Controlled Mobility in Sensor Networks

http://nsrc.cse.psu.edu/

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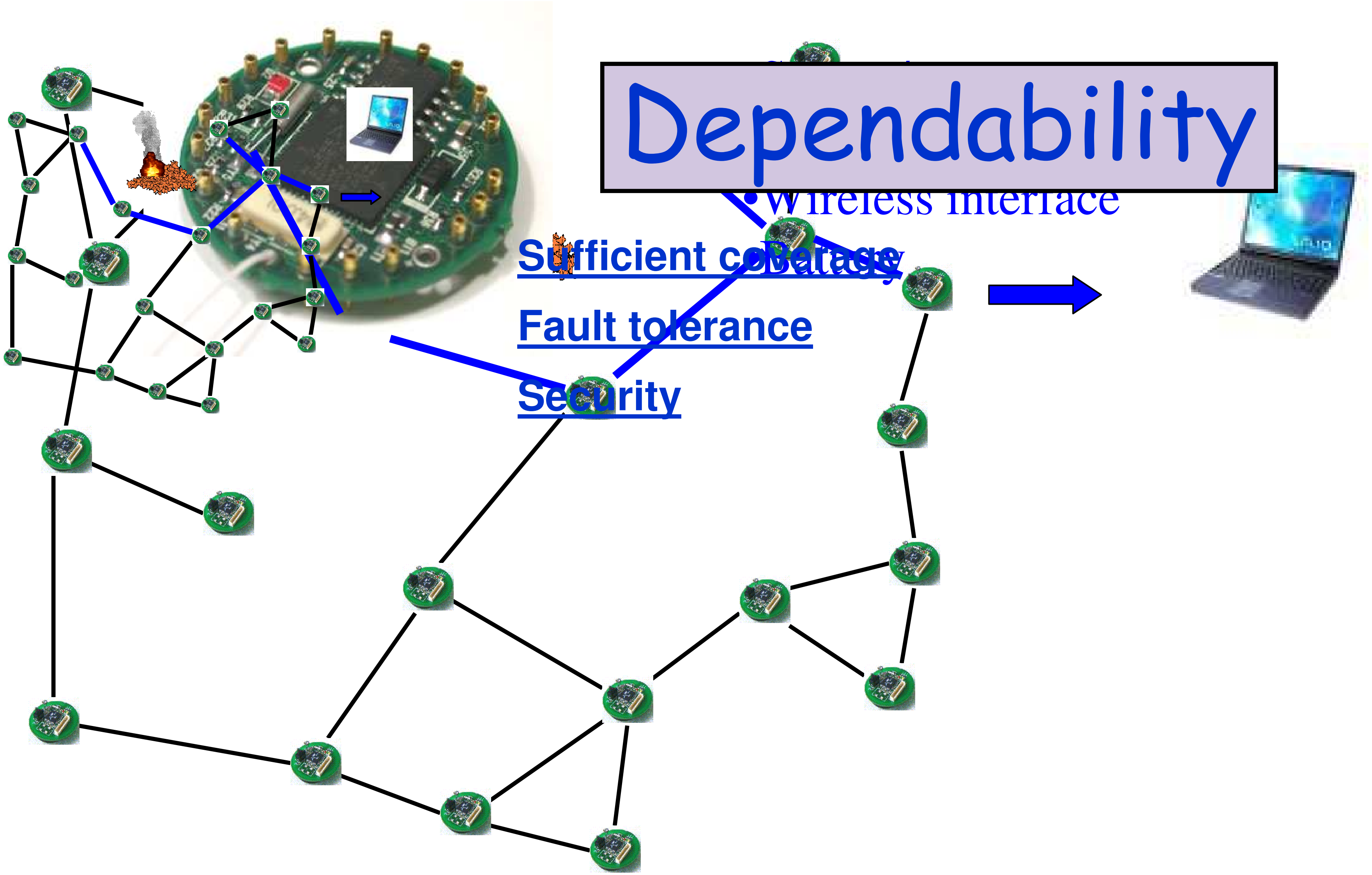
– Coverage

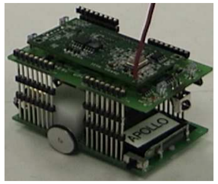
– Reliability

– Future work

Wireless Sensor Networks



Mobile Sensors



Size: 7 x 4.5 x 3.5 (cm)
By USC

Size: 13 x 6.5 (cm) base
By UC Berkely

Size: 2.7 x 2.1 x 4 (cm)
By NASA

Controllable Mobile Sensors

- Power consumption:

  Movement >> Communication
- Communication:
  - Range: 10ft~100ft
  - Bandwidth: 40kpbs
- Sensing range < Comm range/2
- Mobility: 20cm/s
- Cost: $150

Dependable Sensor Networks

Network initialization:

Sensor Deployment for Sufficient Coverage

All sensors are mobile

INFOCOM'04
IEEE TMC

A mix of mobile and static sensors

ICNP'03
MASS'04

Motion Planning

ISLPED'05

Network operation:

Maintaining Dependability

Coordinated Detection

MILCOM'03

Sensor Relocation

INFOCOM'05

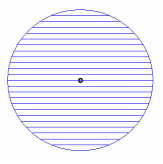
Outline

- Self-deployment protocols for a mix of mobile and static sensors
- Sensor relocation
- Future research plans

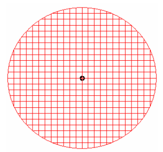
Mobility for Coverage: Problem Statement

