Relay Placement in Sensor Networks

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14 October 2005

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HIIT BRU, Adaptive Computing, NAPS Project

Wireless Sensor Networks

- *Sensor nodes* are very small and cheap *computers* which are equipped with *sensors* and *wireless communication* capabilities
- Sensor nodes may be deployed manually or even dropped from an aeroplane
- After deployment, sensor nodes form an *ad-hoc network* which will *route* data from sensor nodes towards a *sink* node
- *Energy consumption* must be very low: nodes may need to operate for years without anyone changing or recharging batteries
- *Possible uses* include environmental and weather monitoring; home automation; agriculture; tracking goods in commerce and industry; monitoring machines; health care and medical diagnostics; security systems; and military applications

Optimising Sensor Networks (1)

What to optimise?

- Lifetime before batteries are drained
- Amount of data gathered during lifetime
- Quality of data gathered:
  - coverage: space, time
  - accuracy of data
  - probability of detecting or missing events

We will focus on *balanced data gathering*: $\lambda \min q_\eta + (1 - \lambda) \operatorname{avg} q_\eta$.

- Not only lot of data but also some data from all nodes

Optimising Sensor Networks (2)

How to optimise?

- Node hardware and software
- Node placement
- Scheduling node activity
- Routing
- Aggregating, summarising, and buffering data

We will combine both *node placement* and *routing* issues.

Relay Placement Problem (1)

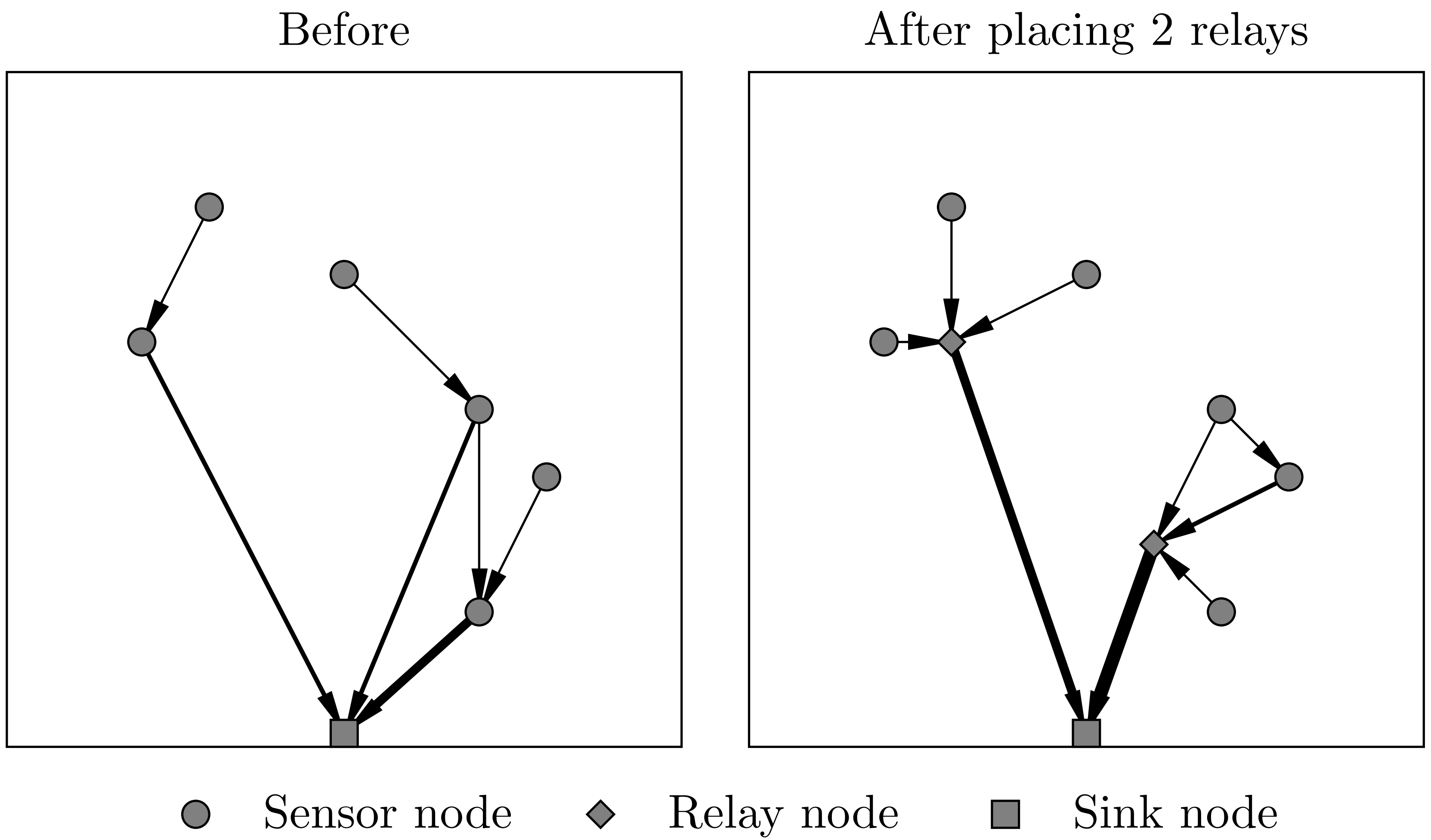
Problem:

- Given a *deployed sensor network*,
- add a small number of new *relay nodes*
- in order to maximise *balanced data gathering*

Typically, the relay nodes would be more expensive devices with larger batteries. Relays do not sense, they only forward data.

If we can afford a few relay nodes, where should we put them?

Relay Placement Problem (2)



Problem Classes (1)

The general relay placement problem needs to be restricted in order to even have a finite parametrisation of a problem instance. We will consider restrictions in the following five dimensions:

Type:	Decision
	Relay-constrained optimal
	Relay-constrained k-optimal
	Utility-constrained optimal
	Utility-constrained k-optimal
Utility:	Balanced data gathering

Problem Classes (2)

Possible relays:	Unrestricted — Planar — Finite set — Sensor upgrade

Transmission costs:	Unrestricted
	— Location dependent
	    — Line-of-sight
	        — Free space

Batteries:	Unrestricted — Identical

Next: Results

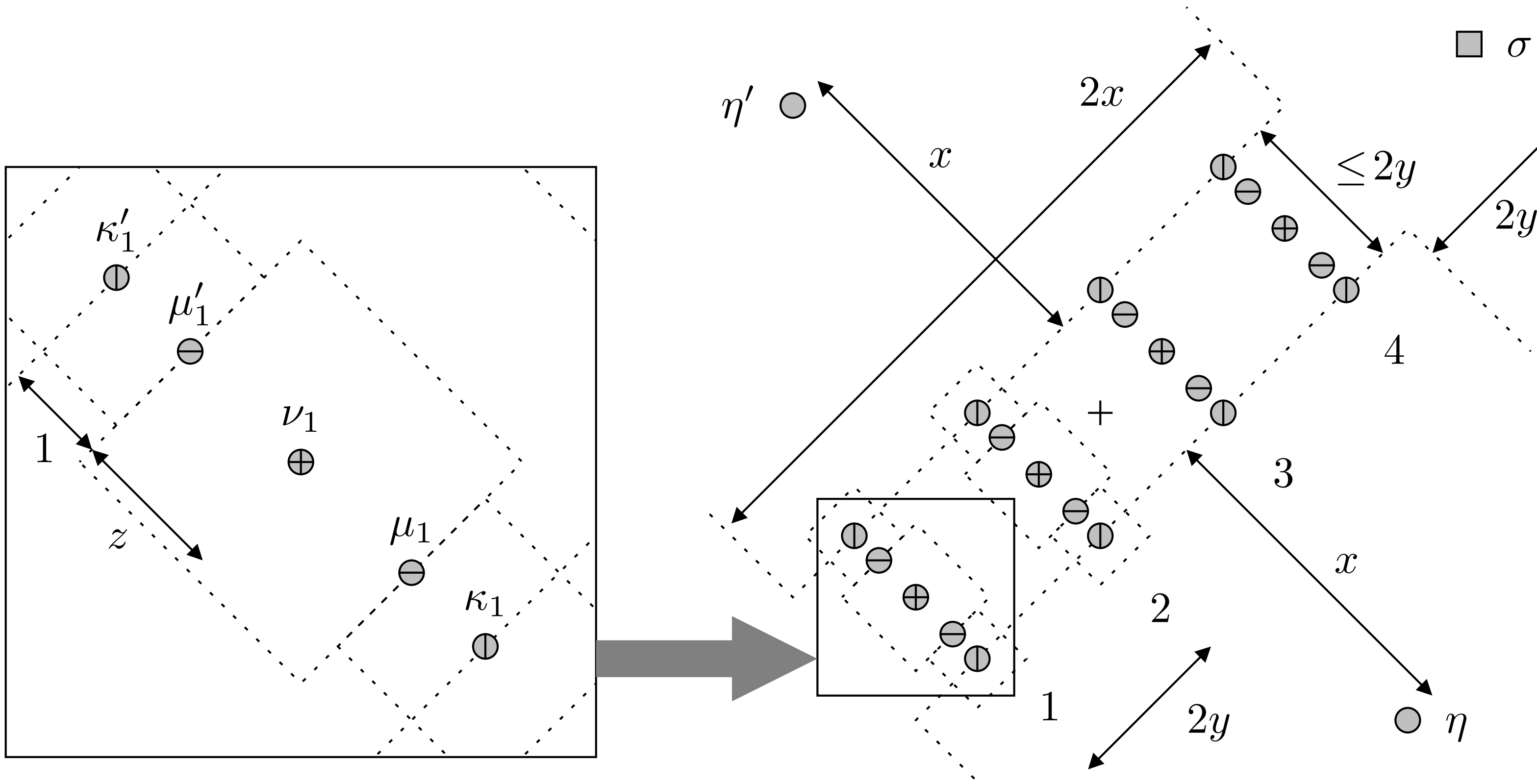
We have formulated the *relay placement problem*.

We will see that the problem is provably hard

. . . but it does not prevent us from trying.

