Bernabé Dorronsoro
Patricia Ruiz

bernabe.dorronsoro@uca.es
www.bernabe.dorronsoro.es
patricia.ruiz@uca.es
patriciaruiz.es

Universidad de Cádiz

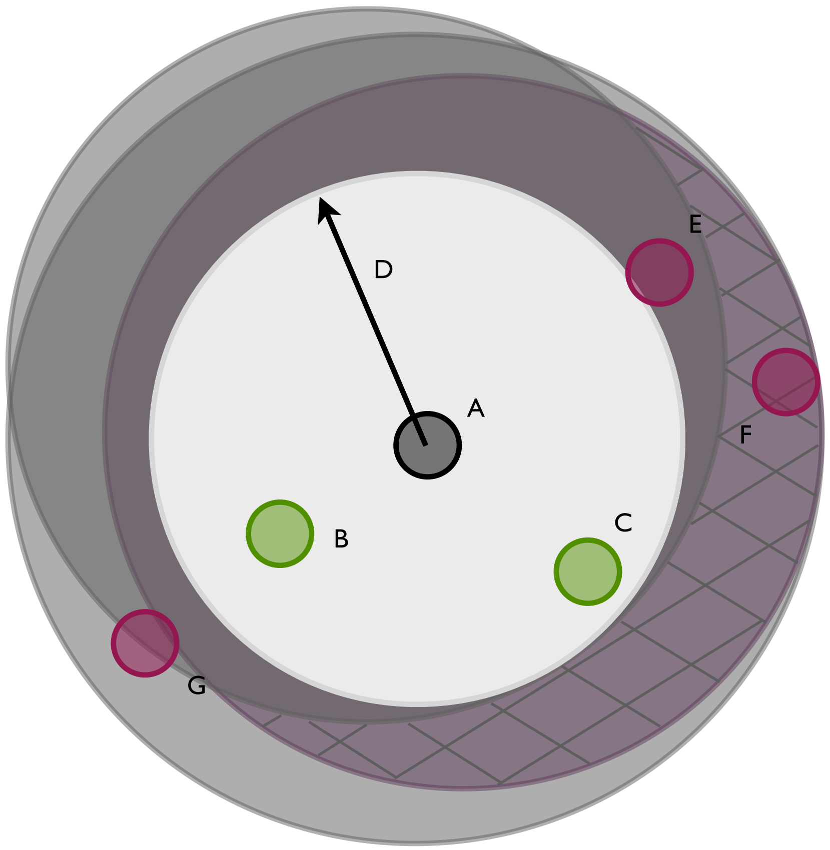
Optimization of Energy use in AEDB Broadcasting Protocol

Adaptive Enhanced Distance Based Broadcasting (AEDB)

Energy Efficient Broadcast Algorithm

Distance based

- candidates to forward message are selected in terms of distance
- selected candidates set a timeout
- copy of message heard ➜ stop timeout, decide to forward



Adaptive Enhanced Distance Based, AEDB

Cross-layer design

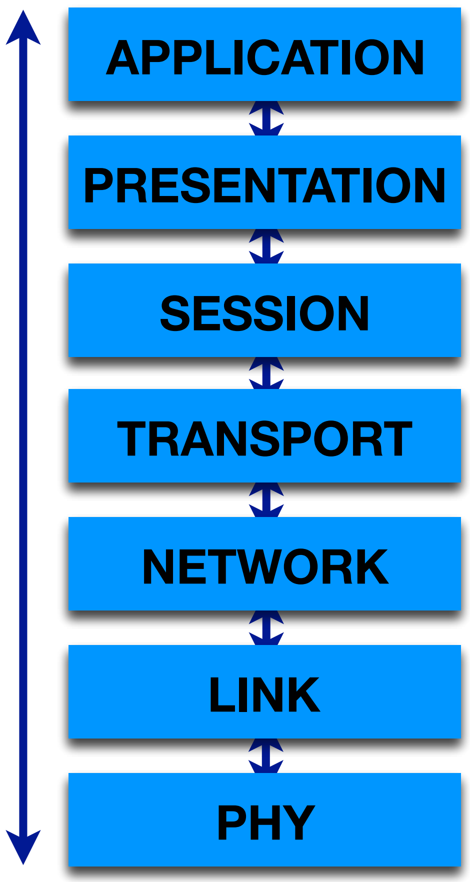
Use power needed to get the furthest neighbours

Advantages of reducing the transmission power:

- reduce the energy consumption
- reduce the interference level and pollution
- help the dissemination

Cross-layer design

"Protocol design by the violation of a reference layered communication architecture is a cross-layer design with respect to the particular layered architecture" [SM05]



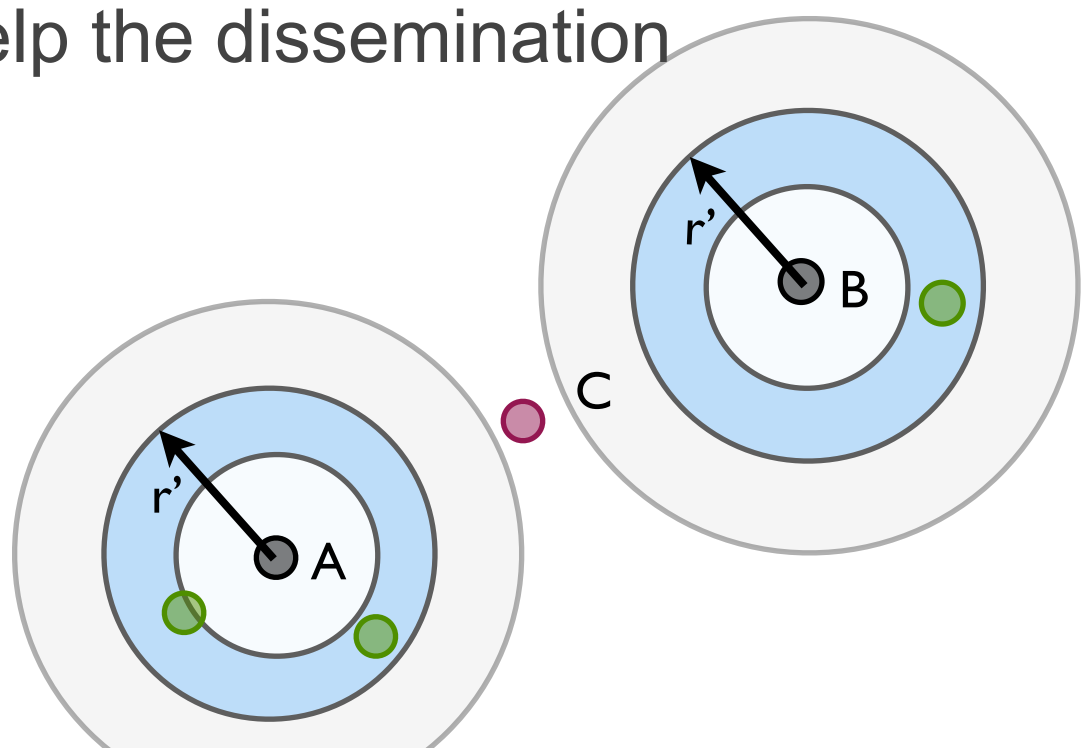
Adaptive Enhanced Distance Based, AEDB

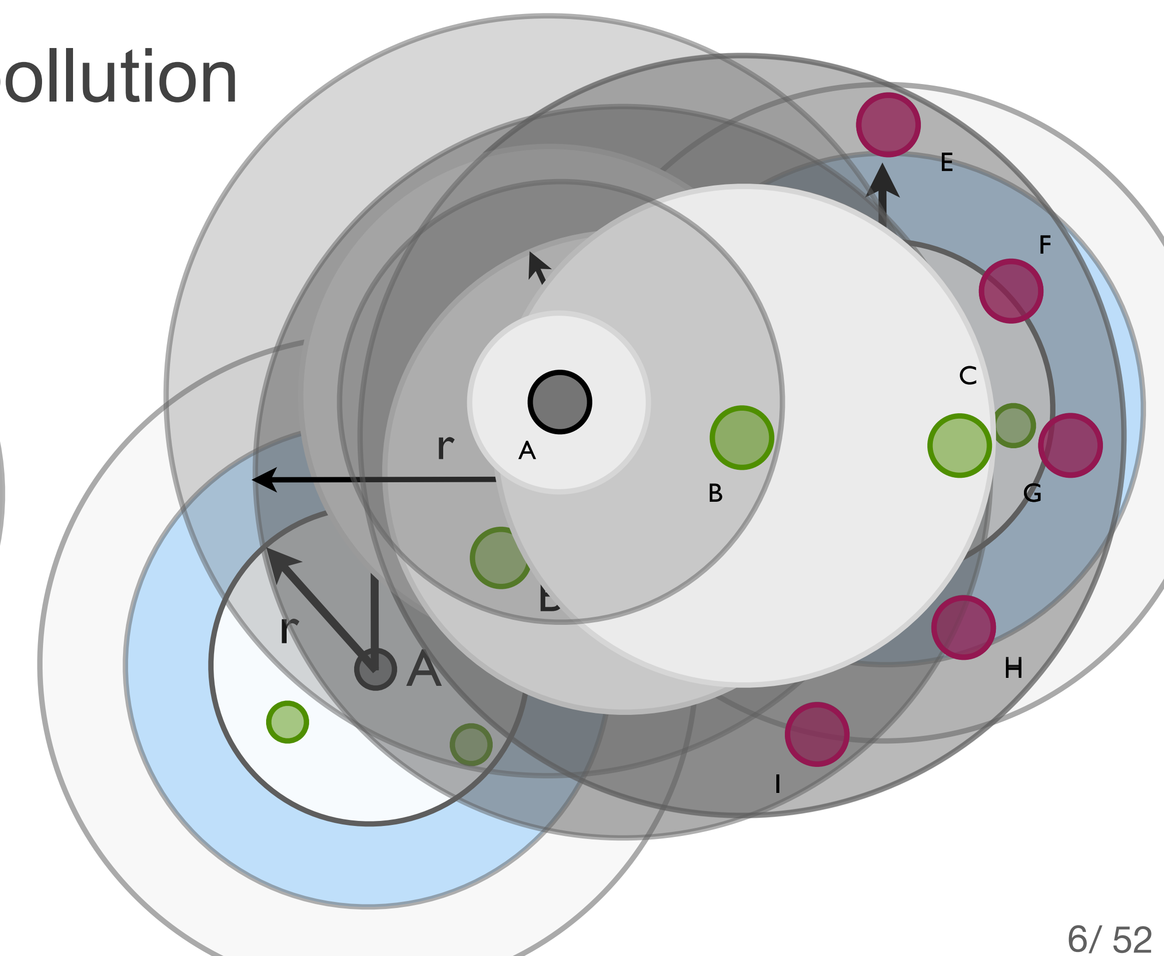
Cross-layer design

Use power needed to get the furthest neighbours

Advantages of reducing the transmission power:

- reduce the energy consumption
- reduce the interference level and pollution
- help the dissemination



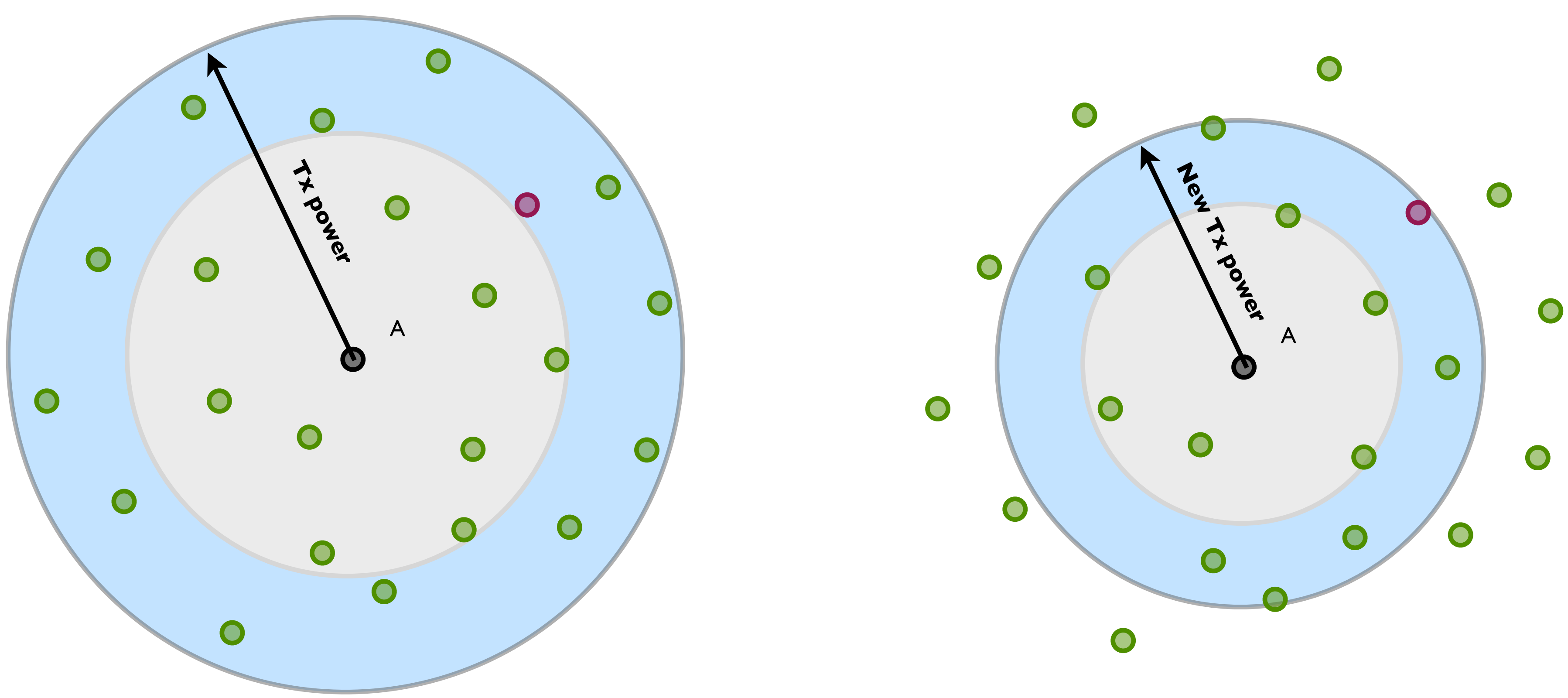


UCA Universidad de Cádiz

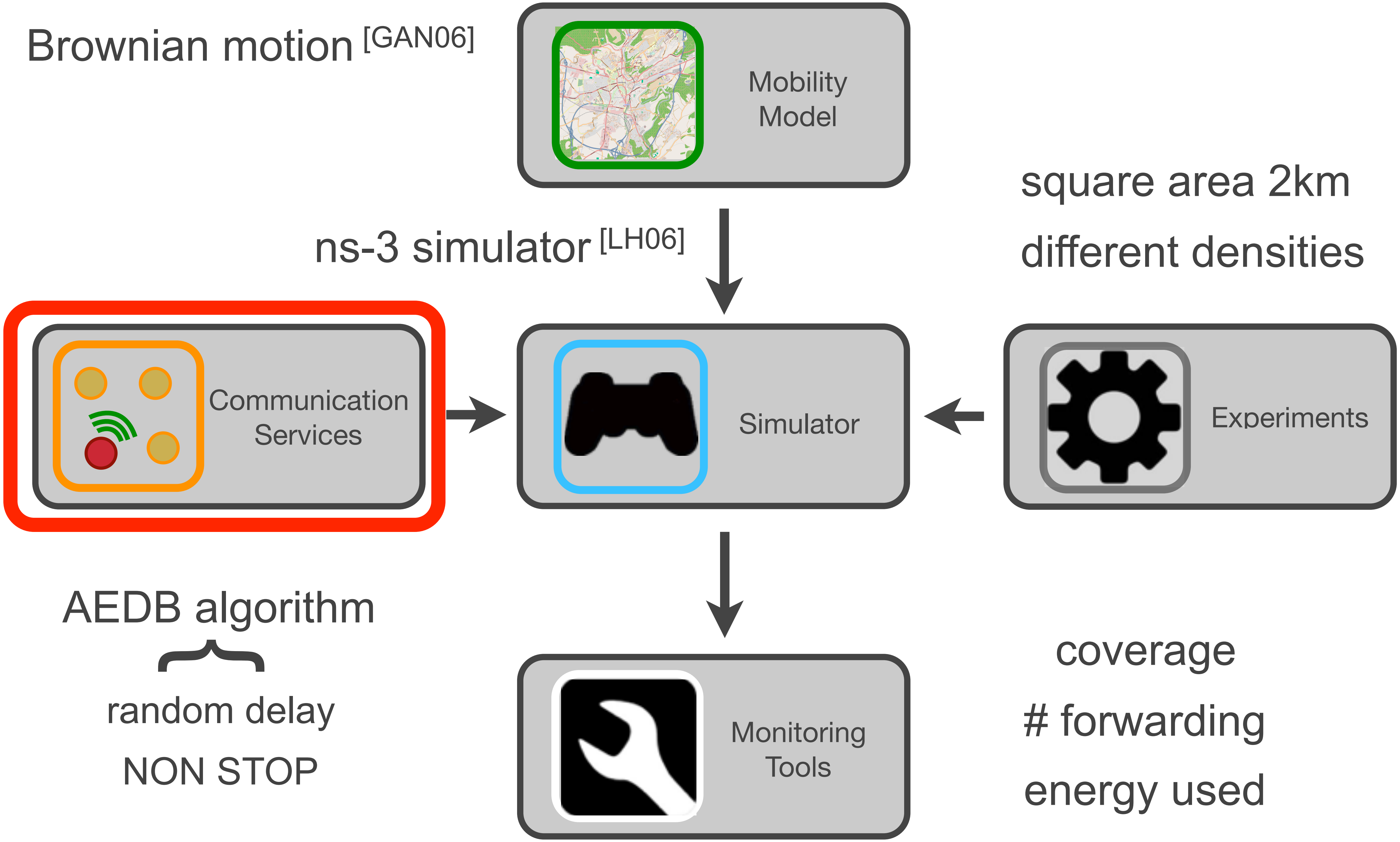
In dense networks:

- low energy reduction
- the dissemination process is easier

Discard 1-hop nodes



AEDB: Experimental Framework



Brownian motion [GAN06]

ns-3 simulator [LH06]

