Robustness of complex networks

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Girona

Broadband Communications and Distributed Systems

NRS2 (Network Research Simulator). An example of using AI to evaluate network robustness

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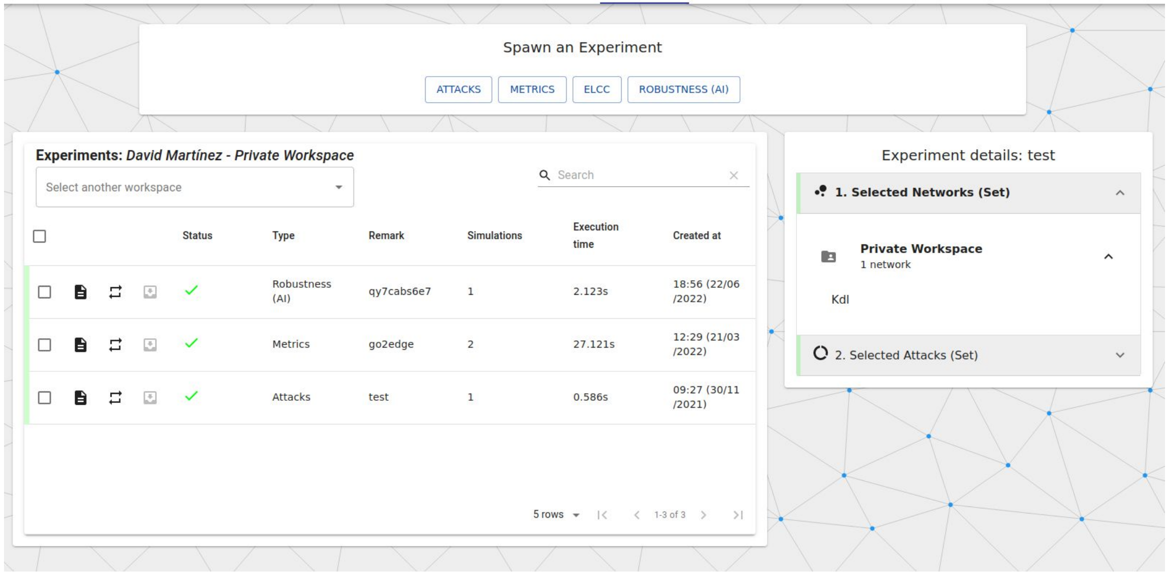
In search of abstraction and scalability

- Our research areas have **increasingly diversified**: We need a more generic and time efficient simulator.
- We propose the **Network Research Simulator** (NRS2) that works at an **abstract level with any network** modeled as nodes and links between them as in Graph Theory.



The Network Research Simulator (NRS2)

- **Objective:** The computation of a set of metrics regarding the topology (graph) of the network.
- **Goal:** Dynamically define experiments based on running computations over networks.