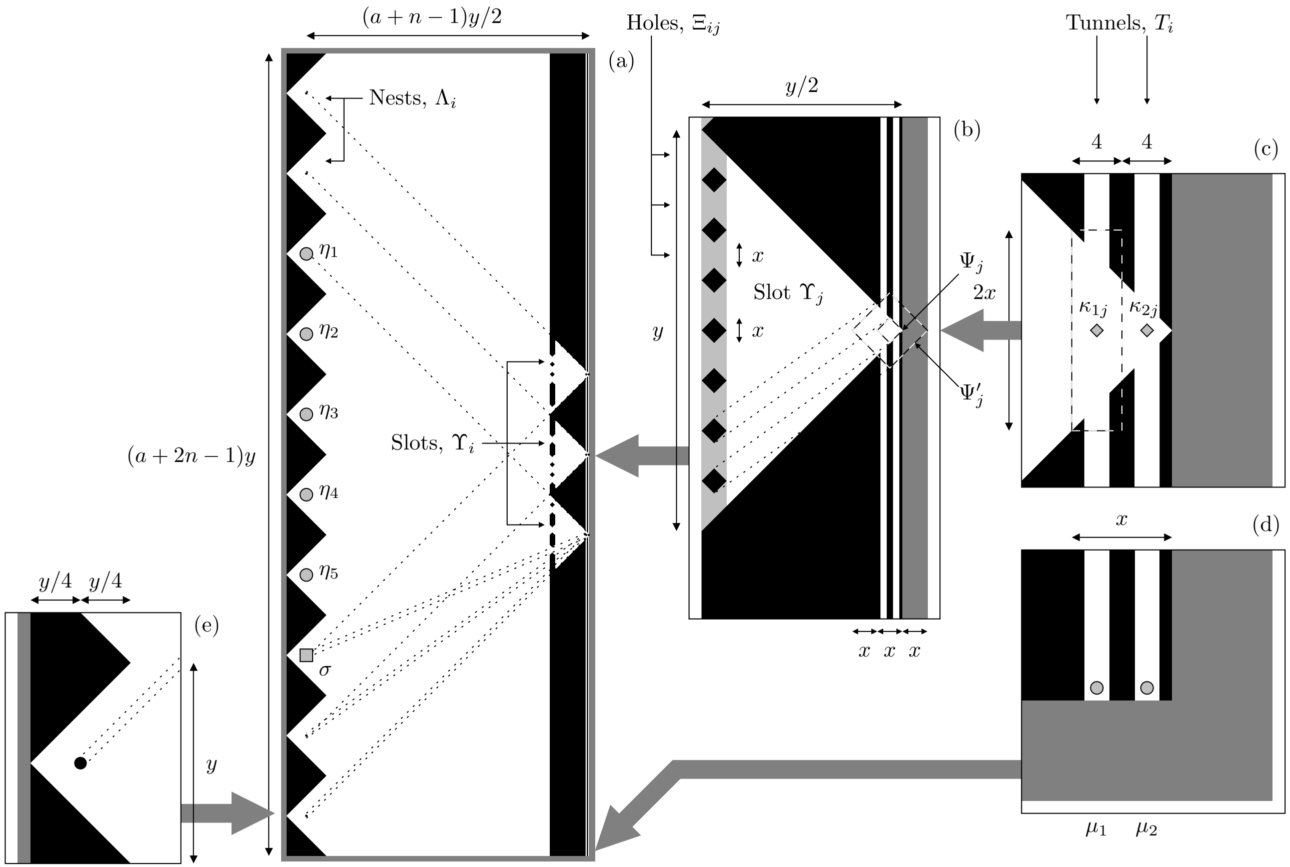
All Classes Are NP-hard

Reduction from PARTITION:



With Obstacles, Approximation Is NP-hard

Reduction from SET COVERING:



Solving the Finite Problem

Use one of the following methods:

- *MIP* (mixed integer linear program) formulation and a generic MIP solver
