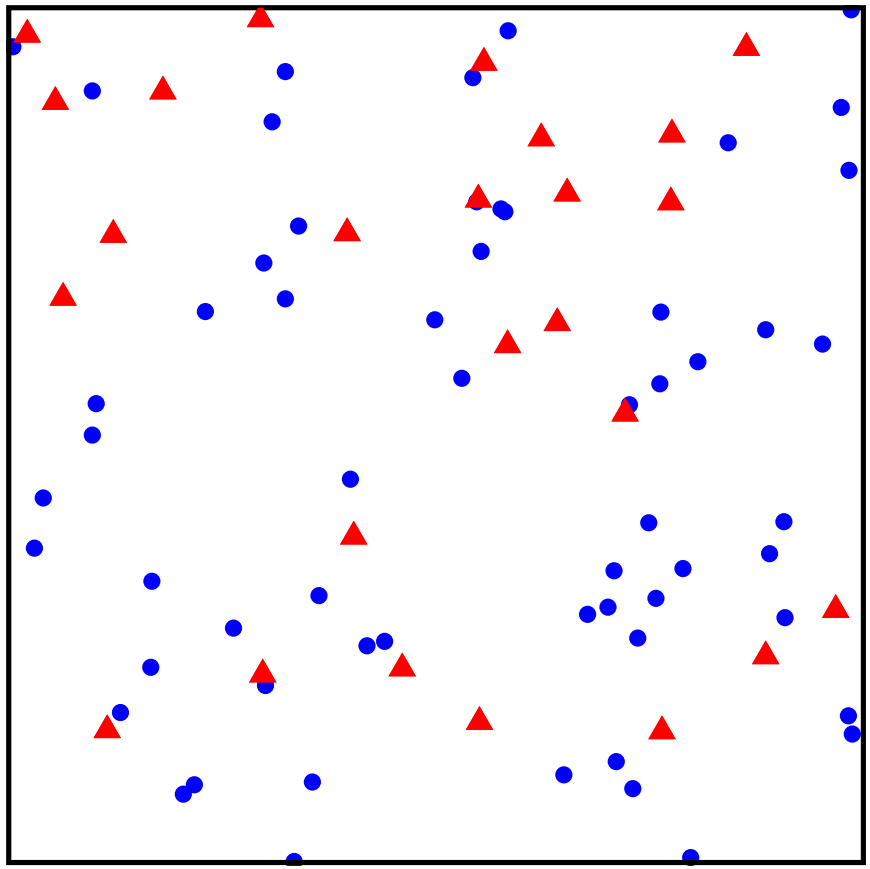
Contents

Our current problem

α-CMLP

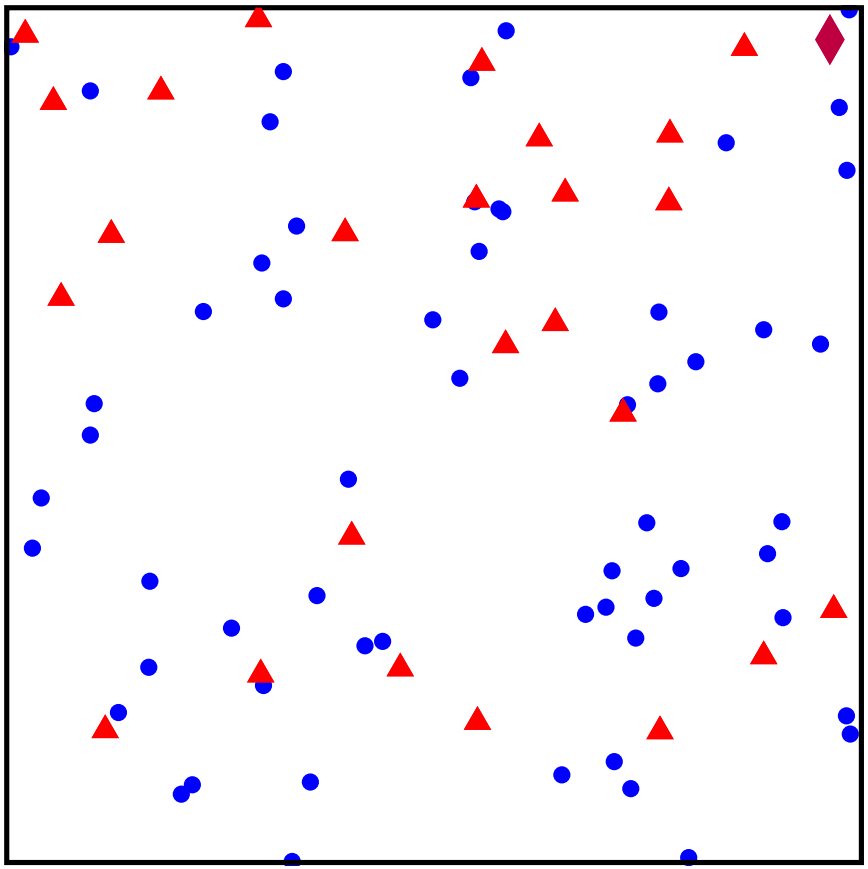
- set of targets and sensors



Our current problem

α-CMLP

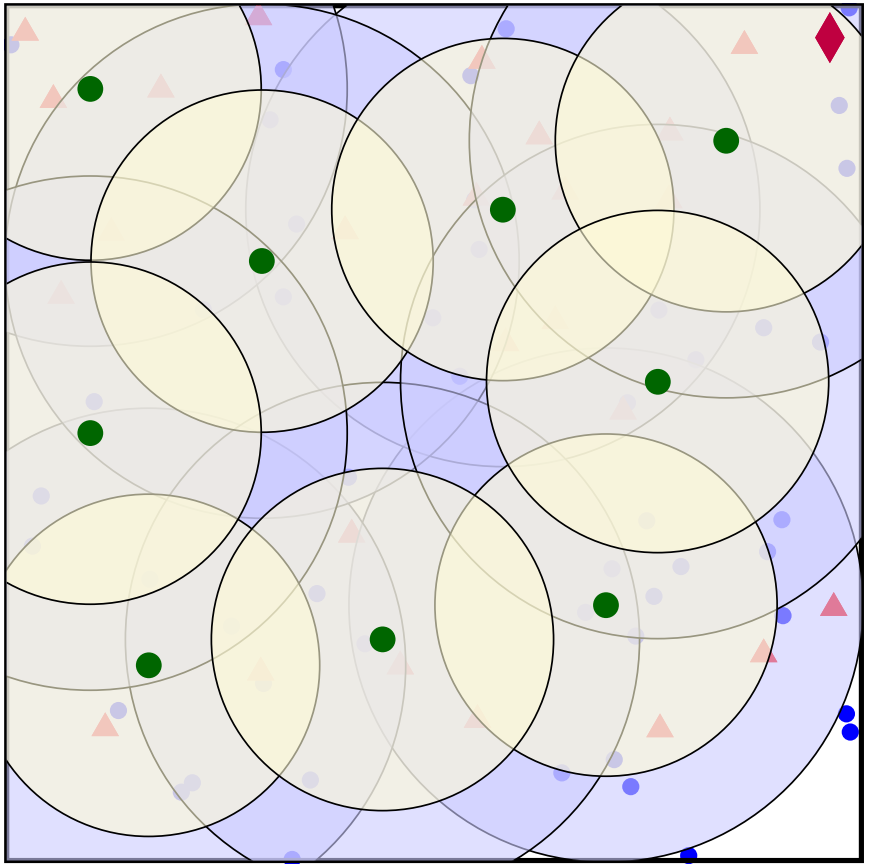
- set of targets and sensors
- base station



Our current problem

α-CMLP

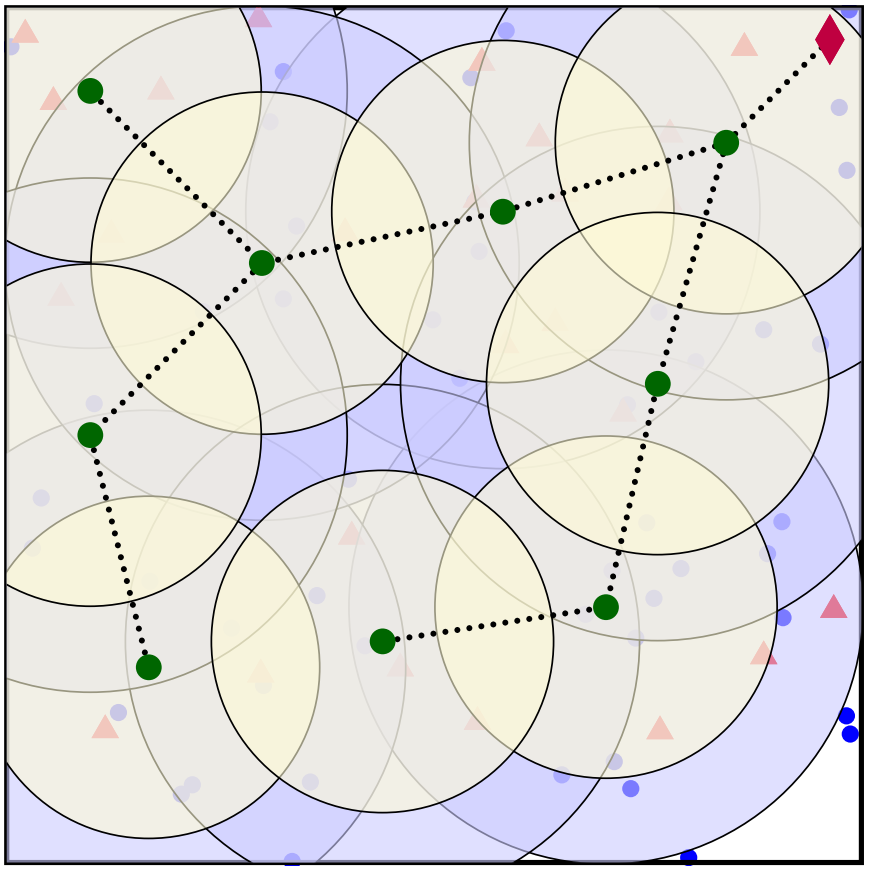
- set of targets and sensors
- base station
- activated sensors



Our current problem

α-CMLP

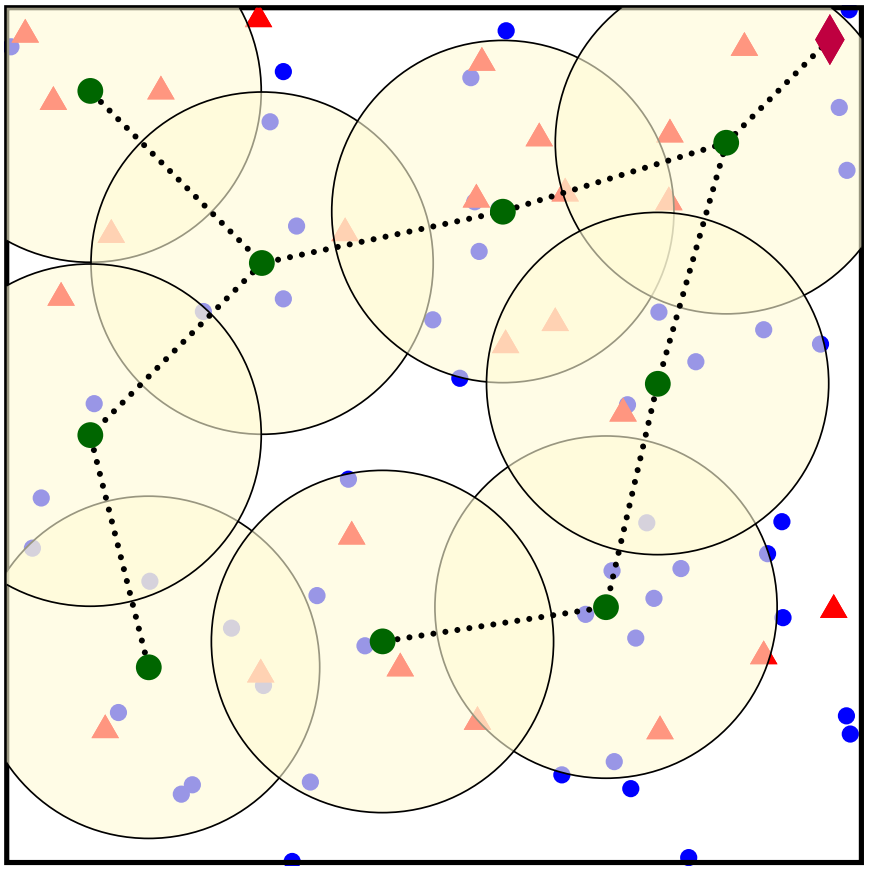
- set of targets and sensors
- base station
- activated sensors
- communication links



