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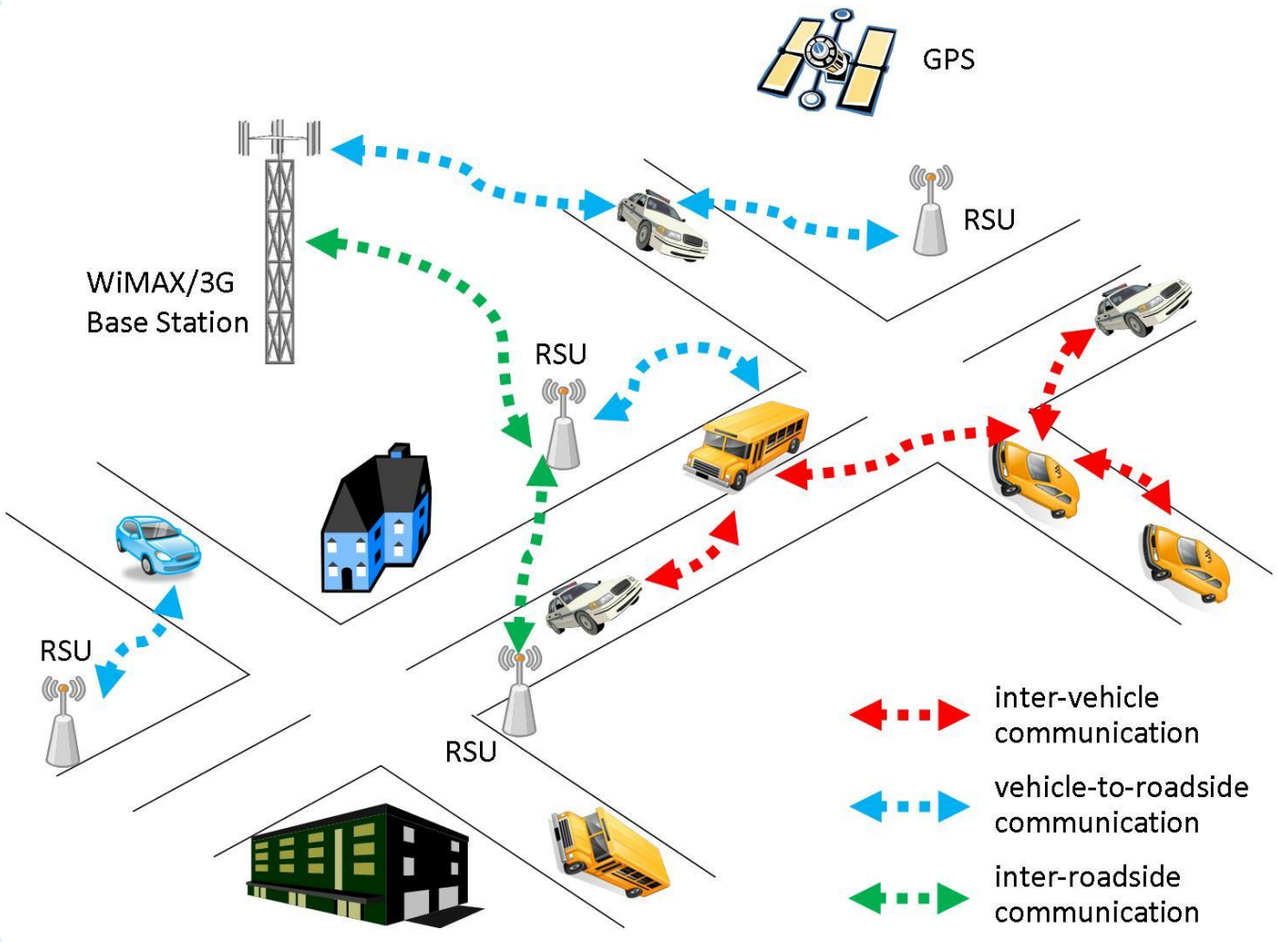
Optimization of the Network Topology

Vehicular Ad hoc Networks (VANETs)

- Wireless ad hoc network
  - No central entity
  - Nodes act as routers
- Mobility induces topological changes
- VANETs make use of infrastructure
  - Use it to enhance connectivity



Vehicular Ad hoc Networks (VANETs)

- Problem 1: the network can be partitioned
  - There exists no path between some pair of nodes

- Solution 1: injection points
  - A subset of nodes use an additional network interface
  - This subset of nodes forms a fully connected overlay network

Vehicular Ad hoc Networks (VANETs)

- Problem 2: the topological properties are not optimal

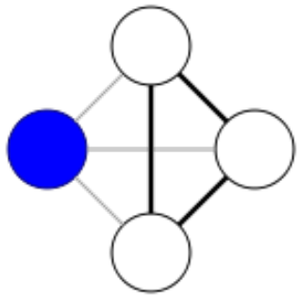
- Solution 2: select injection points in order to obtain better small world properties
  - High CC: better broadcasting efficiency
  - Low APL: faster and easier to maintain routing

Small world Properties

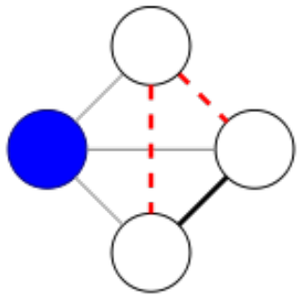
- Small Average Path Length (APL)

$$APL = \frac{1}{n(n-1)} \sum_{i,j} d(v_i, v_j)$$

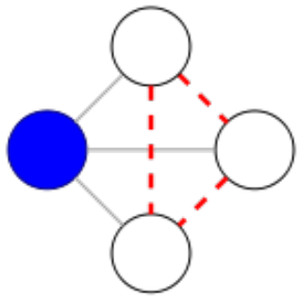
- High Clustering Coefficient (CC)
  - Local $CC_v = \frac{|E(\Gamma_v)|}{k_v(k_v-1)}$
  - Global $CC = \frac{1}{n} \sum_v CC_v$