- *Heuristic* search with an LP problem as an admissible heuristic, combined with a *local* search
- *Exhaustive* search

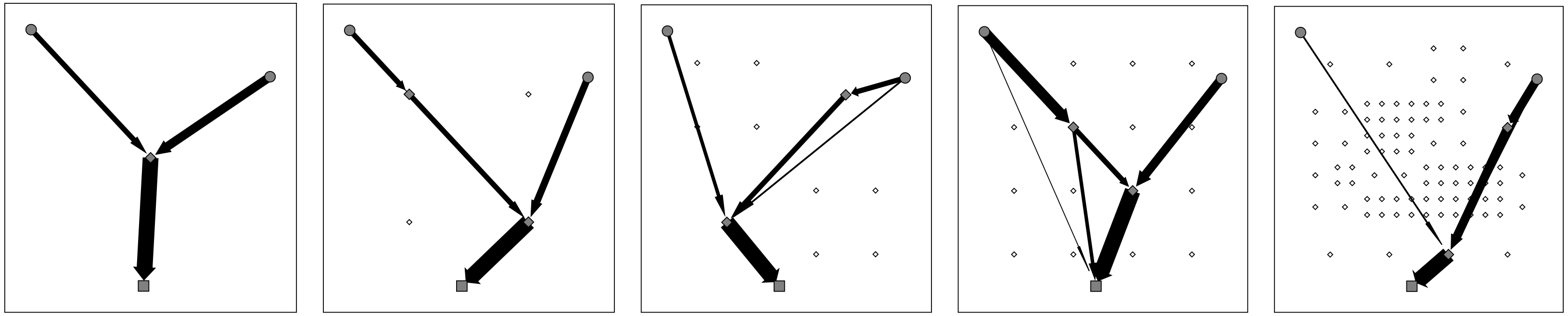
Any of these methods gives us a k-optimal (or optimal) solution.

Time complexity is typically high, but we may interrupt search at any point, and we will have an approximate solution of a known quality.