Our current problem

α-CMLP

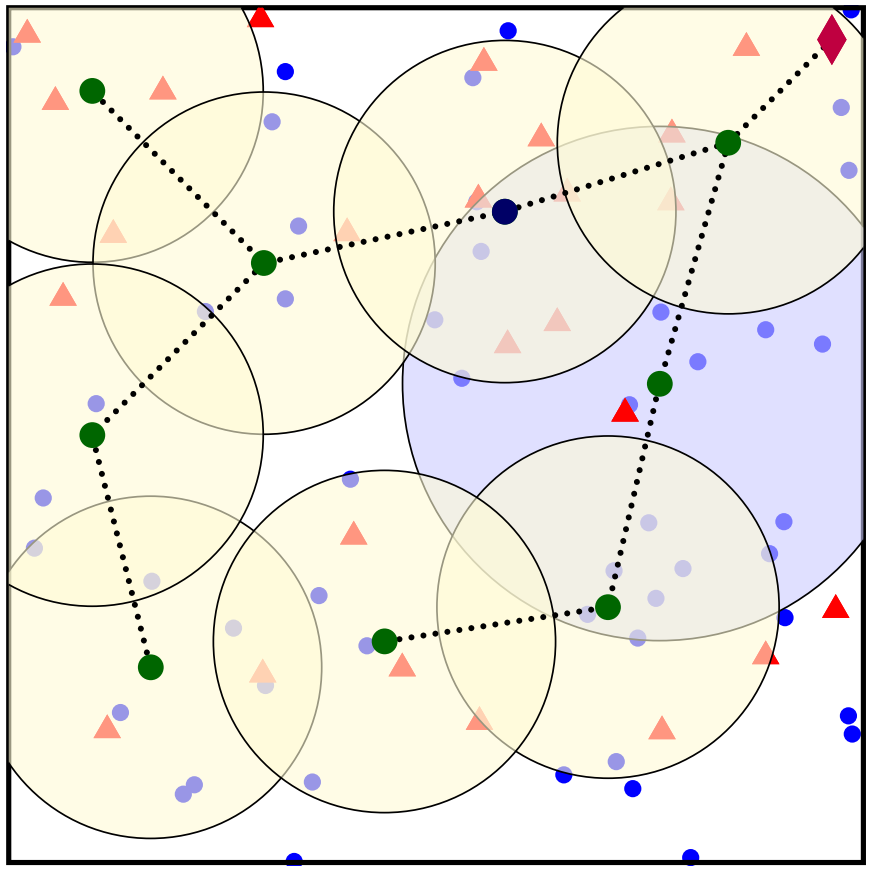
- set of targets and sensors
- base station
- activated sensors
- communication links
- α-coverage



Our current problem

α-CMLP-MR

- set of targets and sensors
- base station
- activated sensors
- communication links
- α-coverage
- some sensors can be used for communication only!

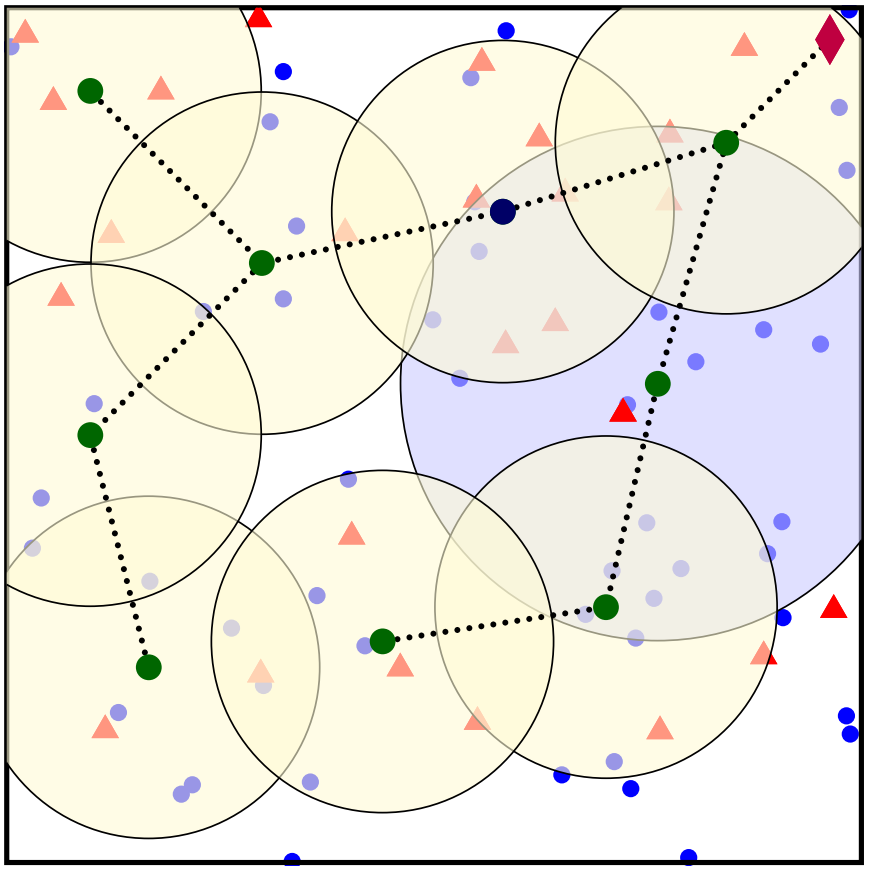


Our current problem

α-CMLP-MR

- set of targets and sensors
- base station
- activated sensors
- communication links
- α-coverage
- some sensors can be used for communication only!

We are now looking for subsets of active sensors and their role



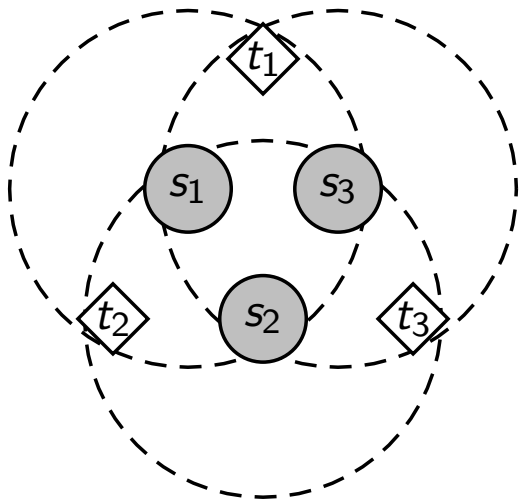
Covers

Definition (Cover)

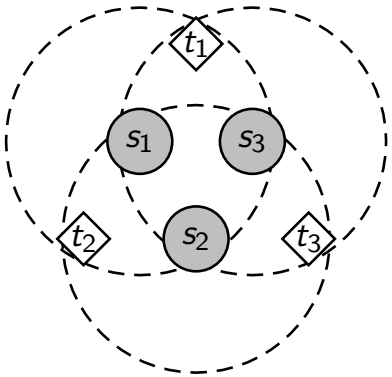
A cover is a subset of sensors used at the same time for covering a subset of targets

Examples:

- cover $\{s_1\}$ covers t_1 and t_2
- cover $\{s_1, s_2\}$ covers all the targets
- cover $\{s_1, s_3\}$ also covers all the targets

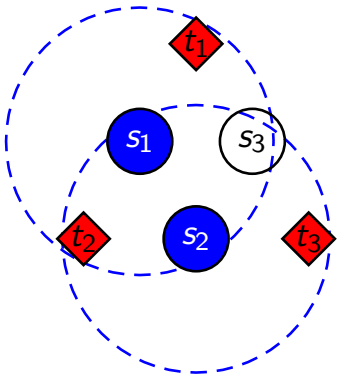


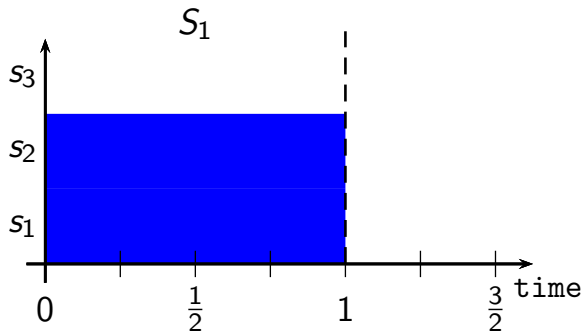
Scheduling the covers (disjoint covers)



In that small example, we have 3 covers $S_1 = \{s_1, s_2\}$, $S_2 = \{s_1, s_3\}$ and $S_3 = \{s_2, s_3\}$ that cover all the targets

Continuous use of covers (disjoint covers)



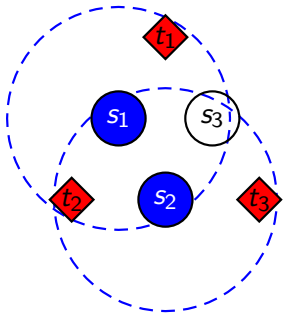


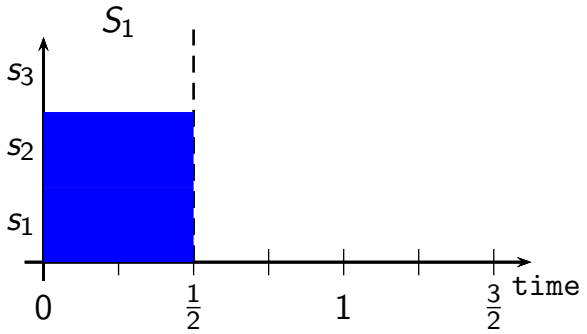
Battery depleted for s_1 and s_2, other covers cannot be used.