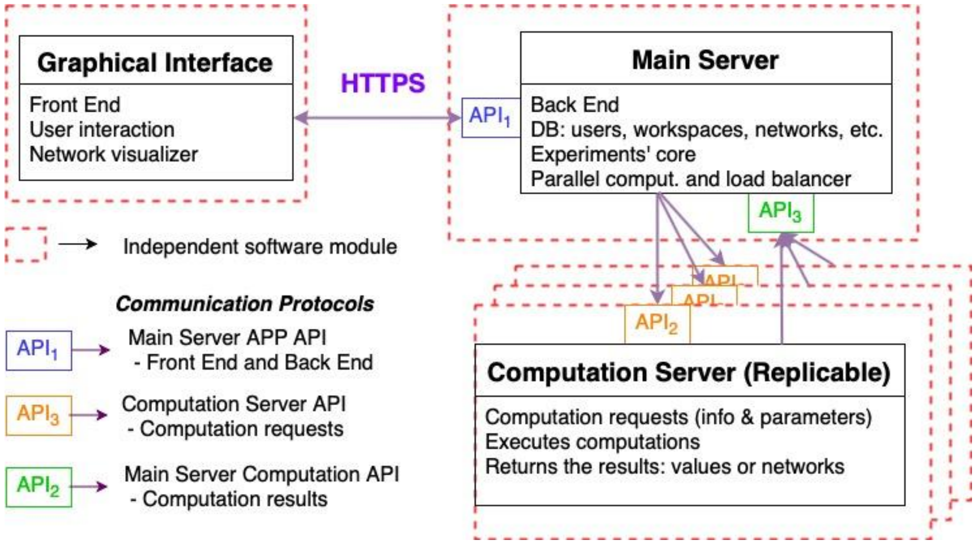


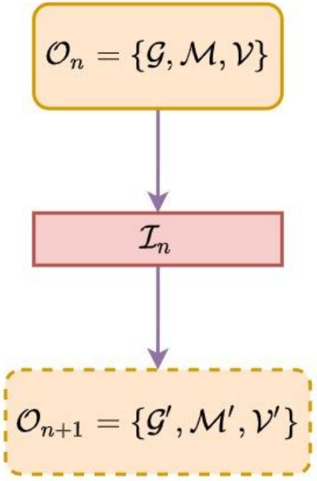
Fig 1. NRS2 architecture

NRS2 Abstract Model Formulation

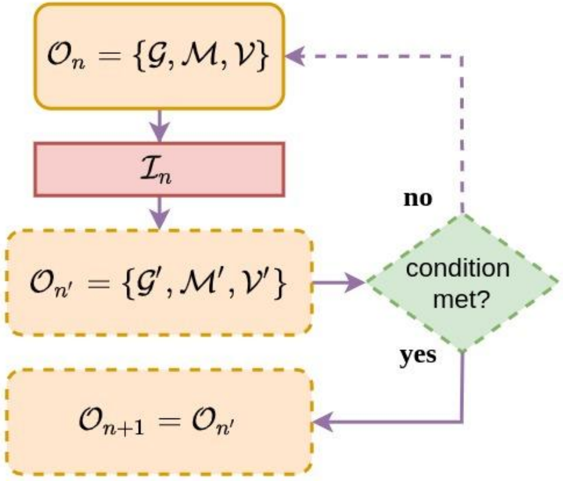
The NRS abstract model is composed by:

- Set of **objects:** $\mathcal{O} = \{\mathcal{G}, \mathcal{M}, \mathcal{V}\}$. $\mathcal{G}$ = graphs, $\mathcal{M}$ = metrics, $\mathcal{V}$ = values
- Set of **iterations** $\mathcal{I}$. An iteration I_n transforms an object set $\mathcal{O}_n$ in a new one $\mathcal{O}_{n+1}$:

$$\mathcal{O}_n : \mathcal{I}_n \rightarrow \mathcal{O}_{n+1}, n = \{0, 1, 2, \ldots, \mathcal{I}_{Max}\}$$



a) Sequential iteration



b) Conditional iteration

Network Robustness

- Our previous works established a unified measure quantifying **network robustness**: The robustness of a network is calculated based on an analysis of metrics over the network under several failures.

- NRS2 is able to **dynamically create** the Network Robustness experiment providing the necessary computations (attacks, metrics, robustness) and the experiment description.

