Maximisation de la durée de vie des réseaux de capteurs sans fil hétérogènes

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Plan

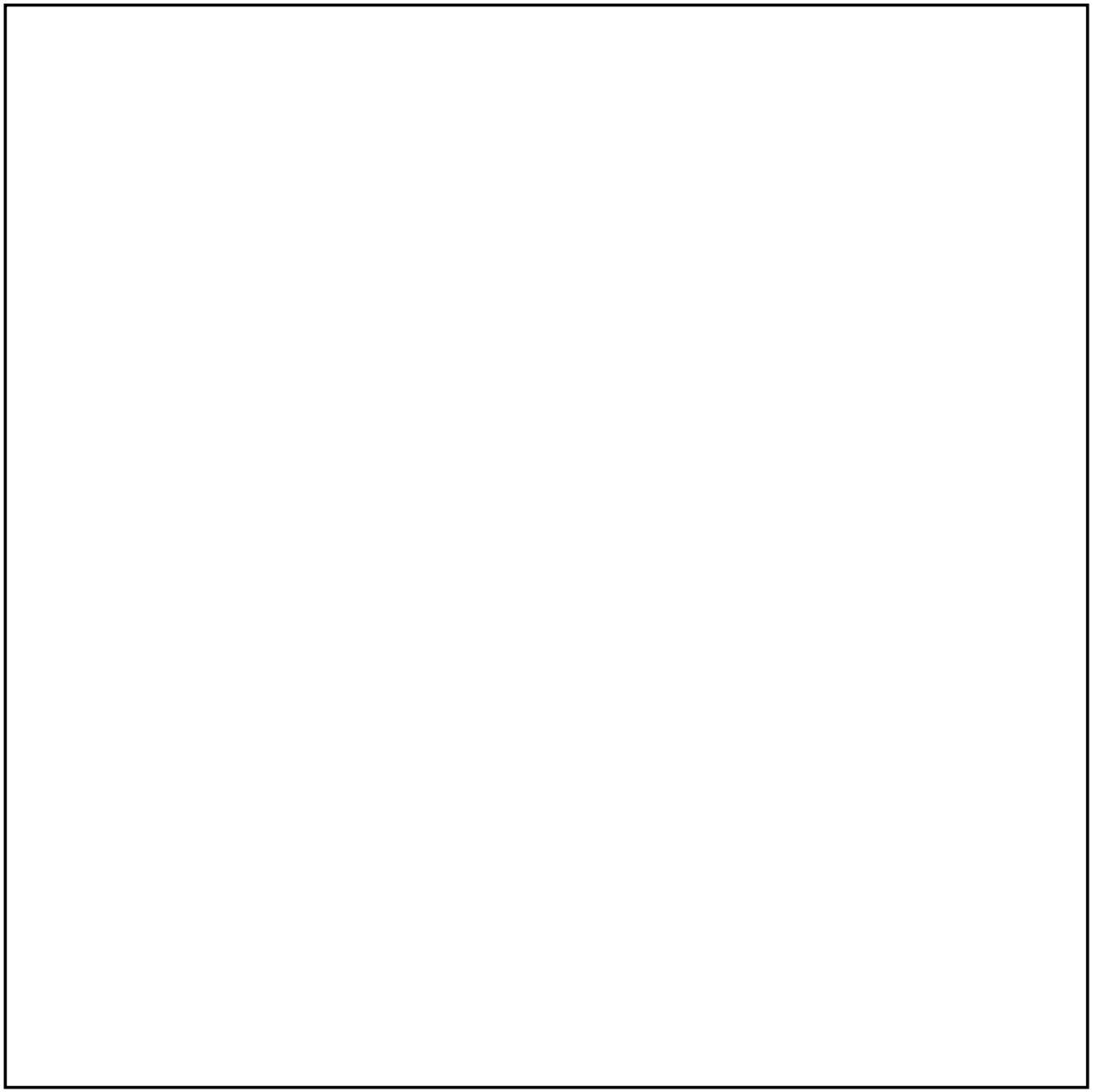
Motivations

- Multiphysics requirements
  - Fire detection $\Rightarrow$ light, temperature and smoke
  - Water quality $\Rightarrow$ pH, temperature, chemical and biological measures
  - Mental stress detection $\Rightarrow$ heartbeat, respiratory frequency
- Embedded system technology allows for multiphysic sensor nodes
  - A sensor node is equipped with a single battery, and multiple sensor units operating on that battery
- In this work we consider the joint use of three types of sensor nodes
  - Sensor nodes in N_1 are equipped with a omnidirectional sensor unit
  - Sensor nodes in N_2 are equipped with a directional sensor unit
  - Sensor nodes in N_{12} are equipped with an omnidirectional and a directional sensor unit
- Objective: Maximize the network lifetime

Classical approach

- A group is a set of sensors such that:
  - For all targets, there exist an omnidirectional sensor unit and a directional sensor unit in the group that can cover it
- Group j is used t_j units of time (t_j is a decision variable)
- The network lifetime is $\sum_{j=1}^{c} t_j$
- Enumerating all the groups is generally unpracticable (and unnecessary) $\Rightarrow$ Column generation