c = 1



c = 1/3

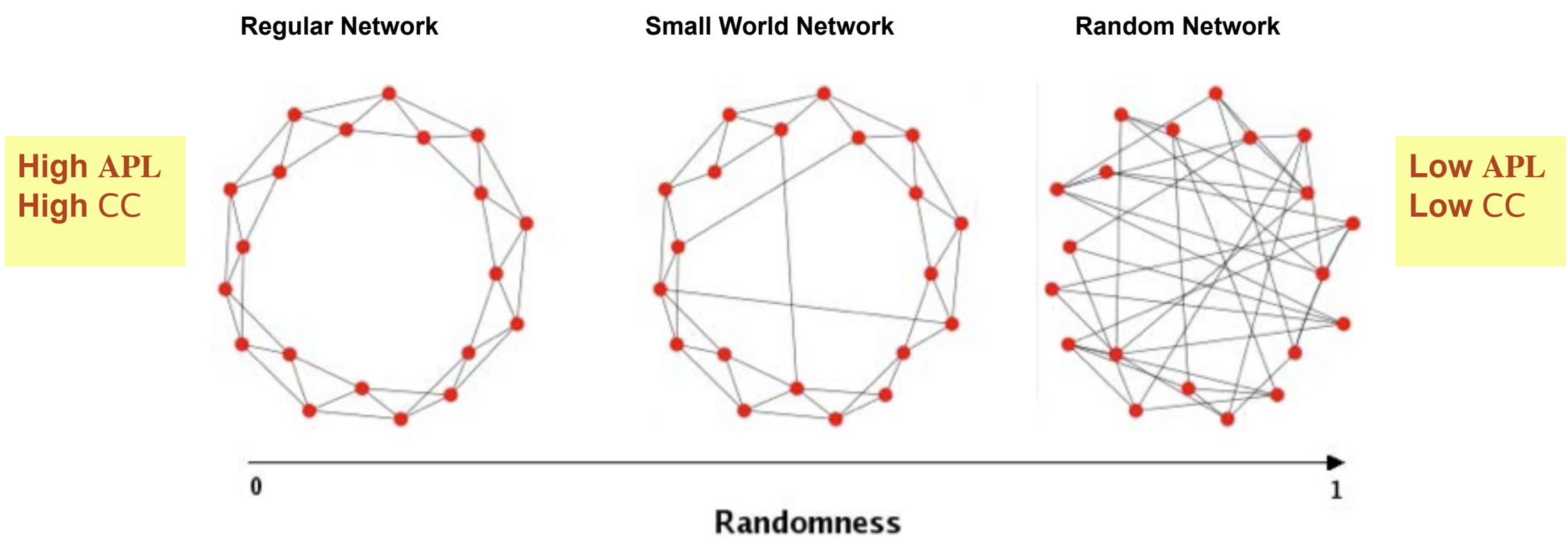


c = 0

Small-world graphs

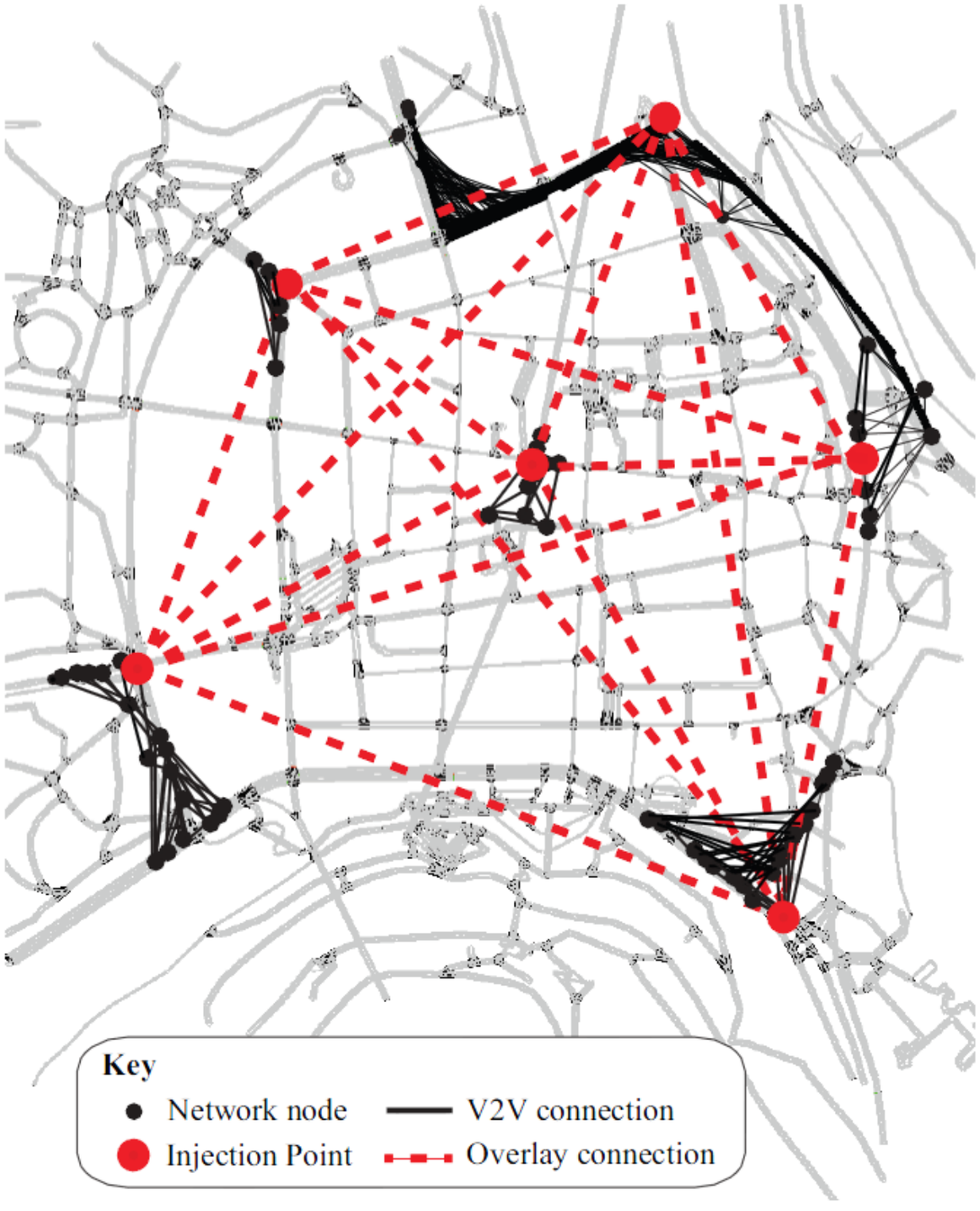
- Topology generation: Watts and Strogatz algorithm

