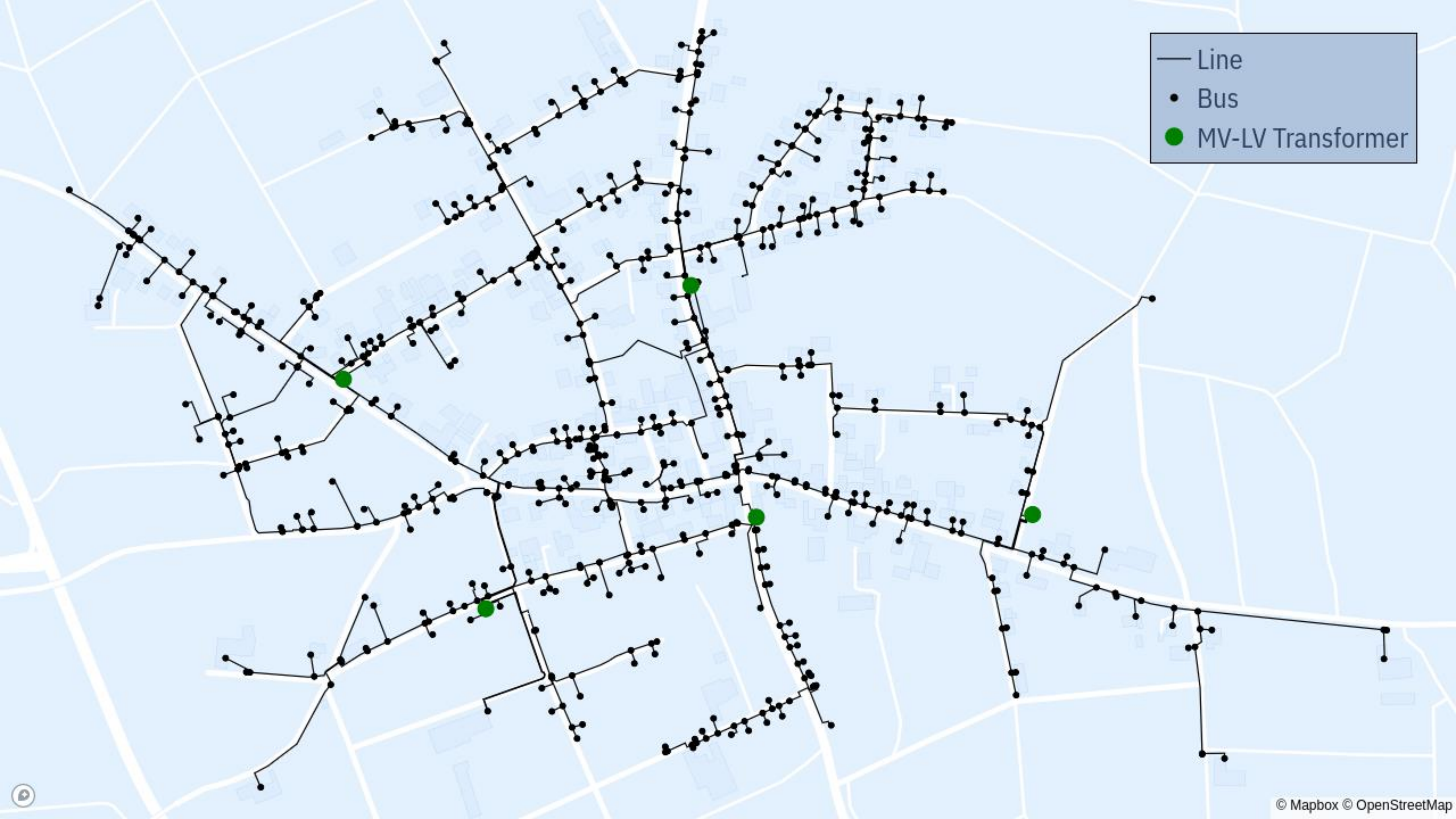
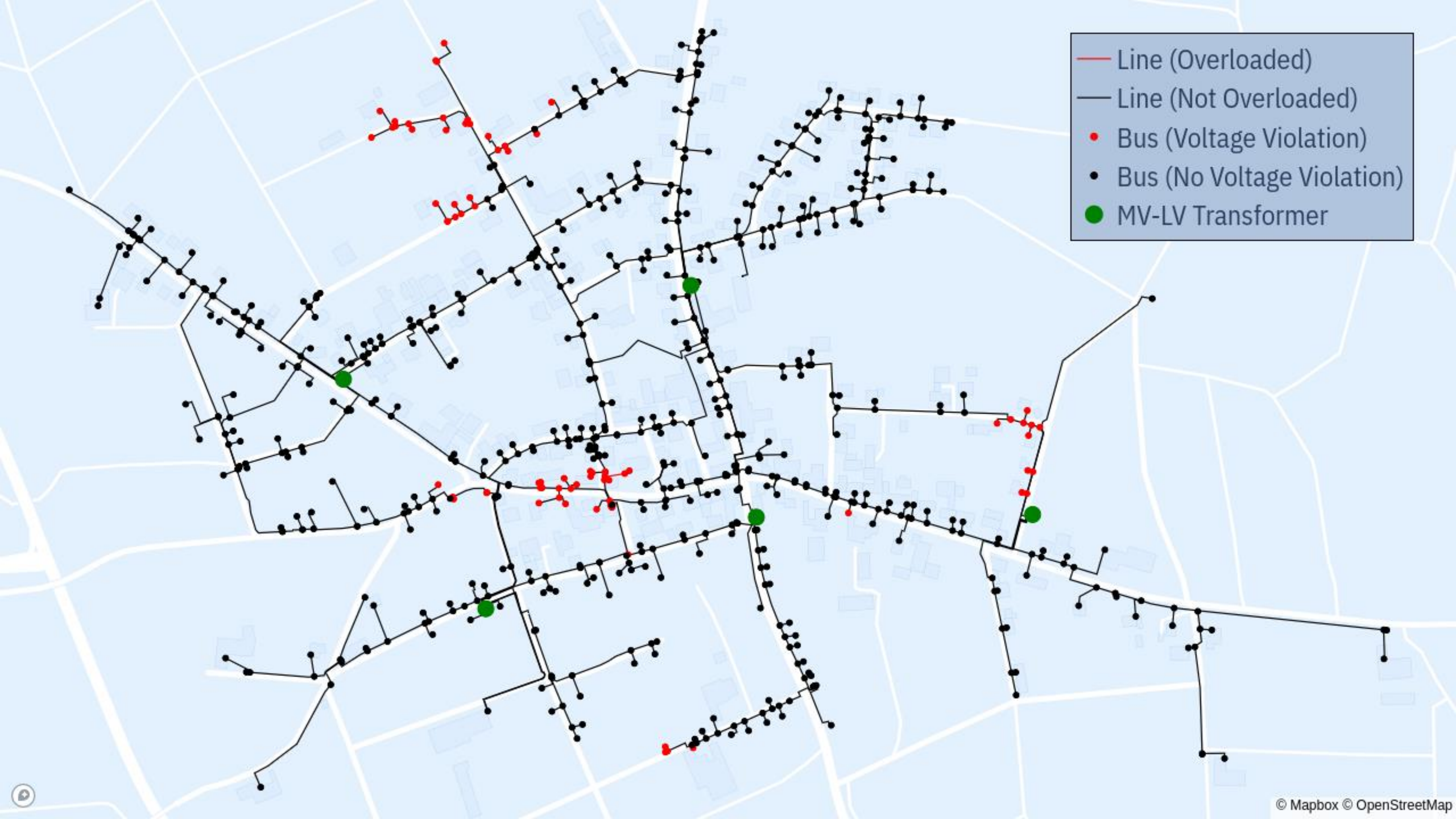