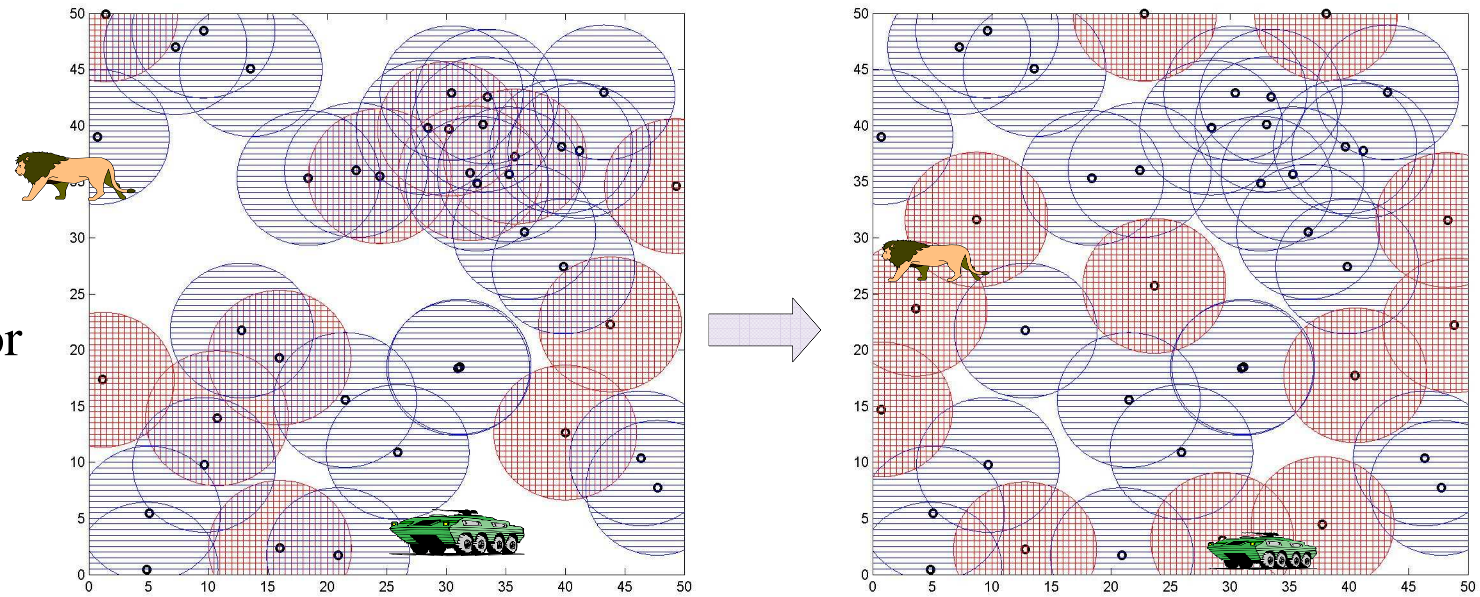
Direct the movement of mobile sensors to increase coverage

Static sensor



Mobile sensor





Our Solution

Greedy heuristic

- Moving sensors to the largest holes

Framework

- Coverage hole detection
  - Voronoi diagram
- Distributed allocation of mobile sensors to the holes
  - Basic bidding protocol
  - Proxy-based bidding protocol

Allocating Mobile Sensors to the Holes

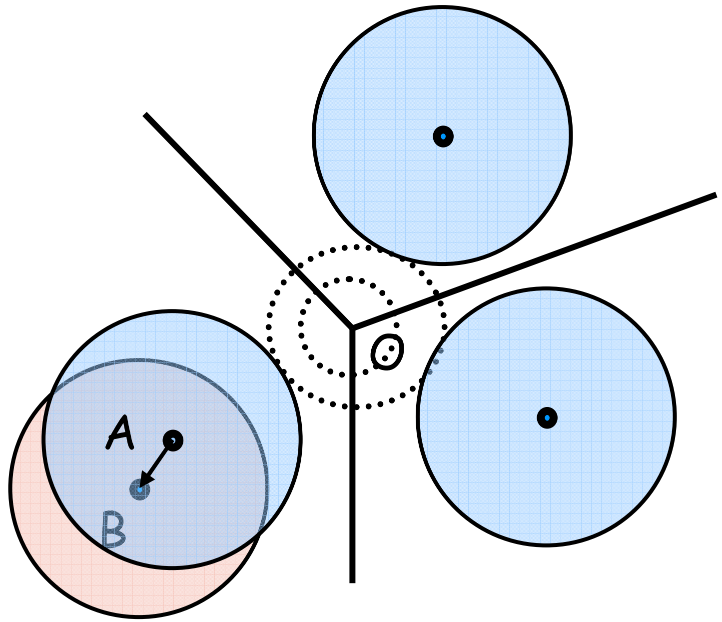
Challenge:

