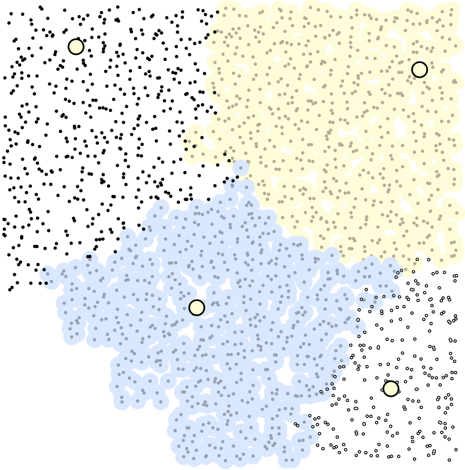
A distributed approximation scheme for sleep scheduling in sensor networks

Patrik Floréen,
Petteri Kaski,
Topi Musto,
Jukka Suomela

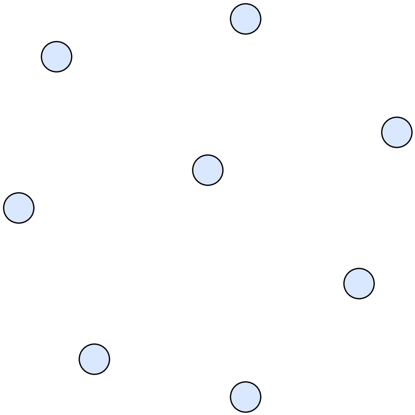


HIIT seminar
23 March 2007

A sensor network

Battery-powered sensor devices

Maximise the lifetime by letting each node sleep occasionally

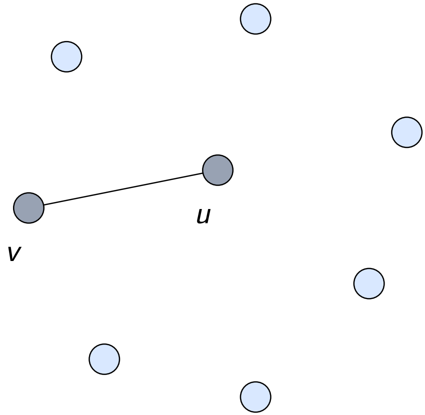


Pairwise redundancy relations

Two sensors close to each other may be pairwise redundant

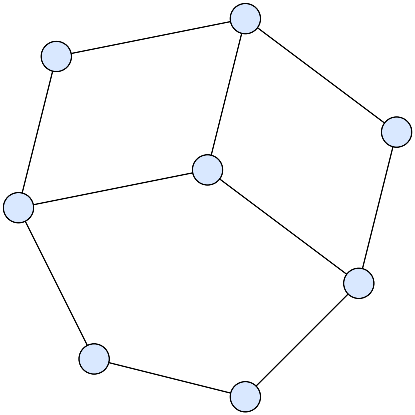
If v is active then u can be asleep and vice versa

Detecting pairwise redundancy: e.g., Koushanfar et al. (2006)



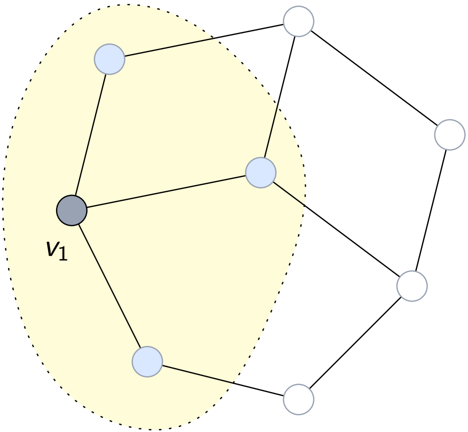
Redundancy graph for the sensor network

All pairwise
redundancy relations



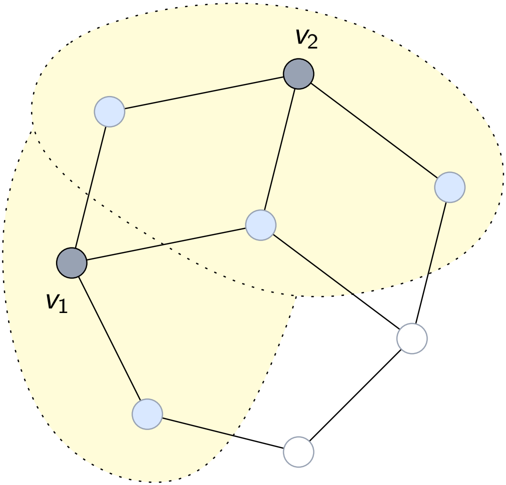
A dominating set in the redundancy graph