Line
Bus
MV-LV Transformer
© Mapbox © OpenStreetMap


Line (Overloaded)
Line (Not Overloaded)
Bus (Voltage Violation)
Bus (No Voltage Violation)
MV-LV Transformer
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Expansion Planning of Low-Voltage Grids Using Ant Colony Optimization

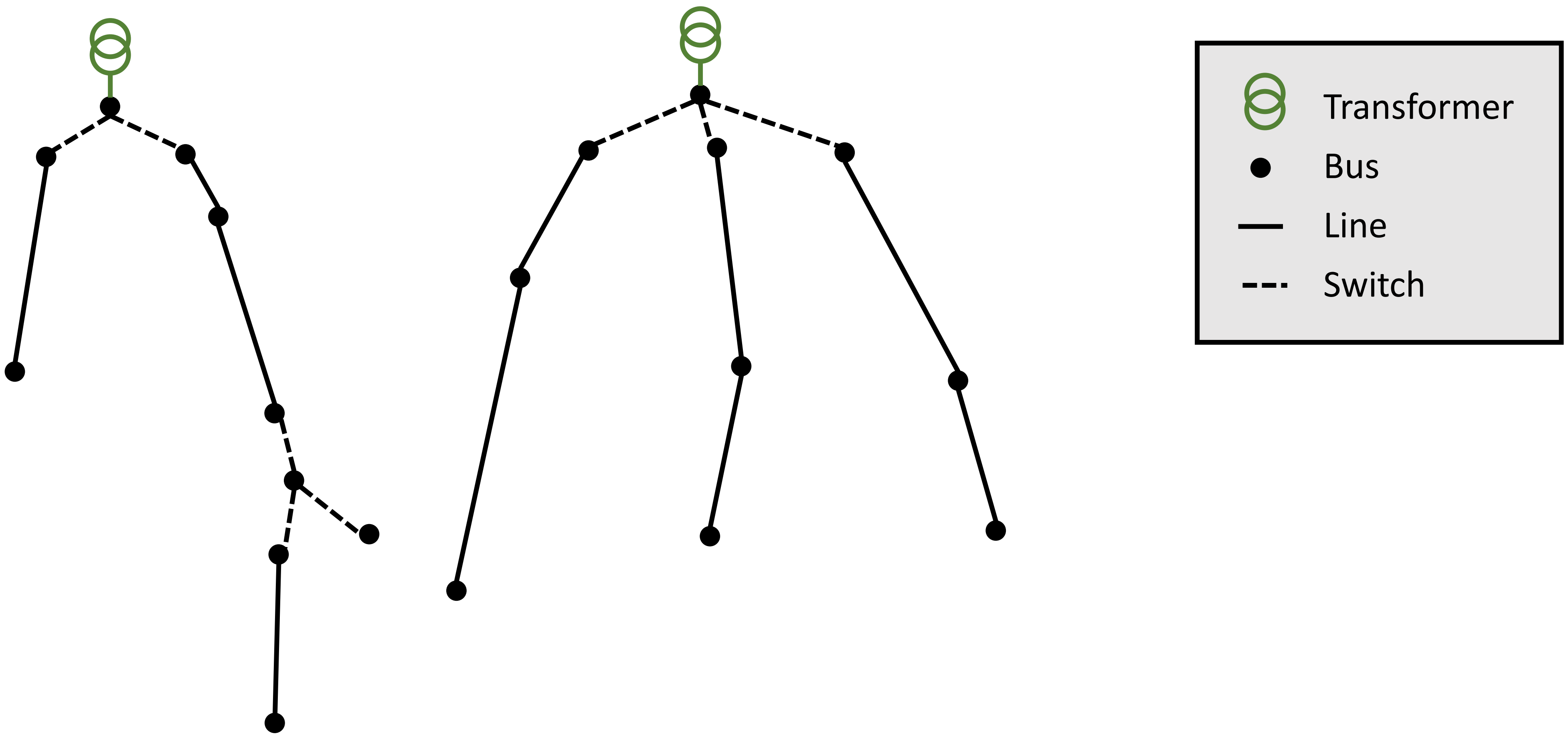