Illustration of a group



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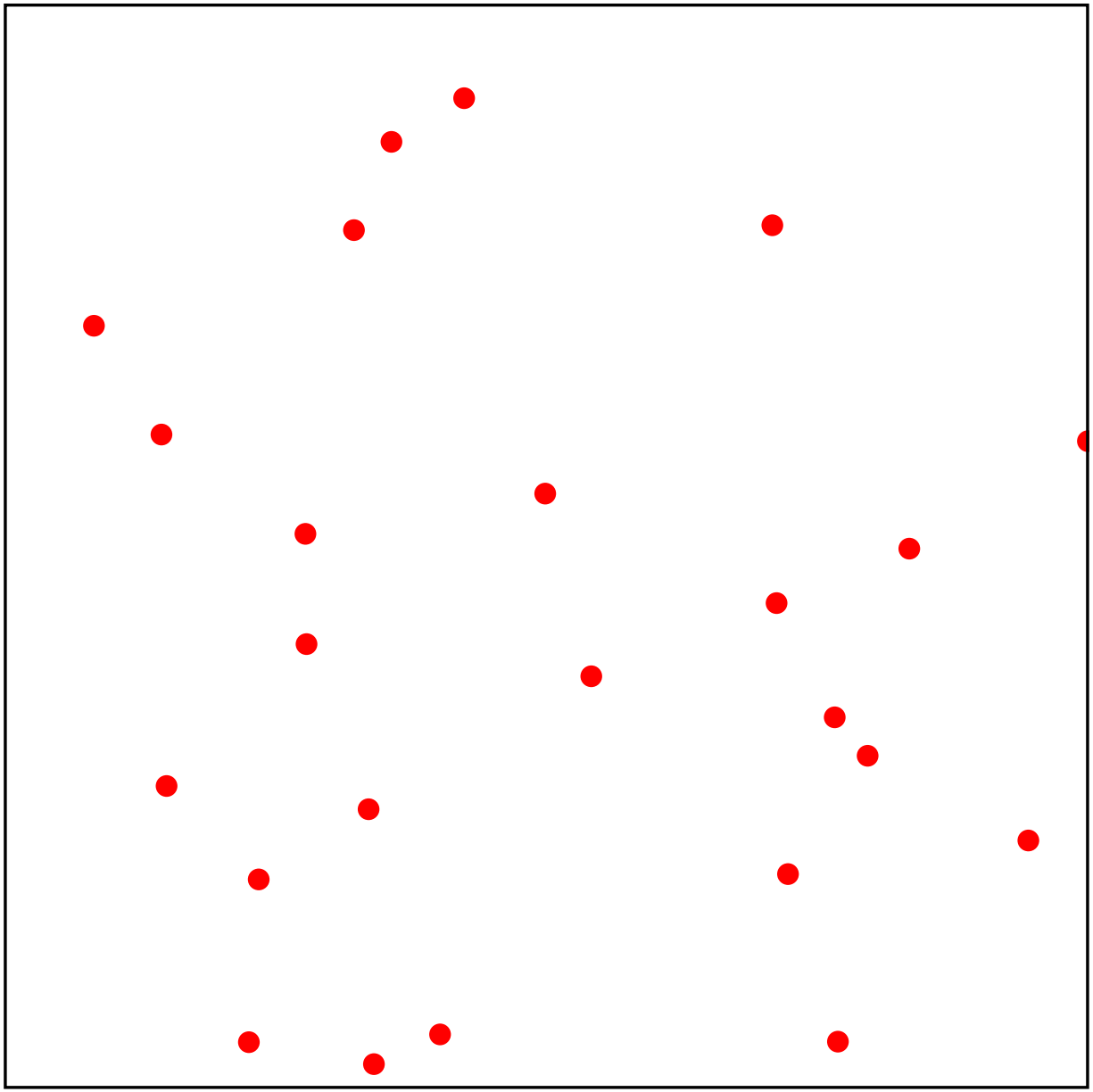

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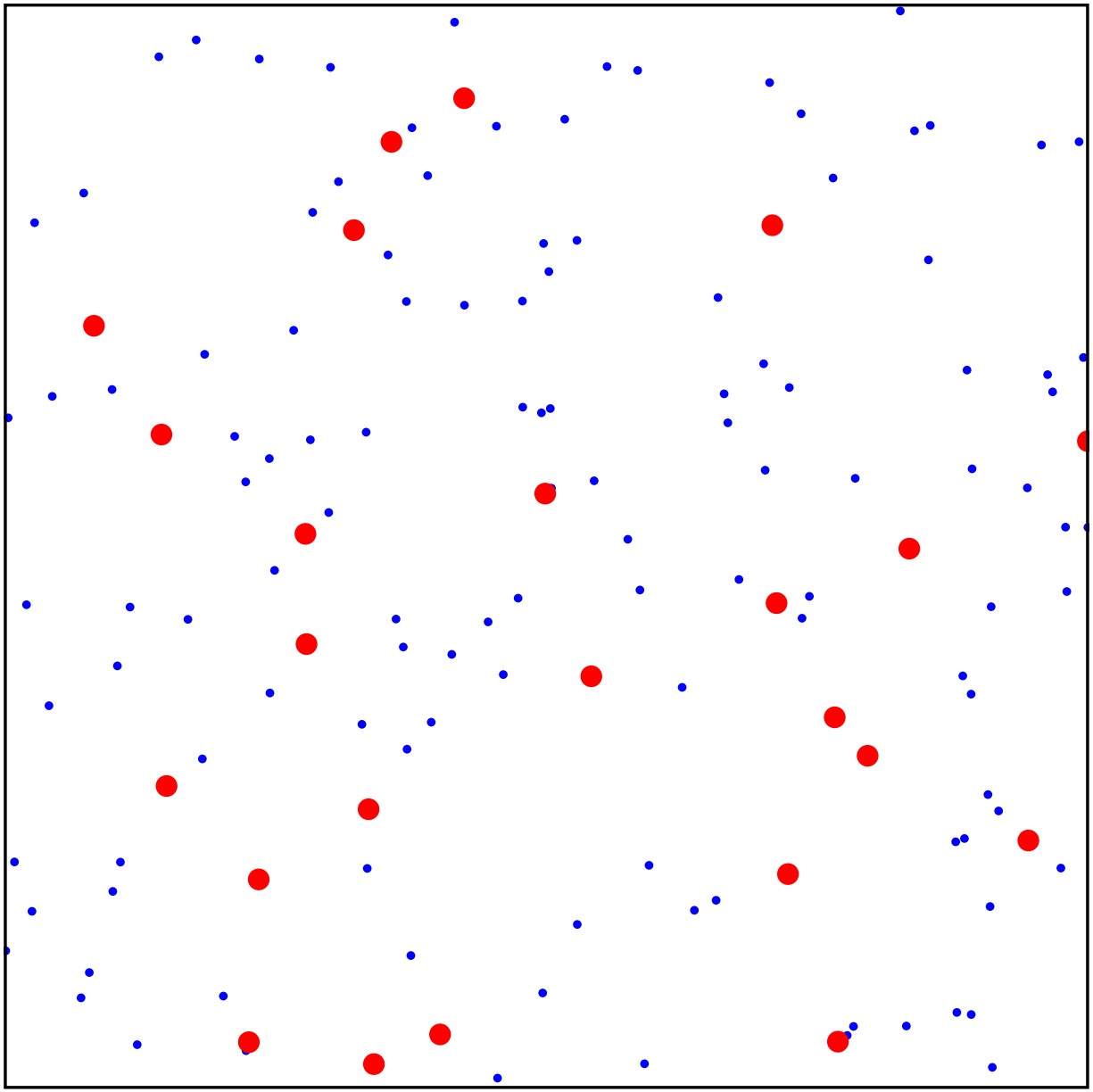