If v_1 is active
then its neighbours
can be asleep



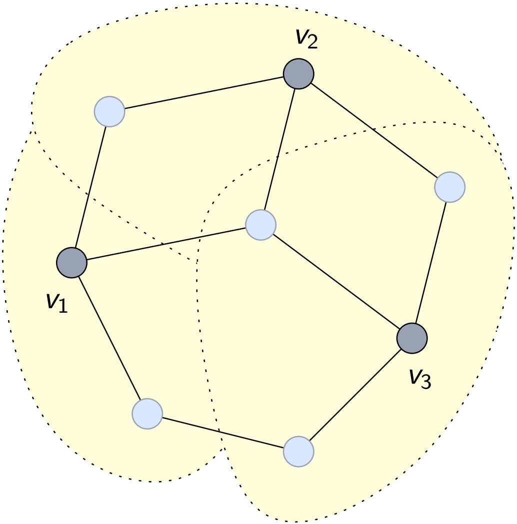
A dominating set in the redundancy graph

If v_2 is active
then its neighbours
can be asleep



A dominating set in the redundancy graph

If v_3 is active
then its neighbours
can be asleep

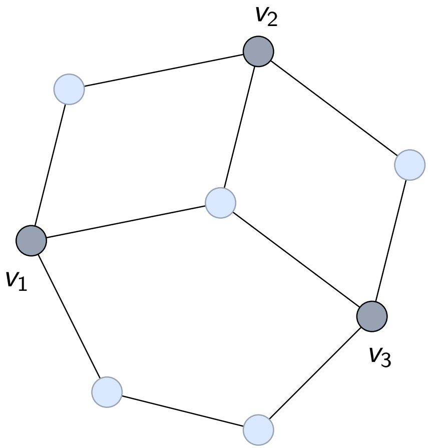


A dominating set in the redundancy graph

If nodes $\{v_1, v_2, v_3\}$ are active then all other nodes can be asleep

$\Updownarrow$

$D = \{v_1, v_2, v_3\}$ is a dominating set in this redundancy graph

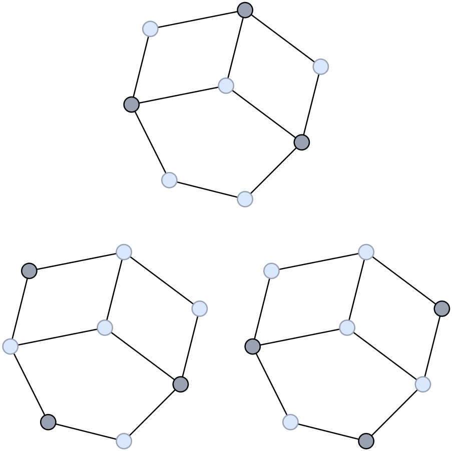


Sleep scheduling in sensor networks

Task: find multiple dominating sets and apply them one after another

Objective: maximise total lifetime

Constraints: the battery capacity of each node



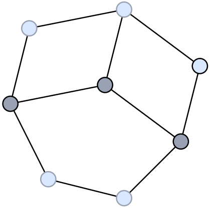
Domatic partition

One approach:
find disjoint
dominating sets

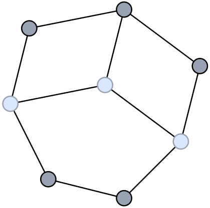
Achieved lifetime:
2 time units

Each node active
for 1 time unit

Feasible but
not optimal!