The finite solver by itself is not very exciting, but it is a component for the planar solver.

Solving the Planar Problem

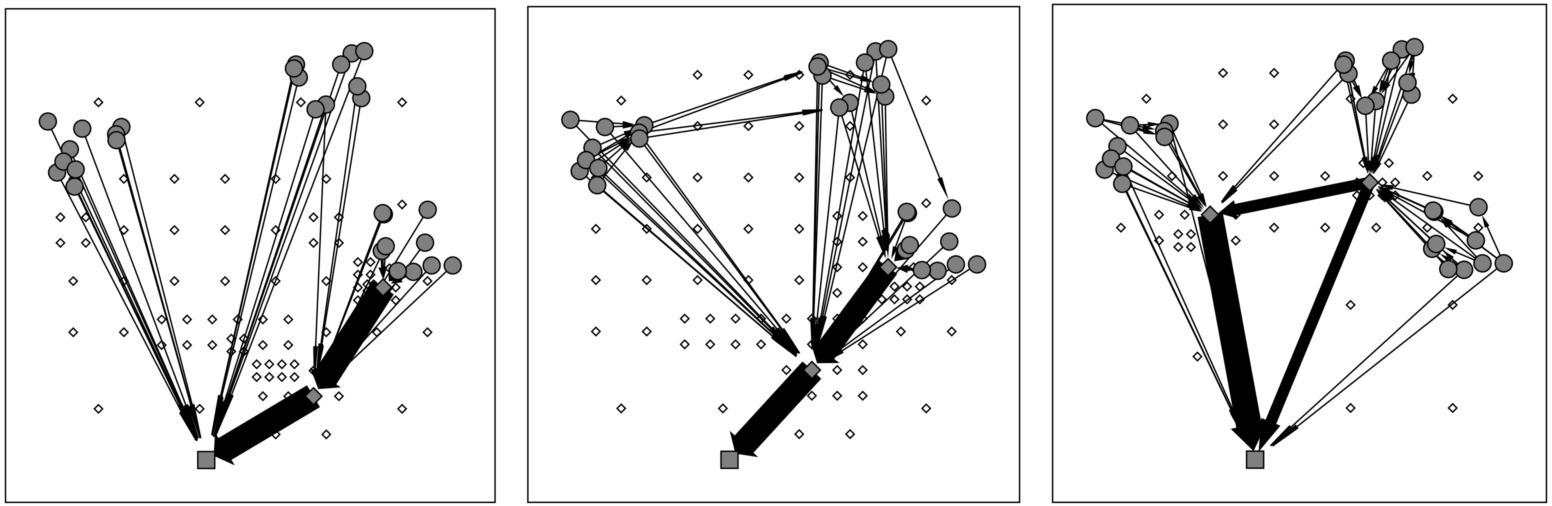
Partition the plane into cells and use the finite solver:



Step 1:	Step 2:	Step 3:	Step 4:	Step 15:
utility 0.10	utility 0.11	utility 0.08	*utility 0.14*	utility 0.07
bound 1.04	bound 0.48	bound 0.39	bound 0.27	*bound 0.17*

Examples

1.25-optimal solutions:



$\lambda = 0.0$ maximise sum

$\lambda = 0.5$

$\lambda = 1.0$ maximise minimum

Papers

- J. Suomela: Computational Complexity of Relay Placement in Sensor Networks. Accepted for SOFSEM 2006.
- P. Floréen, P. Kaski, J. Kohonen and P. Orponen: Exact and approximate balanced data gathering in energy-constrained sensor networks. To appear in Theoretical Computer Science, 2005.
- E. Falck, P. Floréen, P. Kaski, J. Kohonen and P. Orponen: Balanced data gathering in energy-constrained sensor networks. Proc. Algosensors 2004.

Software

- Source code for k-optimal relay placement is freely available.

Summary

- How to optimise data gathering in wireless sensor networks by adding a small number of new relay nodes

Future Research

- Focus on the amount of new relevant information instead of the amount of raw sensor readings
- Not only relay placement and routing but also sensor placement and data aggregation

Questions?

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