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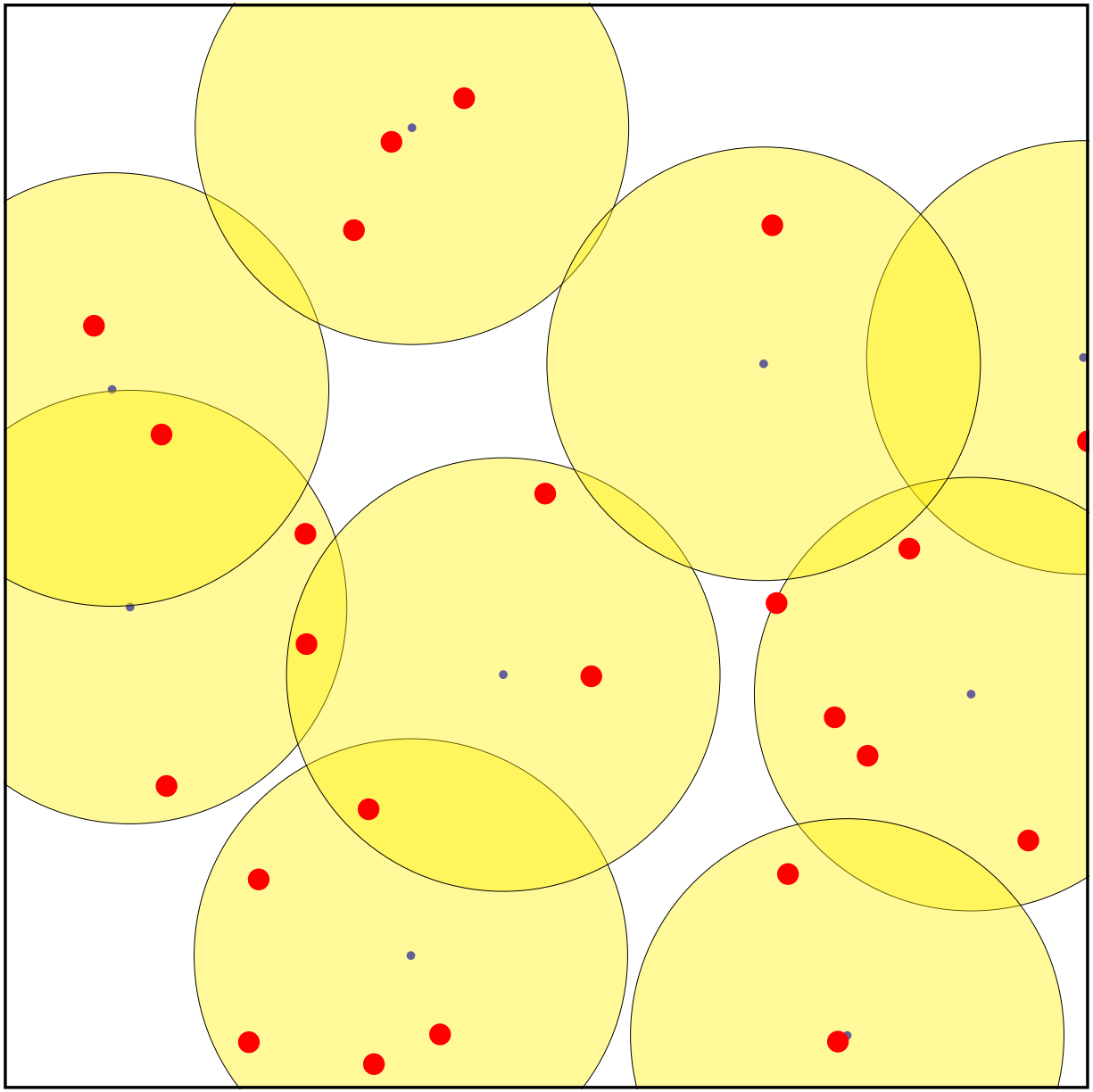