Lukas Gebhard

August 2021

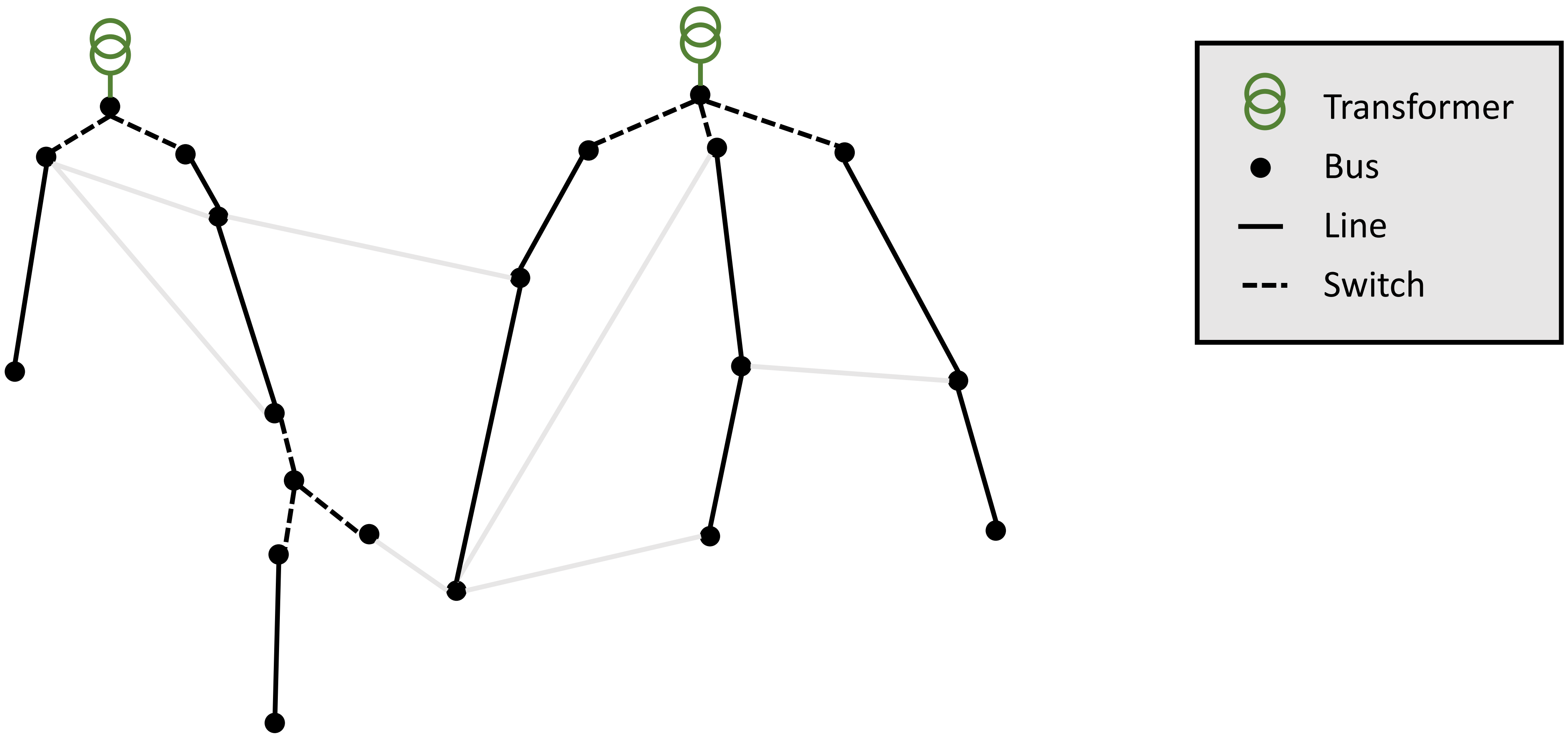
Agenda

1. Problem (7 min)
   → Q&A
2. Solution (9 min)
   → Q&A
3. Evaluation (4 min)
   →Q&A

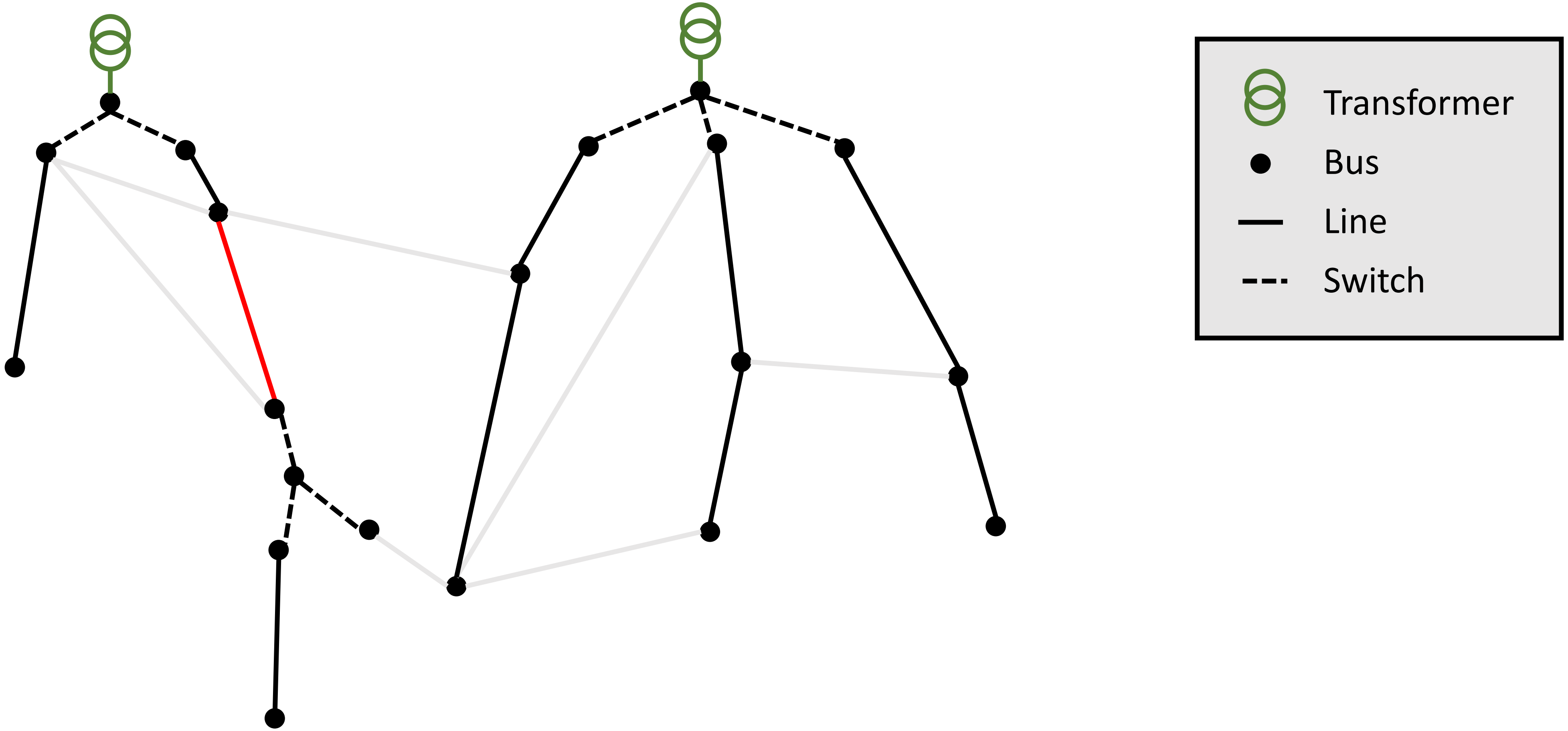
Example



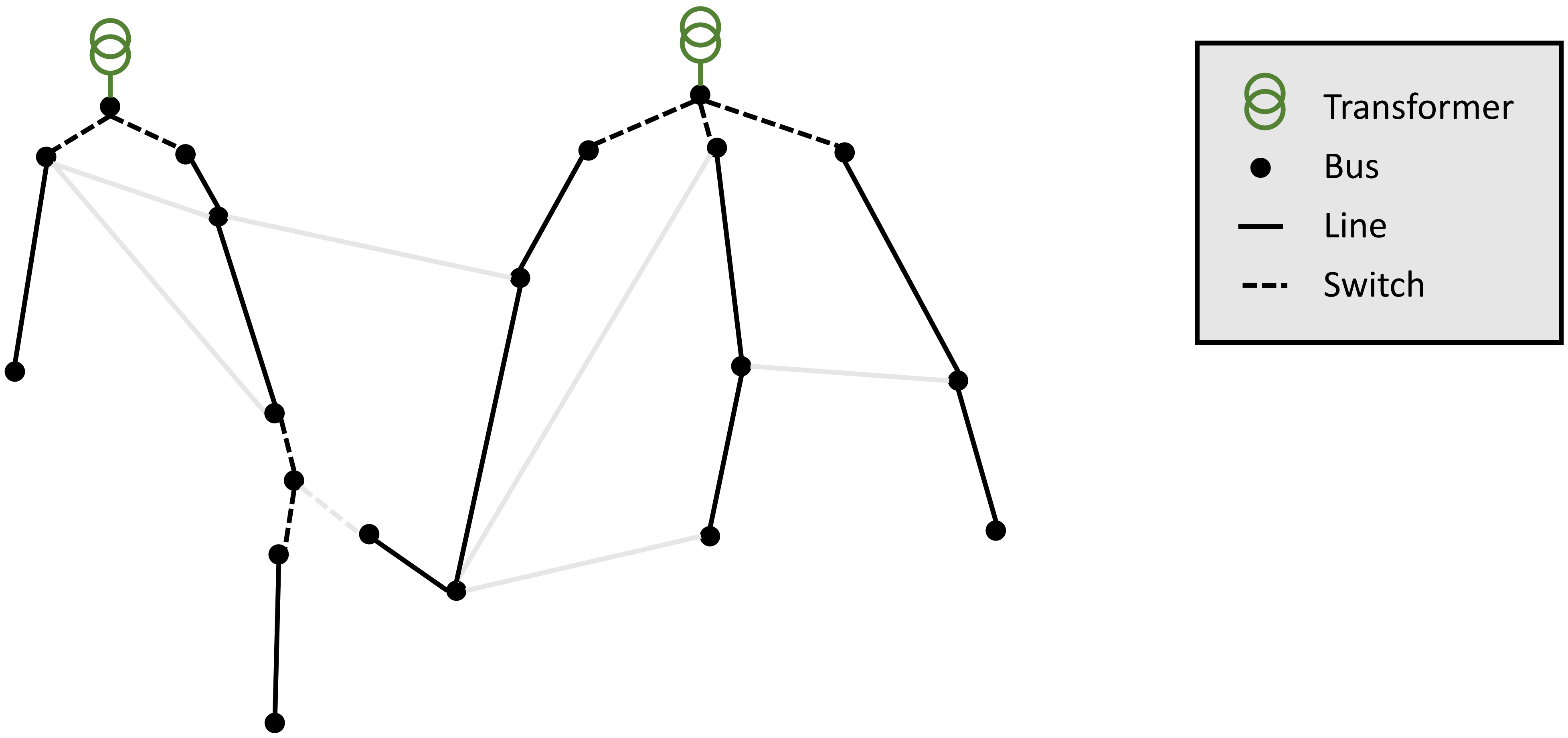
Example: Additional Lines



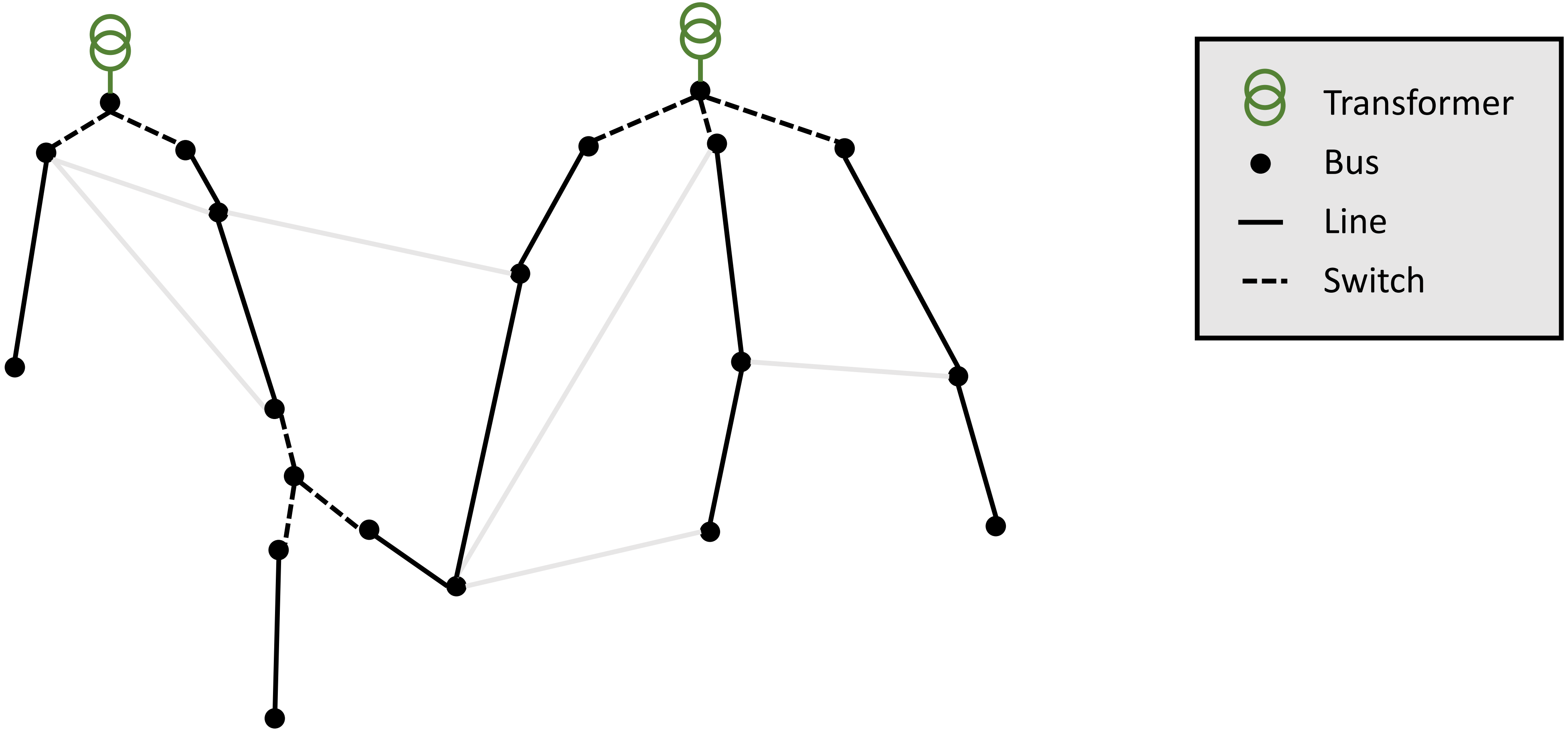