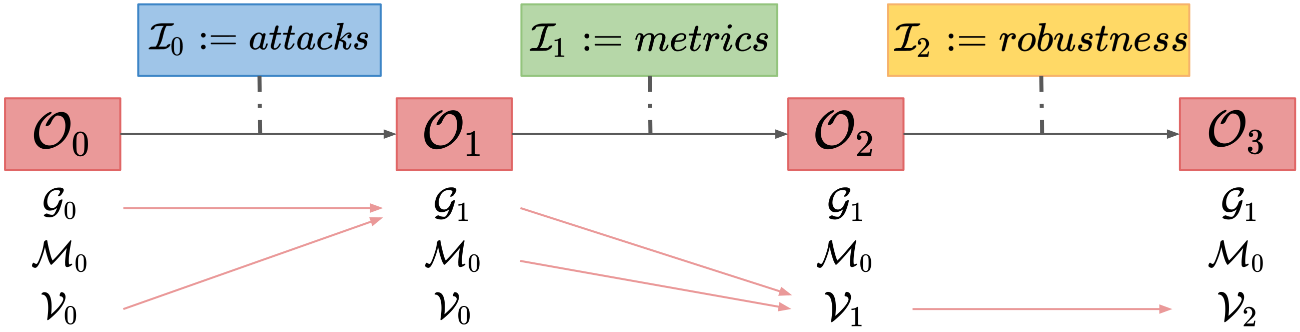
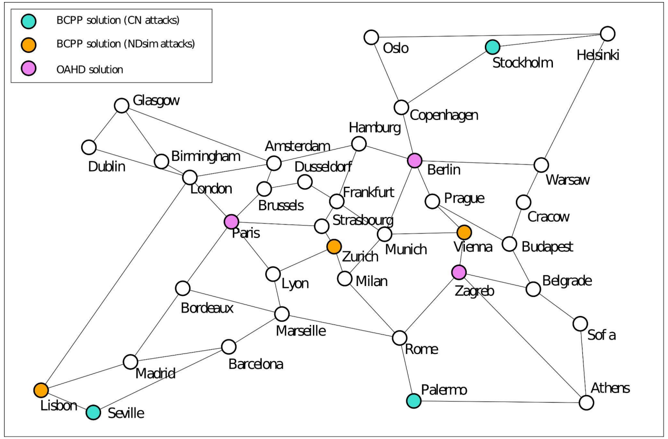
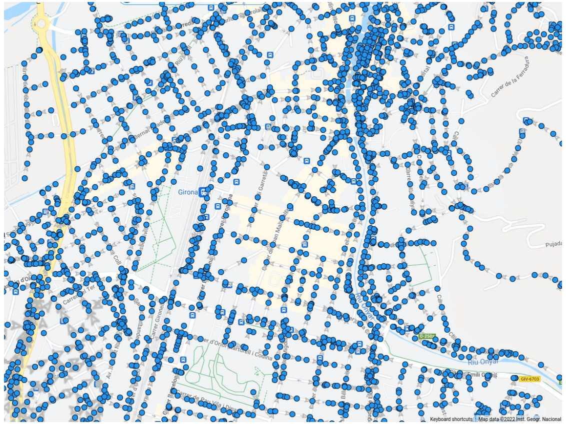


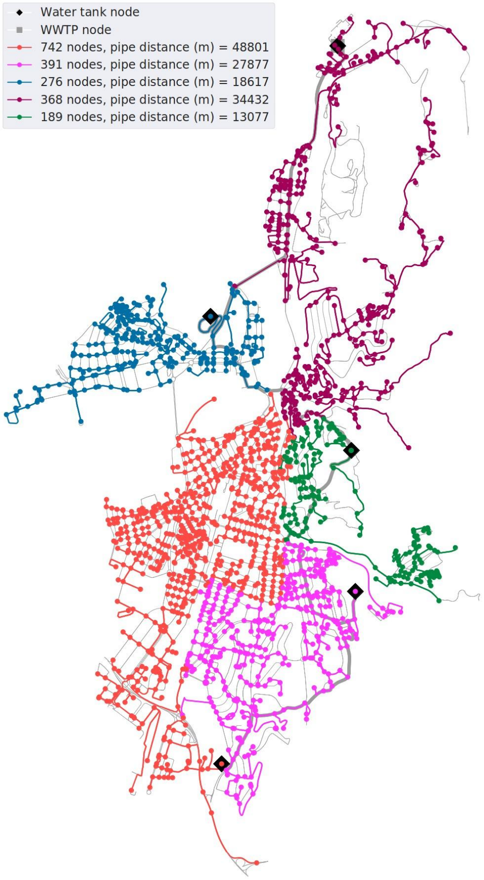
Fig 3. Assignment of particular objects and iterations (Robustness experiment).

Water networks

- Currently, NRS2 is also being used to place sars-cov-2 sensors in sewage networks and to build reclaimed or reused water networks.







TO DO

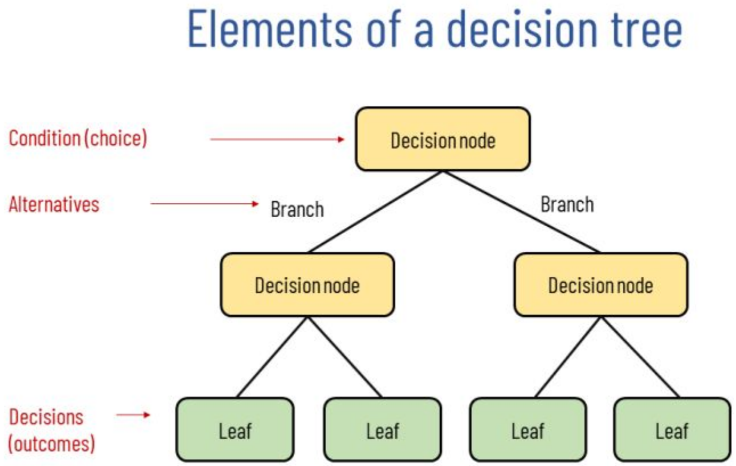
- To do

Network Robustness: AI Approach

- Computing Robustness in large volumes of networks takes a long time (hours)

Metrics	DatasetAI TcnNS M100 v2	243	49h 39m 52s	15:43 (12/05/2022)

- A solution to this problem could be an AI algorithm that computes the robustness of a network.