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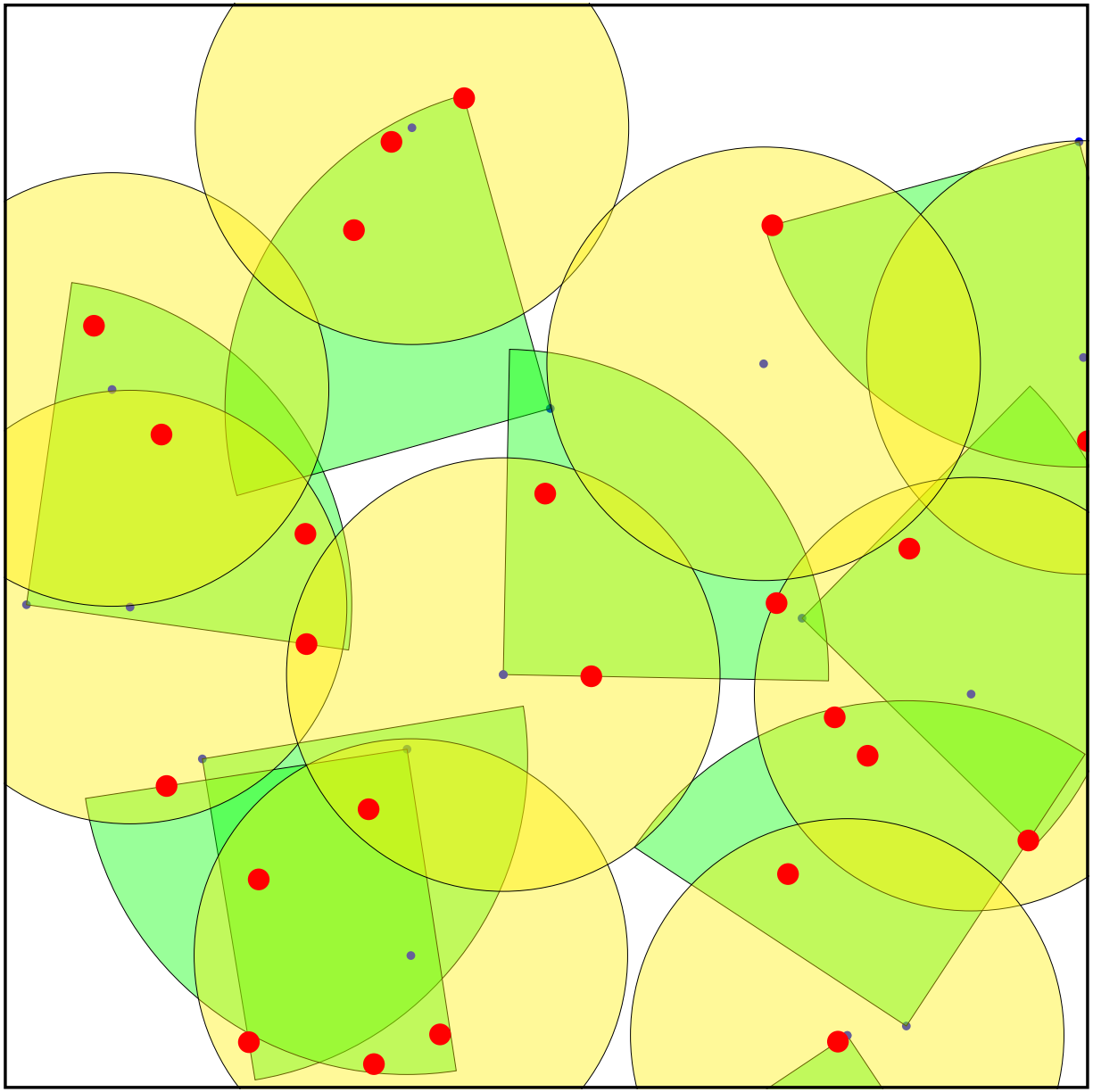
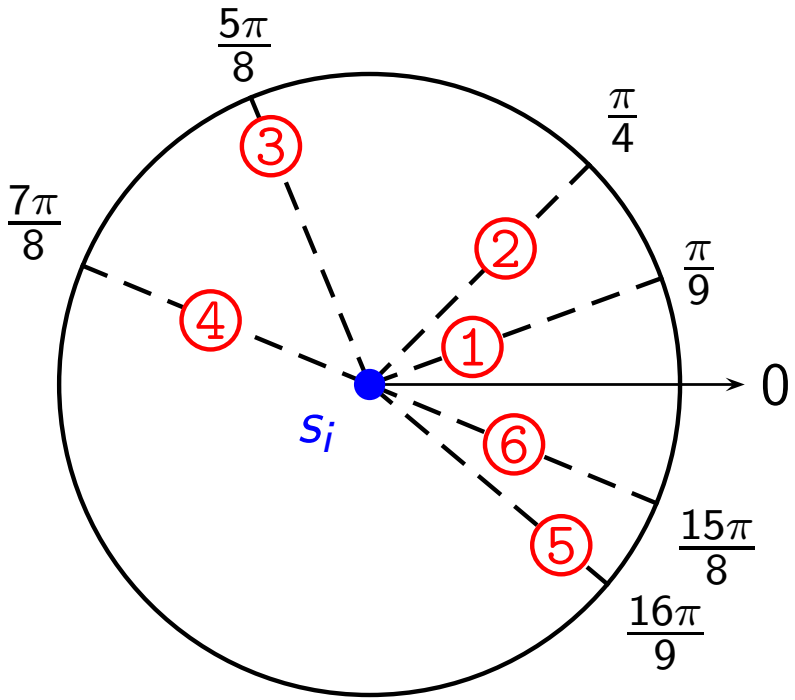