If we want to cover **all the targets** with disjoint covers, maximum network lifetime is equal to 1

Scheduling the covers (non-disjoint covers)

Sequentially use $\{s_1, s_2\}$, $\{s_1, s_3\}$ and $\{s_2, s_3\}$ for 0.5 units of time each





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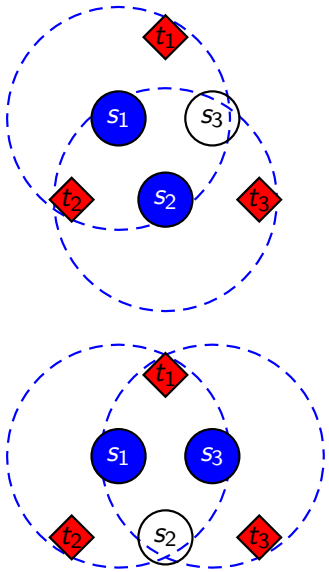

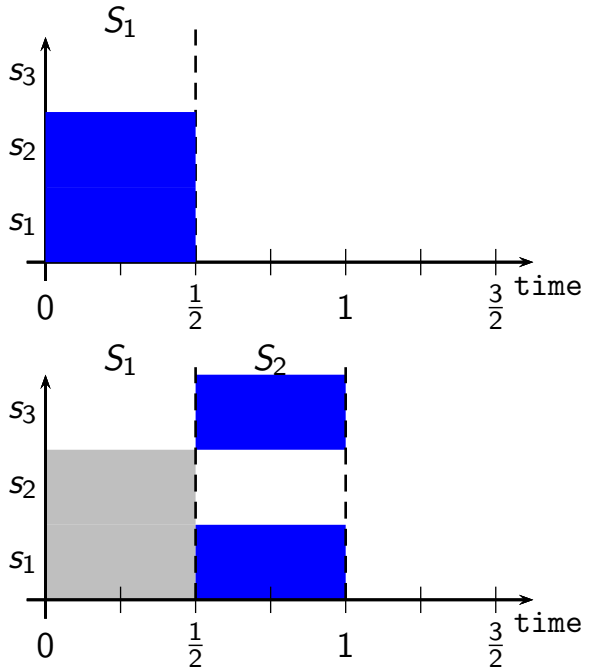

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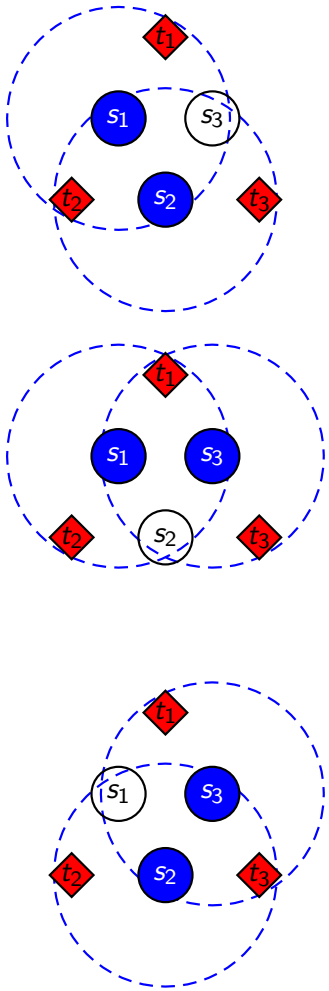
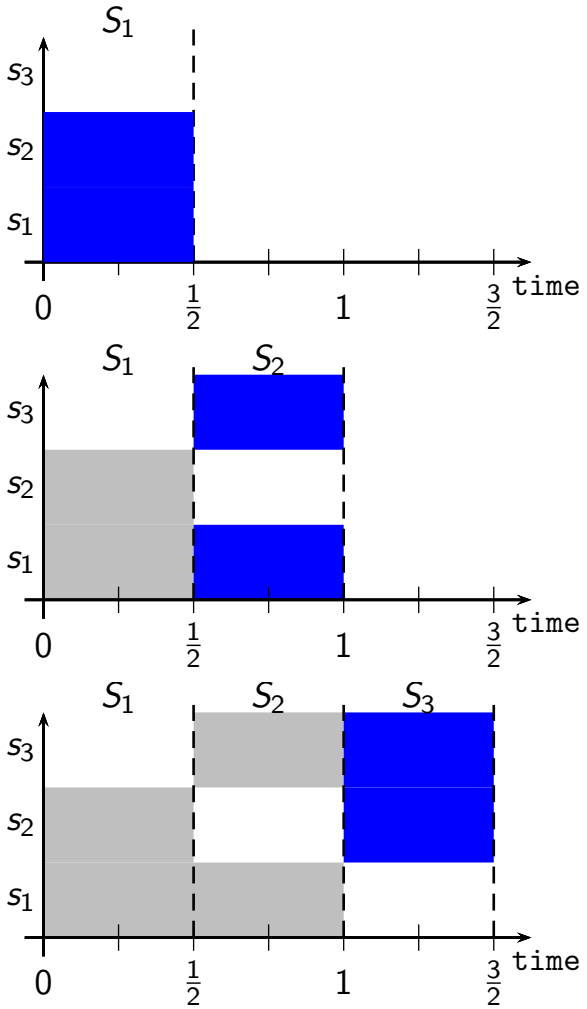
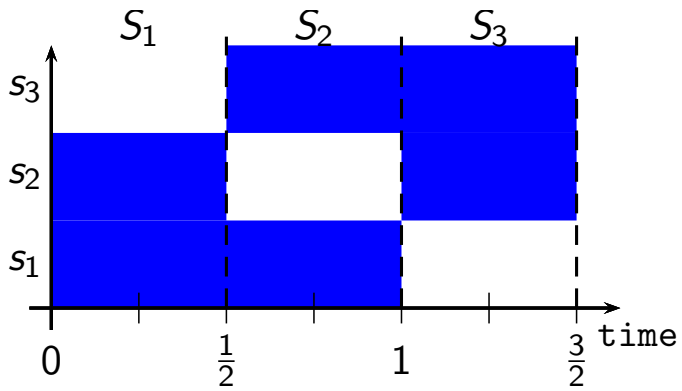
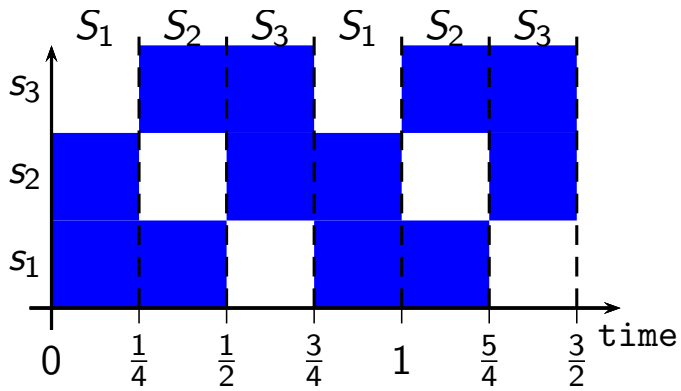




Scheduling the covers

Different schedules can conduct to equivalent solutions





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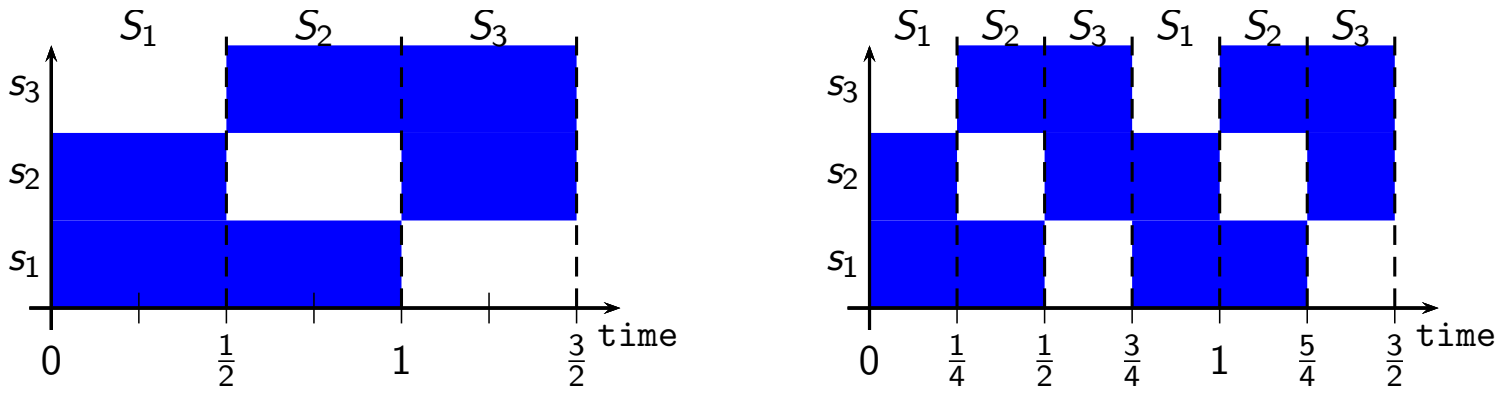


Questions:

- How can we find these covers?
- How long are we going to use them?

A very simple model

If we know how to build the covers, α-CMLP-MR is simply formulated by:

General LP model

$$\text{Maximize:} \quad \sum_{j|C_j \in \Omega} t_j$$

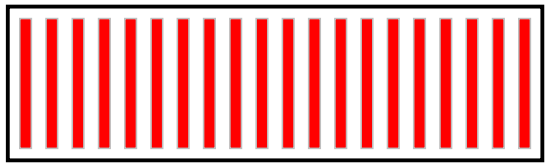
$$\sum_{j|C_j \in \Omega} (E_{s_v}) t_j \leq \beta_{s_v} \qquad \forall\ s_v \in S$$

$$t_j \geq 0 \qquad \forall\ j|C_j \in \Omega$$

A simple model, but...

Remarks:

- Too many columns
  15 sensors $\approx$ 14 million columns



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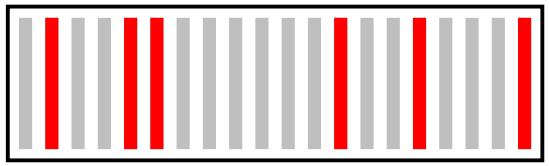
- Few columns are useful
  15 sensors: at most 15 columns



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- Strategy: generate them on the fly

A simple model, but...

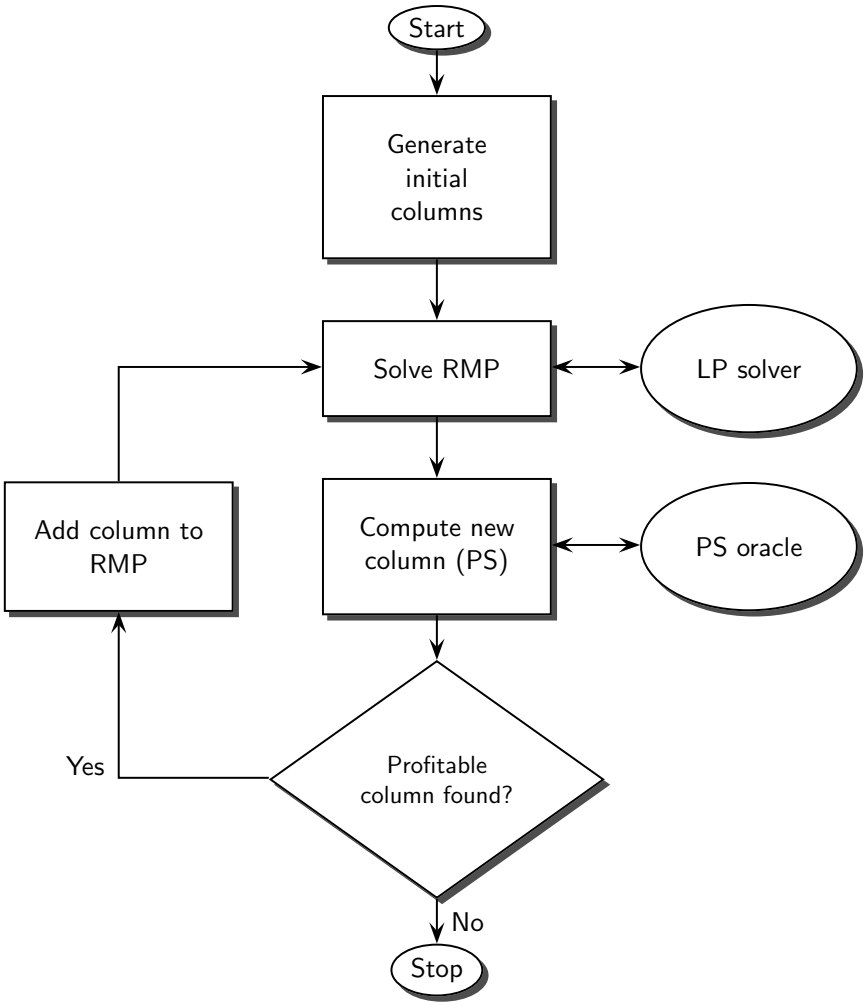
Remarks:

- Too many columns
  15 sensors $\approx$ 14 million columns
- Few columns are useful
  15 sensors: at most 15 columns
- Strategy: generate them on the fly

Solution approach

Column generation is a natural approach to solve the problem

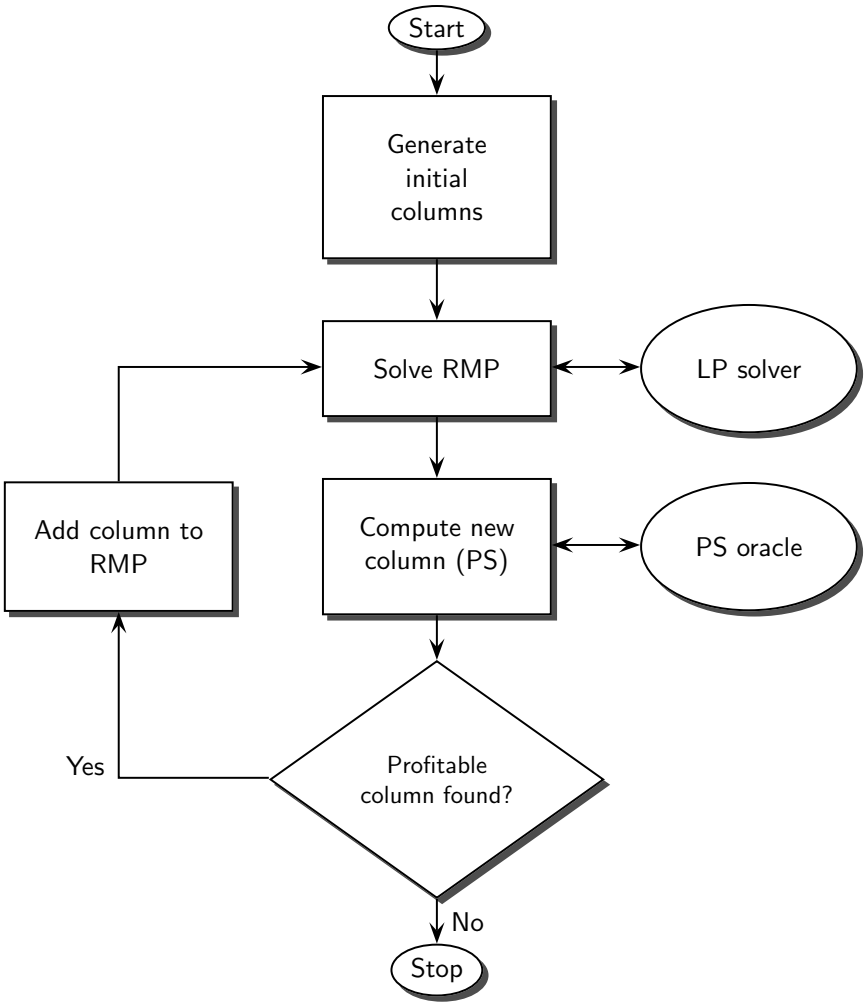
Principle of column generation approaches (CG)



Master Problem (RMP)

Maximizes network lifetime for the available set of columns

Principle of column generation approaches (CG)



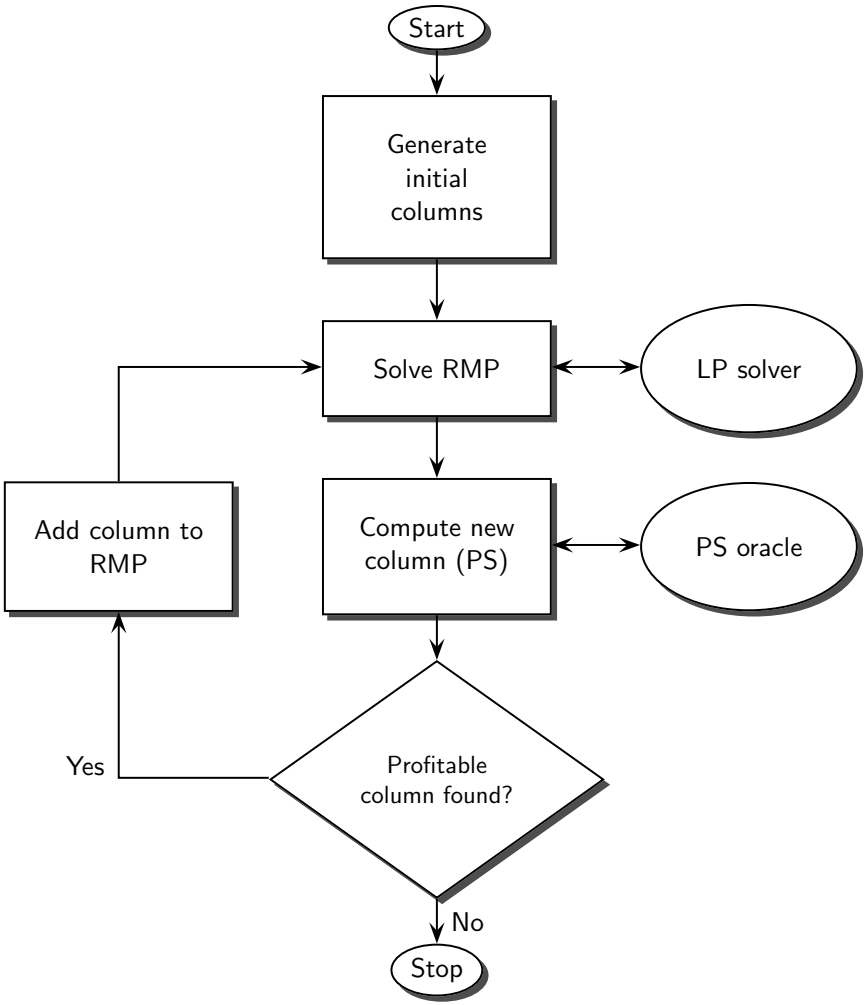
Master Problem (RMP)

Maximizes network lifetime for the available set of columns

Pricing Subproblem (PS)

Identifies new columns that can help to extend lifetime

Principle of column generation approaches (CG)



Master Problem (RMP)

Maximizes network lifetime for the available set of columns

Pricing Subproblem (PS)

Identifies new columns that can help to extend lifetime

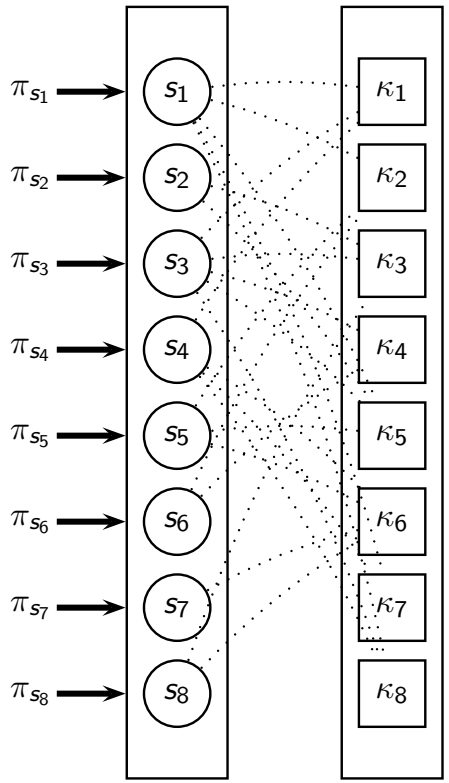
Performance might be poor...

- PS implementation issues
- Heading-in effect
- Tail-off effect

Solving the pricing subproblem

Data

- π_{s_i}: Dual variable value associated to battery constraint for sensor s_i



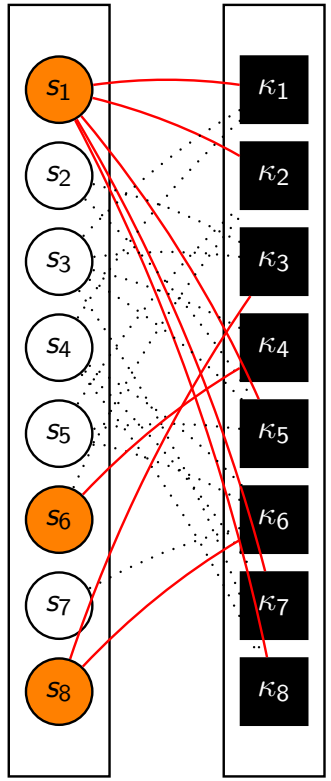
Solving the pricing subproblem

Decision variables

- sensor activity
  - $y_{s_i} \in \{0, 1\}$

Objective

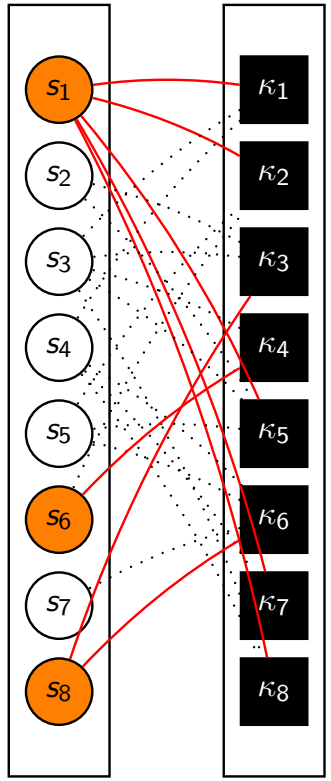
- Min: $\sum_{s_i \in \mathcal{S}} y_{s_i} \pi_{s_i}$
- Identify a subset of sensors with interesting reduced cost