square area 2km

different densities

AEDB algorithm

random delay

NON STOP

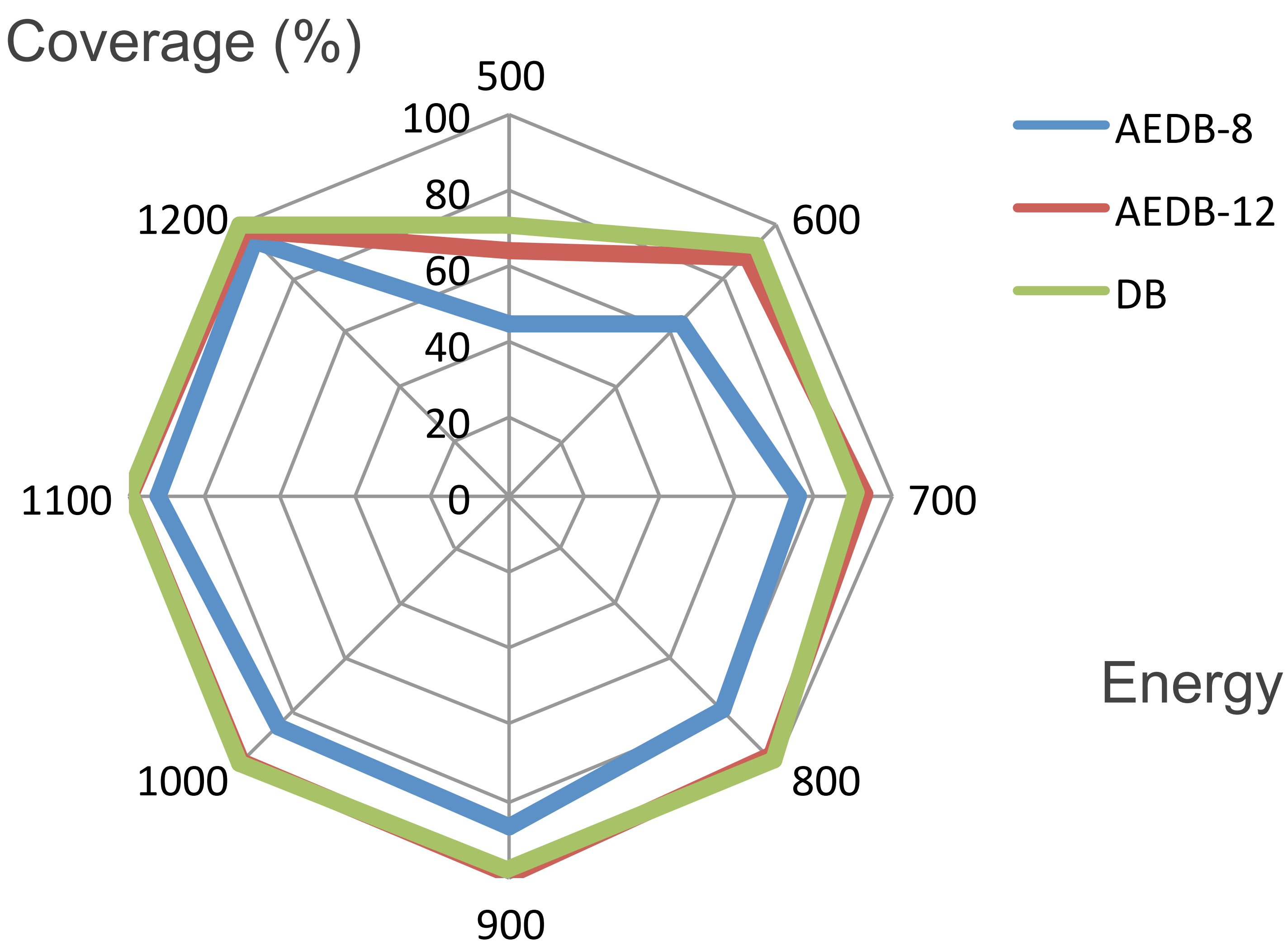
coverage

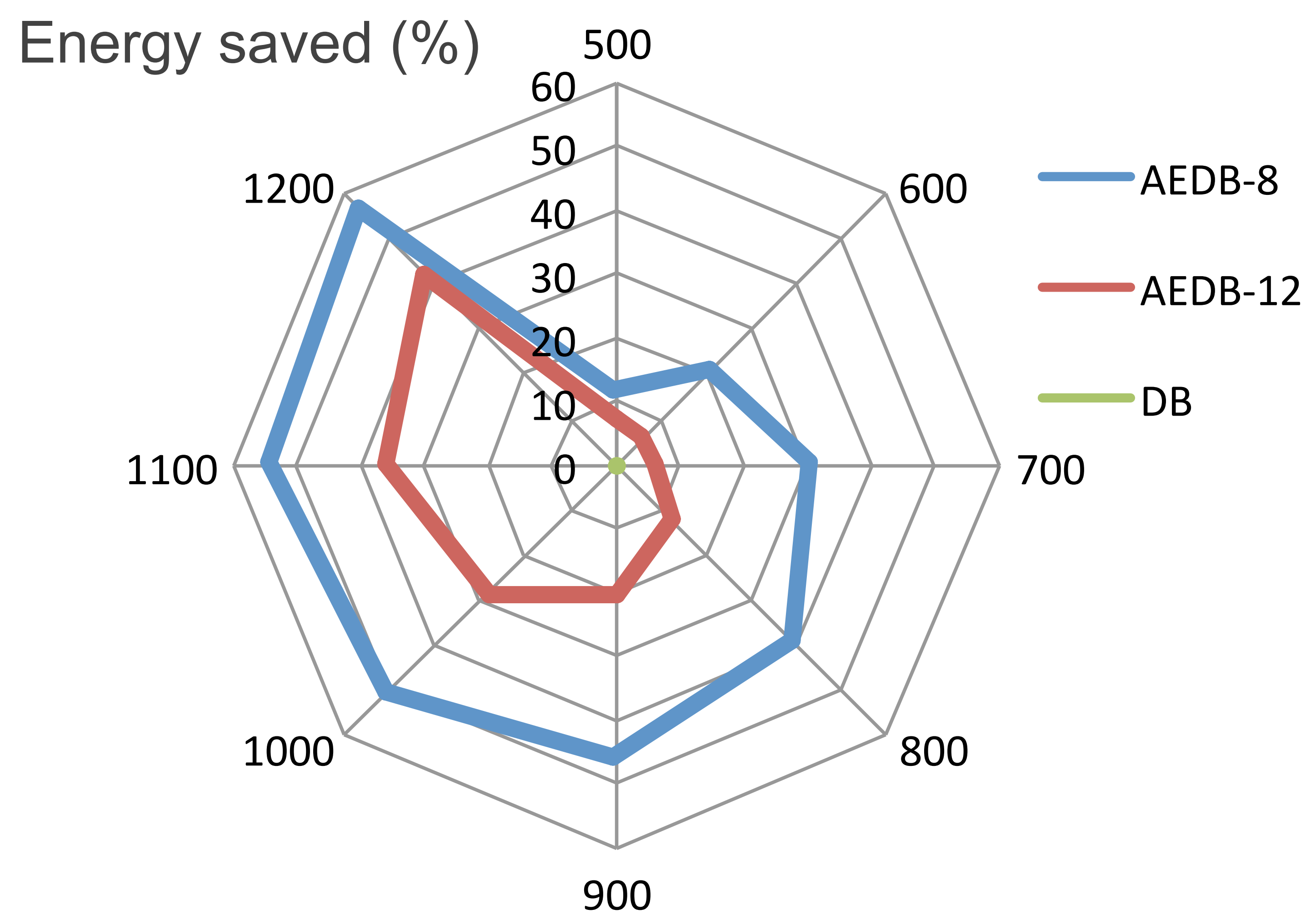
forwarding

energy used

broadcast time

AEDB: Simulation Results





AEDB: Summary

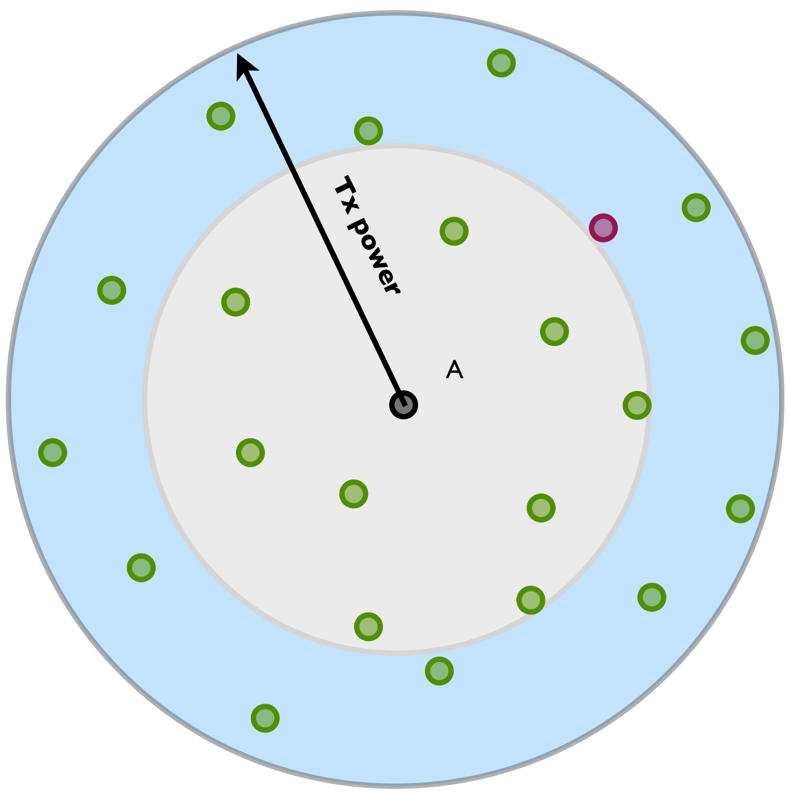
NEEDS OPTIMISATION

AEDB is very competitive in terms of:

- network resources
- coverage
- energy used
- broadcast time

AEDB relies on different thresholds:

- minDelay & maxDelay
- marginT
- borderT
- neighborsT



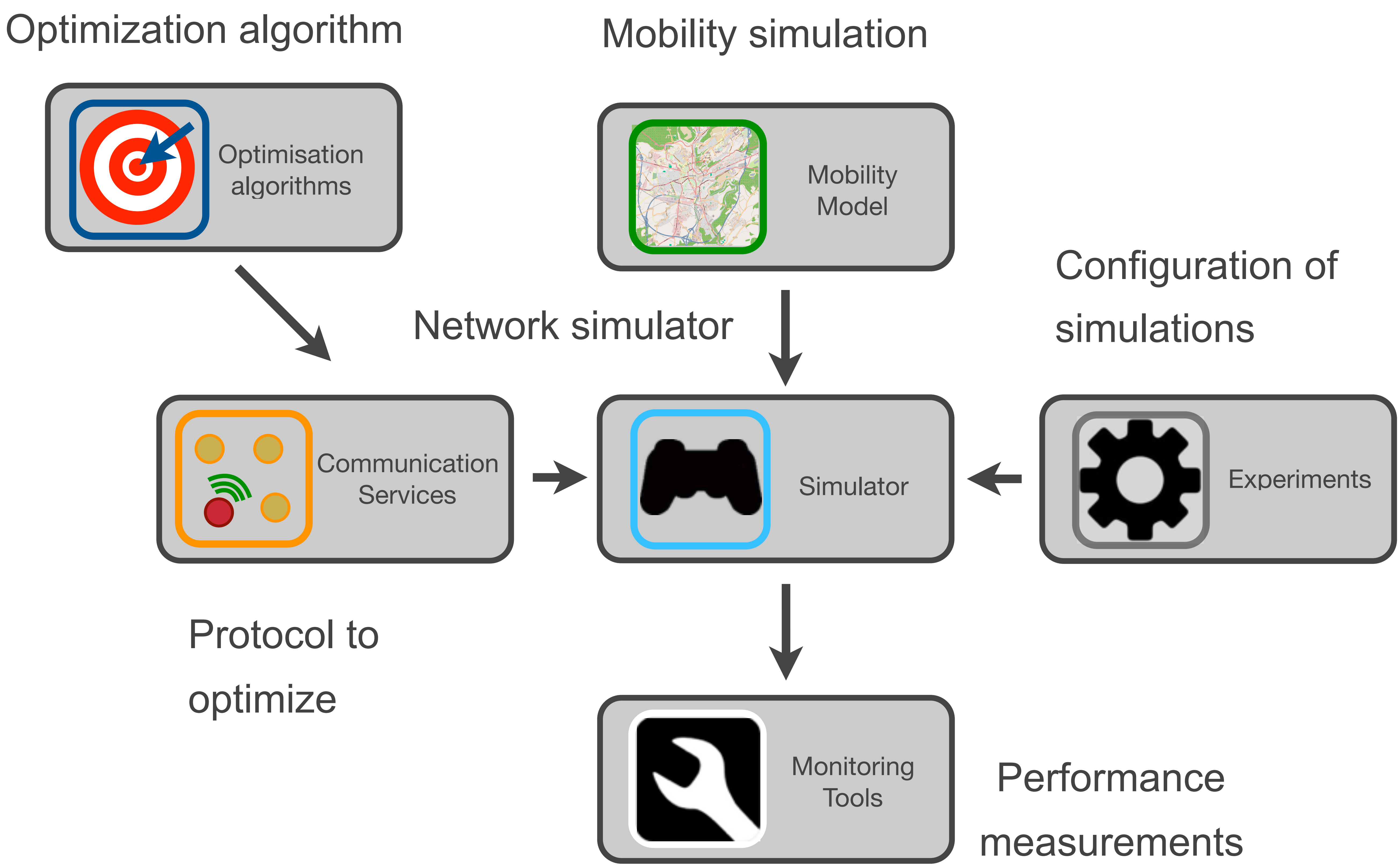
AEDB: Parameters & Delay Techniques

- ***Borders_Threshold***: the size of the forwarding area
- ***margin_Forwarding***: extra amount of energy added to the estimated one
- ***neighbours_Threshold***: number of nodes in the forwarding area
- ***delay_interval***: the value of the delay. Different techniques were studied:
  - random delay $\in$ [0 1]
  - fixed delay inversely proportional to the received power (*powerDelay*)
    - nodes further have shorter delay
  - random delay $\in$ [0 *powerDelay*]
  - stoping or not the delay when a copy is heard

Best option NON STOP with Random delay $\in$ [0 1]

Multi-objective Optimization of AEDB

Optimization of AEDB



Optimization algorithm

- Maximize coverage
- Minimize number of messages
- Minimize energy used
- Minimize broadcasting time

Population size	100 (ssGA, NSGAII)
	10×10 (cGA, CellDE)
	$100\times$ number of subpopulations (CCGA, CCNSGAII)
Termination Condition	$10,000$ function evaluations
Selection	Binary tournament (BT)
	Current individual + BT for cGA
Neighborhood	C9 for cellular topologies
Crossover probability	$p_c = 1.0$
Mutation probability	$p_m = 1/\text{chrom\_length}$

AEDB optimization problem representation

- Problem representation

BordersT	lowerBoundRAD	upperBoundRAD	ForwardT	neighbT
Double	Double	Double	Double	Integer

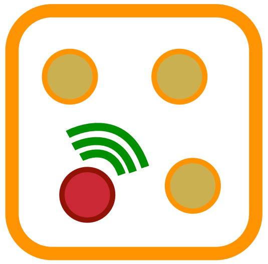
- CCNSGAII

BordersT	lowerBoundRAD	upperBoundRAD	ForwardT	neighbT
32 bits	32 bits	32 bits	32 bits	8 bits

Optimization algorithm parameters

- Maximize coverage
- Minimize number of messages
- Minimize energy use
- Subject to broadcasting time ≤ 2 s

$minGain$	[0.0, 1.0]
$lowerBoundRAD$	[0.0, 10.0] seconds
$upperBoundRAD$	[0.0, 10.0] seconds
$proD$	[0, 100] devices
$safeDensity$	[0, 100] devices



- AEDB broadcasting protocol

Network and mobility simulators parameters

- Network simulator: ns3
- Transmission power: 16.02 dBm
- Signal loss model: Log distance
- IEEE 802.11b
- Simulation sime: 40 s

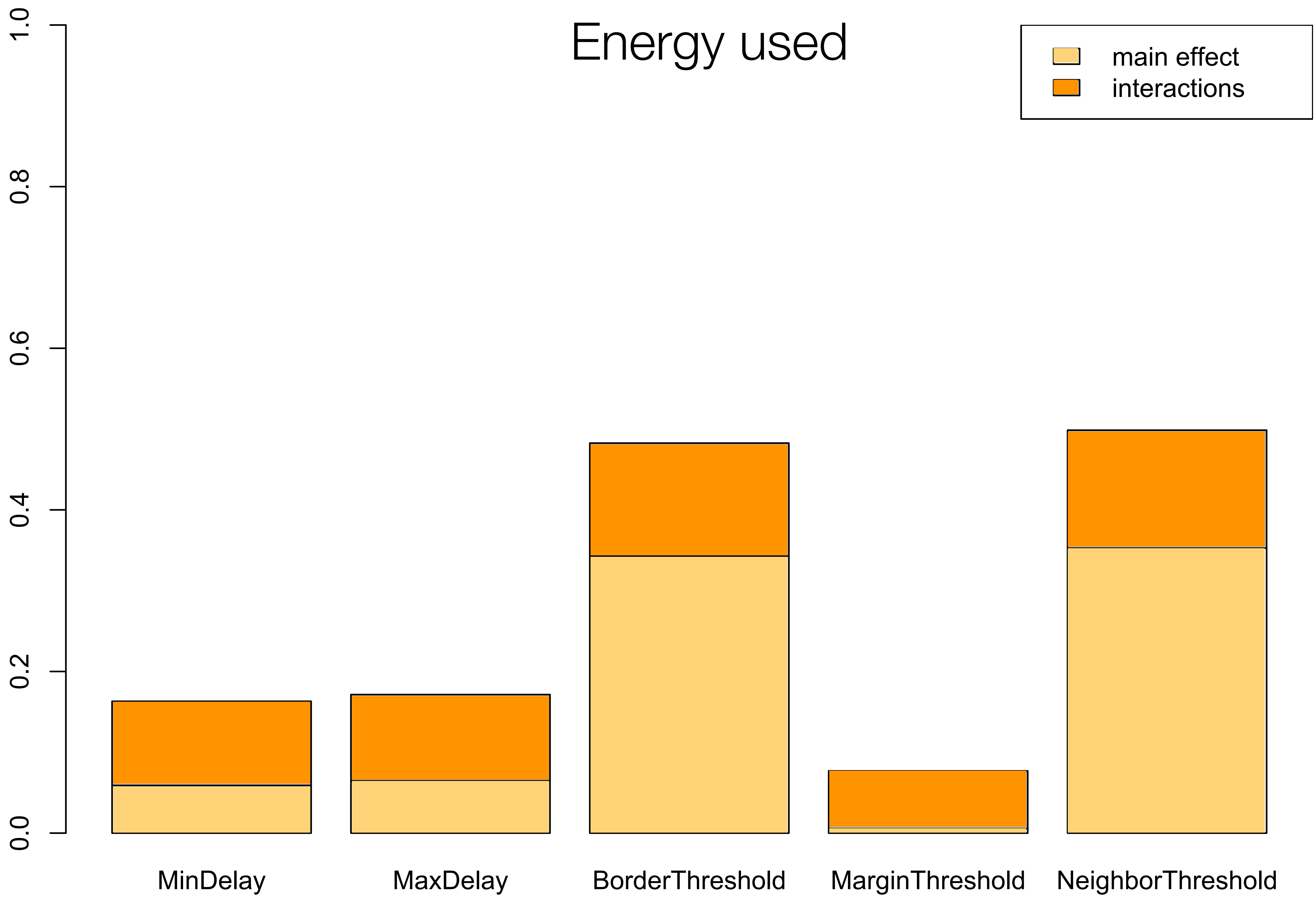
- Mobility simulator: ns3
- Random waypoint mobility model
- Speed: [0, 2] m/s
- Direction and speed change: every 20 s

Configuration of simulations and performance

- Square area 500m x 500m
- Different network densities
  - 100 devices / km^2
  - 200 devices / km^2
  - 300 devices / km^2
- Runs on 10 different networks (10 fixed seeds)

- Process the output of the simulator
  - Number of devices reached
  - Number of forwardings
  - Broadcast time
  - Energy used

MO: Sensitivity Analysis



MO: Sensitivity Analysis

neighboursT

Coverage

maxDelay
minDelay

Bc Time

bordersT
neighboursT

Energy used
forwardings

MO: Optimising AEDB

Generic cutting edge algorithms

Problem specific parallel local search

MO: Optimising AEDB using EAs

Generic cutting edge algorithms:

- explore different regions of the search space at the same time
- most suitable algorithms for multi-objective optimisation