– Mobile sensors do not know where the largest holes are

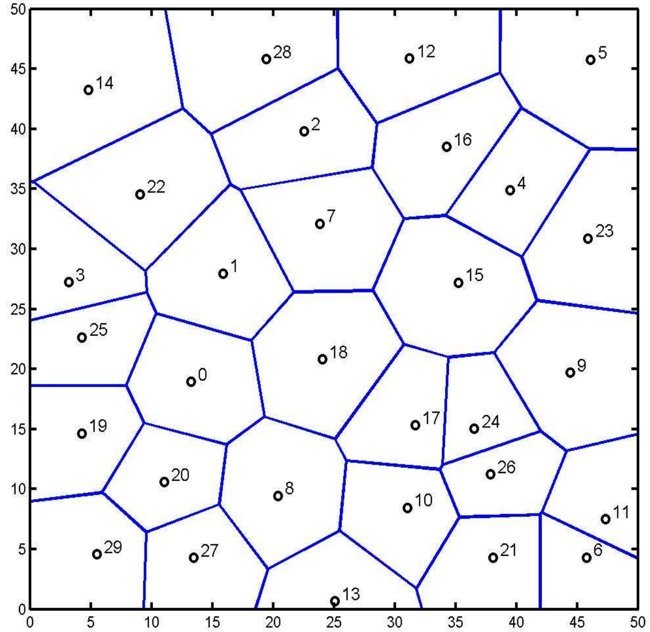
Idea: Bidding

– Mobile sensor: hole-healing server
  - **Base price**: area currently covered

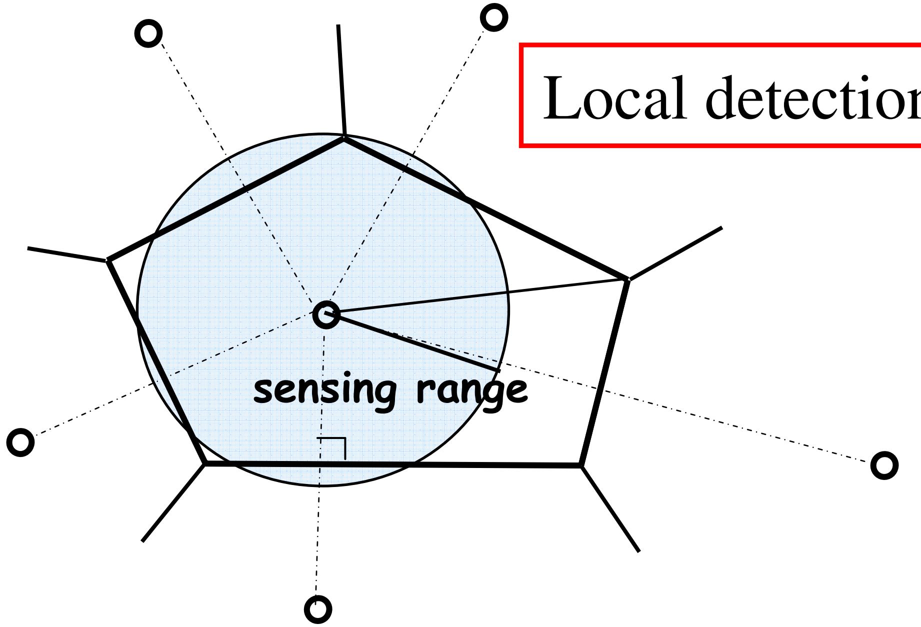
– Static sensor: bidder
  - **Bid**: estimated size of the detected coverage hole
  - **bid > base price**