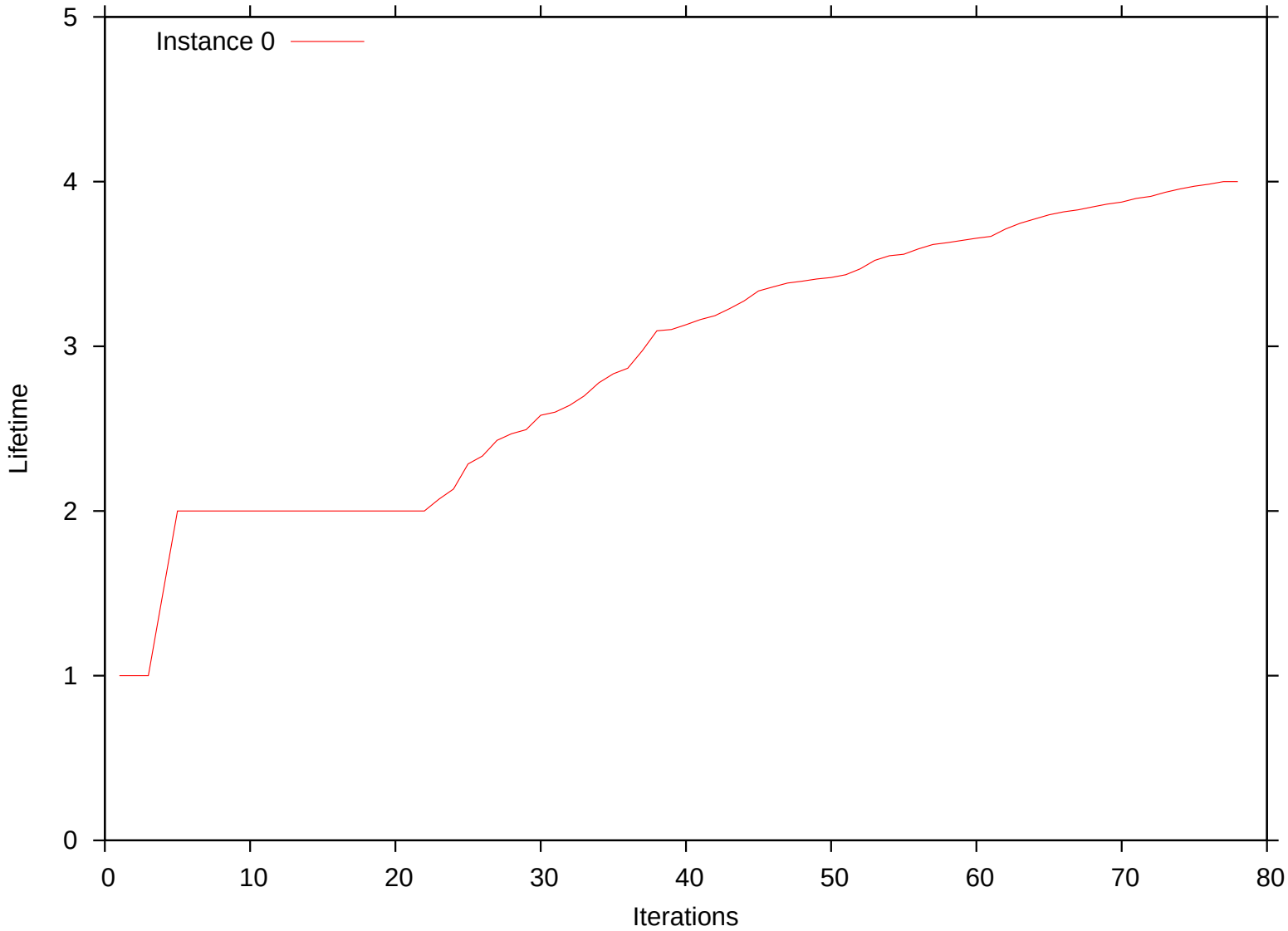
Solving the pricing subproblem

Remarks

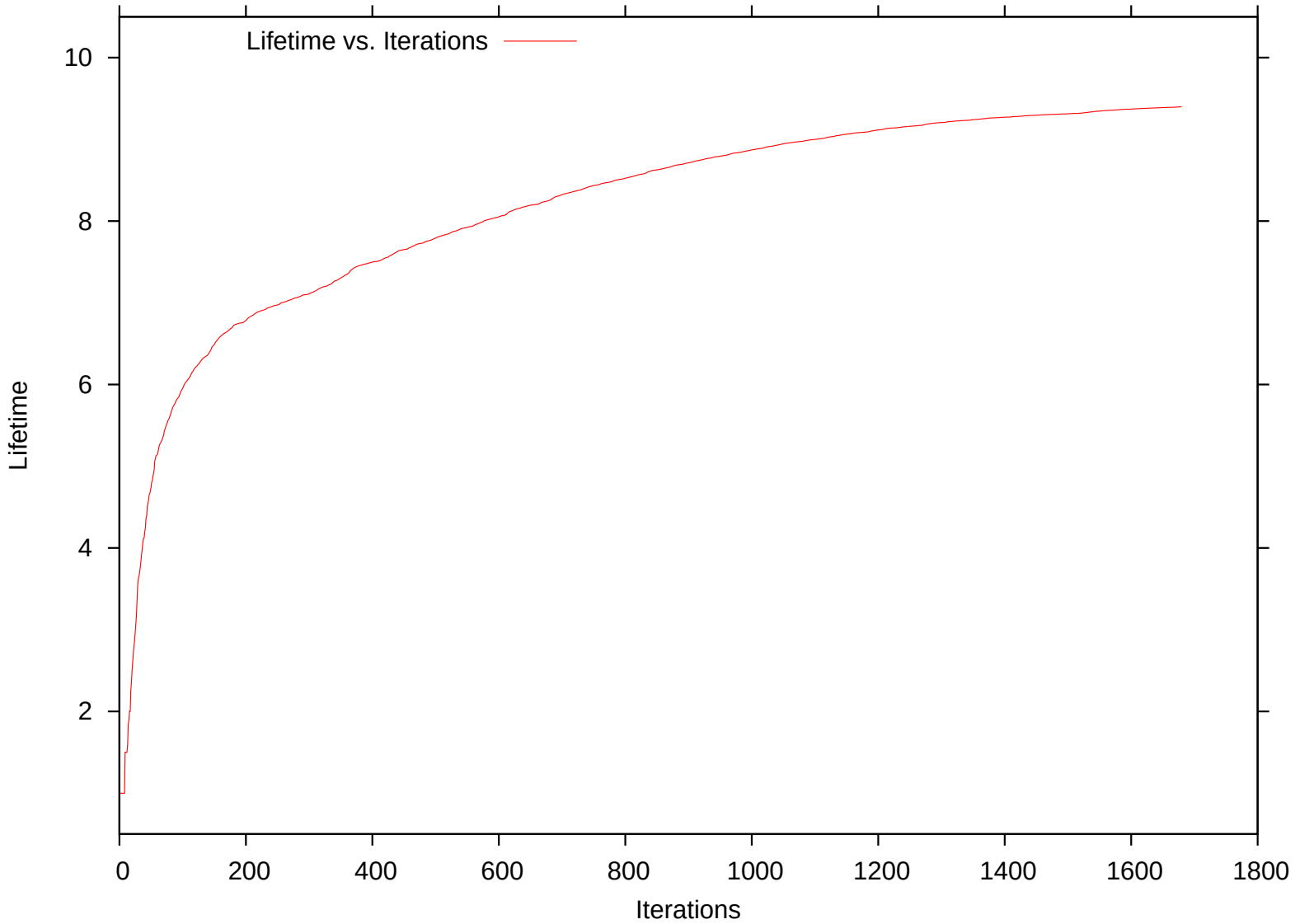
- Weighted set covering NP-Hard
- One column per iteration
- Approximations lead to premature convergence



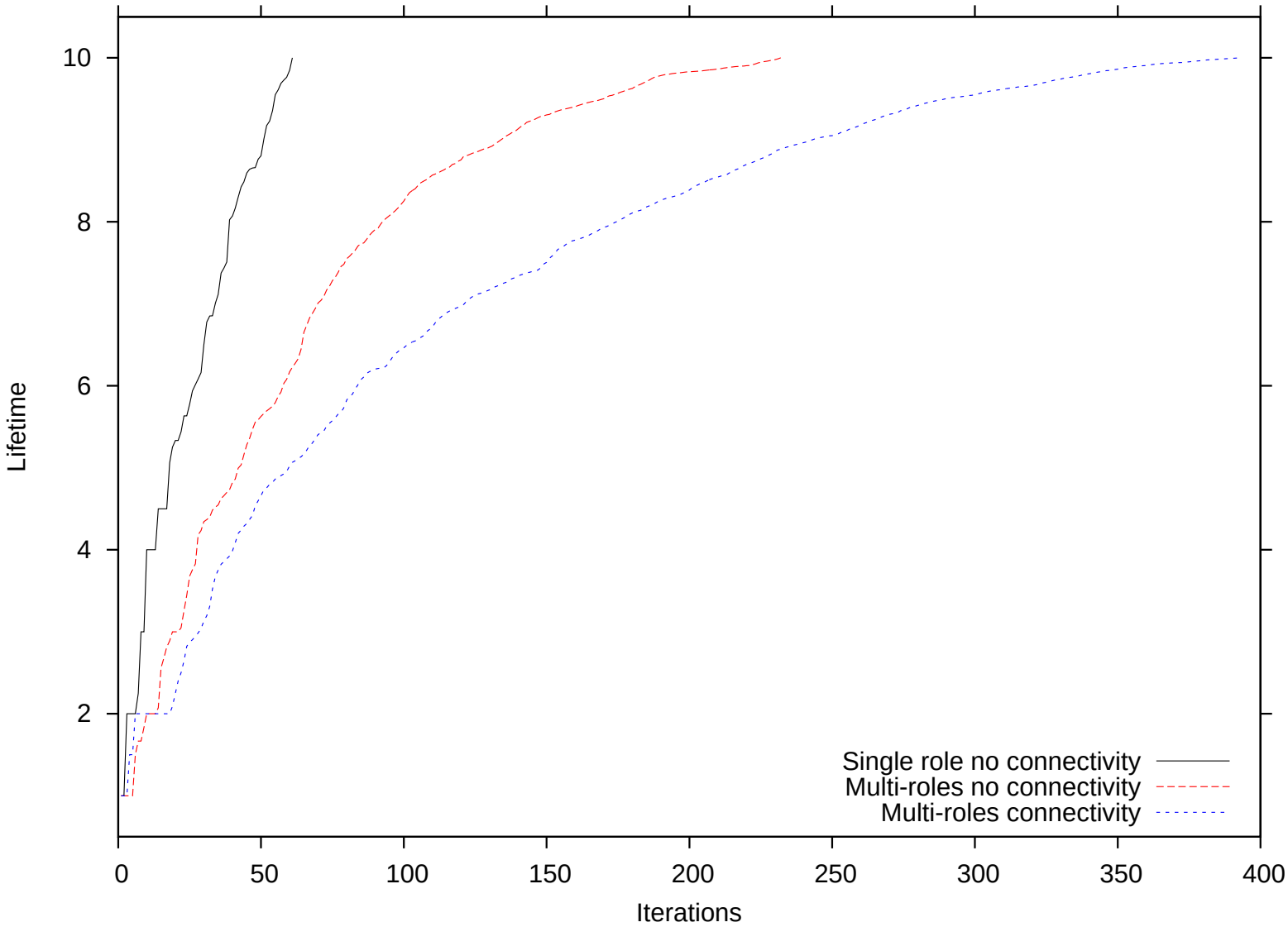
Heading-in effect



Tail-off effect



Tail-off effect



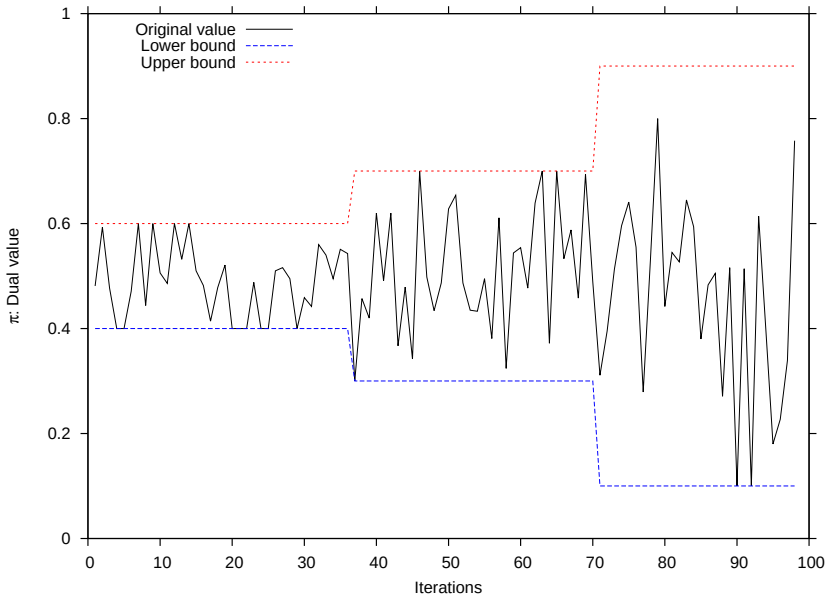
Improvements – Stabilization

Classical stabilization strategies are explored

Stabilized CG

Manage dual variables:

- Dual variable stabilization
- Dual variable smoothing



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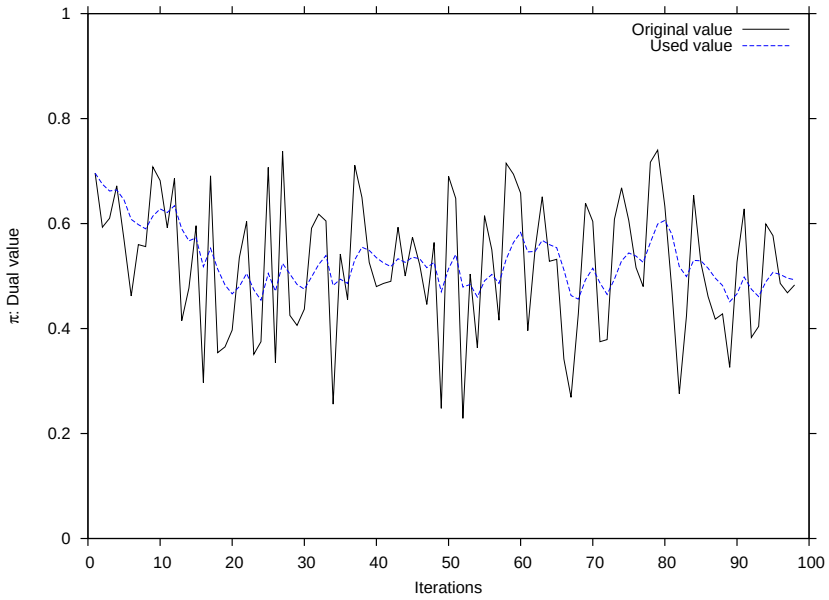

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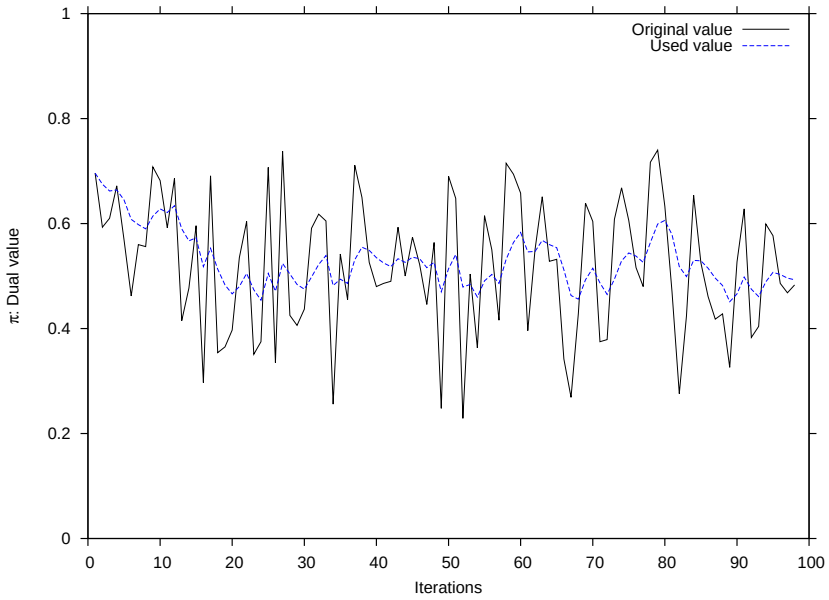


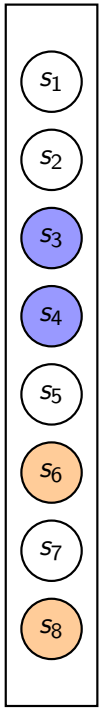
Nice, but not very efficient. . .

Improvements – Intensification & diversification

Metaheuristics are used to intensify/diversify the search

Intensification

- GRASP
- VNS



Improvements – Intensification & diversification

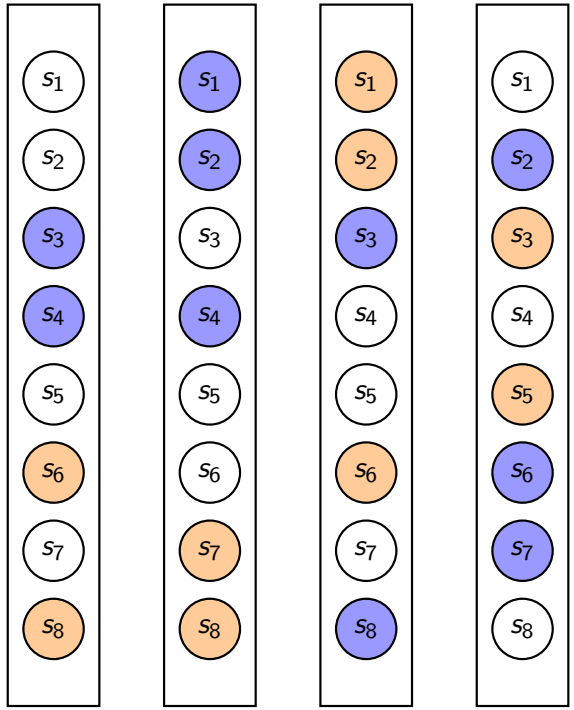
Metaheuristics are used to intensify/diversify the search

Intensification

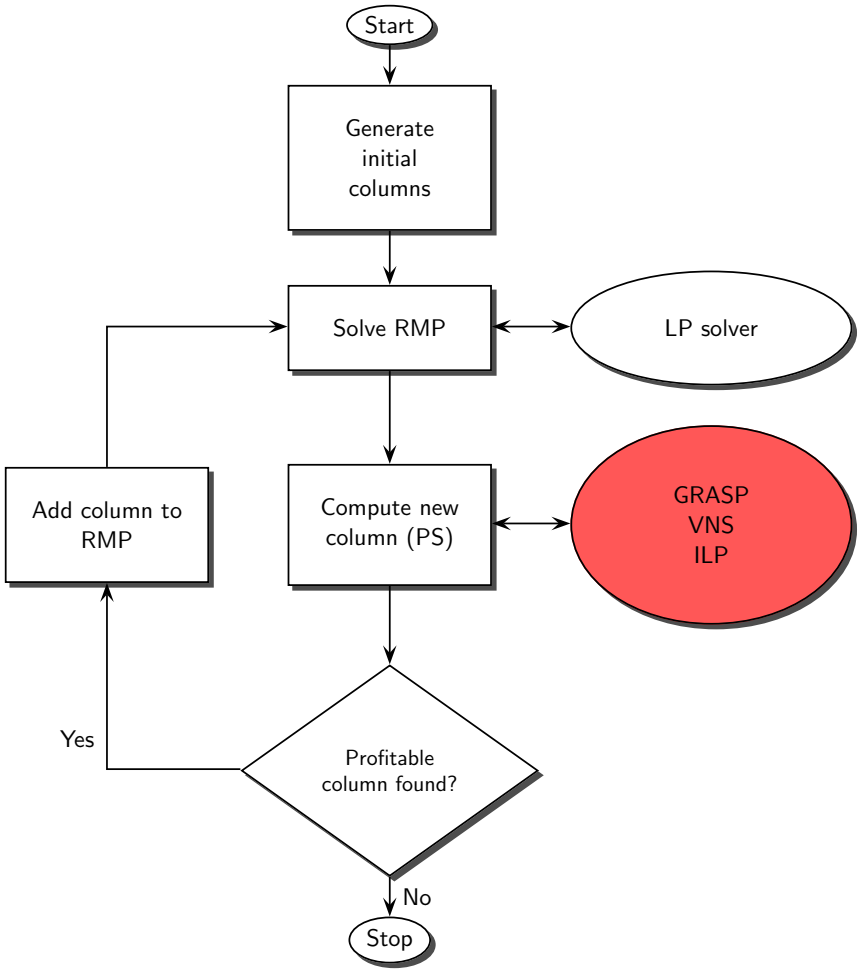
- GRASP
- VNS
- Evolutionary algorithms

Diversification

- Return multiple profitable columns



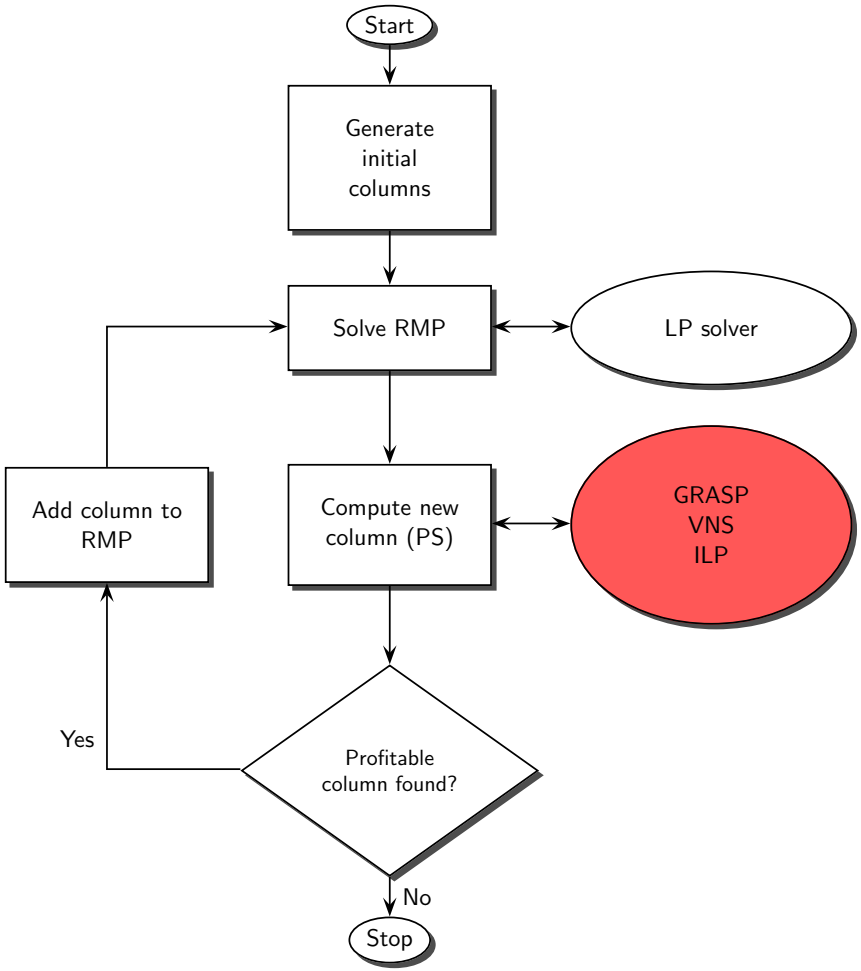
A new matheuristic framework



GRASP

Set covering with relaxed connectivity constraints + repair

A new matheuristic framework



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VNS

Considering connectivity and coverage constraints

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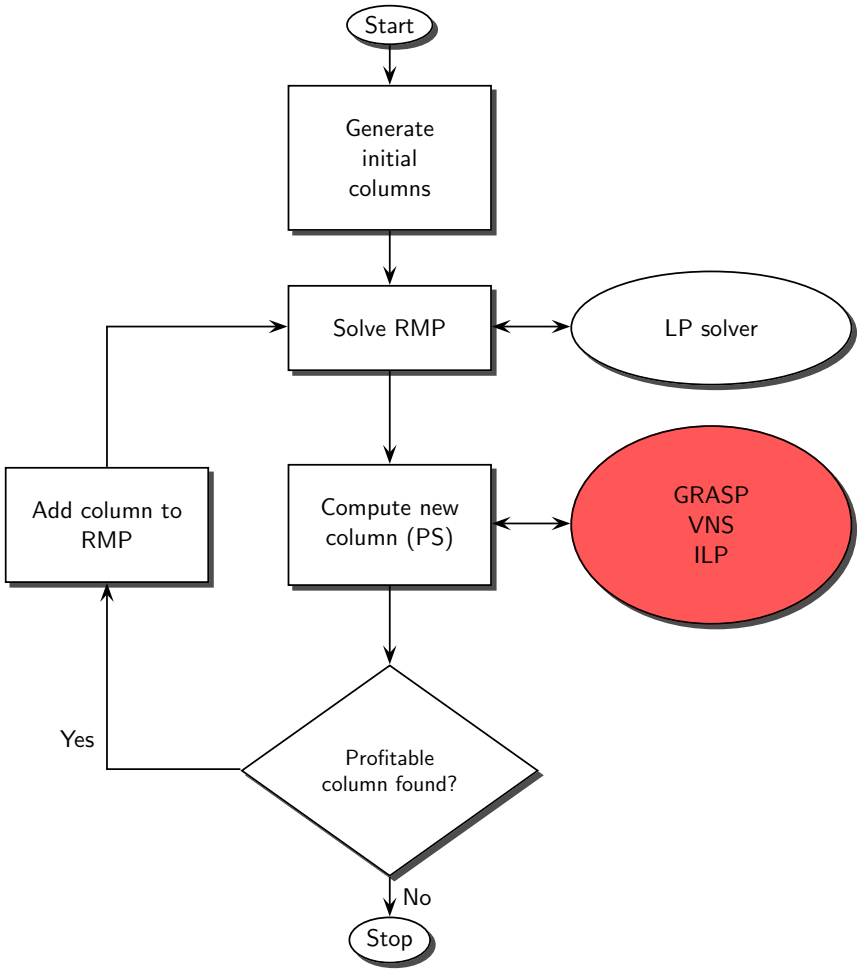