1. Create ring topology (every individual has K neighbors)
2. For every edge
3. Rewire to random destination individual with probability β



$$APL \approx APL_{random}$$
$$CC \gg CC_{random}$$

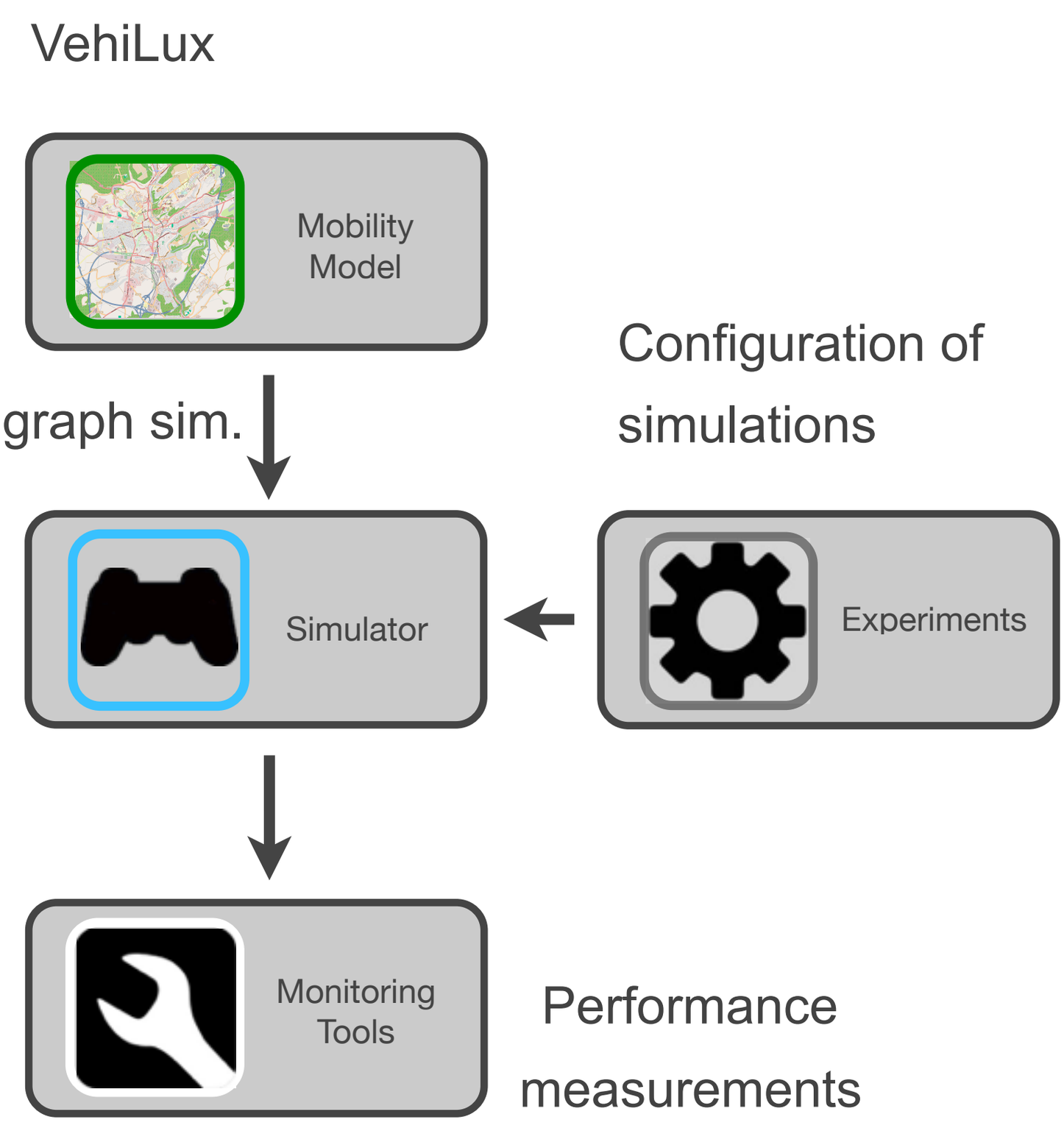
Network topology optimization



Heuristics

- Centralized
  - Random Injection Point Per Connected Component (RandomInjPerCC)
  - Connected Component Centers (CCCenter)
- Decentralized
  - Highest Degree
  - Highest Clustering Coefficient
  - Khopca