Coverage Hole Detection

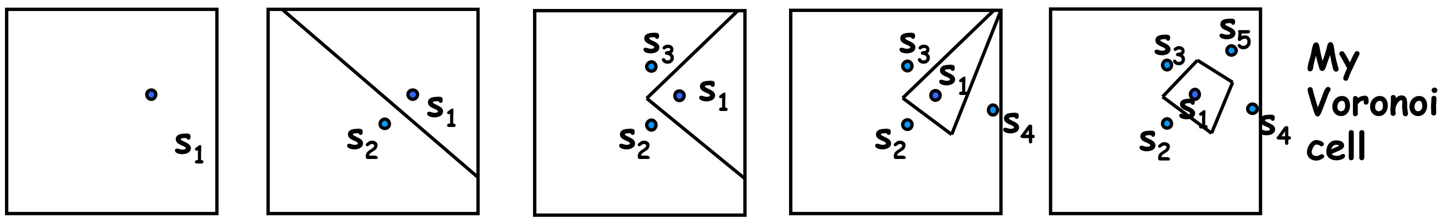


Voronoi diagram



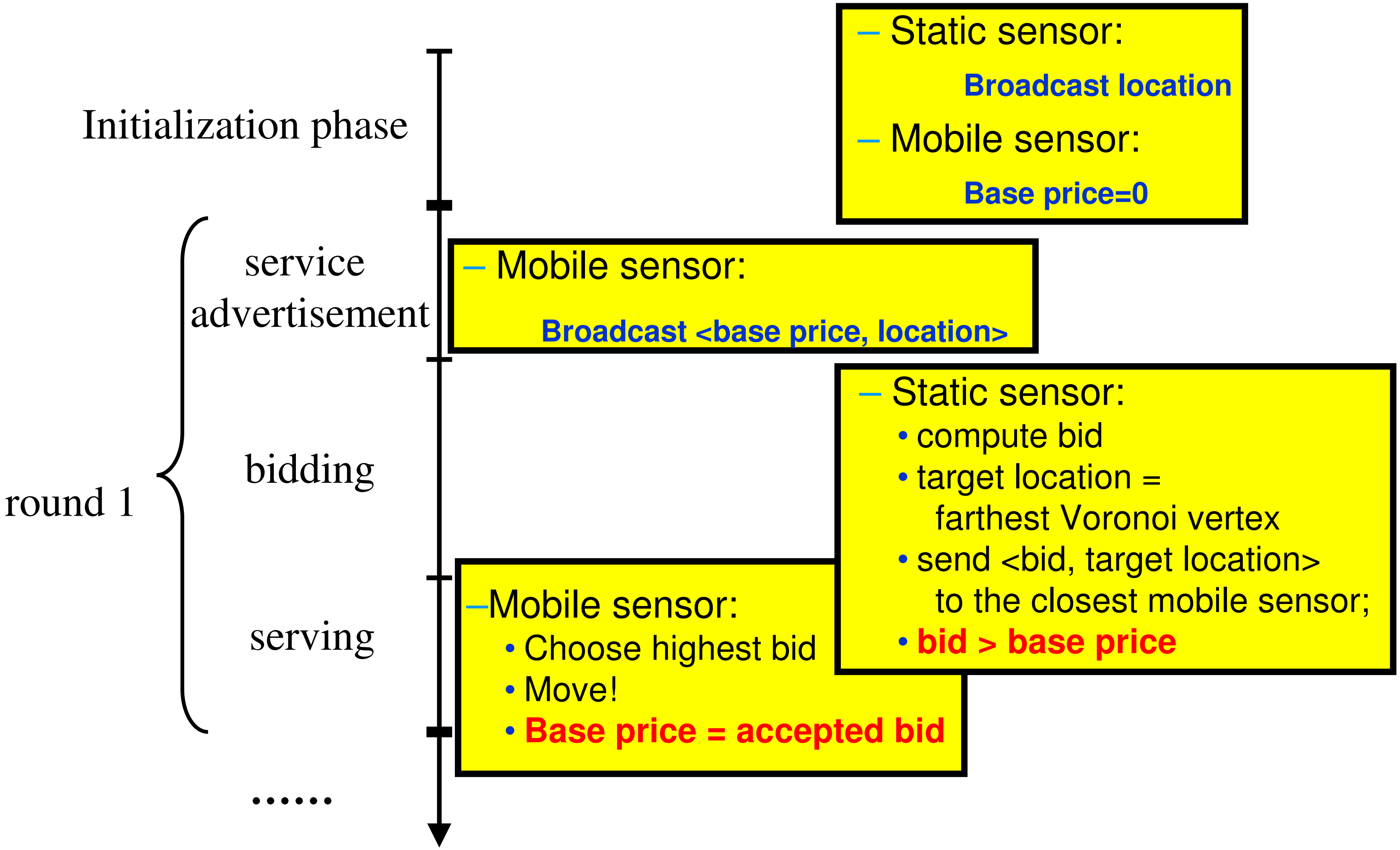
Voronoi cell

Local detection



initially | after hearing s_2 | after hearing s_3 | after hearing s_4 | after hearing s_5

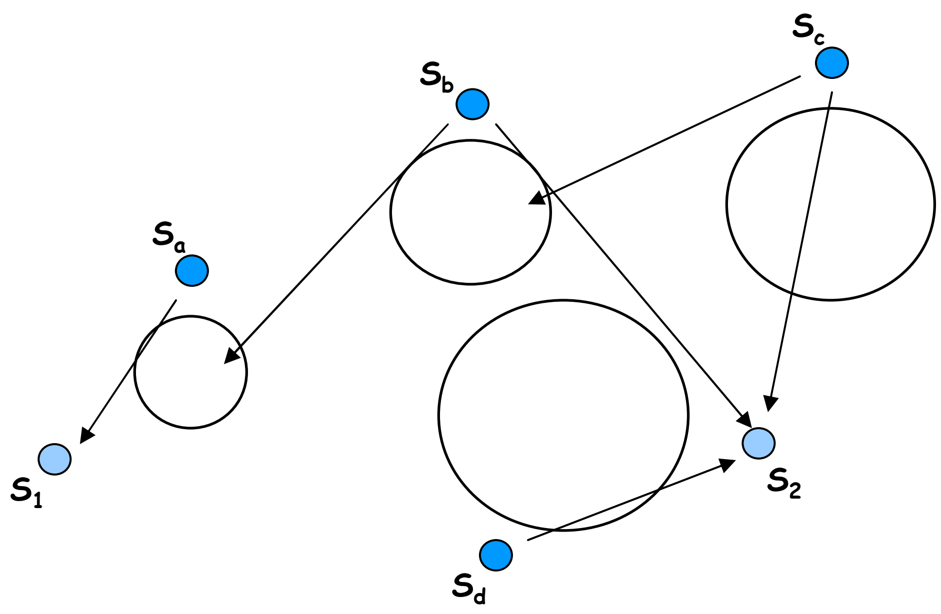
Basic Bidding Protocol



Base price increases monotonically and protocol terminates when no bidder can provide a higher bid than the lowest base price of mobile sensors

A Limitation of Basic Bidding Protocol

Iterative physical movement

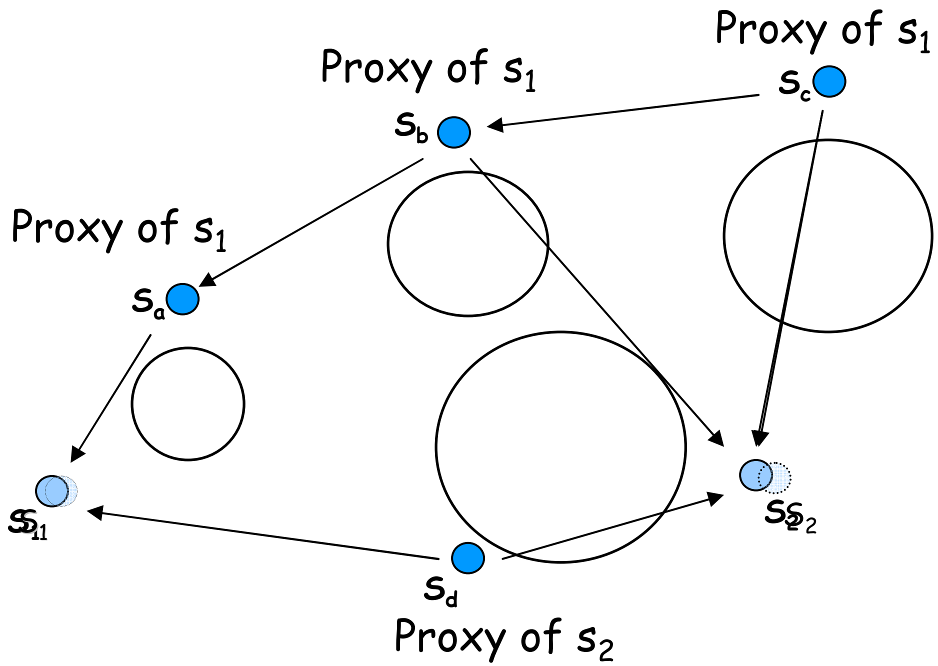


Proxy-based bidding protocol

Key idea: Virtual movement

Proxy sensor (winning bidder):

