Graph Topology-Based District Heating Network Preparation for Probabilistic Resilience Assessment

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METHODS

- **Graph theory** for DHN formulation and analysis.
- **KD Tree** – 2-dimensional tree for **consumer** assignment.
- **HDBSCAN** – for building density maps (**urban**, **suburban**, and **rural** areas).
- **Adaptive Segmentation Algorithm** – for dividing pipe sections into smaller segments based on building density.
- **Topology metrics** – for DHN assessment.

Degree centrality - redundancy

$$C_D = \frac{\deg(v)}{N-1}$$

Betweenness centrality - robustness

$$C_B = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}}$$

Clustering centrality - density

$$C_{Cl}(v) = \frac{1}{d(v)\cdot(d(v)-1)} \sum_{r,s \in N(v)} A_{rs}$$

"**PageRank**"- node importance

$$PR(v) = \frac{1-d}{N} + d \sum_{t \in In(v)} \frac{PR(t)}{OutDeg(t)}$$

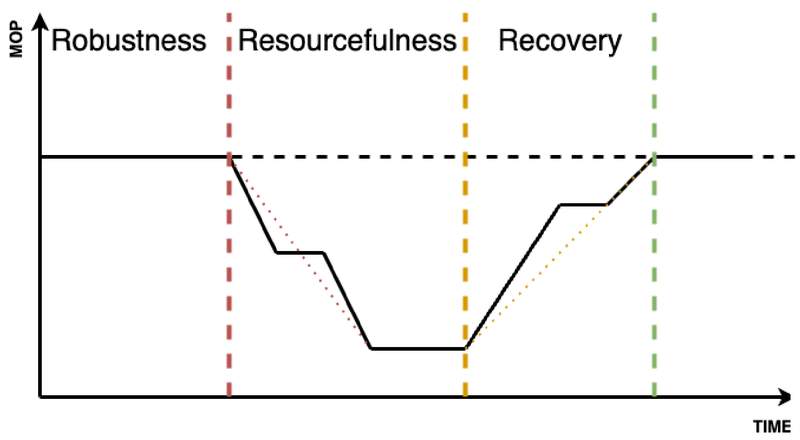
Closeness centrality - flexibility

$$C_C(v) = \frac{N-1}{\sum_{t \neq v} d(v,t)}$$

MOTIVATION – HILP EVENTS

- Cyber attacks on ICS
- Natural disasters
- Industrial disasters
- Political conflicts

HILP – High Influence Low Probability events



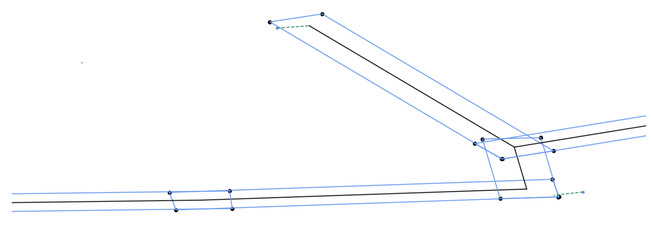
RESILIENCE:

- Robustness
- Resourcefulness
- Recovery

$$\mathcal{R} = \alpha R_o + \beta R_e + \gamma R_c$$

DATASETS

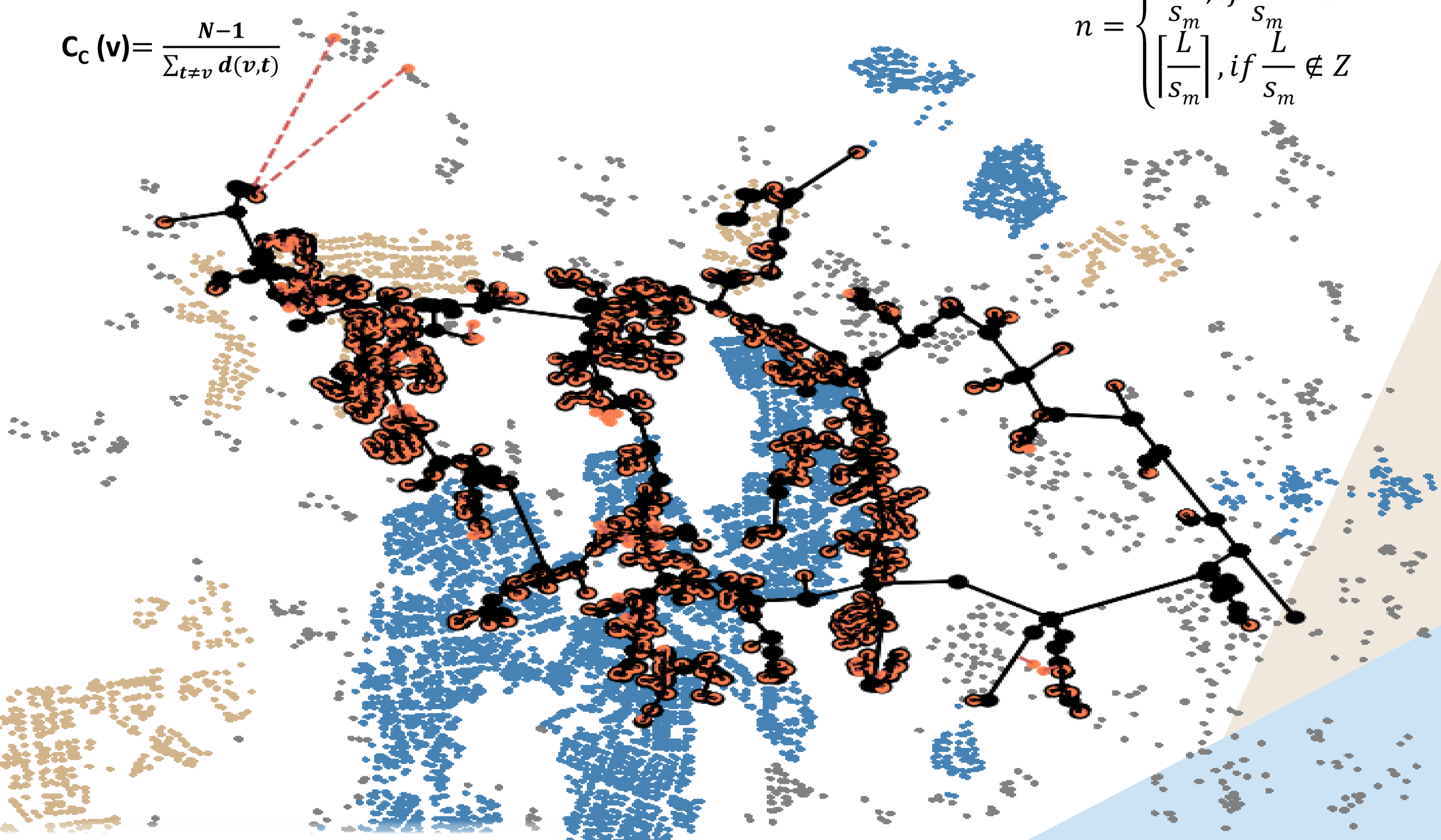
- **Utena city DHN GIS data** – geographical and physical pipeline information (pipe width, length, material, coordinates, etc).
- **Consumer dataset** – includes power allocation, heating area, year of construction, apartment count, etc.
- **OpenStreetMap (OSM)** – provides environmental context such as street types, building coordinates, and related features.
- **SoilGrids** – soil data for buried pipes, including chemical characteristics.
- **GlobalSurfaceWater** – provides data on changes in surface water, including historical and forecasted flooding.



$$s_i = \left(\frac{\mu x' + \kappa x_0}{n}, \frac{\mu y' + \kappa y_0}{n}\right)$$

$$\kappa = n - \mu, \qquad \mu = \overline{1, n-1}$$

$$n = \begin{cases} \frac{L}{s_m}, if \frac{L}{s_m} \in Z \\ \left\lceil \frac{L}{s_m} \right\rceil, if \frac{L}{s_m} \notin Z \end{cases}$$



FUTURE RESEARCH

- Resilience evaluation
- System optimization to increase resilience
- Chain reactions

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