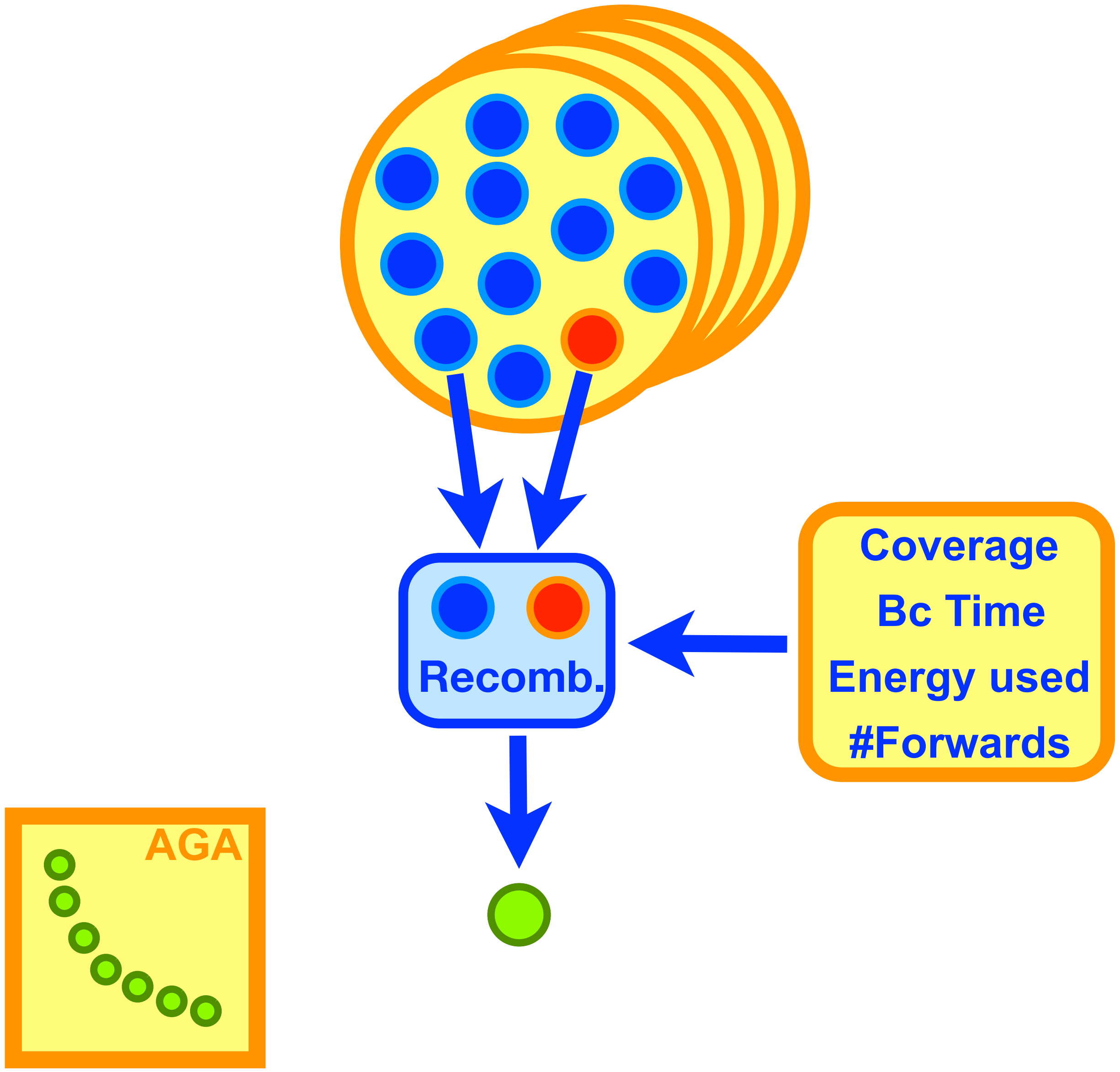
Non-dominated Sorting Genetic Algorithm, **NSGAII**[DPA02]

- reference algorithm in MO

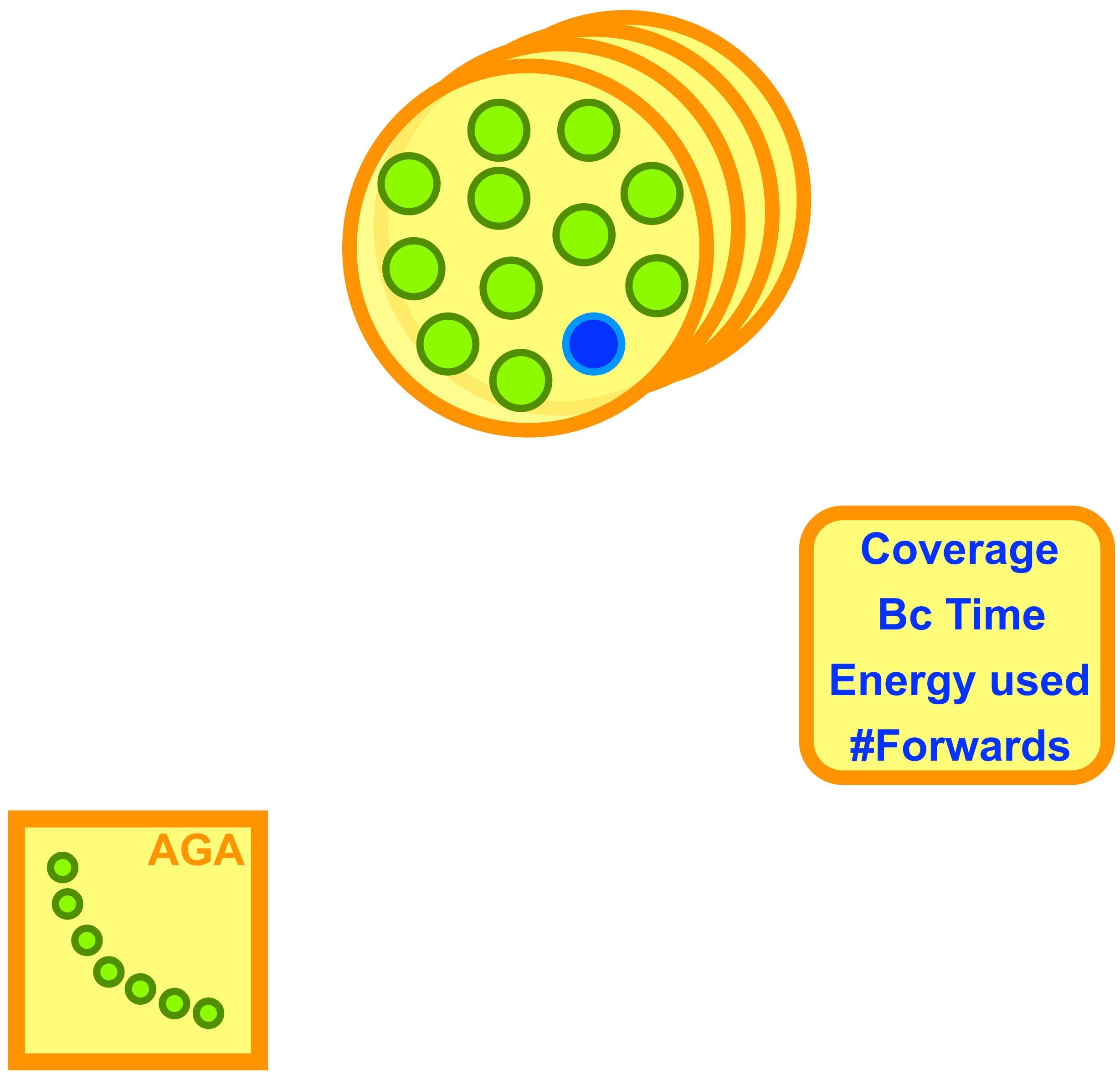
Cellular Differential Evolutionary algorithm, **CellDE**[DNL08]

- cellular MO with DE

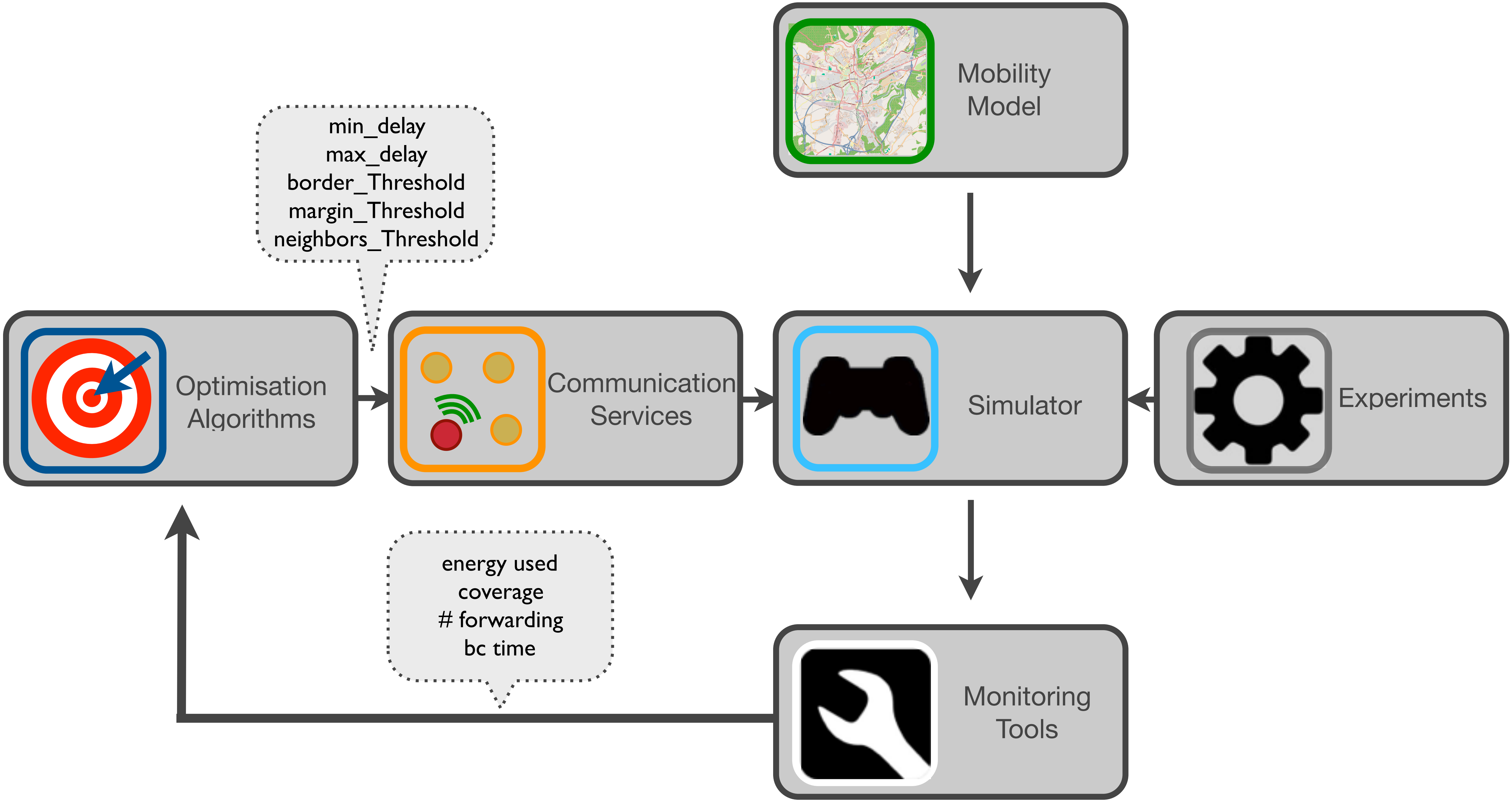
MO: Parallel Iterated Local Search, AEDB-MLS