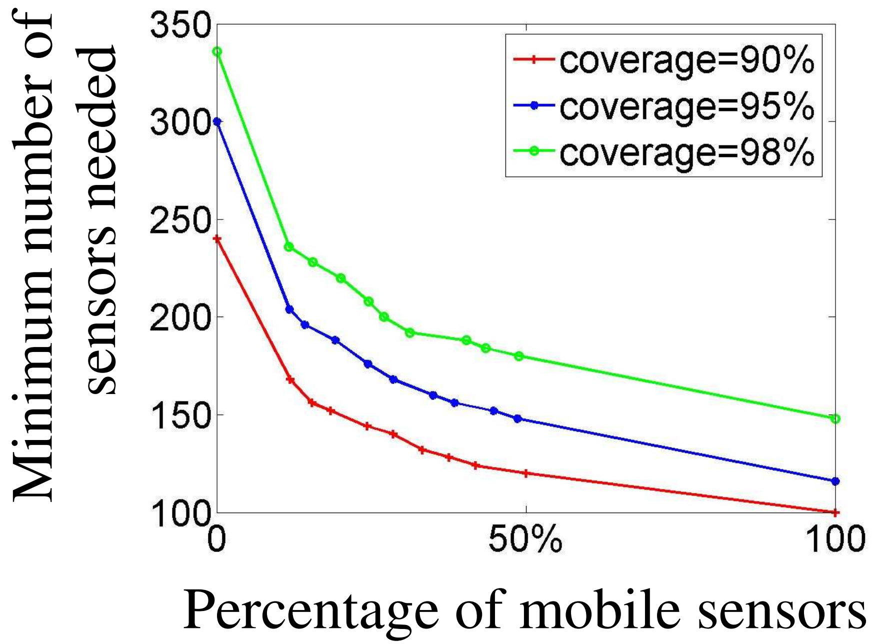
- Processes bidding messages
- Advertises services
- Notifies the mobile sensor to move

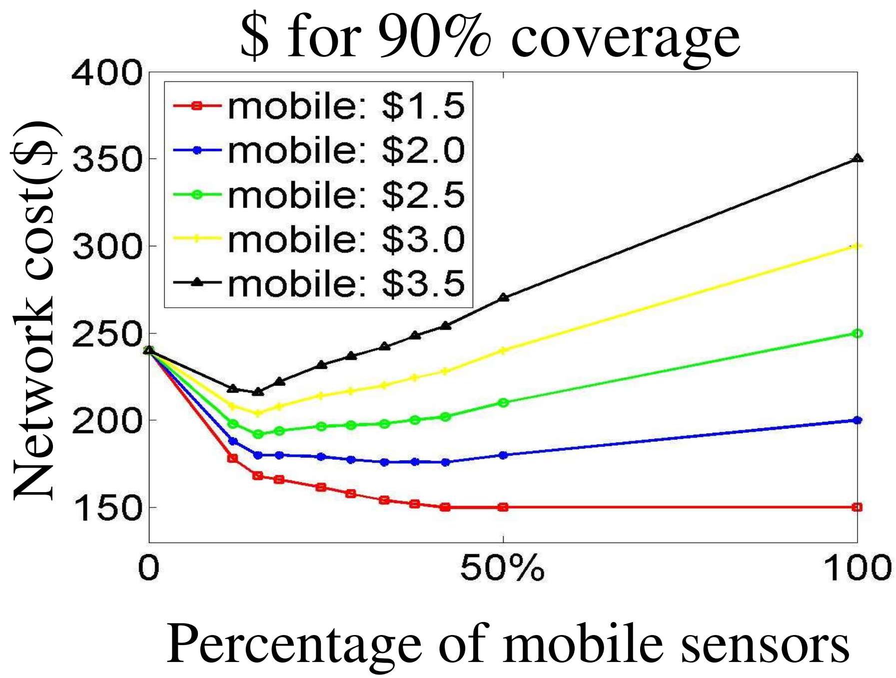


Tradeoff between sensor coverage and cost

Percentage of mobile sensors	Algorithm tested
100%	**VEC protocol ([Infocom04])**
10%~50%	**Bidding protocol**
0%	**Random deployment**

