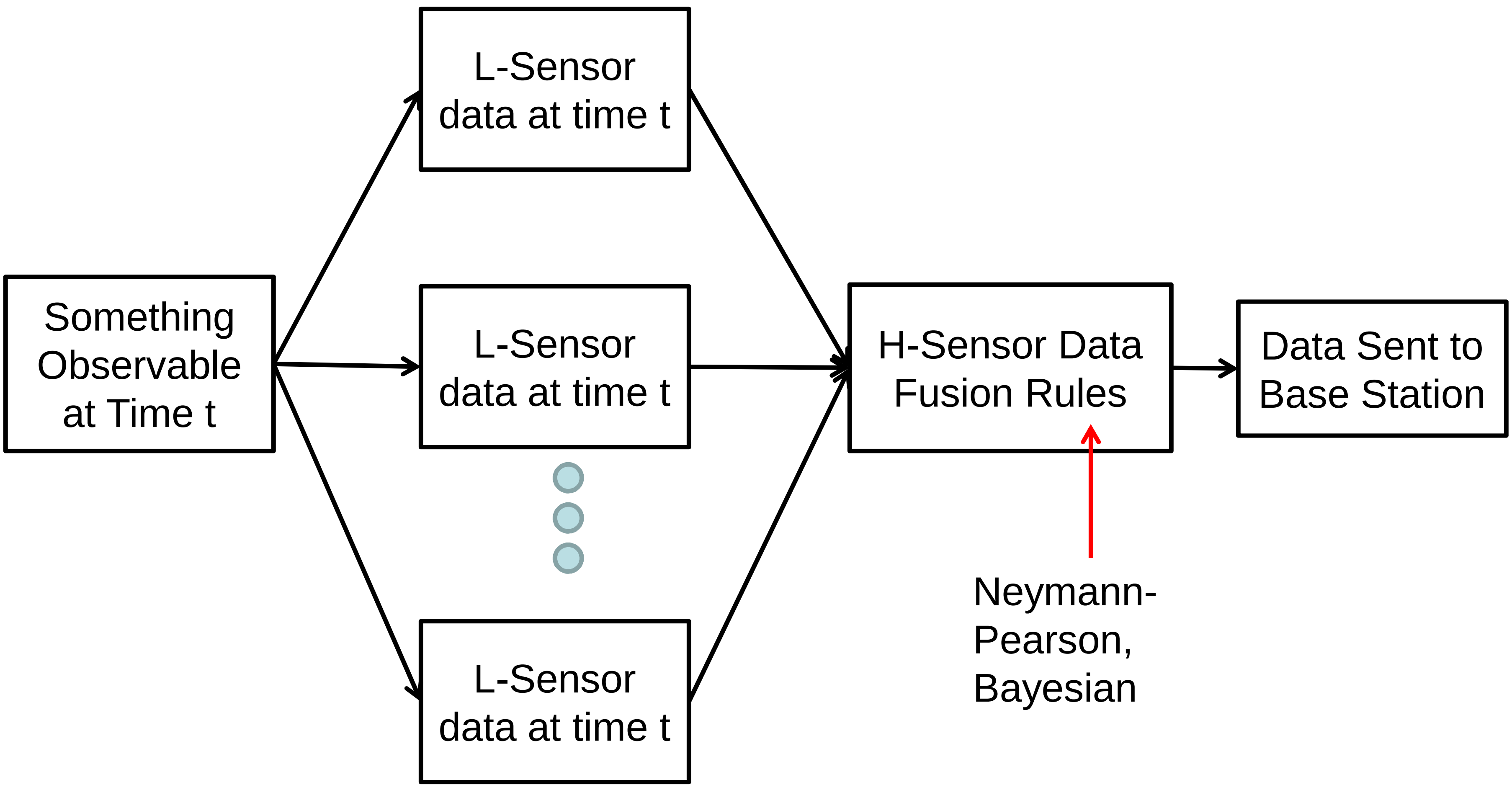
Step 4: Choose the best cluster set i from Steps 2 and 3 in terms of a routing metric (distance or hop count)

Step 5: Compare metrics. If $f(i) < f(i^*)$ then set i* = i.

Step 6: Update the Tabu list.

Step 7: If a stopping condition is met then stop. Else go to Step 2.

