Relay Placement in Sensor Networks

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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 \textit{balanced data gathering}: \( \lambda \min q_\eta + (1 - \lambda) \text{avg } q_\eta \).

- 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)

Before placing 2 relays

After placing 2 relays

- Sensor node
- Relay node
- Sink node
## 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:

<table>
<thead>
<tr>
<th>Type:</th>
<th>Decision</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Relay-constrained optimal</td>
</tr>
<tr>
<td></td>
<td>Relay-constrained $k$-optimal</td>
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<tr>
<td></td>
<td>Utility-constrained optimal</td>
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<tr>
<td></td>
<td>Utility-constrained $k$-optimal</td>
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</tbody>
</table>

| Utility:       | Balanced data gathering |


### Problem Classes (2)

<table>
<thead>
<tr>
<th>Possible relays:</th>
<th>Unrestricted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>— Planar</td>
</tr>
<tr>
<td></td>
<td>— Finite set</td>
</tr>
<tr>
<td></td>
<td>— Sensor upgrade</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transmission costs:</th>
<th>Unrestricted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>— Location dependent</td>
</tr>
<tr>
<td></td>
<td>— Line-of-sight</td>
</tr>
<tr>
<td></td>
<td>— Free space</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Batteries:</th>
<th>Unrestricted</th>
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<td></td>
<td>— Identical</td>
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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:

\[
\begin{align*}
\kappa_1' & \leq 2y \\
x & \leq 2y \\
\end{align*}
\]
With Obstacles, Approximation Is NP-hard

Reduction from Set Covering:

\[ \text{Nests, } \Lambda_i \]

\[ \text{Slots, } \Upsilon_i \]

\[ \text{Holes, } \Xi_{ij} \]

\[ \text{Tunnels, } T_i \]
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:
utility 0.10
bound 1.04

Step 2:
utility 0.11
bound 0.48

Step 3:
utility 0.08
bound 0.39

Step 4:
utility 0.14
bound 0.27

Step 15:
utility 0.07
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.


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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