Tradeoff between Sensor Coverage and Cost

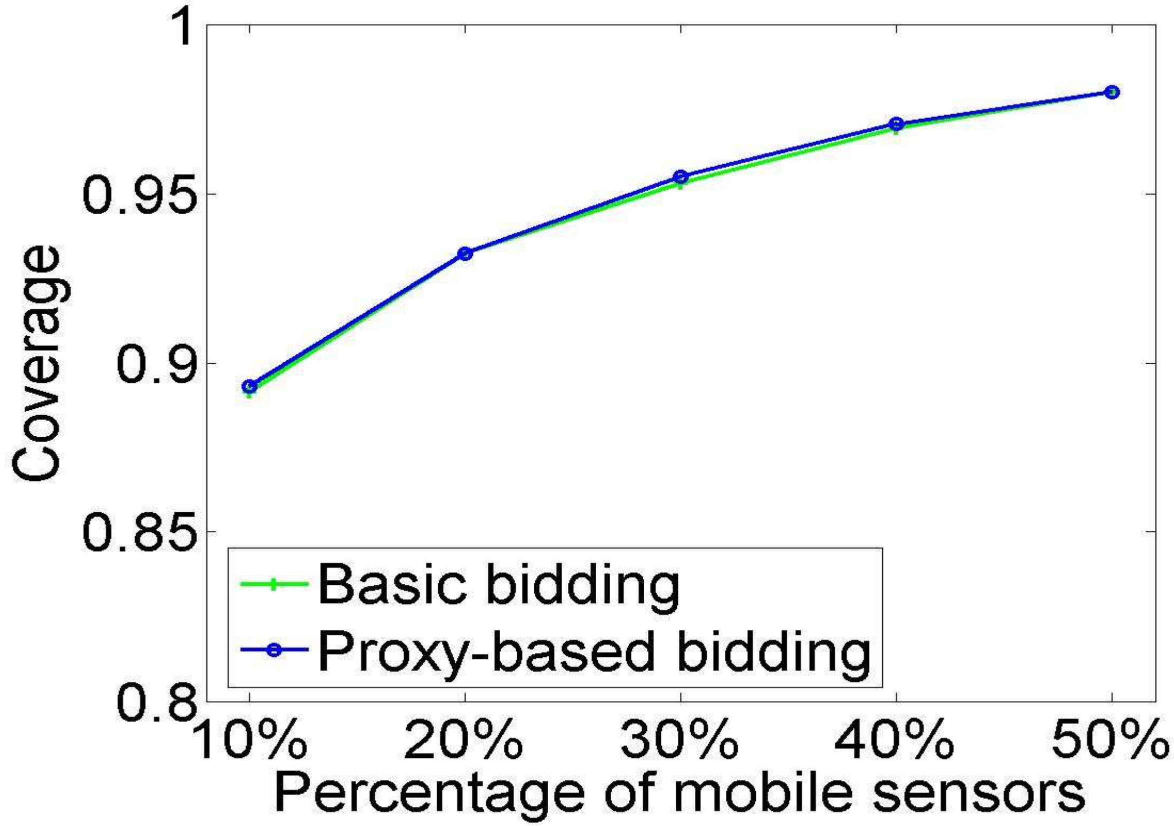




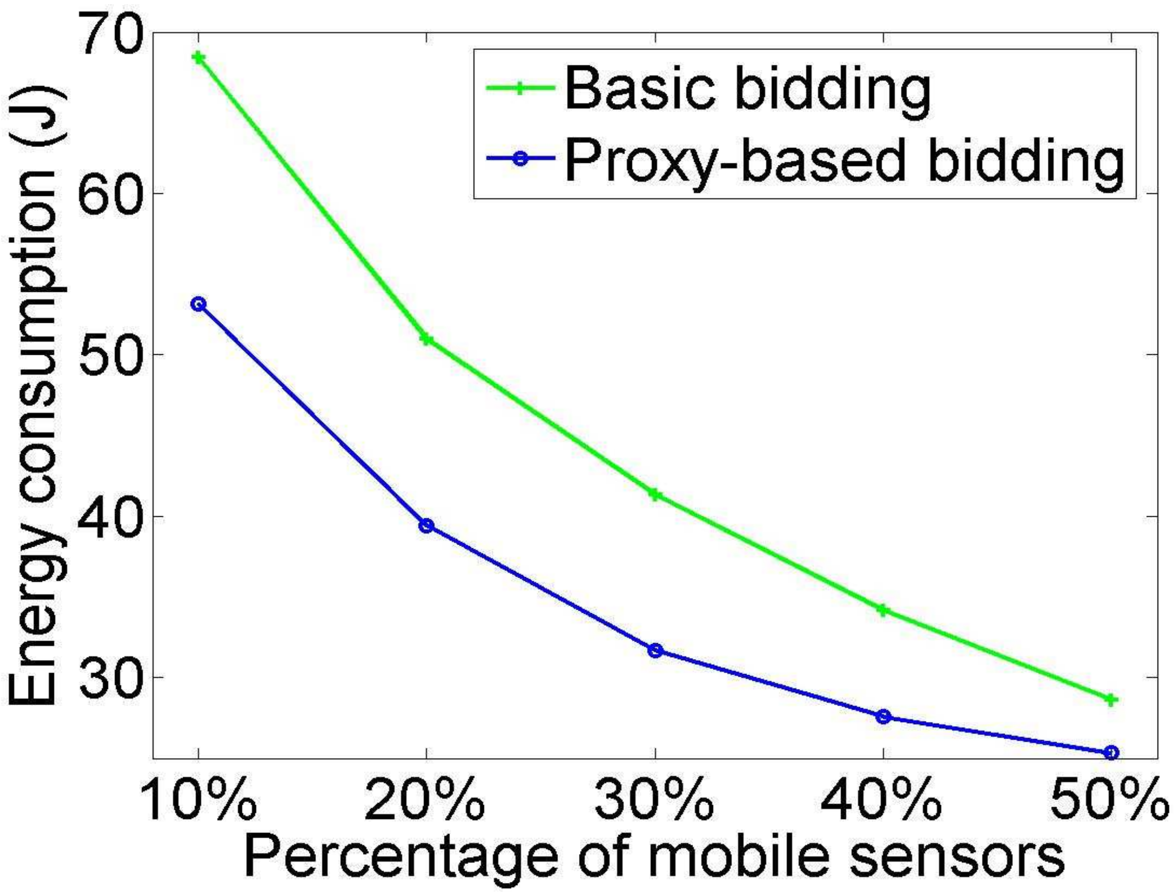
Static sensor: $1

Mobile sensor: $n

Comparisons



Comparisons



Outline

- Self-deployment protocols for a mix of mobile and static sensors
- Sensor relocation
- Future research plans

Mobility for Reliability: Problem Statement

Direct the movement of sensors to overcome failures under a time/energy constraint