Data Fusion at an H-Sensor Relay Node

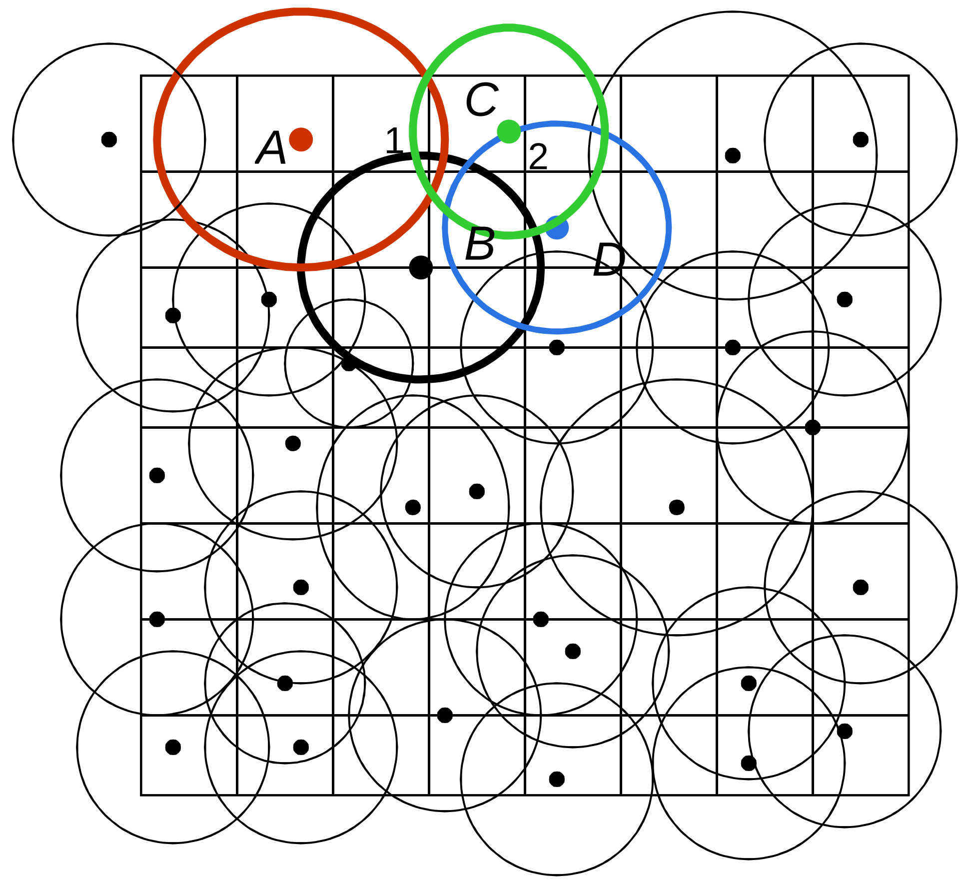


Research Problems in Scheduling Differentiated Sensors

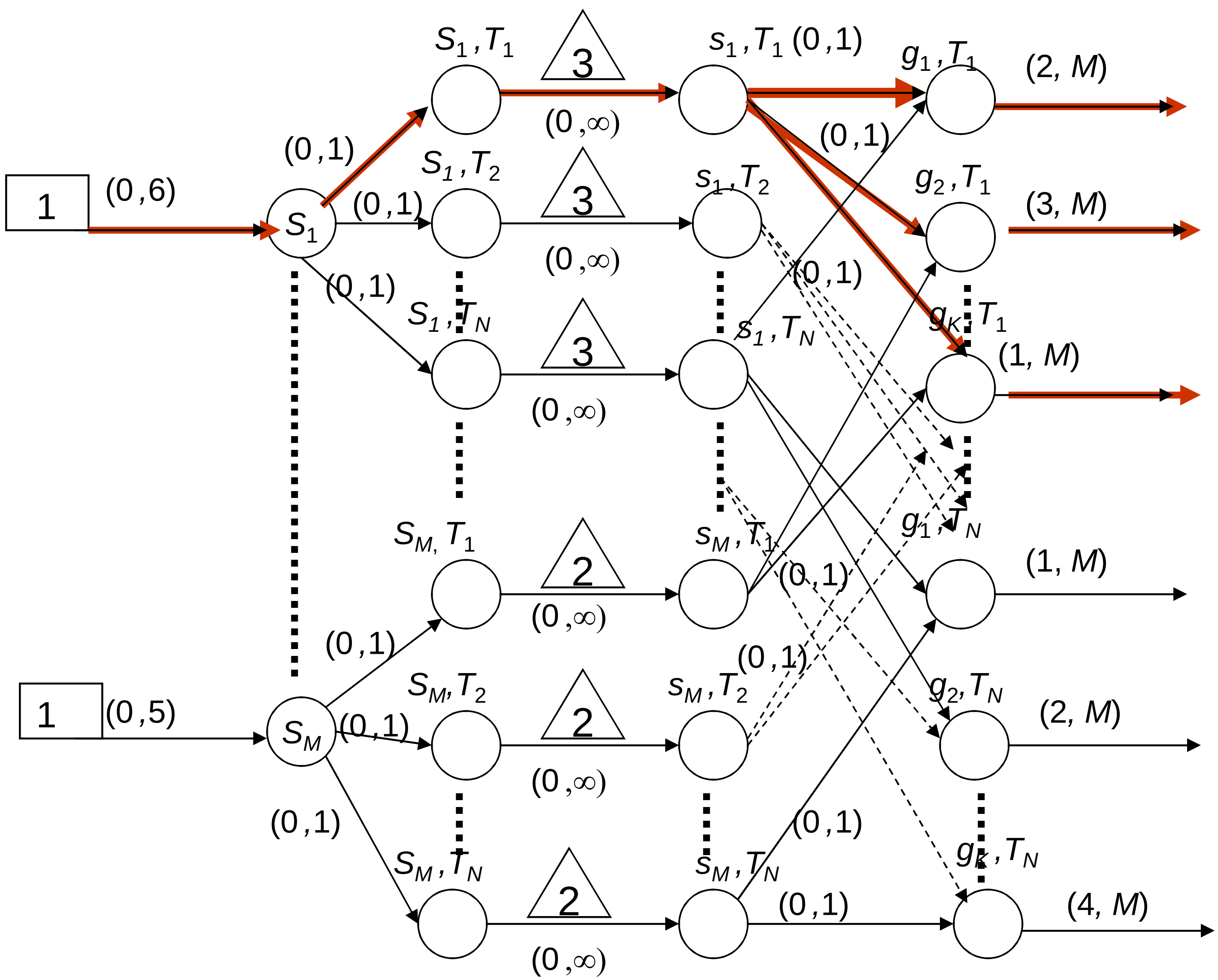
Problem	Goal of Algorithmic Approaches
Extend useful sensor lifetime	Build on/off times for all sensors while maintaining a threshold percentage of coverage
Self-heal sensor schedule when sensors fail	Rebuild on/off times for all sensors while maintaining a threshold percentage of coverage

Scheduling Problem Approach

- Superimpose a grid
- Calculate grid cells covered by each sensor
- Discretize time periods
- Configure supply/demand network



Generalized Network Flow Model For Sensor Scheduling



Generalized Network Flow Model

x_{ij} = amount of flow on arc (i, j)

μ_{ij} = multiplier of arc (i, j)

b_i = demand at node i

c_{ij} = cost of unit flow on arc (i, j)

u_{ij} = upper bound on flow on arc (i, j)

l_{ij} = lower bound on flow on arc (i, j)

$$Min\ \sum_{i,j} c_{ij}\, x_{ij}$$

Subject to:

$$\sum_i \mu_{ij} x_{ij} - \sum_j x_{ji} = b_i \qquad \forall\ node\ i$$

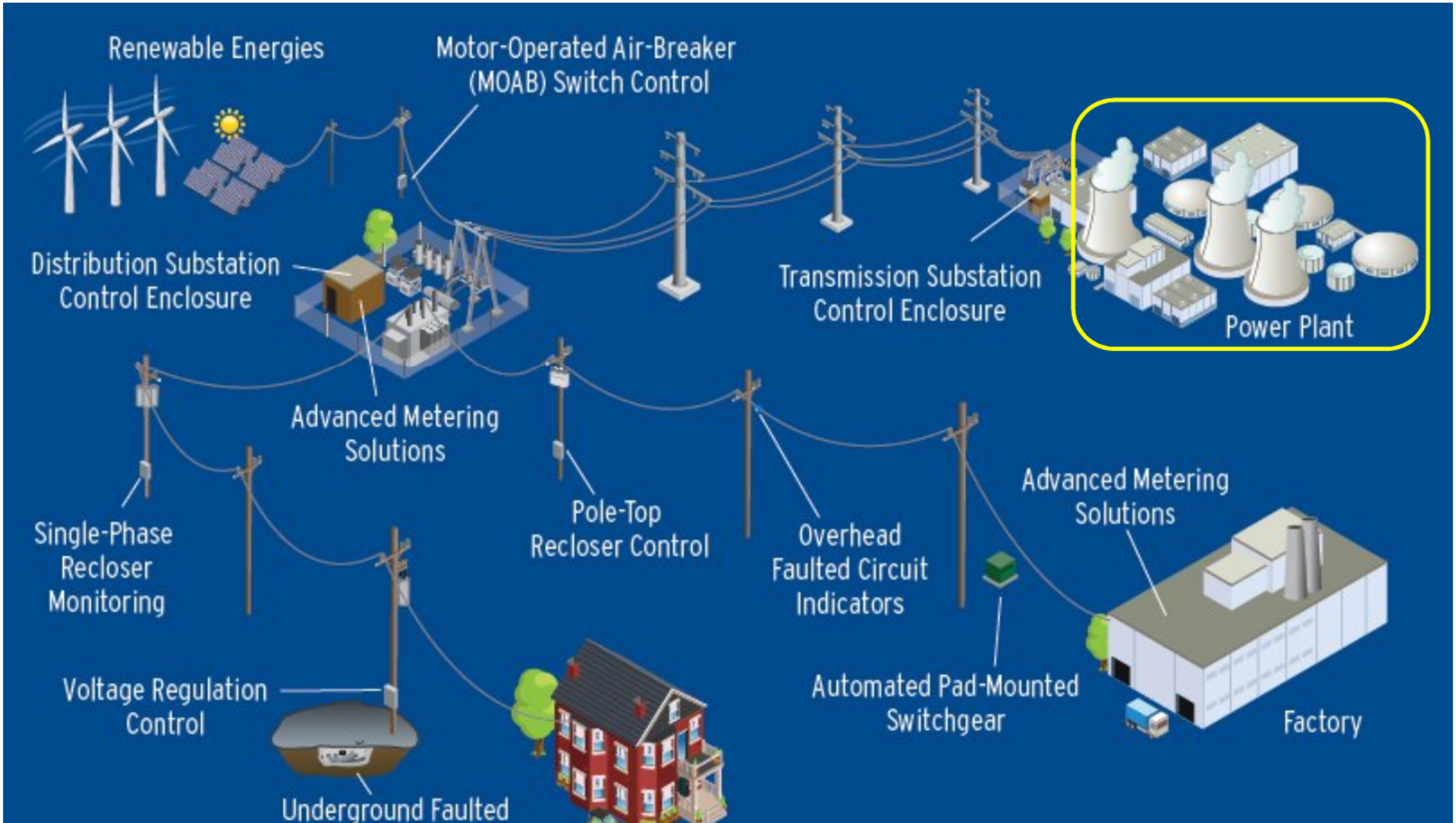
$$l_{ij} \le x_{ij} \le \le u_{ij} \qquad \forall\ arc\ (i, j)$$