Directional sensor units

- Each sensor has a given sensing angle φ
- Each active sensor has a working direction θ in $[0, 2\pi)$



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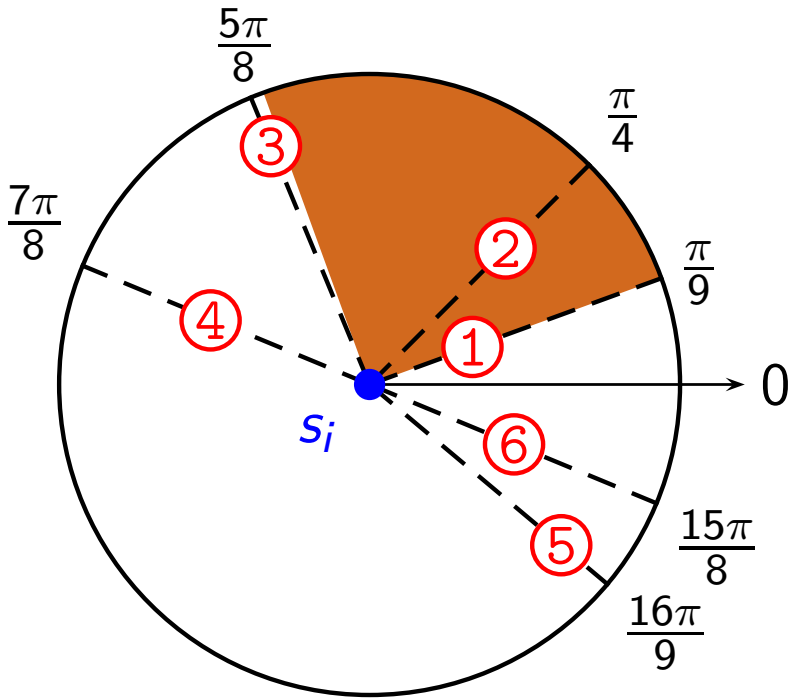

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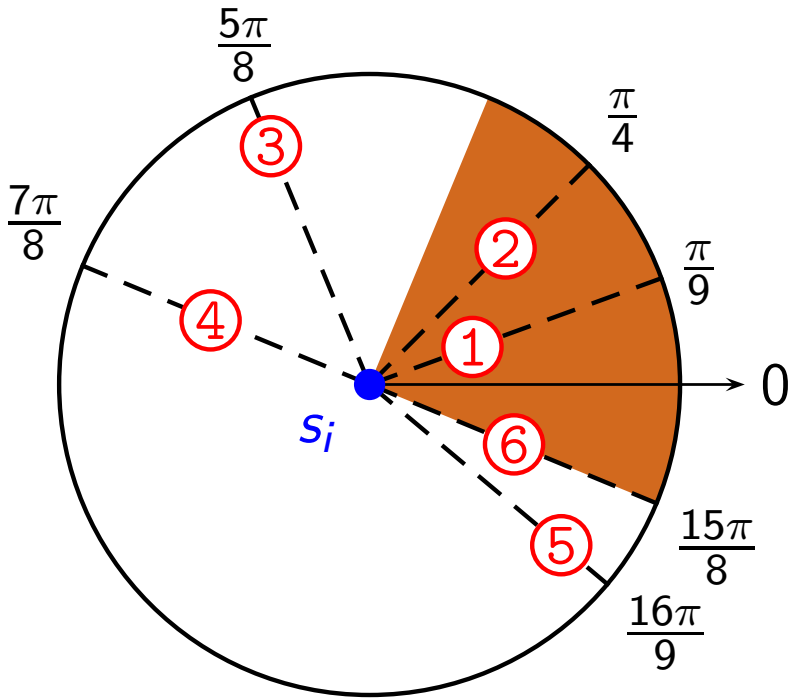

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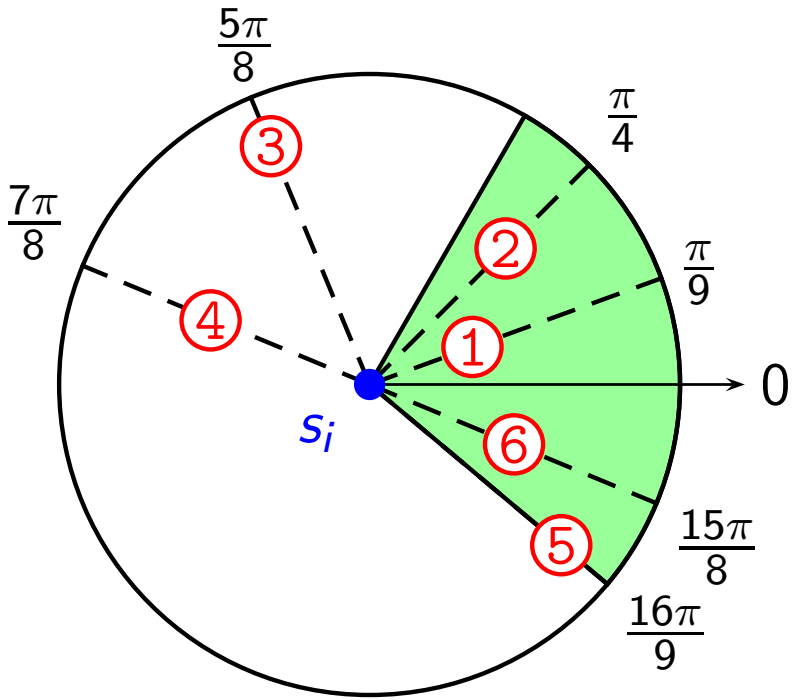