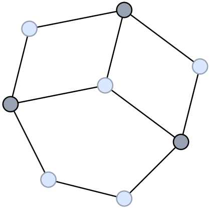


1 time unit

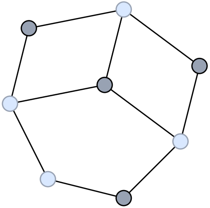


1 time unit

Fractional domatic partition



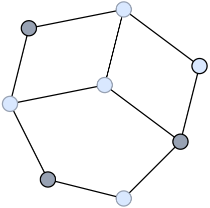
$\frac{1}{2}$ units



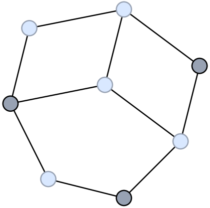
$\frac{1}{2}$ units

Achieved lifetime:
$\frac{5}{2}$ time units

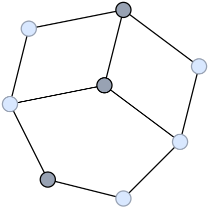
Each node active for 1 time unit



$\frac{1}{2}$ units



$\frac{1}{2}$ units

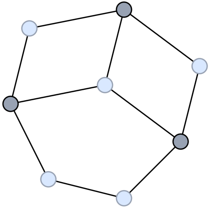


$\frac{1}{2}$ units

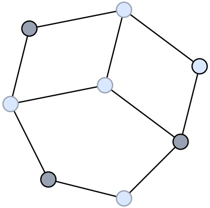
Towards the distributed algorithm

Optimal sleep scheduling =
optimal fractional domatic partition

- Hard to optimise and hard to approximate in general graphs
- Centralised solutions are not practical in large networks



$\frac{1}{2}$ units



$\frac{1}{2}$ units

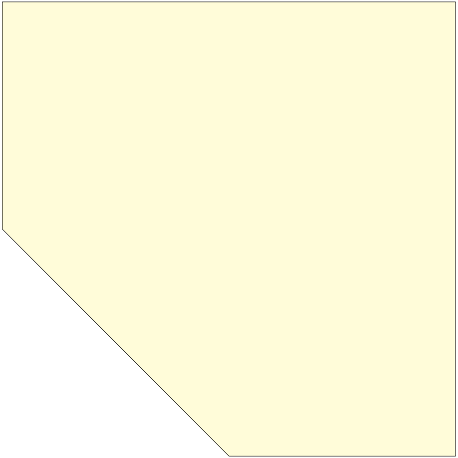
...

Plan:

- Identify the features of typical redundancy graphs
- Exploit the features to design a distributed approximation scheme

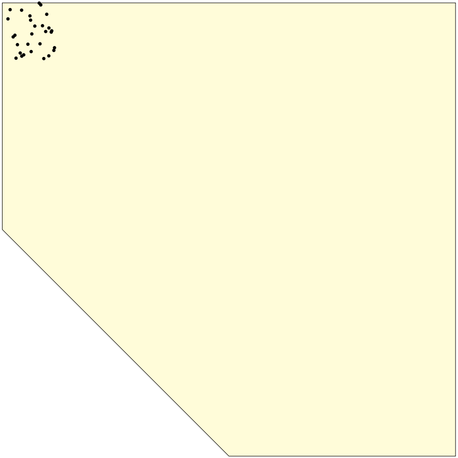
Construction of a typical redundancy graph

A potato field



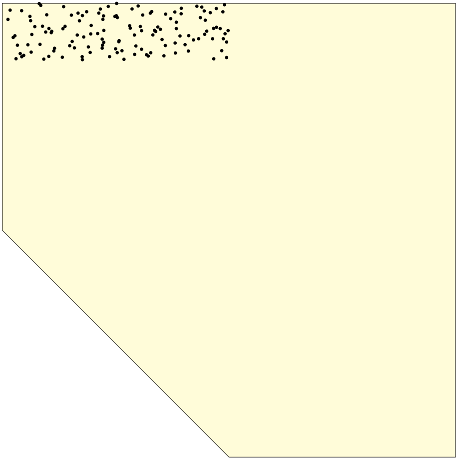
Construction of a typical redundancy graph

Planting sensors. . .



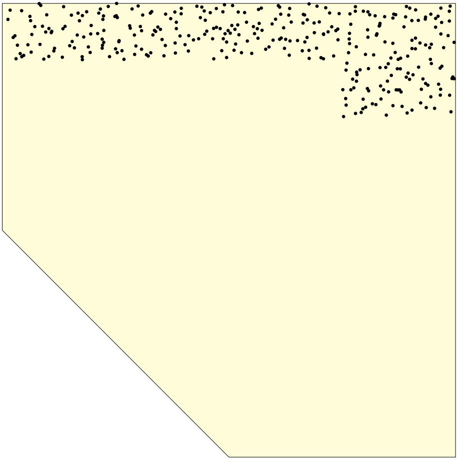
Construction of a typical redundancy graph

Planting sensors. . .



Construction of a typical redundancy graph

Planting sensors. . .