GRASP

Set covering with relaxed connectivity constraints + repair

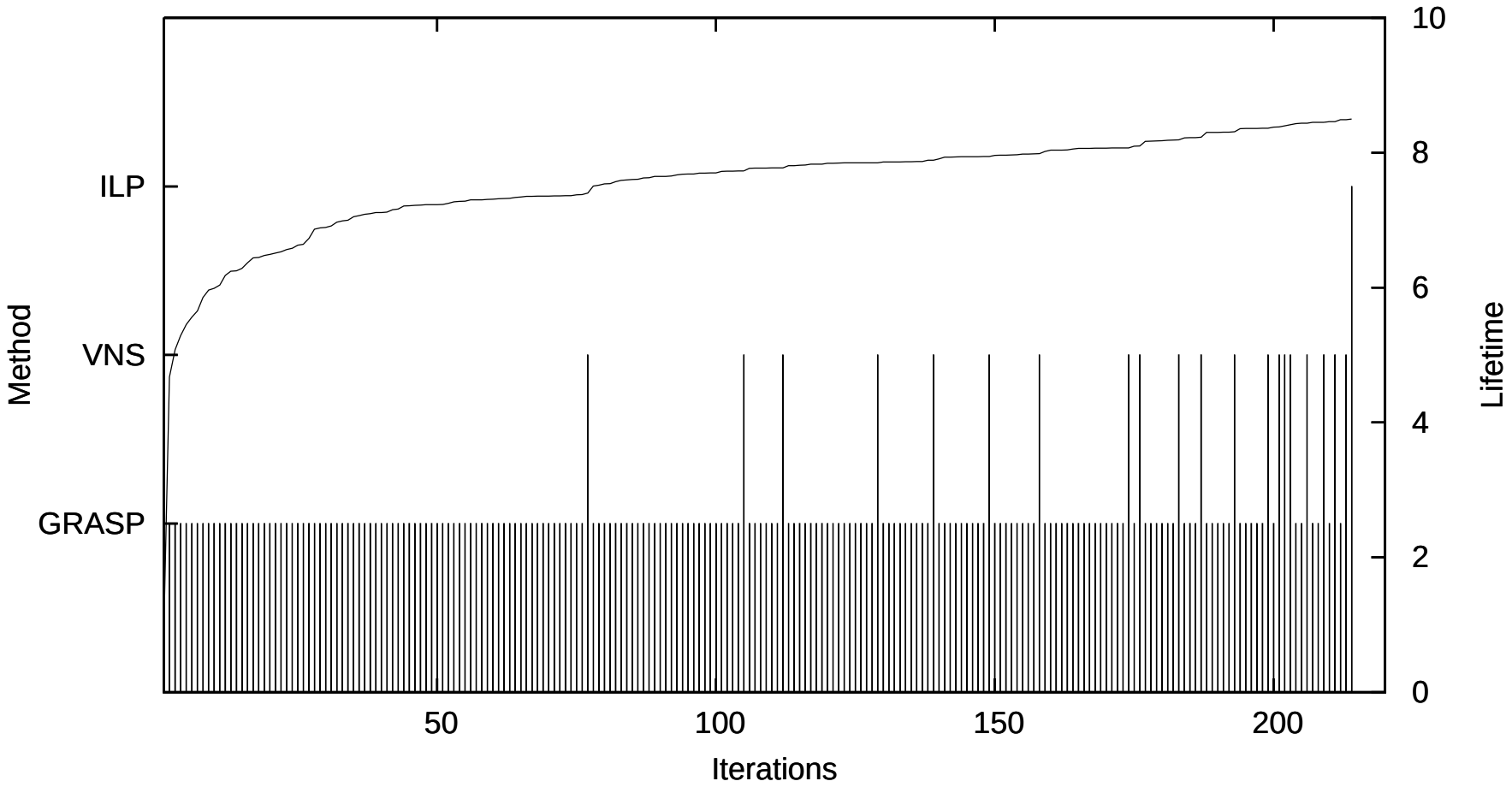
VNS

Considering connectivity and coverage constraints

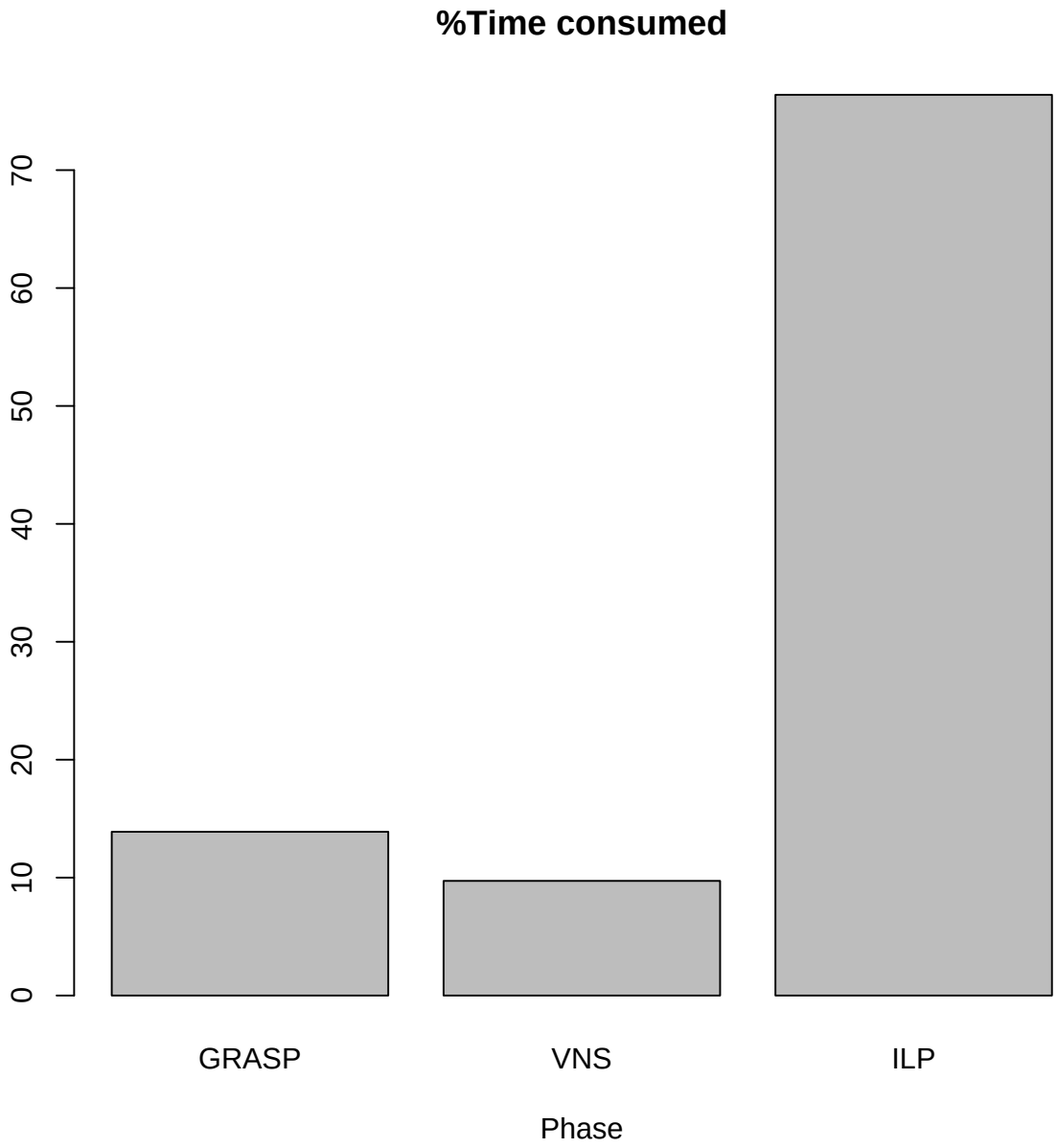
ILP solver

Used to check optimality or discover difficult columns

Results


Method
ILP
VNS
GRASP
Iterations
50
100
150
200
Lifetime
0
2
4
6
8
10

Results



Other techniques and variants

Techniques used for the pricing subproblem

- Evolutionary algorithm – find quickly several columns
- Constraint Programming – prove optimality
  use specific tree variables and propagation

Other techniques and variants

Techniques used for the pricing subproblem

- Evolutionary algorithm – find quickly several columns
- Constraint Programming – prove optimality
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Variants of the problem

- Multiple base stations
- Irregular shapes
- Directional sensors
- Obstacles
- Area coverage

Publications

A. Rossi, A. Singh, and M. Sevaux.

Column generation algorithm for sensor coverage scheduling under bandwidth constraints.
Networks, 60(3):141–154, 2012.

A. Rossi, A. Singh, and M. Sevaux.

An exact approach for maximizing the lifetime of sensor networks with adjustable sensing ranges.
Computers and Operations Research, 39(12):3166–3176, 2012.

A. Rossi, A. Singh, and M. Sevaux.

Lifetime maximization in wireless directional sensor network.
European Journal of Operational Research, 231(1):229–241, 2013.

A. Singh, A. Rossi, and M. Sevaux.

Matheuristic approaches for Q-coverage problem versions in wireless sensor networks.
Engineering Optimization, 45(5):609–626, 2013.

F. Castaño, A. Rossi, M. Sevaux, and N. Velasco.

A column generation approach to extend lifetime in wireless sensor networks with coverage and connectivity constraints.
Computers and Operations Research, 52(B):220–230, 2014.

F. Castaño, E. Bourreau, N. Velasco, A. Rossi, and M. Sevaux.

Exact approaches for lifetime maximization in connectivity constrained wireless multi-role sensor networks.
European Journal of Operational Research, 241(1):28–38, 2015.

M. Sevaux, M. Vecchio, and A. Bounceur, editors.
Special issue on Algorithms for Wireless Sensor Networks, volume x of *Algorithms*.
MDPI, 2015. Available online.

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Two important references

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Contents

Demo CupCarbon

www.cupcarbon.org

Launch the demo movie, if it works!!!

Contents

Conclusions and perspectives

Our matheuristic framework

- is well suited for WSN lifetime maximization
- can adapt to many variants
- is fully customisable

And after...

- combination of all variants?
- moving targets ($\rightarrow$ target tracking)
- moving sensors
- full integration in cup-carbon

And now, what's next?

UAV for professionals and for all

And now, what's next?