Simulation of the network topology heuristics



Network and mobility simulators parameters

- GraphStream dynamic graphs simulator

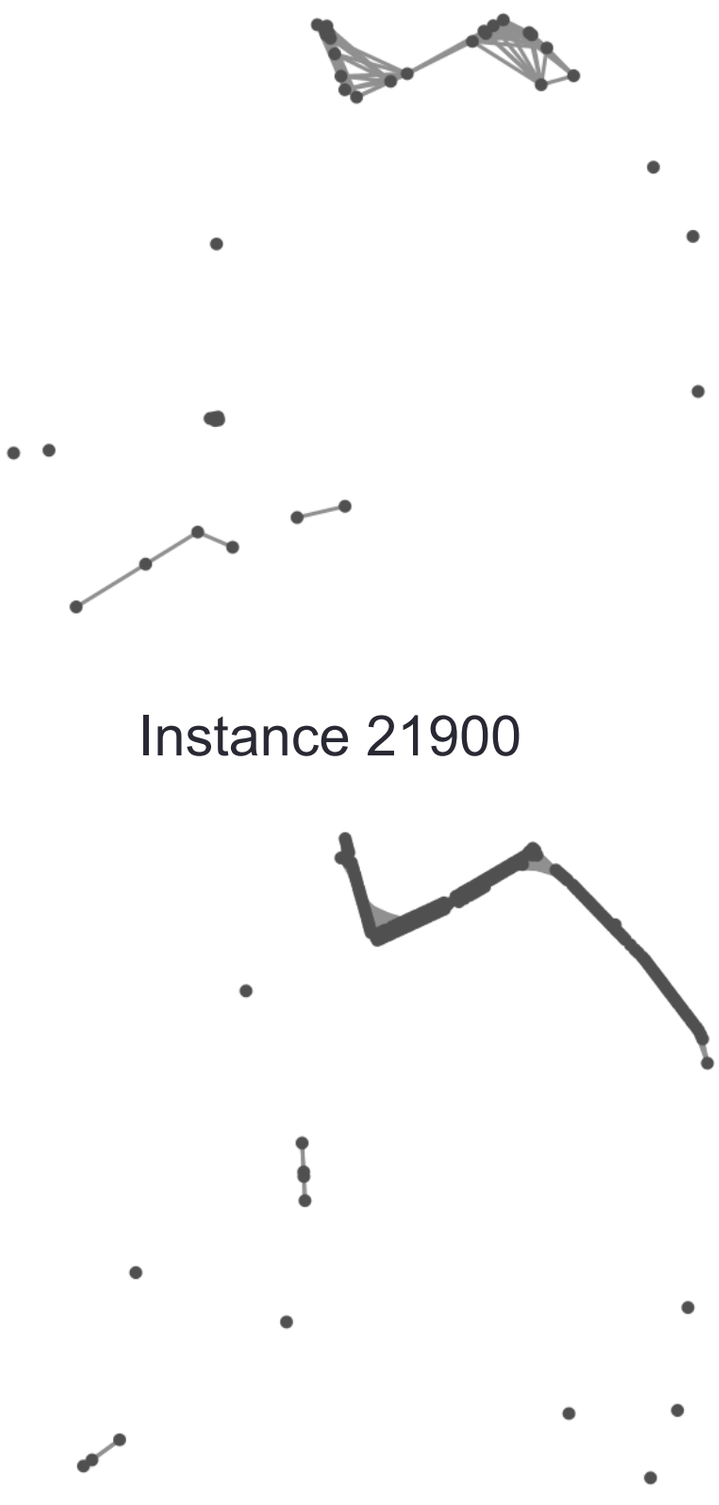
- VehiLux
  - Realistic road network topology (OpenStreetMaps)
  - Real traffic counting data from the Luxembourg Ministry of Transport

	Surface		$0.6\ km^2$	
	Coverage radius		100 m	
6 a.m.	Network Number	21900	22200	22500
	Number of Nodes	40	62	60
	Partitions	10	8	6
	Solution space	1^{12}	4.61^{18}	1.15^{18}
7 a.m.	Network Number	25500	25800	26099
	Number of Nodes	223	248	301
	Partitions	10	6	7
	Solution space	1.34^{67}	4.52^{74}	4.07^{90}

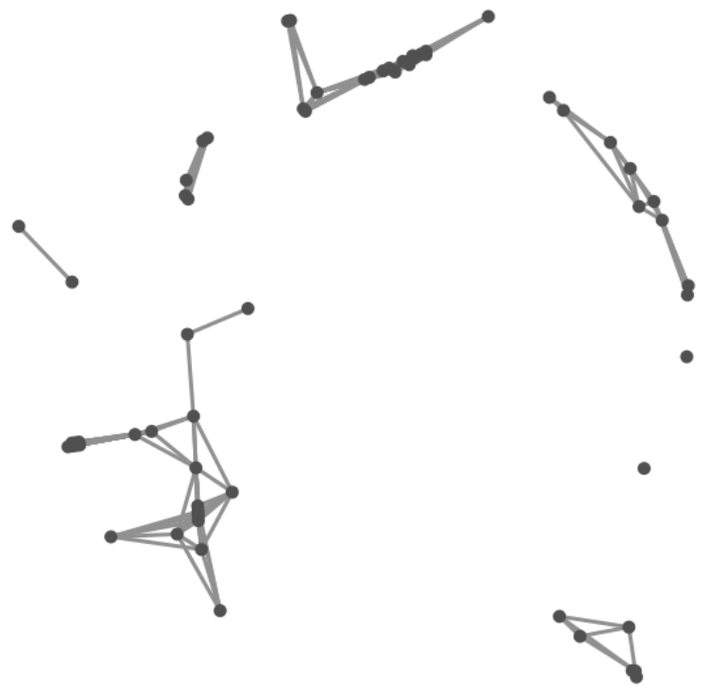
Configuration of simulations and performance

- Process the output of the simulator
  - Average path length of 30 similar random graphs
  - Average path length of the network
  - Clustering coefficient
  - Number of injection points