Example: Overloading



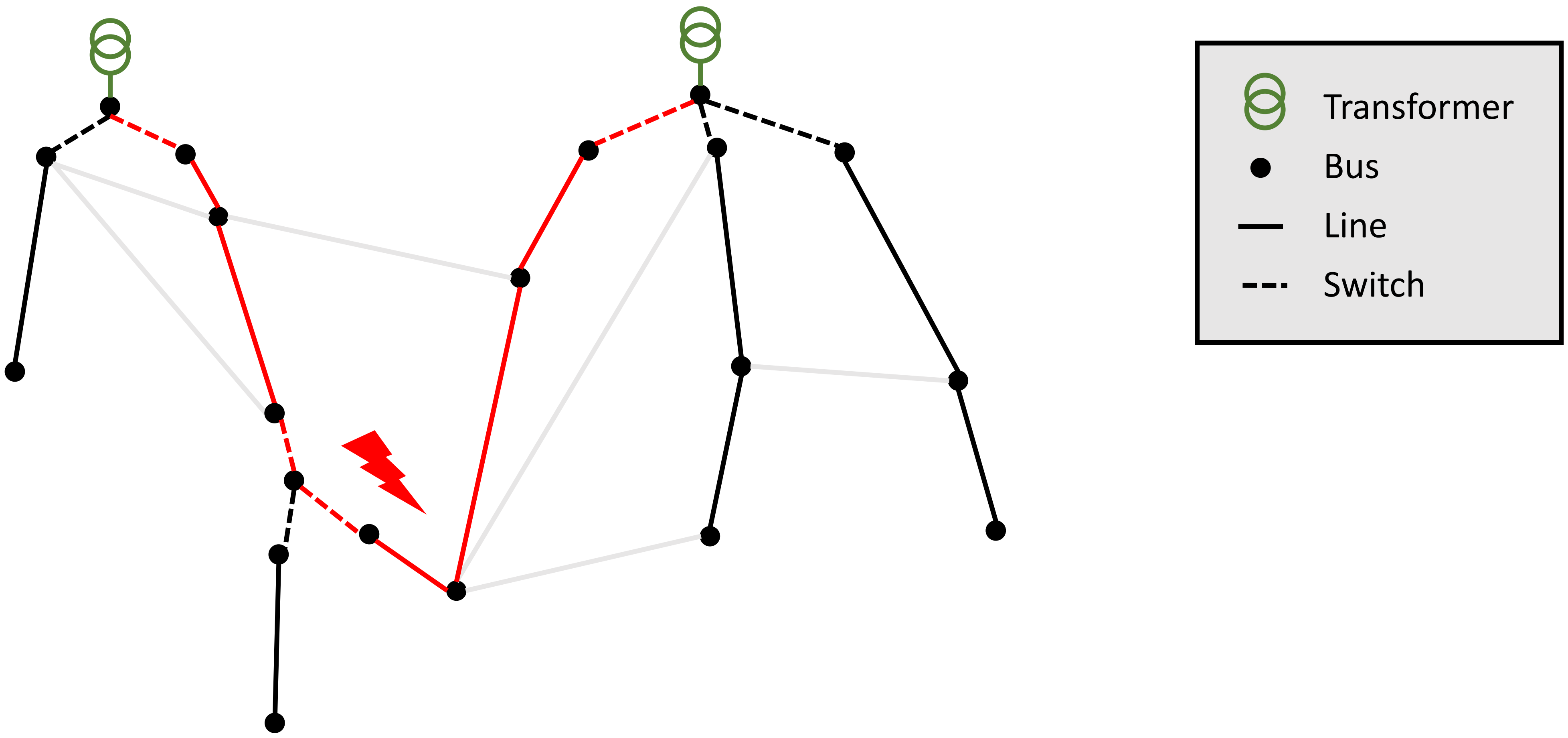
Example: Expansion



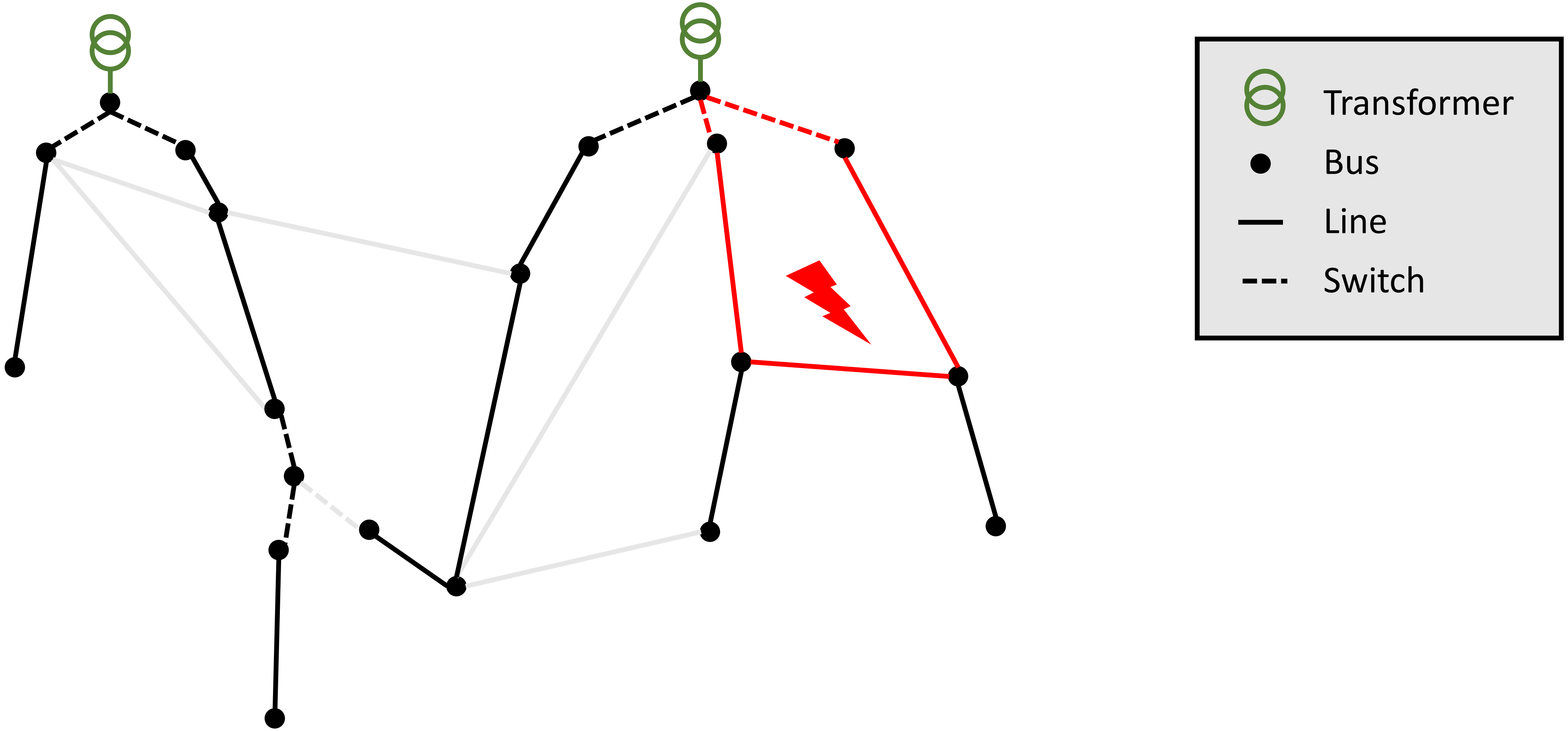
Example: Invalid Topology



Example: Invalid Topology



Example: Invalid Topology



Constraints

Topological constraint:

Graph is a forest with one transformer per tree

Constraints

Topological constraint:

Graph is a forest with one transformer per tree

Electrical constraints

Voltages & line loadings must not exceed given limits

→ *Power Flow Analysis*

Problem statement

- Inputs:
  - Grid $G_{now} = (B, E_{now})$
  - Expansion options E_{add}
  - Electricity generation & demand
- Outputs:
  - Expanded grid $G_{exp} = (B, E_{exp})$ with $E_{exp} \subseteq E_{now} \cup E_{add}$
  - Expansion cost $c(G_{now}, G_{exp})$
- Objective: Minimize $c(G_{now}, G_{exp})$
- Constraints: topological & electrical
- Degrees of freedom:
  - Installation, reinforcement, dismantling of lines
  - Opening & closing of switches