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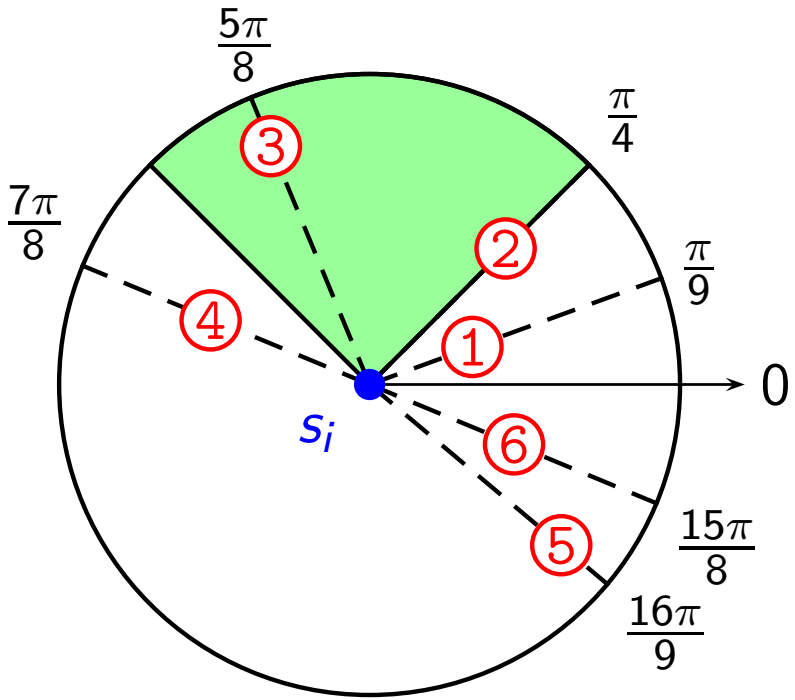

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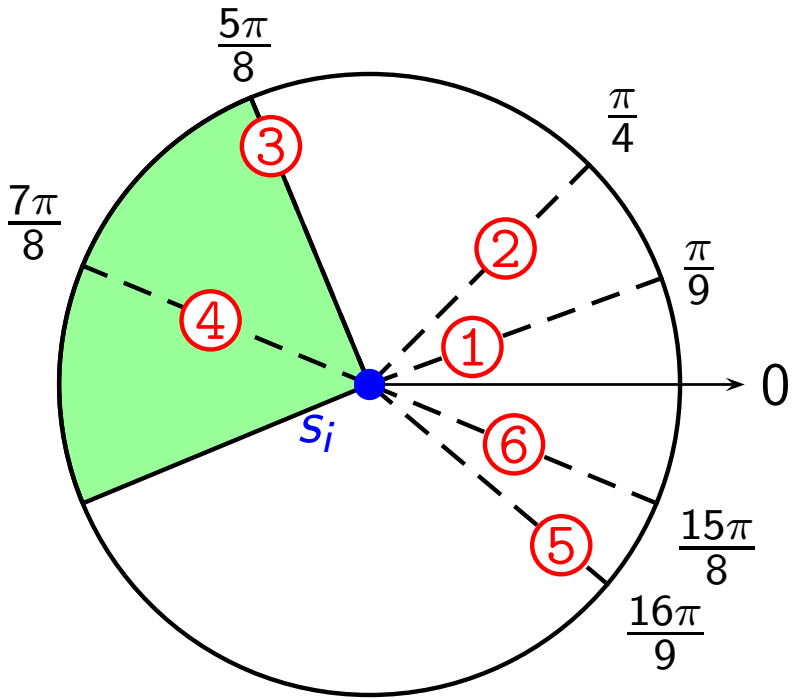

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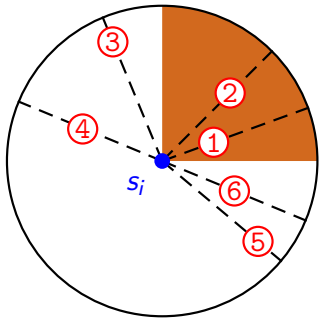
Directional sensor units

- A normalized direction is associated with each target



Non-normalized direction

- A (normalized) direction is dominated if the targets it covers are a proper subset of the targets covered by another direction

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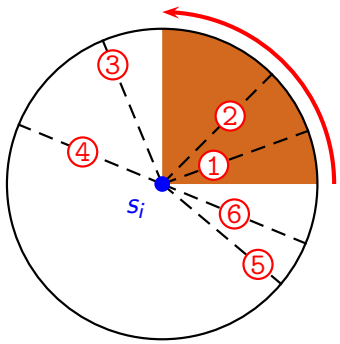

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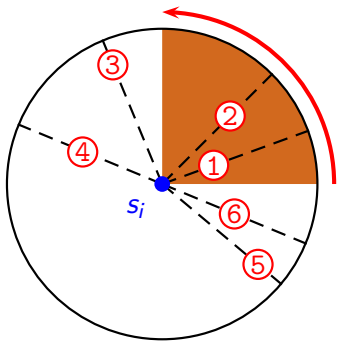

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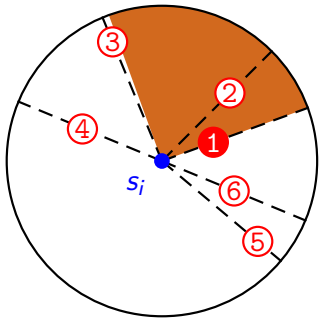