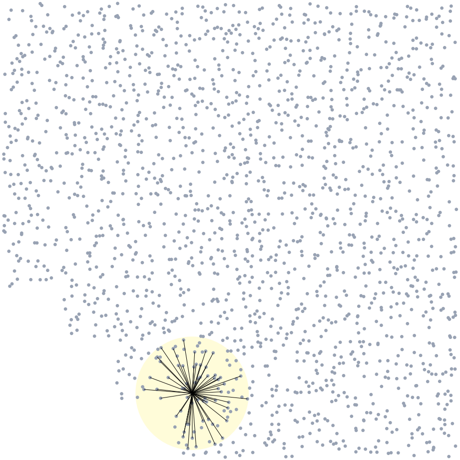


Construction of a typical redundancy graph

A sensor network

Construction of a typical redundancy graph

Wireless
communication links

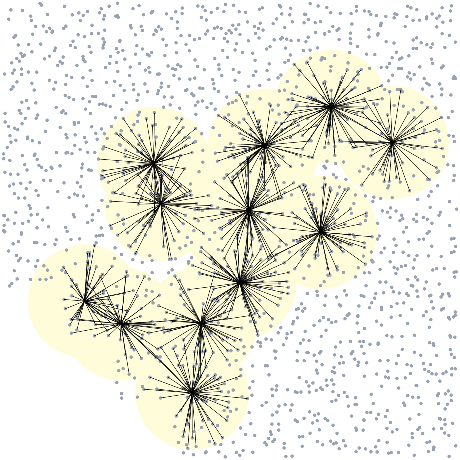


Construction of a typical redundancy graph

Wireless communication links

Some example nodes highlighted

Not necessarily a unit disk graph

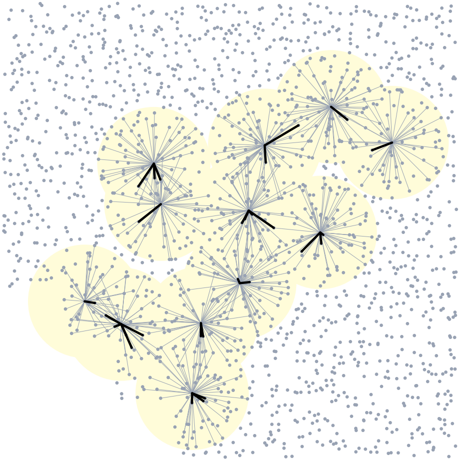


Construction of a typical redundancy graph

Redundancy relations

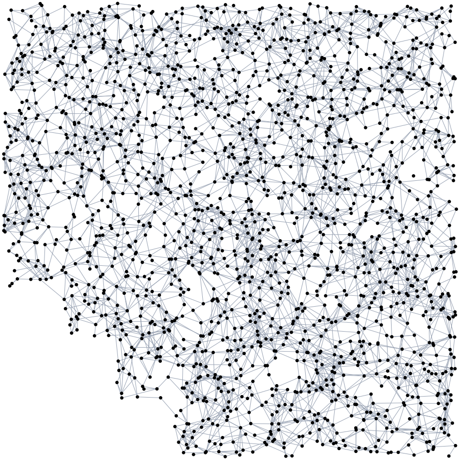
An arbitrary subgraph of the communication graph

Nodes that can communicate with each other can also determine whether they are pairwise redundant



Construction of a typical redundancy graph

The complete redundancy graph

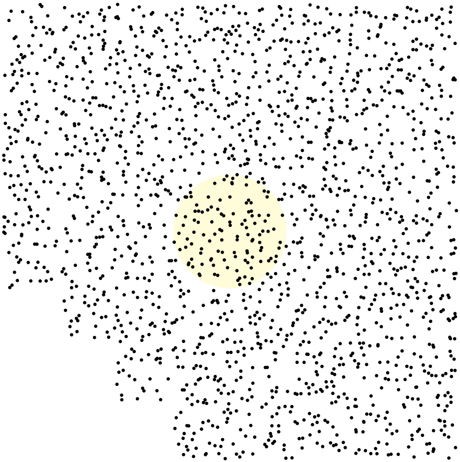


In this example: approx.
2000 nodes
6000 redundancy edges
100000 communication links (not shown)

Features of a typical redundancy graph (1)