Challenges

– Recovery may have to occur before a deadline

– Relocation should not affect other missions supported by the network

– Relocation must consider network lifetime

Outline of Solution

- **Phase I**

– Locate redundant sensors: quorum-based solution

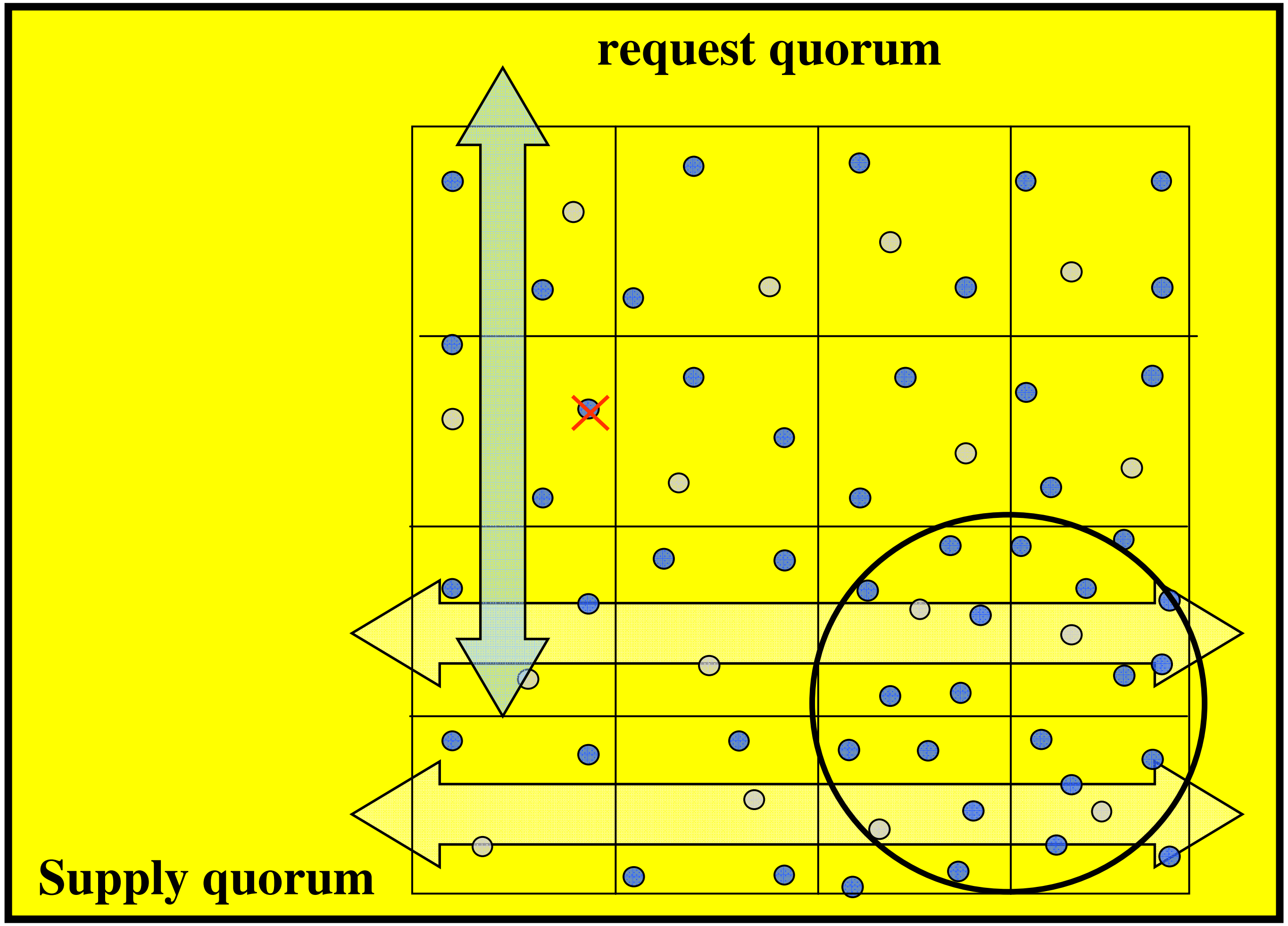
- **Phase II**

– Relocate sensors to target positions

Locating Redundant Sensors

Apply grid-quorum to reduce searching overhead

- Grids in one row form a supply quorum
- Grids in one column form a request quorum