Sample network instances



Instance 21900

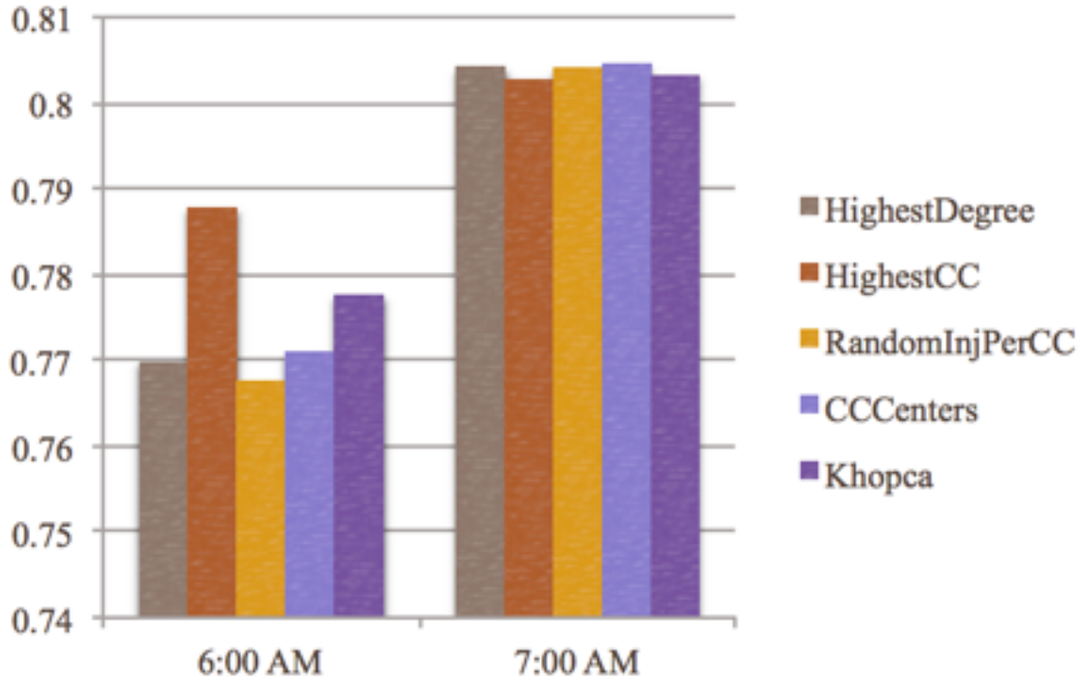


Instance 22200

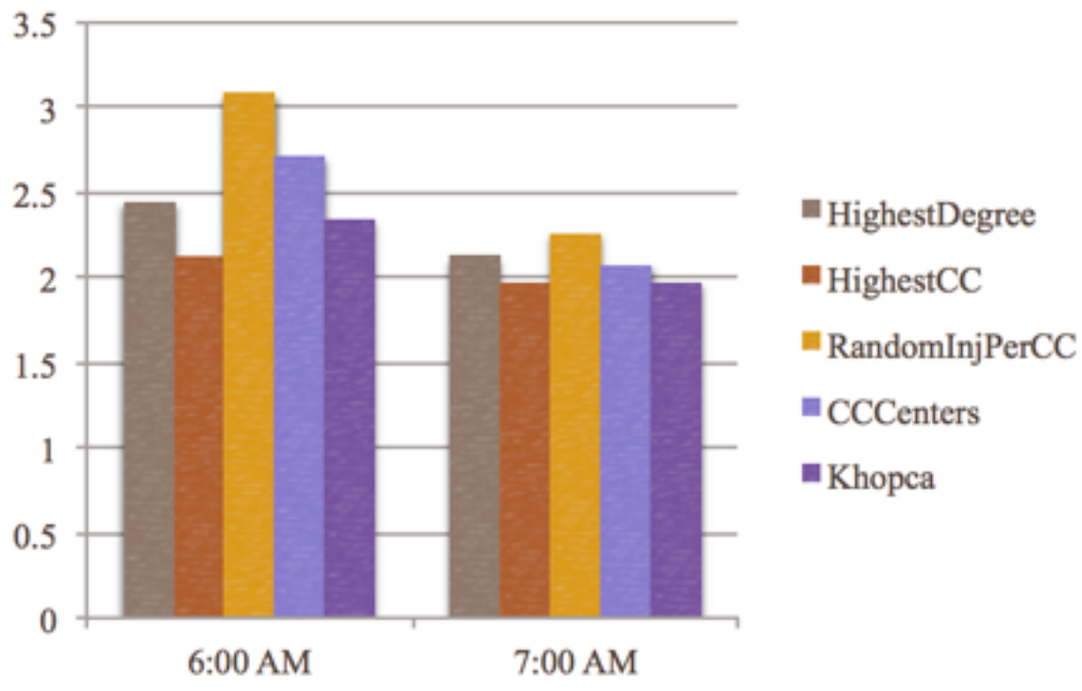
Instance 25500

Instance 25800

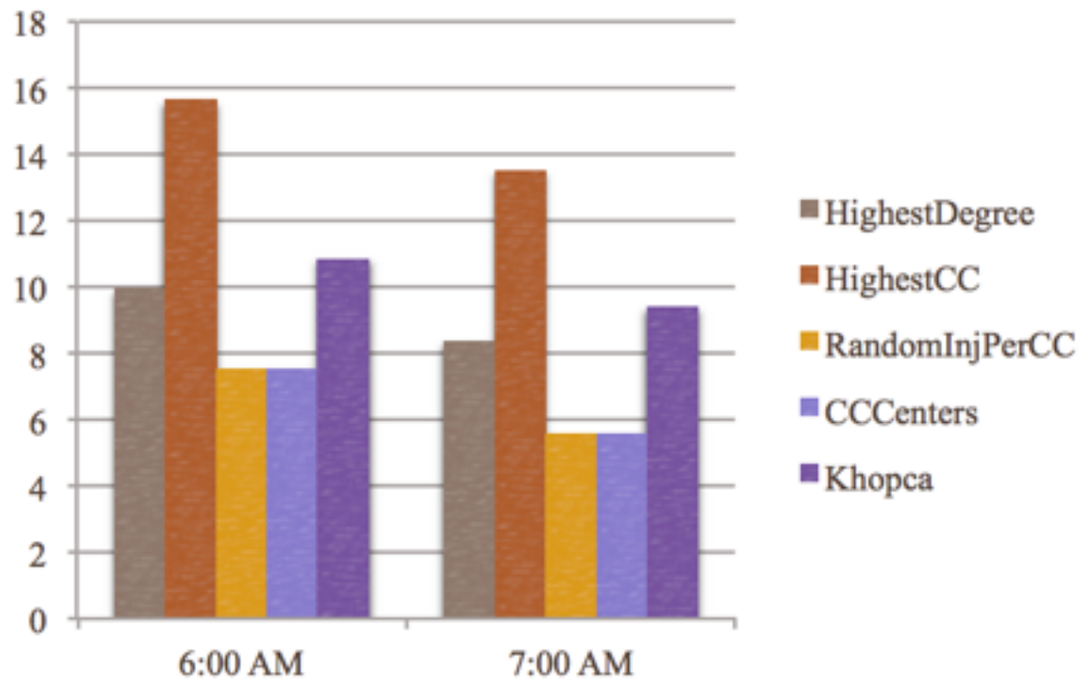
Comparison of heuristics



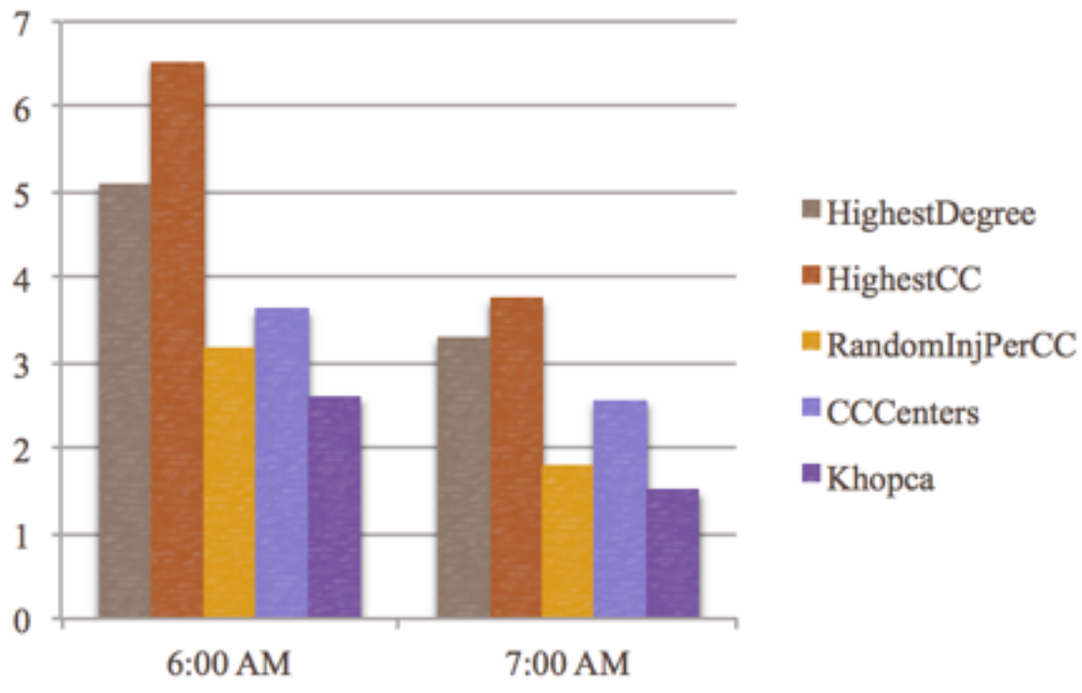
(a) Clustering Coefficient



(b) Average Path Length



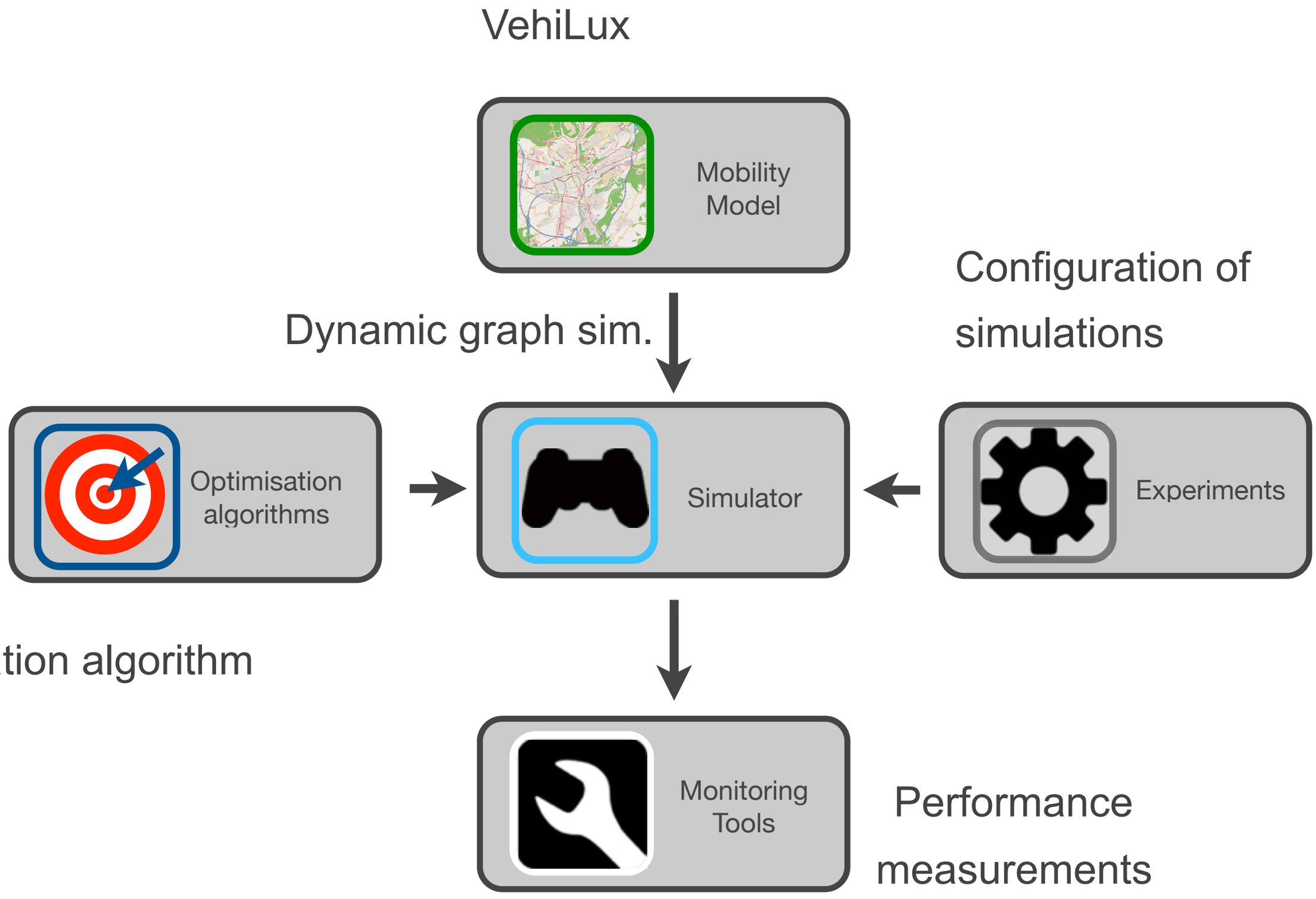
(c) Injection Points



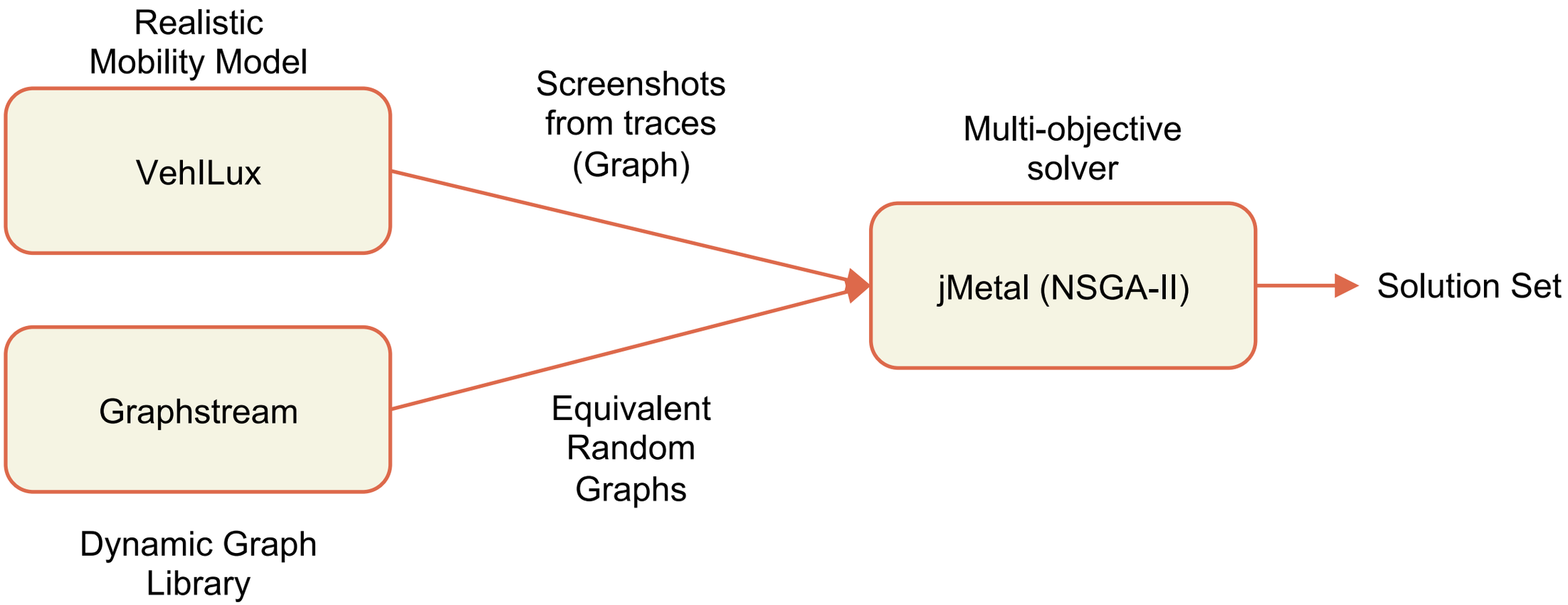
(d) Stability

Multi-objective Optimization of the Network Topology

Optimization of the network topology



MO: Experimental Setup



- Not realistic solution for VANETs
- Study of the problem
- Validation of decentralized approaches

Optimization algorithm

- Minimize the number of injection points
- Maximize the clustering coefficient
- Minimize apl_{diff}

$$apl_{diff} = |apl - apl_{random}|$$

- Equivalent random graph
  - same number of nodes and average density
  - averaged over 30 different instances
- Generated using Watts rewiring process
  - with randomness, i.e. p = 1

Topol. optimization problem representation

- Problem representation

Dev0	Dev1	Dev2	…	DevN-1
bit	bit	bit	bit	bit

Population size	100
Final archive size	100
Max. evaluations	50,000
Pop. initialisation	Random
Selection	Binary tournament —NSGAII
	Random with incest threshold —CHC
Recombination	Two-point (DPX) —NSGAII
	HUX —CHC
Probability	$p_c = 0.9$ —NSGAII
	$p_c = 1.0$ —CHC
Mutation	Bit-flip
Probability	$p_m = \frac{1}{Chrom\_Length}$ —NSGAII
	$p_m = 0.35$ —CHC
Independent runs	30