Bounded
density of nodes

Cover a larger area $\implies$ still at most N sensors in any unit disk

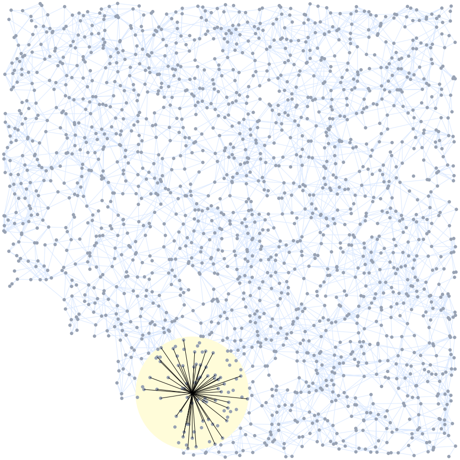


Features of a typical redundancy graph (2)

Bounded
length of edges

In the communication graph and thus also in the redundancy graph

Limited range of radio,
limited range of sensor



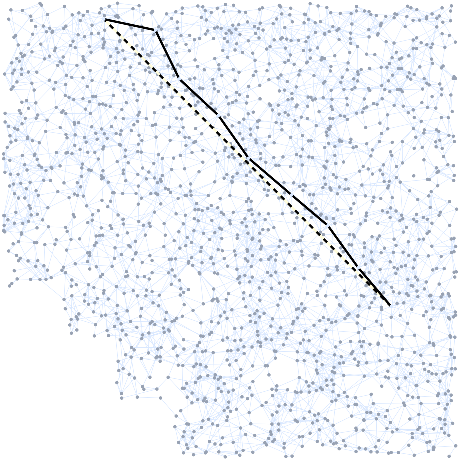
Features of a typical redundancy graph (3)

The communication graph is a geometric spanner

A shortest path in the graph is not much longer than the shortest path in the plane

"Sensible" network topology; here guaranteed by the deployment process

No such assumption is made about the redundancy graph



Features of a typical redundancy graph

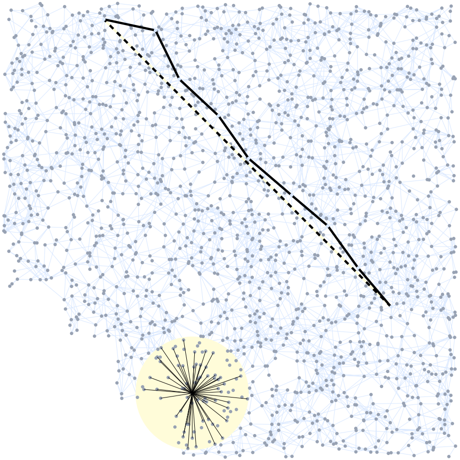
Communication graph

1. Density of nodes
2. Length of edges
3. Geometric spanner

Redundancy graph

- Any subgraph

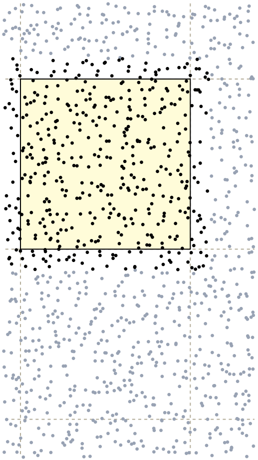
Given these assumptions, there exists a distributed approximation scheme



The distributed approximation scheme

Idea 1:

1. Partition the graph into small cells
2. Solve the scheduling problem locally in each cell
   - Nodes near a cell boundary help in domination
   - Local optimum at least as good as global optimum
3. Merge the local solutions



Problem:

- Nodes near a cell boundary work suboptimally

The distributed approximation scheme

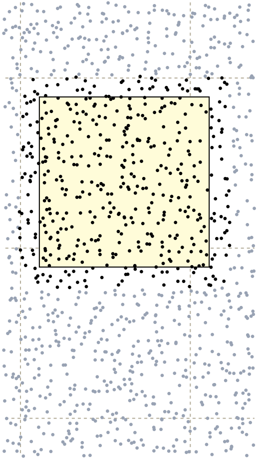
Idea 2: shifting strategy

(e.g., Hochbaum & Maass 1985)

1. Form several partitions
2. Make sure no node is near a cell boundary too often
3. Construct a schedule for each partition and interleave

Works fine if the nodes know their coordinates

Can we form the partitions without using any coordinates?