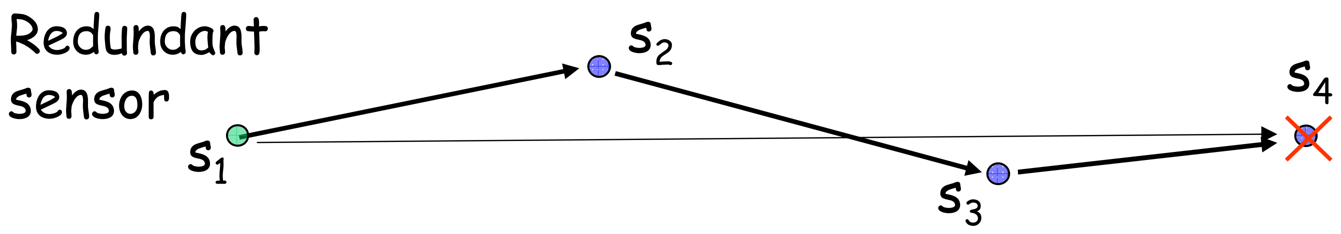


Relocating Sensors

Directly moving the sensor to the destination may not be a good solution

– Long delay and unbalanced power consumption

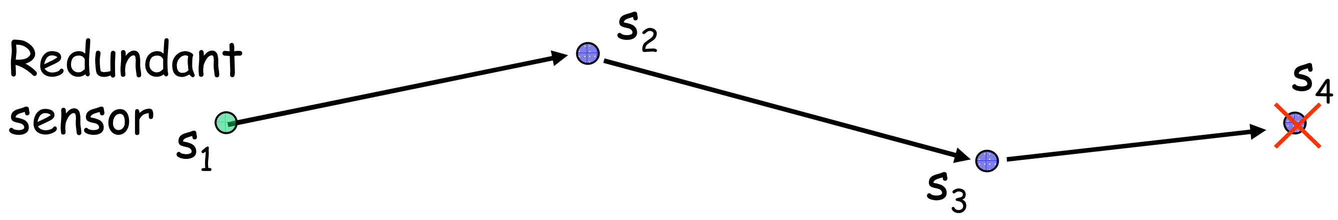
Use cascaded movement



Challenges in choosing cascading nodes

- Bounded relocation delay
- Energy balance

Controlling Delay



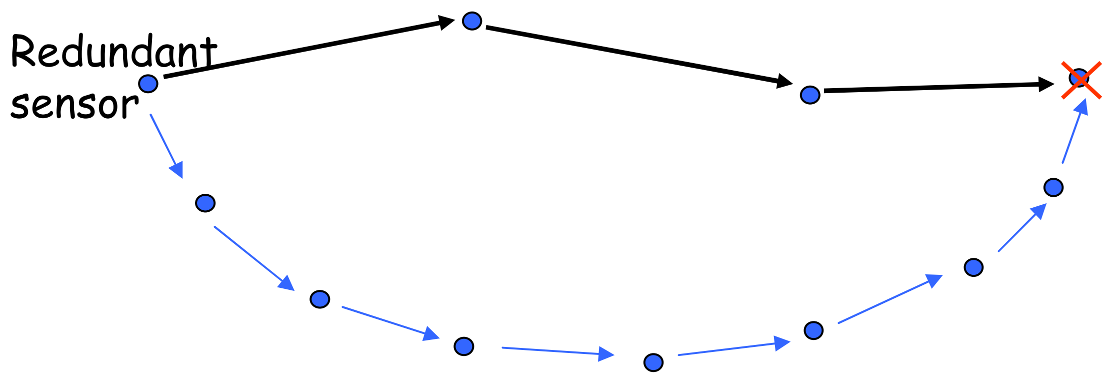
- Let recovery delay of s_4 be T_4
- $distance(s_3, s_4) \leq speed * T_4$
- s_3 can leave at $(0, T_4 - distance(s_3, s_4) / speed)$
- Let recovery delay of s_3 be T_3
- Let s_3 leave at $t_3 = T_4 - distance(s_3, s_4) / speed$
- $distance(s_2, s_3) \leq speed * (T_3 + t_3)$
- ……

$$\boxed{distance(s_i, s_{i+1}) \leq speed * (T_{i+1} + t_{i+1})}$$

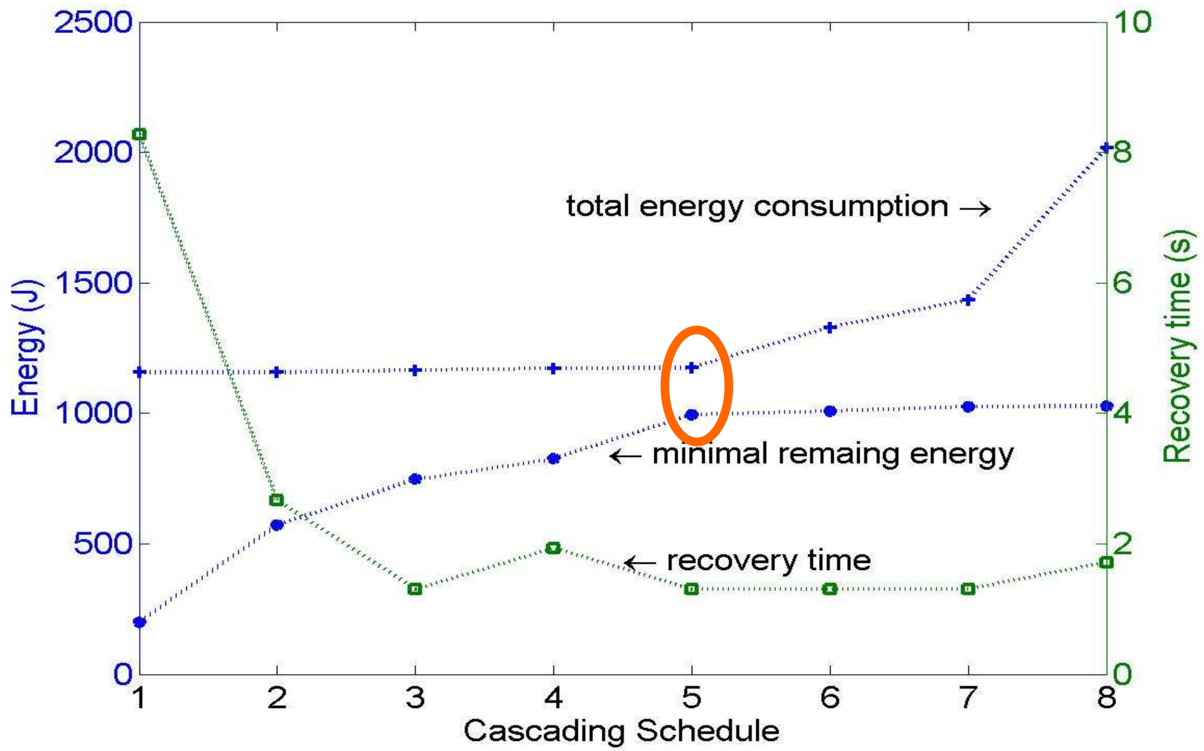
Tradeoffs of Using Cascading

Tradeoff between Load balance and energy efficiency

- Maximize minimum remaining energy E_{min} ?
- Minimize total energy consumption E_{total} ?



Tradeoffs of Using Cascading



Heuristic: Minimize (E_{total} - E_{min})

Using Modified Dijkstra's Algorithm

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Joint Sensing and Communication

Optimize value of a network over its lifetime

- Quality of data - coverage
- Ability of data to be collected – communication
- Energy required for reconfiguration and communication
- Value of mission

Value of data for mission *j*

Value of configuration k

$$v_{i,j}^{k} = u_c(X_k)s_i(m_j, X_k)$$

$$V = \sum_{k=1}^{K} V_k$$

Value over lifetime

$$C_k = M(X_{k-1} \rightarrow X_k) + E(X_k)t_k$$

Cost of moving

Communication energy

Summary

Sensor deployment in mixed sensor networks

- Balancing sensor cost and coverage
- First effort to address the problem

Sensor relocation

- Small impact on the topology
- In a timely and efficient way

Challenges

- Joint optimization between sensing and communication
- Accommodation of multiple missions
- Value of data

Possible Extensions

Varying density requirements

- Redundant will not mean the same thing in all grids

React to events, not just failure

- Multiple events
- Priorities

Proactive movement

- Pre-position sensors in anticipation of failure or event
- Request replacement sensor before death