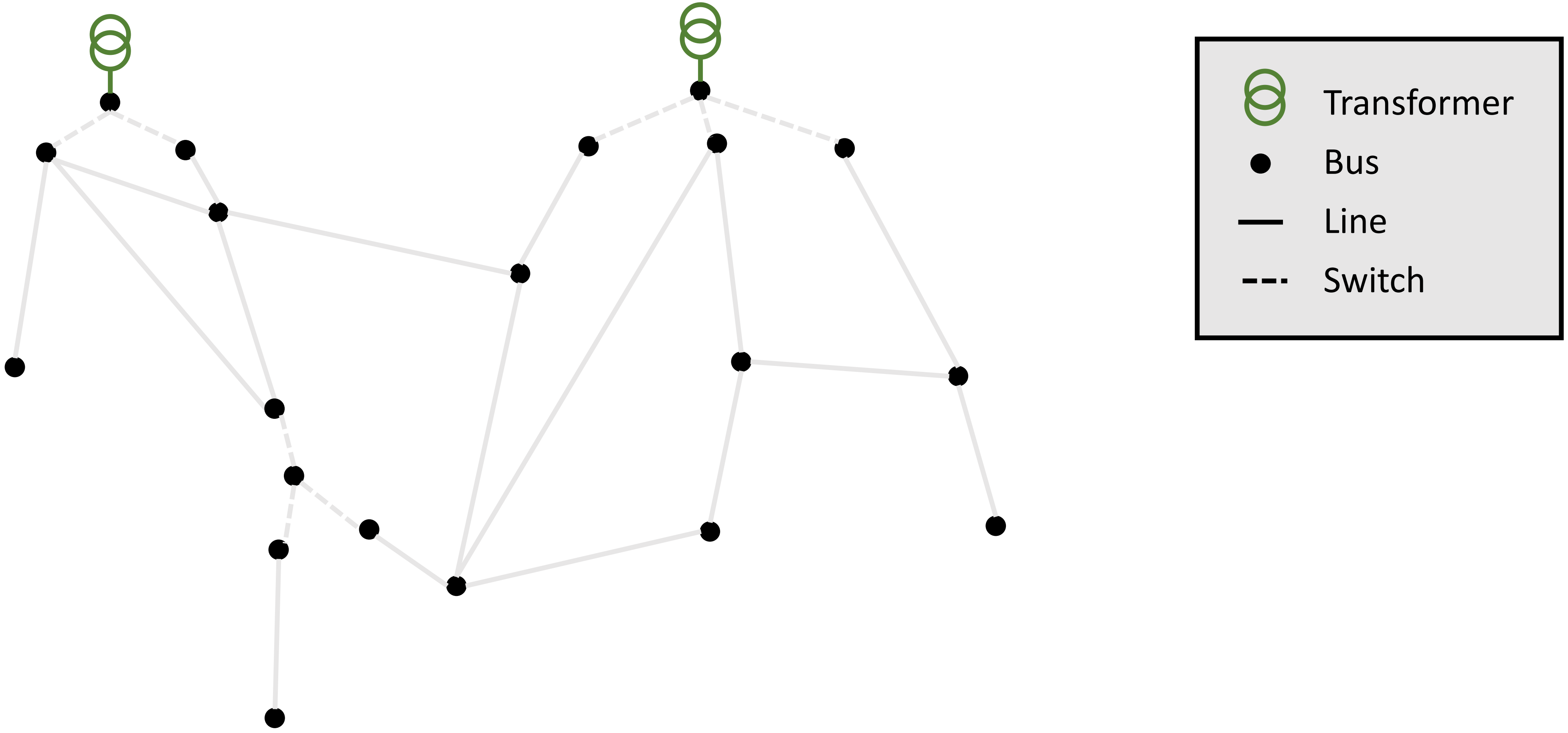
Q&A

Ant Colony Optimization [1]