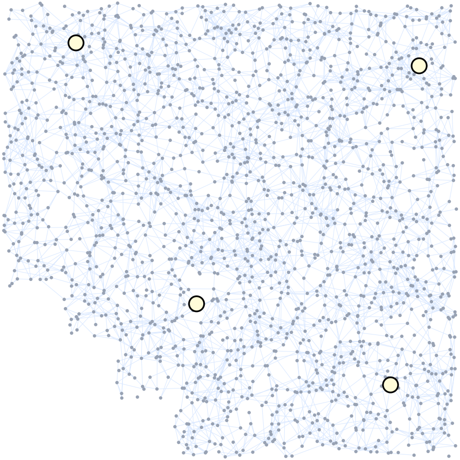
The distributed approximation scheme

Install anchor nodes

Or use a distributed algorithm to find suitable anchors: e.g., any maximal independent set in a power graph of the communication graph

Not too sparse,
not too dense

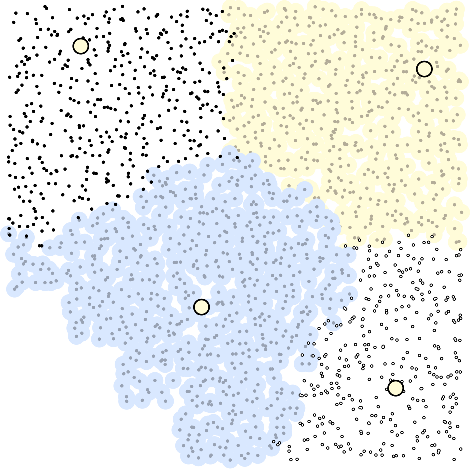
1 bit of information:
"I am an anchor"



The distributed approximation scheme

Finding one partition is now easy: Voronoi cells for anchors

- Metric: hop counts in communication graph



How do we get more partitions?

No global consensus on left/right, north/south

The distributed approximation scheme

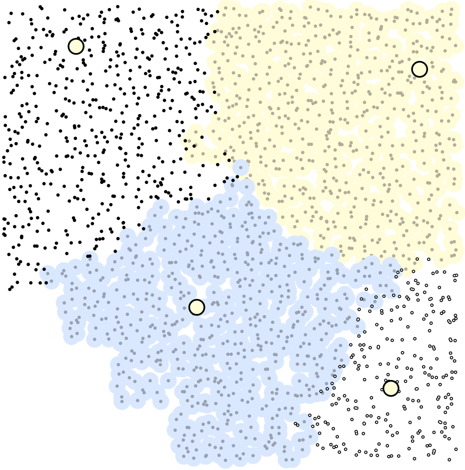
Assumption: locally unique identifiers for anchors

- MAC addresses
- Random numbers

Shift borders towards those anchors with larger identifiers

Key lemma

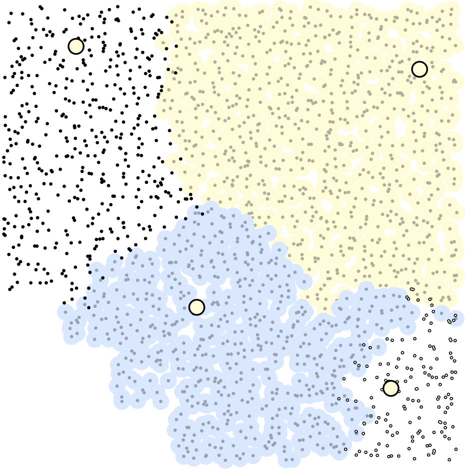
No node is near a cell boundary too often



The distributed approximation scheme

A constant number of partitions suffices

Cell size is constant



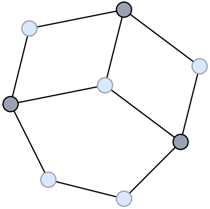
Main result

For any $\epsilon > 0$, with suitable anchor placement, sleep scheduling can be approximated within $1 + \epsilon$ in constant time per node

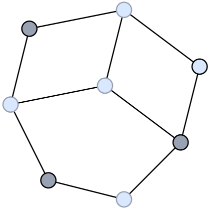
Summary

- Sleep scheduling in sensor networks = fractional domatic partition
- Formalise the features which make the problem easier to approximate
- Anchors suffice, coordinates are not needed
- A distributed approximation scheme, constant effort per node
- Demonstrates theoretical feasibility – more work needed to make the constants practical

To appear in *Proc. SECON 2007*



$\frac{1}{2}$ units



$\frac{1}{2}$ units

...