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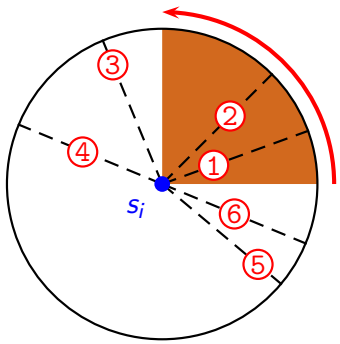

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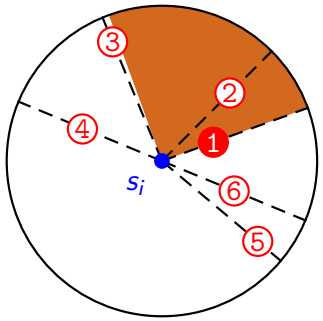

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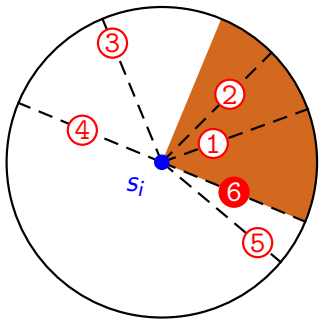

Dominated direction

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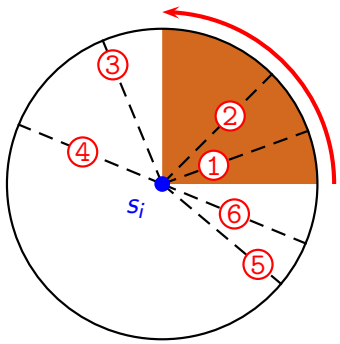

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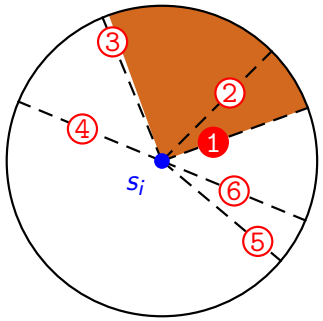

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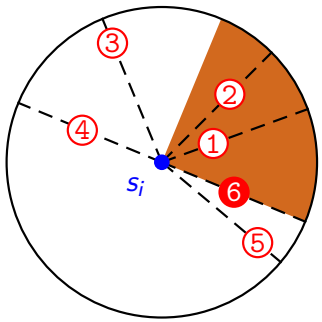

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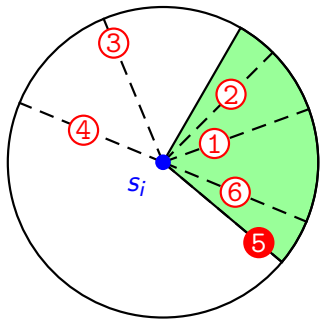
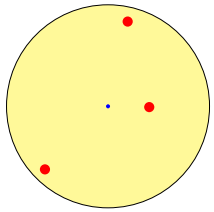


Non-dominated direction

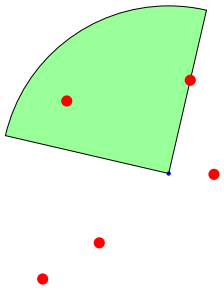
Group encoding

- Sensor nodes in N_1 are equipped with an omnidirectional sensor unit

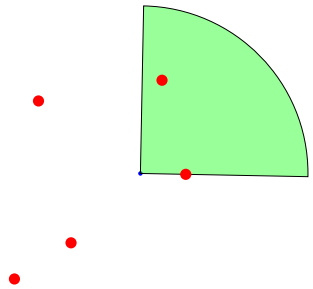


1

- Sensor nodes in N_2 are equipped with a single directional sensor unit

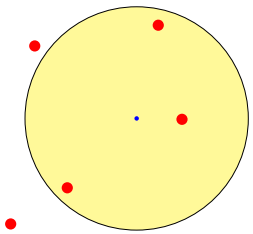


or



0
1
0
0

- Sensor nodes in N_{12} have both sensor units



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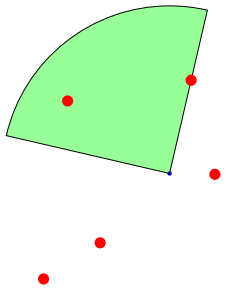

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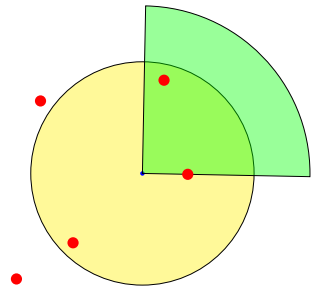


1
0
1
0
0

Group encoding

- Power consumption of node $i \in N_1$ (omnidirectional sensor)
  - $p_1 x_{i,j}$ where p_1 is the power consumption of an omnidirectional sensor
- Power consumption of node $i \in N_2$ (directional sensor)
  - $p_2 \sum_{q=1}^{\sigma_i} x_{g_i+q,j}$ with $\sum_{q=1}^{\sigma_i} x_{g_i+q,j} \leq 1$
    where p_2 is the power consumption of a directional sensor
- Power consumption of node $i \in N_{12}$ (omnidirectional and directional sensor)
  - $p_1 x_{g_i+1} + p_2 \sum_{q=2}^{\sigma_i} x_{g_i+q,j}$ with $\sum_{q=2}^{\sigma_i} x_{g_i+q,j} \leq 1$