MO: Parallel Iterated Local Search, AEDB-MLS

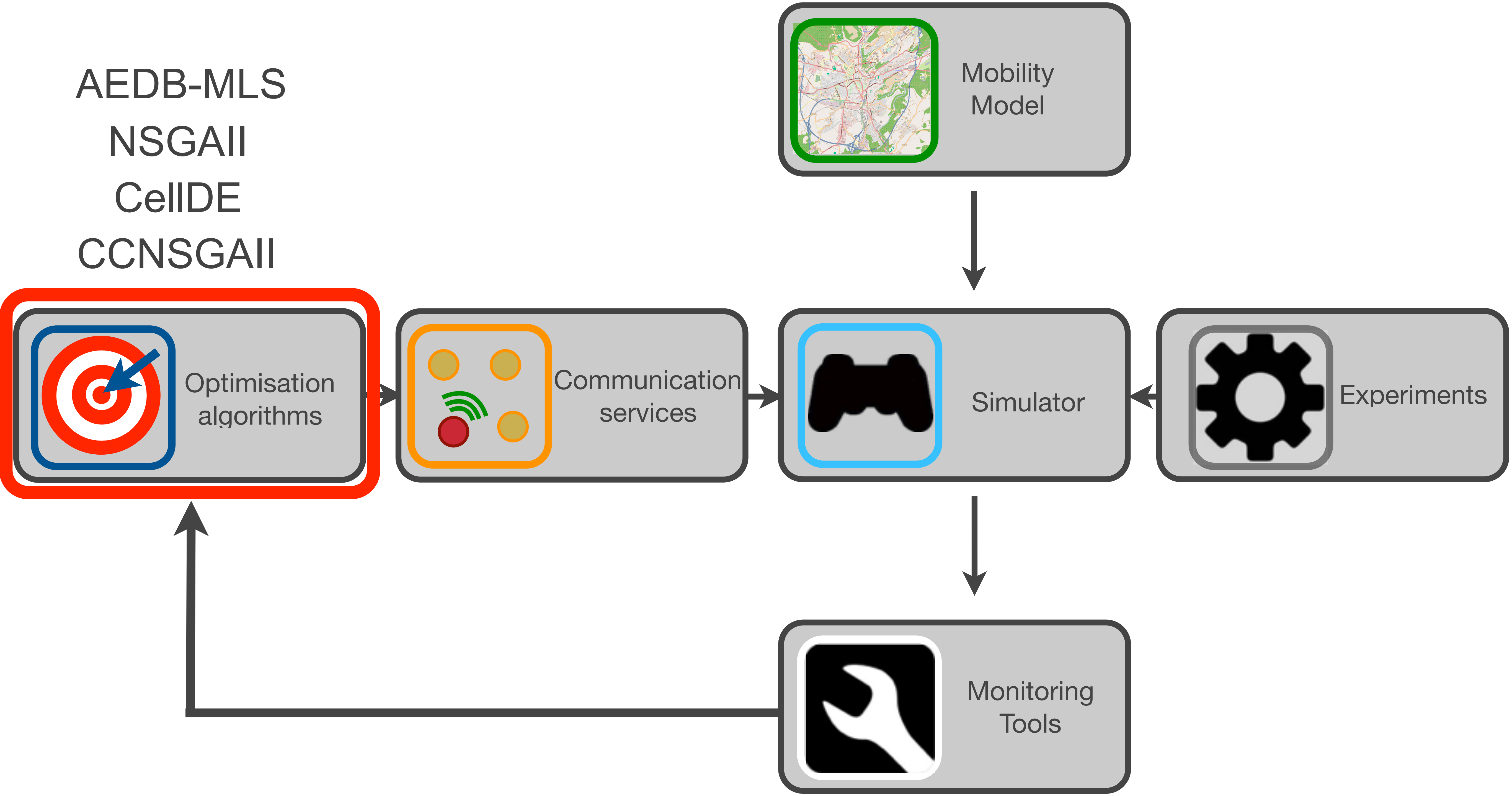


MO: Experimental Setup



MO: Experimental Setup

AEDB-MLS
NSGAII
CellDE
CCNSGAII

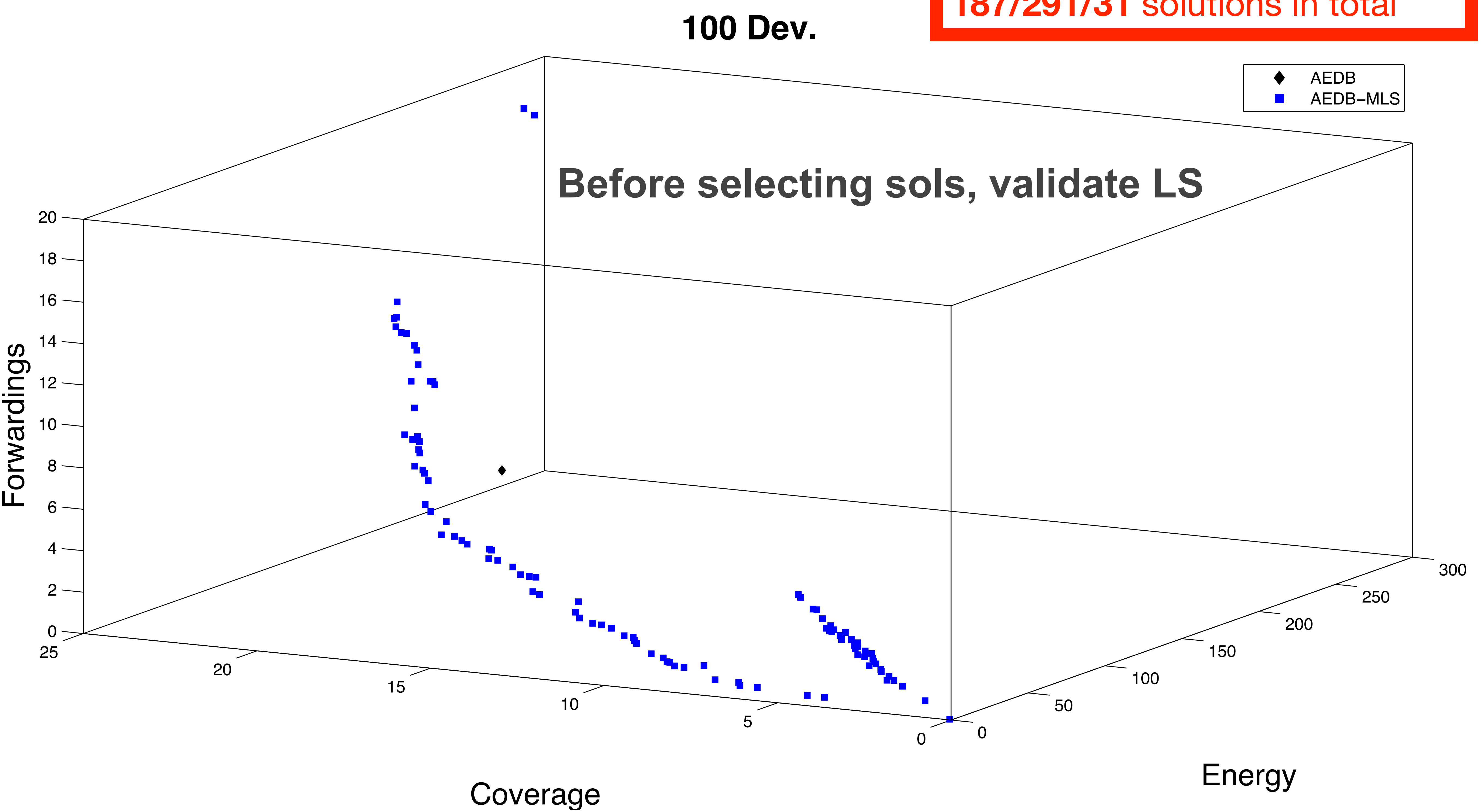


AEDB-MLS: Simulation results

Pareto front 30 executions AEDB-MLS & AEDB

8/15/1 solutions from the front

187/291/31 solutions in total



Evolutionary Algorithms: Simulation results

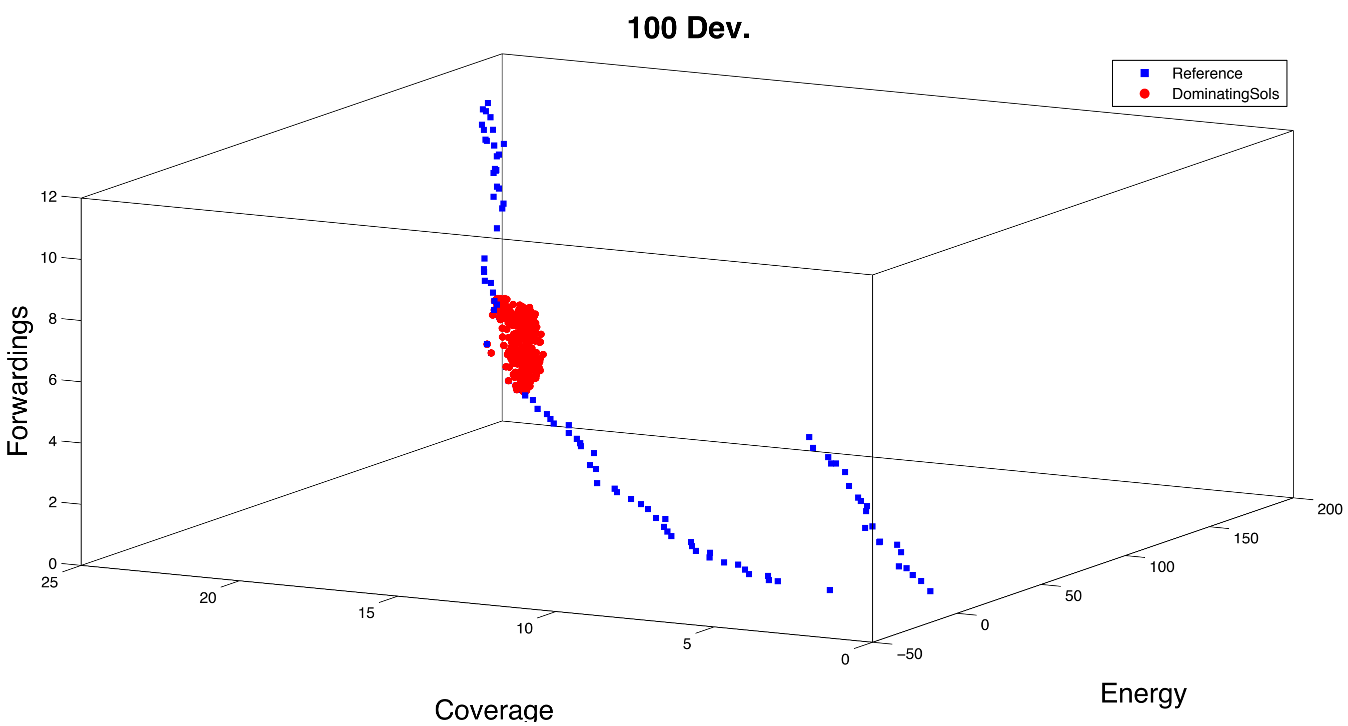
Pareto front 30 executions & AEDB

Solutions that outperform AEDB

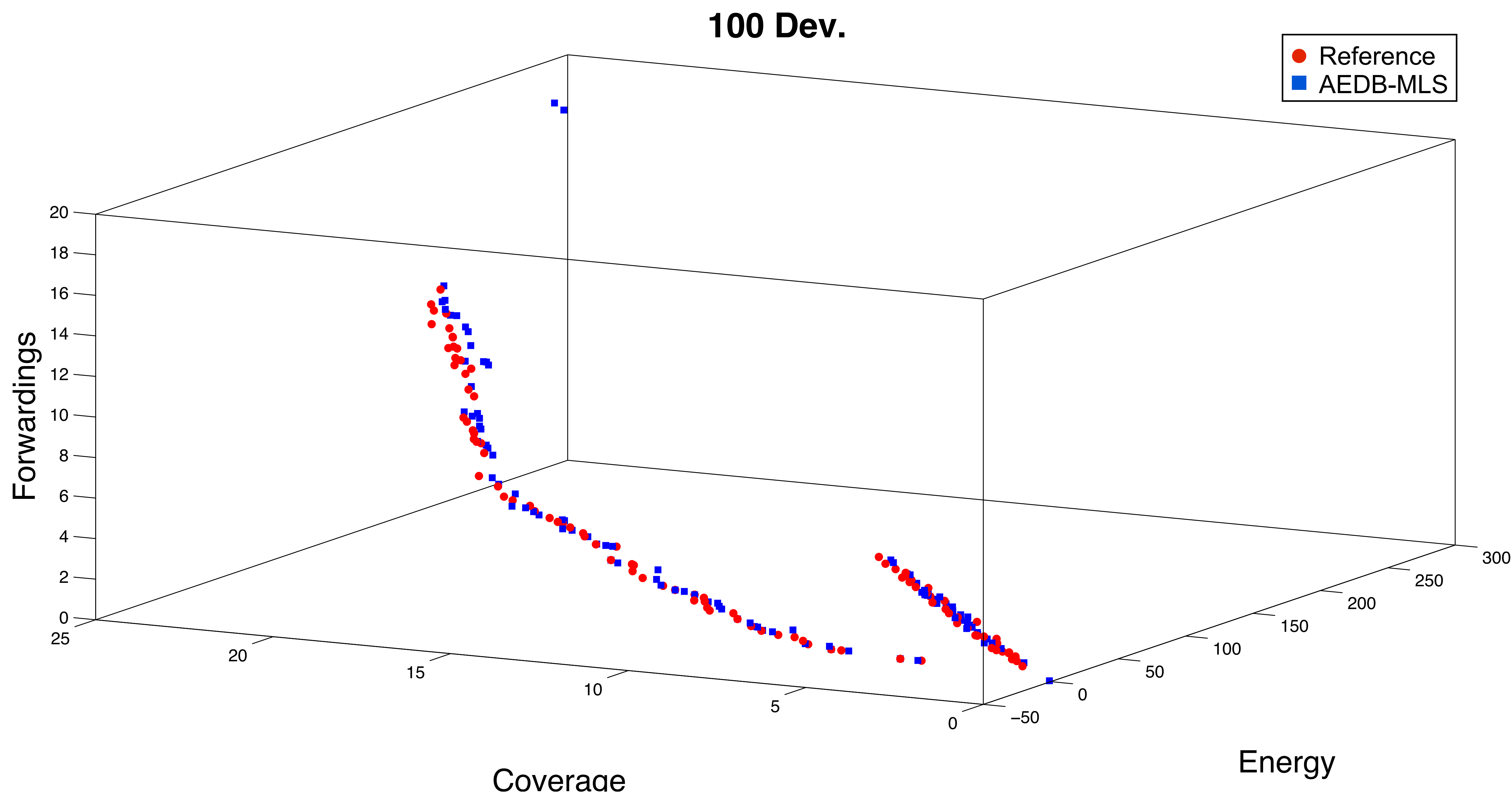
- 100/200/300 d/km2 -> 11/17/1 solutions

All solutions that outperform AEDB

- 100/200/300 d/km2 -> 349-201 527-343 solutions 53-29



Pareto front 30 executions Reference & AEDB-MLS