Security and Key Management in Heterogeneous Sensor Networks

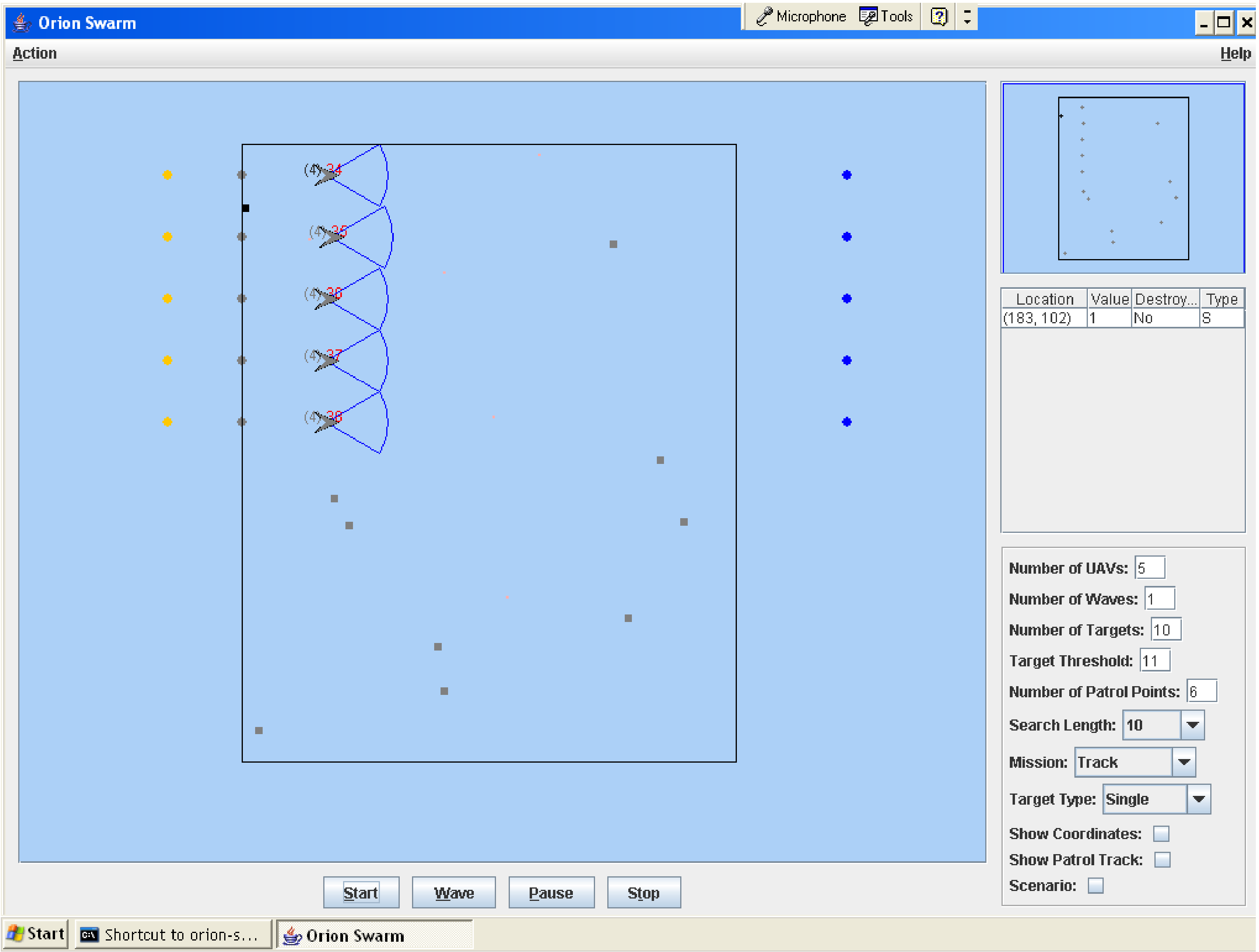
Problem	Goal of Algorithmic Approaches
Reduce communication overhead, computation overhead, and storage requirements for security protocols, while supporting scalability.	Build a management framework using Rabin’s cryptosystem for encryption keys the supports confidentiality, authenticity, and availability and allows H-sensors to establish key space information to L-sensors