Where σ_i is the number of modes under which node i can be used

Mathematical model

$$\text{Maximize} \quad \sum_{j=1}^{c} t_j \tag{1}$$

$$\sum_{j=1}^{c} \left(\sum_{q=1}^{\sigma_i} p_{g_i+q} x_{g_i+q,j} \right) t_j \leq b_i \quad \forall i \in \{1, \ldots, n\} \qquad [\pi_i] \tag{2}$$

$$t_j \geq 0 \qquad \forall j \in \{1, \ldots, c\} \tag{3}$$

$$\text{Maximize} \quad 1 - \sum_{i=1}^{n} \left(\sum_{q=1}^{\sigma_i} p_{g_i+q} x_{g_i+q,c+1} \right) \pi_i \tag{4}$$

$$1 \leq \sum_{i \in C_k^1} x_{i,c+1} \qquad \forall k \in \{1, \ldots, m\} \tag{5}$$

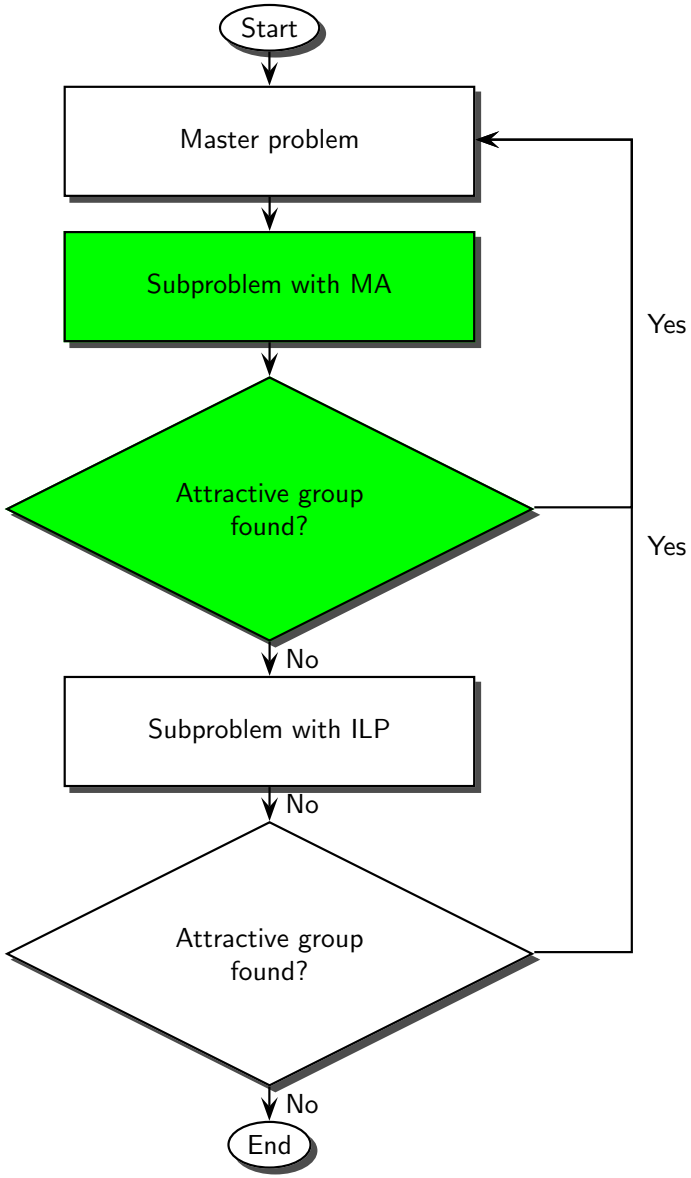
$$1 \leq \sum_{i \in C_k^2} x_{i,c+1} \qquad \forall k \in \{1, \ldots, m\} \tag{6}$$

$$x_{i,c+1} \in \{0, 1\} \qquad \forall i \in \{1, \ldots, g_n + \sigma_n\} \tag{7}$$

Global strategy of the column generation algorithm

- The subproblem is a difficult problem to be solved repeatedly
- A memetic algorithm is used for generating multiple groups at each iteration
- It is faster than solving the ILP formulation of the subproblem
- When no profitable group is found, the ILP is solved as a last resort method
- This is a hybrid exact approach

Global strategy of the column generation algorithm



Preliminary results

n_1	n_2	n_{12}	m	R_1	R_2	φ	LT	CPU
30	30	60	24	100	150	$\frac{\pi}{2}$	14.0333	5.65
30	30	60	24	100	150	$\frac{\pi}{4}$	13.8617	23.18
30	30	60	39	100	150	$\frac{\pi}{2}$	10.77	1.91
30	30	60	39	100	150	$\frac{\pi}{4}$	10.77	19.54
40	40	40	24	100	150	$\frac{\pi}{2}$	11.48	1.5
40	40	40	24	100	150	$\frac{\pi}{4}$	11.48	6.3
40	40	40	39	100	150	$\frac{\pi}{2}$	10.71	1.84
40	40	40	39	100	150	$\frac{\pi}{4}$	10.71	3.58
80	80	80	48	100	150	$\frac{\pi}{2}$	7.25	1.51
80	80	80	48	100	150	$\frac{\pi}{4}$	7.25	2.76
80	80	80	79	100	150	$\frac{\pi}{2}$	9.94	3.63
80	80	80	79	100	150	$\frac{\pi}{4}$	9.94	6.02

Preliminary results

- The memetic algorithm accelerates convergence significantly
- Except when $n_1 = 30$, the lifetime in our instances is limited by the omnidirectional coverage requirement
- Problem is more difficult to solve when φ is small
- For very large networks, the proposed approach can be turned into a heuristic by stopping when the memetic algorithm does not find any profitable group

Conclusion and future works

- Sensor nodes with multiple nodes can be handled efficiently
- Work is still under progress
- More than 2 sensor units
- Consumption profiles
- Adjustable sensing/communication ranges
- Partial coverage
- Multi-hop communication