MO: EAs vs AEDB-MLS

Reference and AEDB-MLS fronts

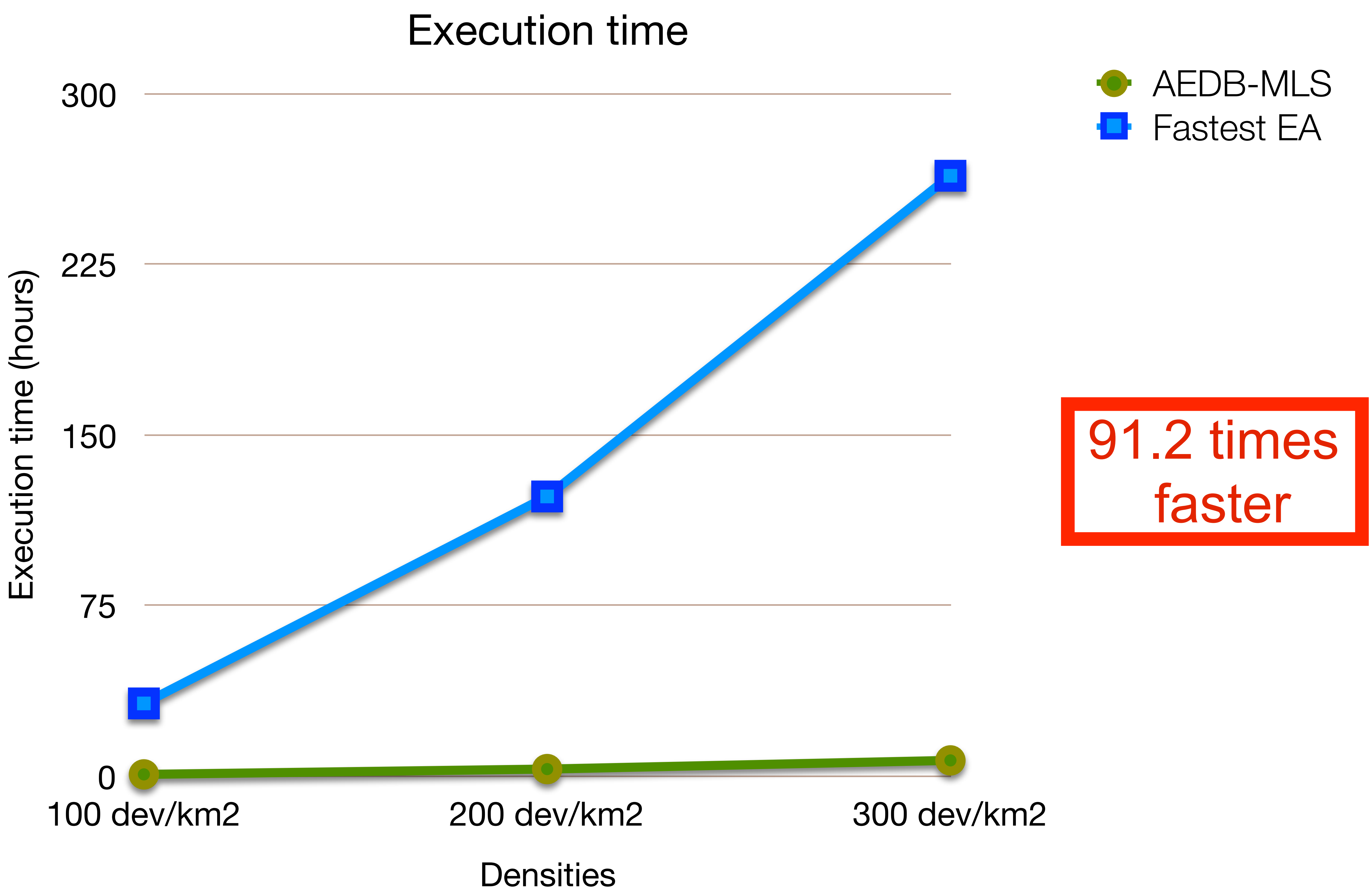
Compare fronts:

- **Inverted generational distance**
  - measures the accuracy
- **Spread**
  - measures the diversity
- **Hypervolume**
  - measures accuracy and diversity

Comparison of the algorithms according to Wilcoxon test

	Spread	
CellDE	▲ ▲ ▲	▲ – –
NSGAII		– ▽ ▽
	Inverted generational distance	
CellDE	▽ ▽ –	▲ ▲ ▲
NSGAII		▲ ▲ ▲
	Hypervolume	
CellDE	▽ ▽ ▽	▲ ▲ ▲
NSGAII		▲ ▲ ▲
	NSGAII	AEDB-MLS

MO: EAs vs AEDB-MLS



AEDB-MLS is **38 times faster** and performs **2.4 times more evaluations**

MO: EAs vs AEDB-MLS

AEDB was optimised using:

- NSGAII & CellDE
- AEDB-MLS

Pareto fronts were compared in terms of:

- inverted generational distance
- spread
- hypervolume
- execution time

MO: Selecting Solutions

Restrict solutions:

coverage achieved > 80%

forwarding nodes < 30%

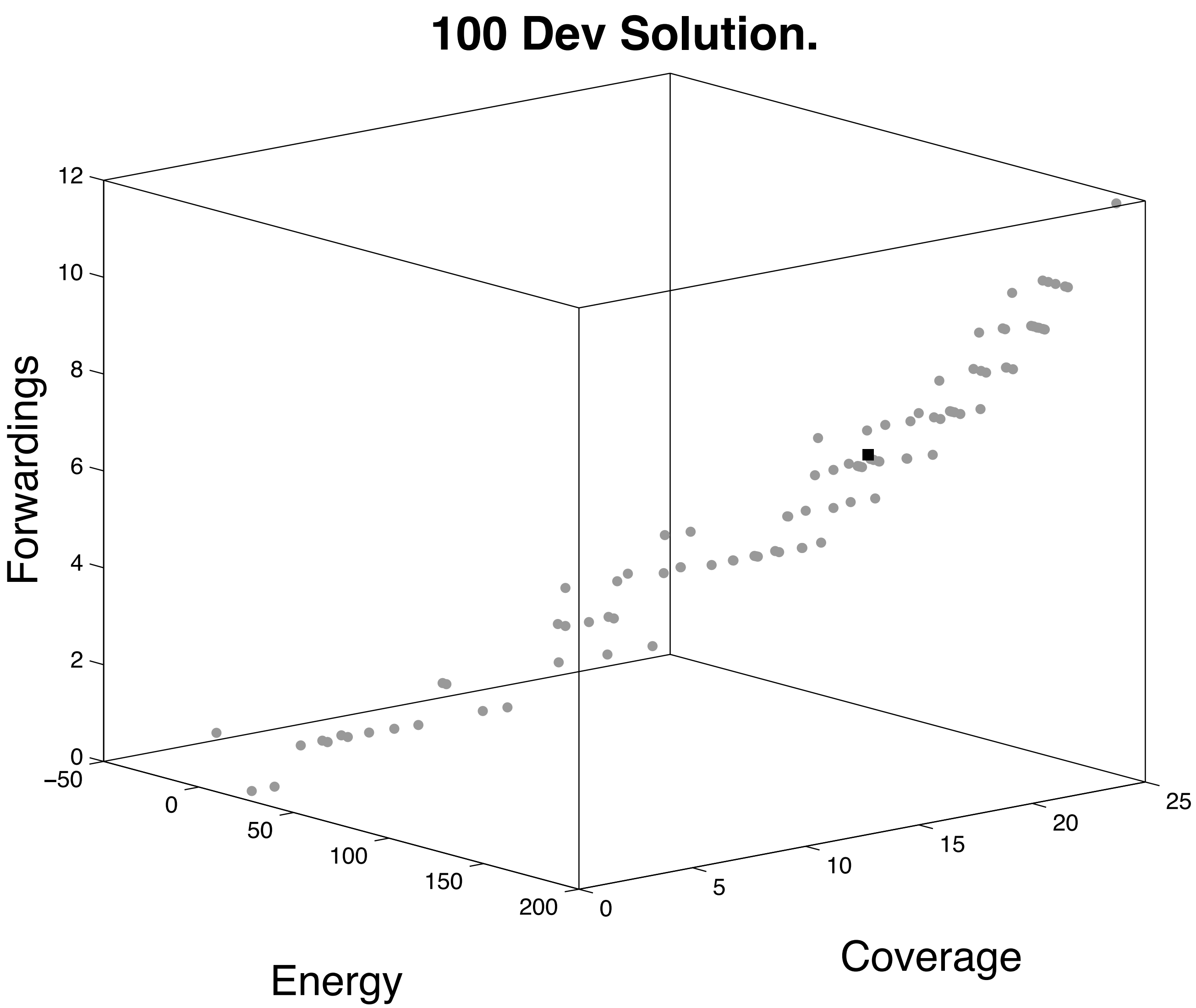
select the ones that save more energy

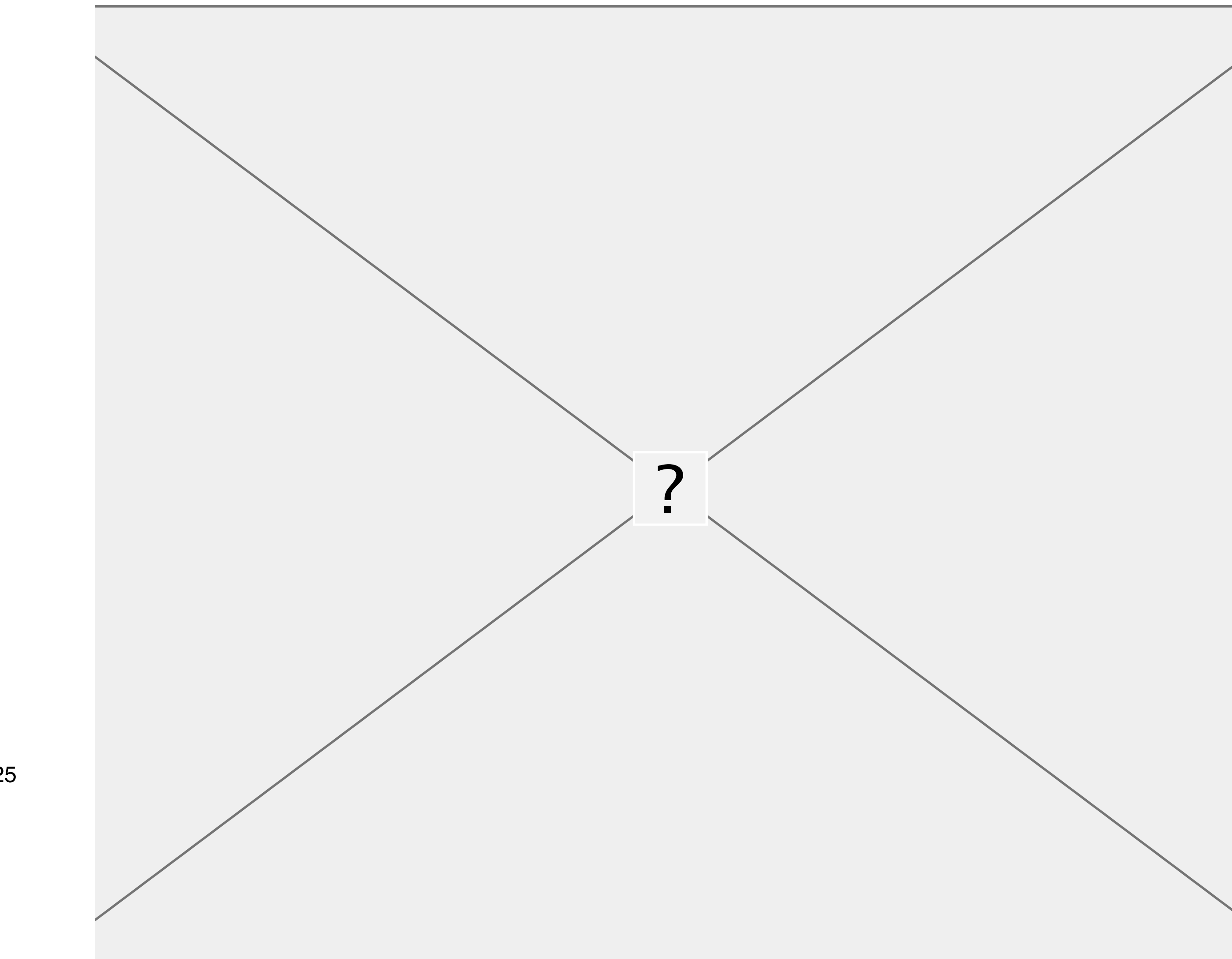
Selecting Solutions: Results

Comparison of the solutions
according to Wilcoxon test

	Energy used	Coverage	Forwarding
100dSol2	--	--	--
100dSol4	▲	--	▲
100dSol5	▲	▽	▲
200dSol2	▲	▽	▲
200dSol3	▲	--	▲
200dSol5	▲	▽	▲
300dSol3	▲	--	▲
300dSol4	▲	▽	▲
300dSol8	▲	▽	▲

Plotting Selected Sols over 100 Networks





Fluctuant Solutions → Include Robustness

Robust Metrics: Average

$$F(\vec{s}) = \begin{cases} \text{Min}\{\text{mean}(\vec{e})\} \\ \text{Max}\{\text{mean}(\vec{c})\} \\ \text{Min}\{\text{mean}(\vec{f})\} \end{cases} \quad \text{s.t. mean}(\vec{bt}) < 2$$

Robust Metrics: Median

$$F_m(\vec{s}) = \begin{cases} \text{Min } \{t(e)\} \\ \text{Max } \{t(c)\} \\ \text{Min } \{t(f)\} \end{cases} \quad \text{s.t.:} \quad \begin{array}{l} t\ (bt) < 2 \\ t = \text{median}_{cov}\ (R) \end{array}$$

Discard the 2 solutions with worst coverage results

Robust Metrics: Constrained

$$F_C(\vec{s}) = \begin{cases} \text{Min } \{\text{mean } (\vec{e}')\} \\ \text{Max } \{\text{mean } (\vec{c}')\} \\ \text{Min } \{\text{mean } (\vec{f}')\} \end{cases}$$

s.t.: s.t. mean $(\vec{bt}) < 2$

$\text{stdev } (\vec{e}') \leq 0.3 * \text{mean } (\vec{e}')$

$\text{stdev } (\vec{c}') \leq 0.3 * \text{mean } (\vec{c}')$

$\text{stdev } (\vec{f}') \leq 0.3 * \text{mean } (\vec{f}')$

Discard the 2 solutions with worst coverage results

Robust Metrics: Worst Coverage

$$F_{wc}(\vec{s}) = \begin{cases} \text{Min } \{t(e)\} \\ \text{Max } \{t(c)\} \\ \text{Min } \{t(f)\} \end{cases} \qquad \text{s.t.:} \quad \begin{array}{l} t\ (bt) < 2 \\ t = worst_{cov}\ (R') \end{array}$$

Discard the 2 solutions with worst coverage results

Robust Metrics: Worst HyperVolumen

$$F_{whv}(\vec{s}) = \begin{cases} \text{Min}\ \{t(e)\} \\ \text{Max}\ \{t(c)\} \\ \text{Min}\ \{t(f)\} \end{cases} \quad \text{s.t.:} \quad \begin{array}{l} t\ (bt) < 2 \\ t = worst_{hv}\ (R') \end{array}$$

Discard the 2 solutions with worst coverage results

Selecting Solutions: % of StDev

Comparison of the solutions
according to Wilcoxon test

	Energy used	**Coverage**	**Forwarding**
Average	▲	▽	▲
Median	▲	▽	▲
Constrained	▲	▽	▲
Worst Coverage	▲	▽	▲
Worst HV	▽	▲	▽