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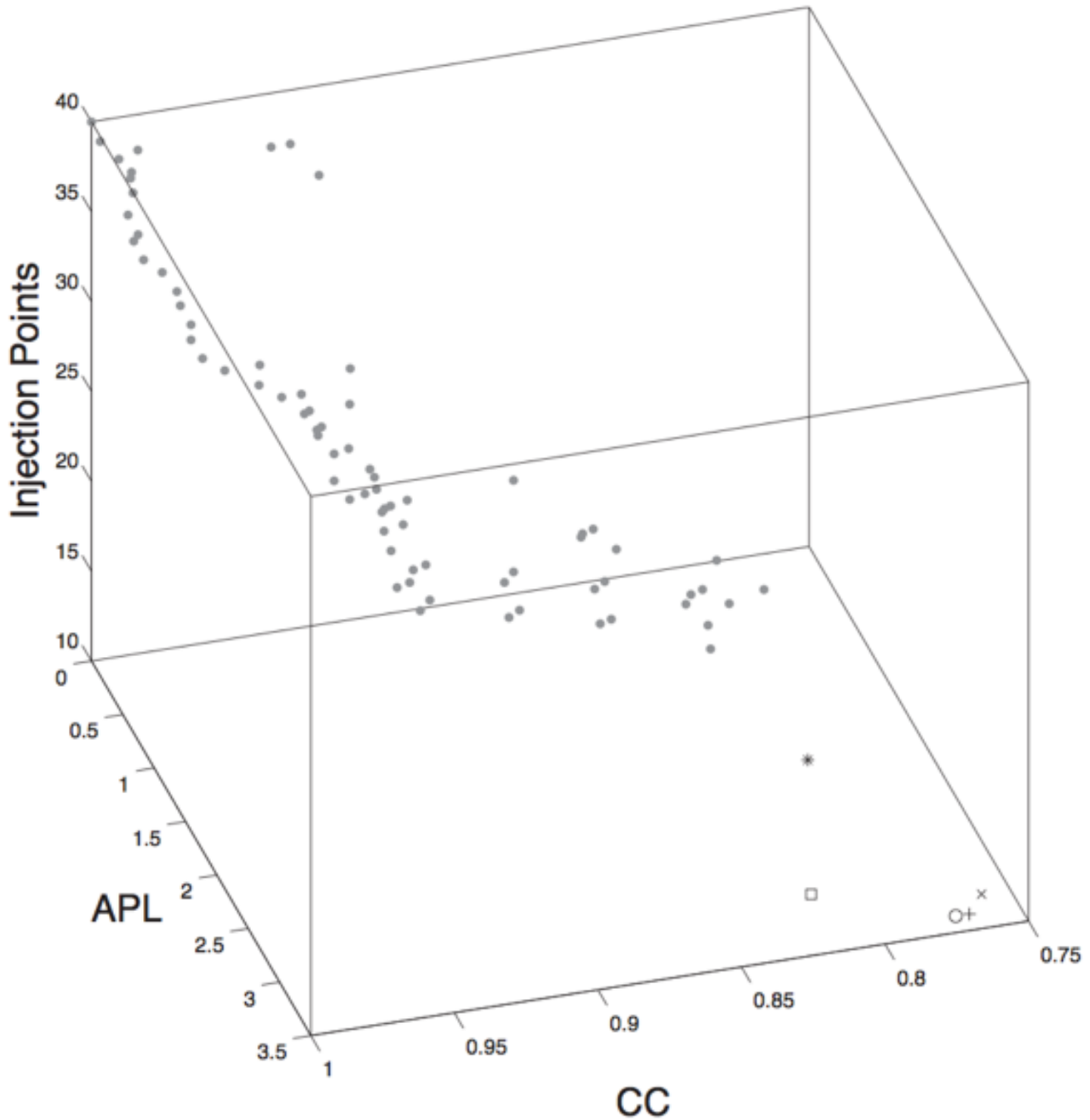
Analysis of the performance of the heuristics

- randomInjPerCC +
- centerInjPerCC ○
- khopca □
- higherDegree x
- higherCC *



(a) 21900

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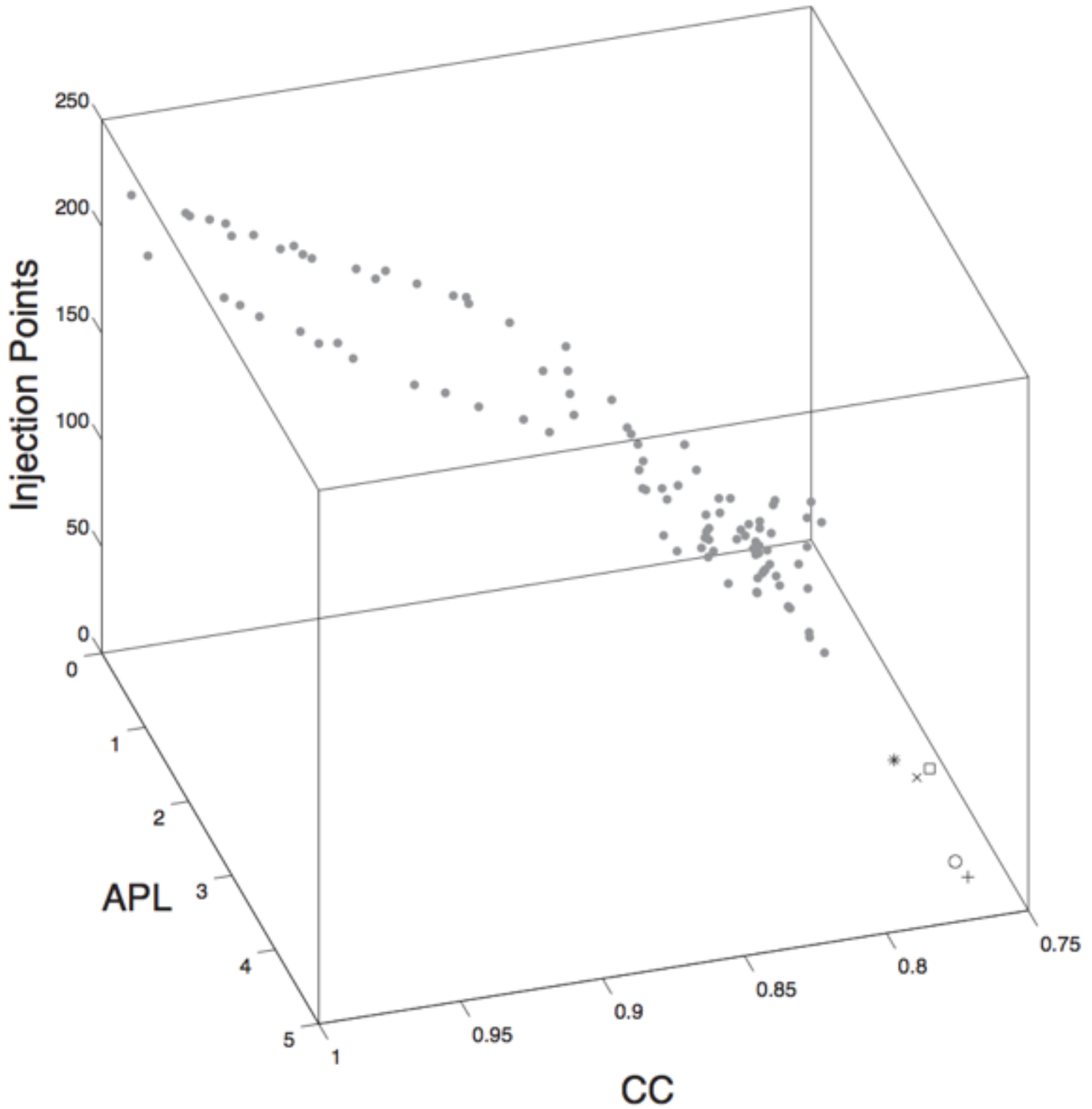

(d) 25500