Miscellaneous Projects

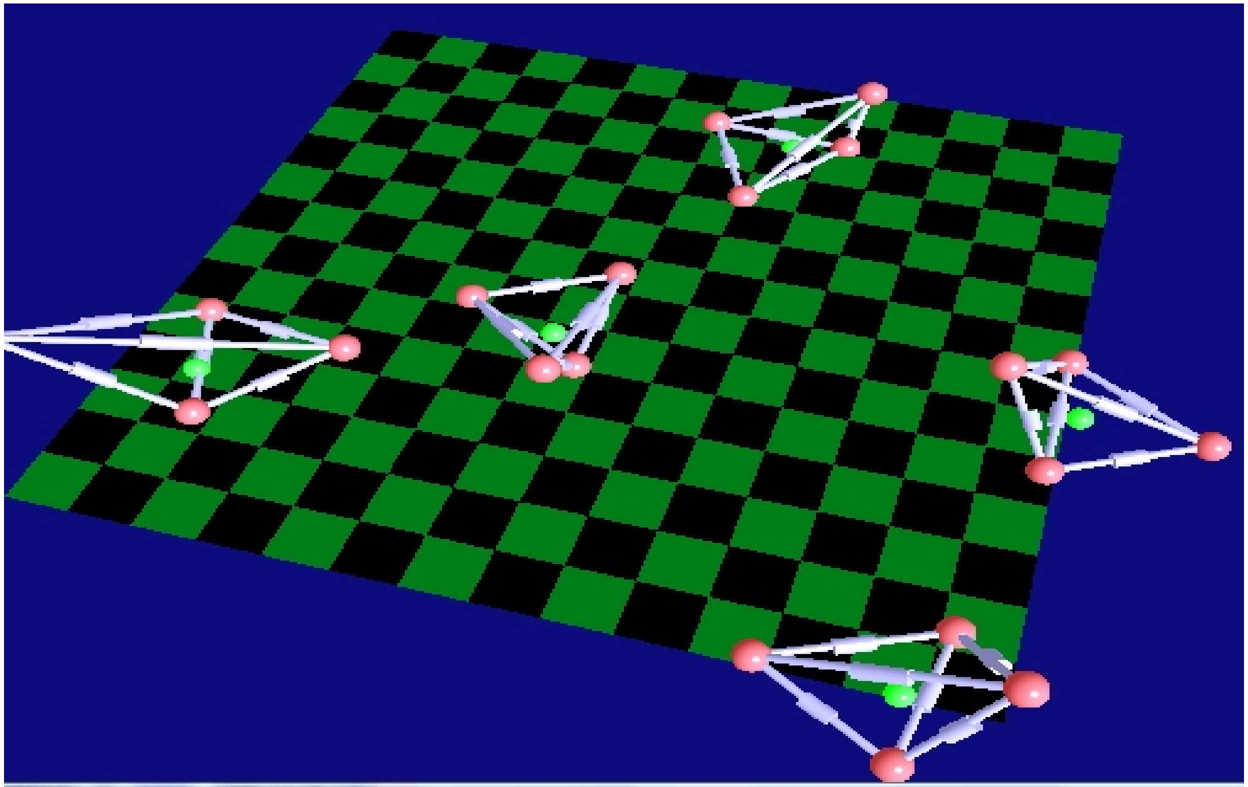
Instrumentation/Sensors in the Smart Grid



Cooperating Unmanned Air Vehicles

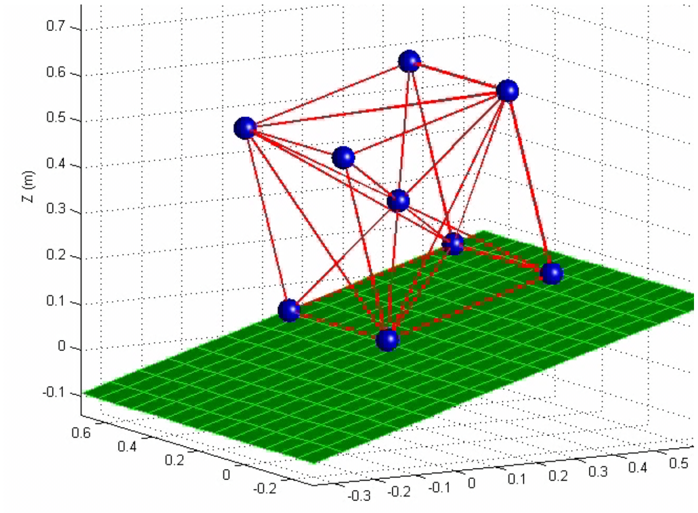


TETWALKERS



Cooperative Control
- Mission goals negotiated
- Waypoints determined
- Rough path planning
- Rough obstacle avoidance

Autonomous Control
- Path planning
- Obstacle avoidance
- Step and gait choices
- Collision avoidance



Wrap-up: Interesting Research Problems Abound in….

- Coverage and Sensor Distribution
- Hierarchies and Clustering
- Mobile Sensors
- Sensor Failures and Self-Healing
- Sensor Scheduling
- Routing
- Security and Encryption