AI Models: Objectives

- The objective of the AI is to predict the robustness of a network given the metrics of it.

ROBUSTNESS VALUE

AI Models: Implemented algorithms

- Many algorithms were implemented.

Model	Average Relative Error
Linear Regression	5.10%
KNN	2.83%
Decision Tree	2.80%
Random Forest	2.36%
Neural Network	4.62%

- All algorithms performed very well.
- Random Forest was the best one.

Random Forest Improvements I

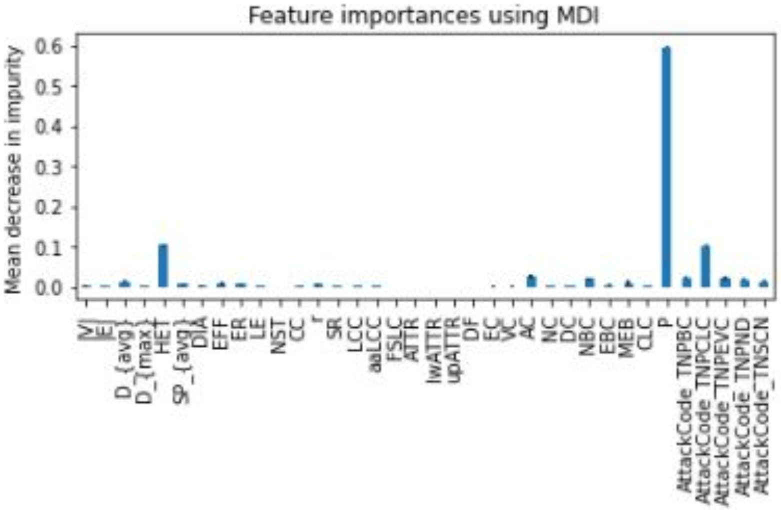
- The first improvement to the model was an hyperparameter optimization.
  - Hyperparameters are intrinsic characteristics of a model.
- A search on some parameters was implemented using an automated search

Parameter	Value range
n_estimators	200-2000
max_features	auto,sqrt
max_depth	10-110
min_samples_split	2,5,10
min_samples_leaf	1,2,4
booststrap	True, False

- The model resulting of this optimization did not improve the original one.

Random Forest Improvements II

- The second improve consisted in adding more metrics to the model.



- The most relevant features after adding all the available metrics were HET and P.

AI Approach: Final results

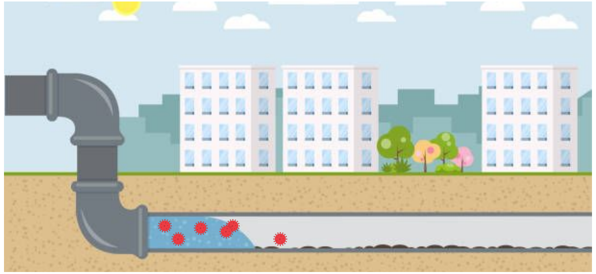
Attack	Computation Time
BetwenessCentrality	29h 06m 52s
ClosenessCentrality	44h 56m 52s
EigenvectorCentrality	44h 45m 5s
NodalDegree	44h 42m 56s
CriticalNodes	49h 39m 52s
Random	10h 12m 38s
AI Model	**0h 0m 5s**

Attack	Precission
Target	98.65%
Random	97.58%

Conclusions

- A novel abstract model formulation of the experiments is presented promising a **flexible and scalable** simulation environment: In the future, new conditional objects will be developed allowing **loops** in the definition of an experiment.

- The final AI Model implemented has exceeded our expectations in terms of precision. The computation time of the robustness is virtually instantaneous. Event hough it's currently an alternative for robustness computation it might end up being the standard for the simulator.



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