UAV for professionals and for all

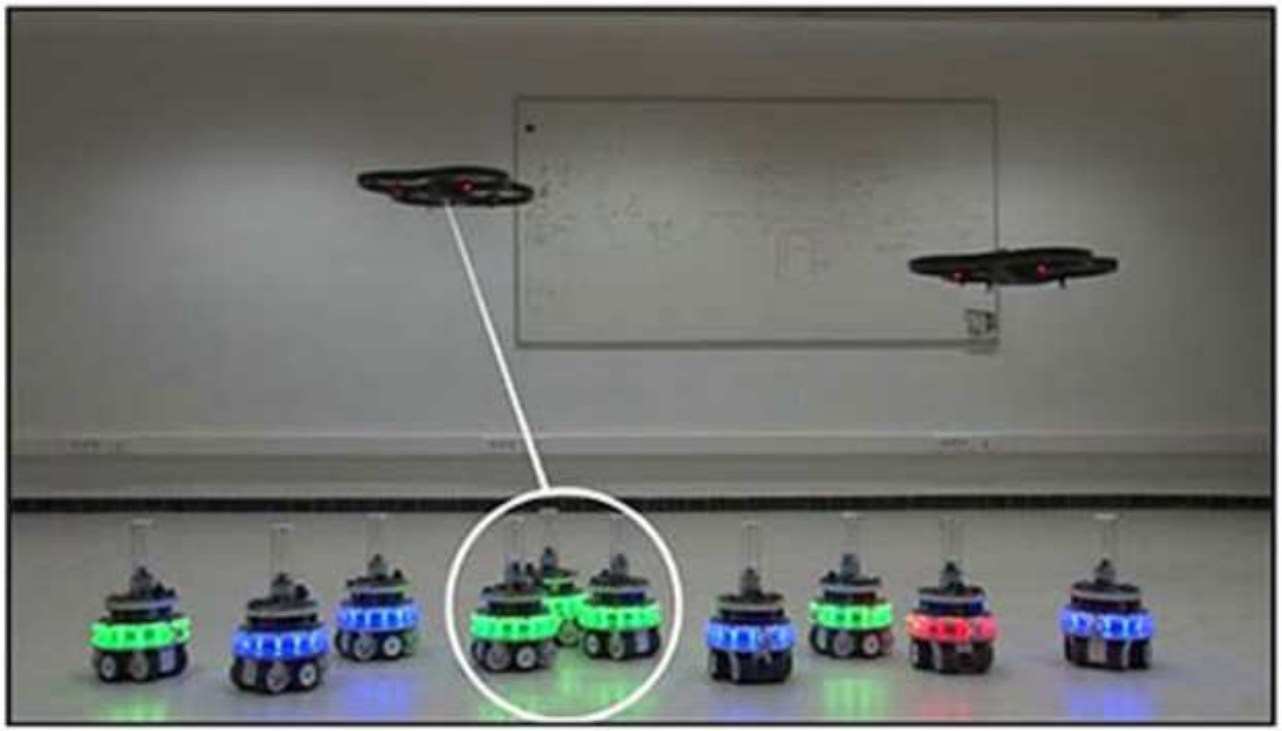
And now, what's next?

UAV for professionals and for all

And now, what's next?

UAV for professionals and for all

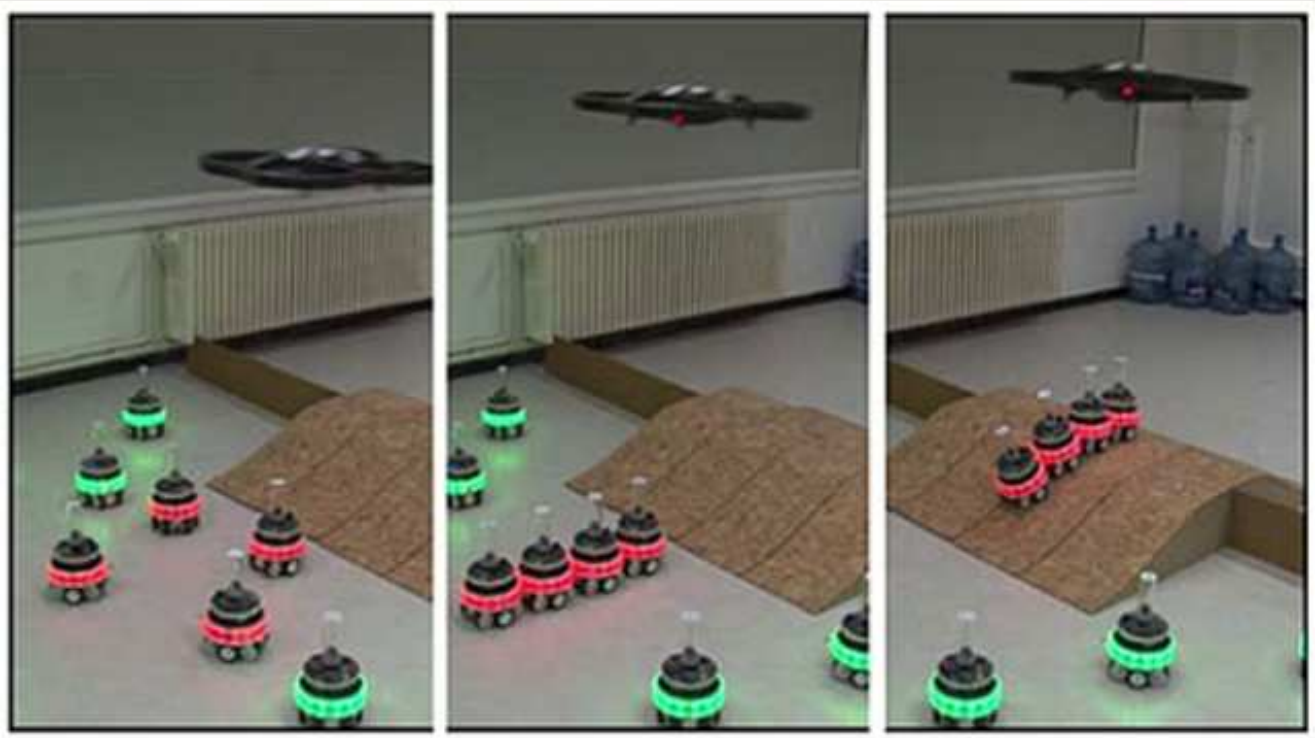
Cooperation among robots and UAV



And now, what's next?

UAV for professionals and for all

Cooperation among robots and UAV



And now, what's next?

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UAV Swarms

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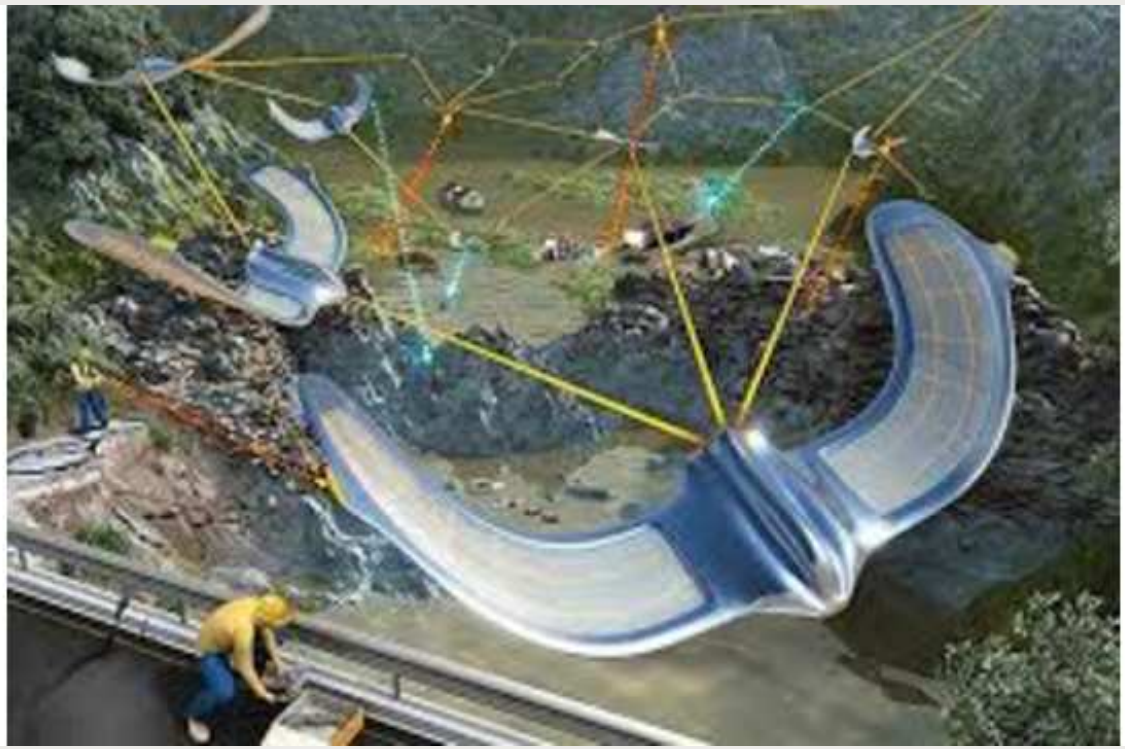
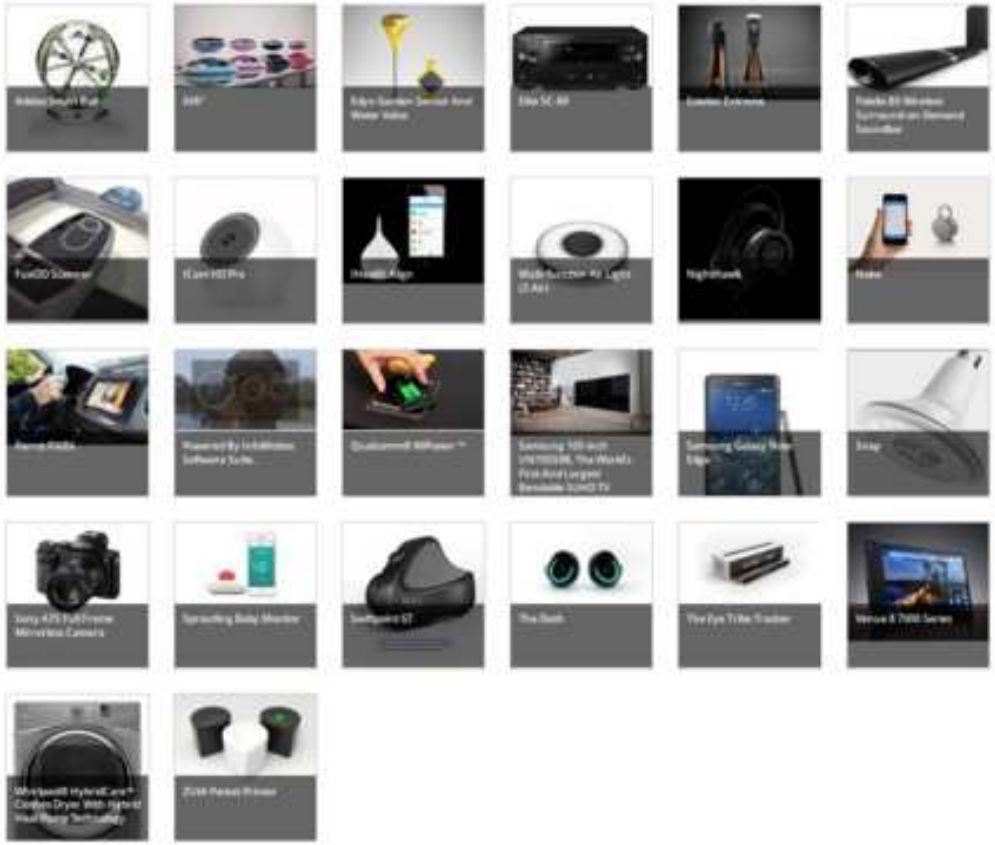


Are we aware?[1]

[1] Quote from a famous Belgian actor!

Are we aware?[1]

Among the 19 categories for innovation, 10 are related to sensors, wireless sensors or wireless sensor networks. . .



[1] Quote from a famous Belgian actor!

Wireless Sensor Networks

A survey on maximizing lifetime in sensor coverage problems

Marc Sevaux

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February 5, 2015