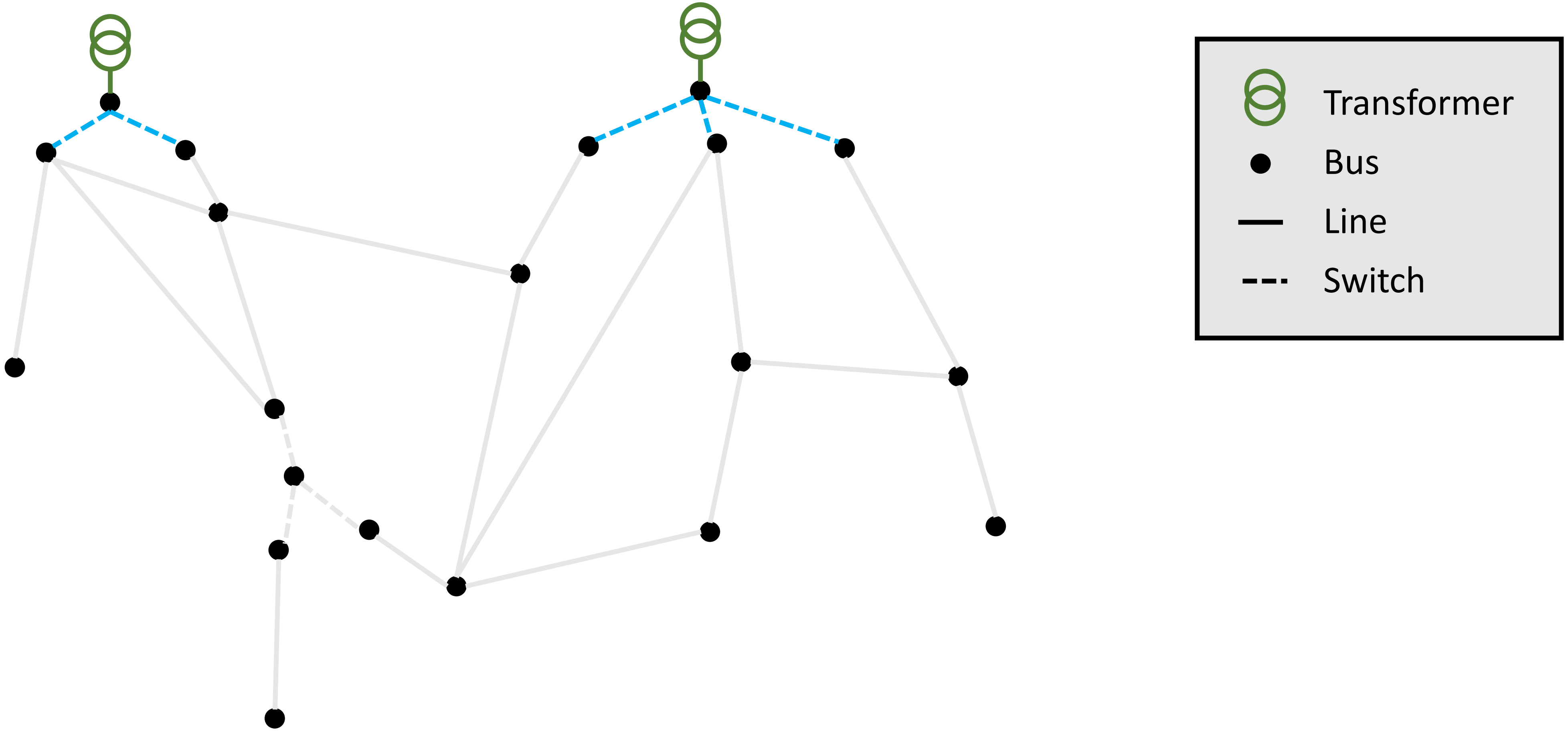
- Set of heuristic concepts
- For combinatorial optimization problems
- *Ant* = simple agent
- *Colony* = group of ants
- *Pheromones* for communication

[1] Dorigo, 1992

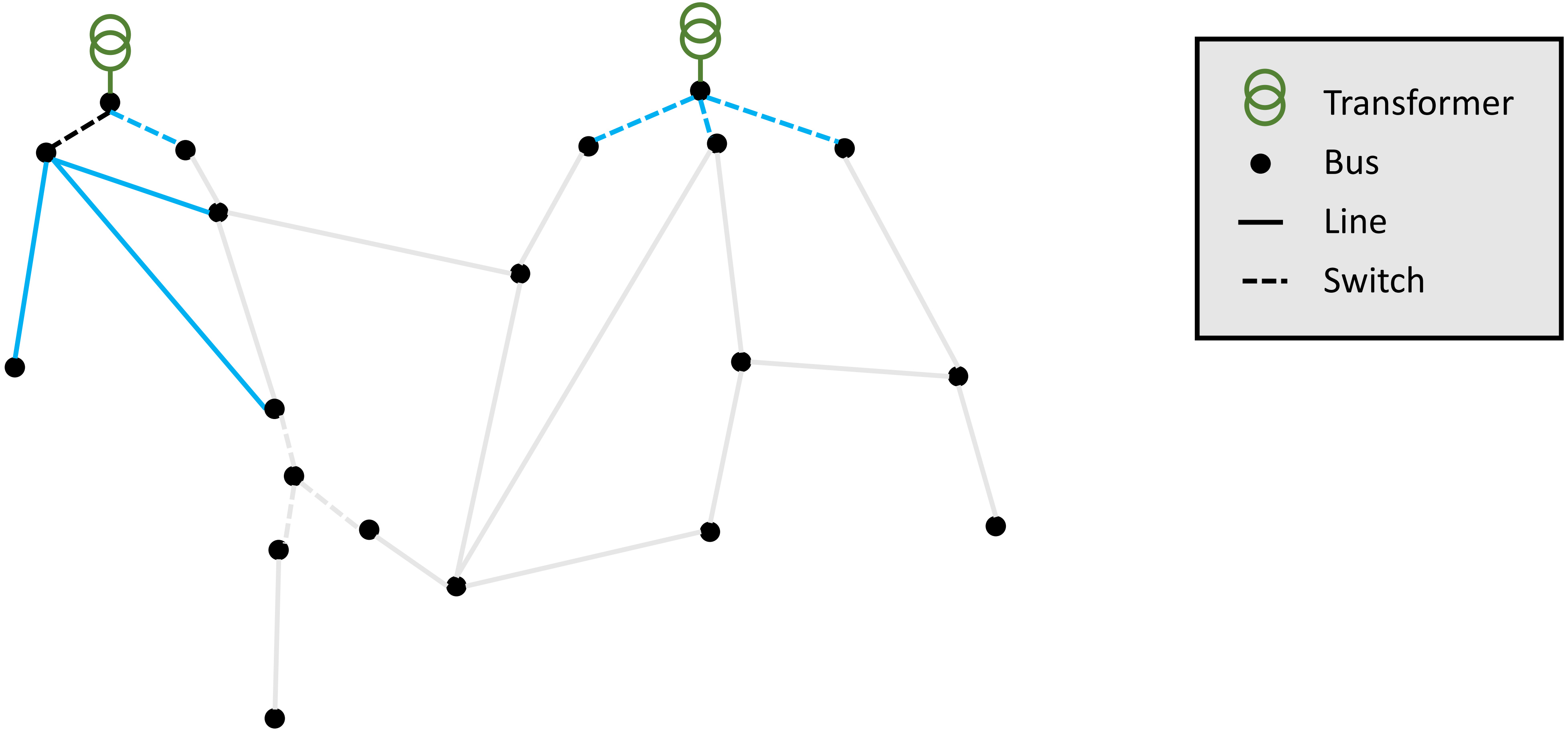
Example



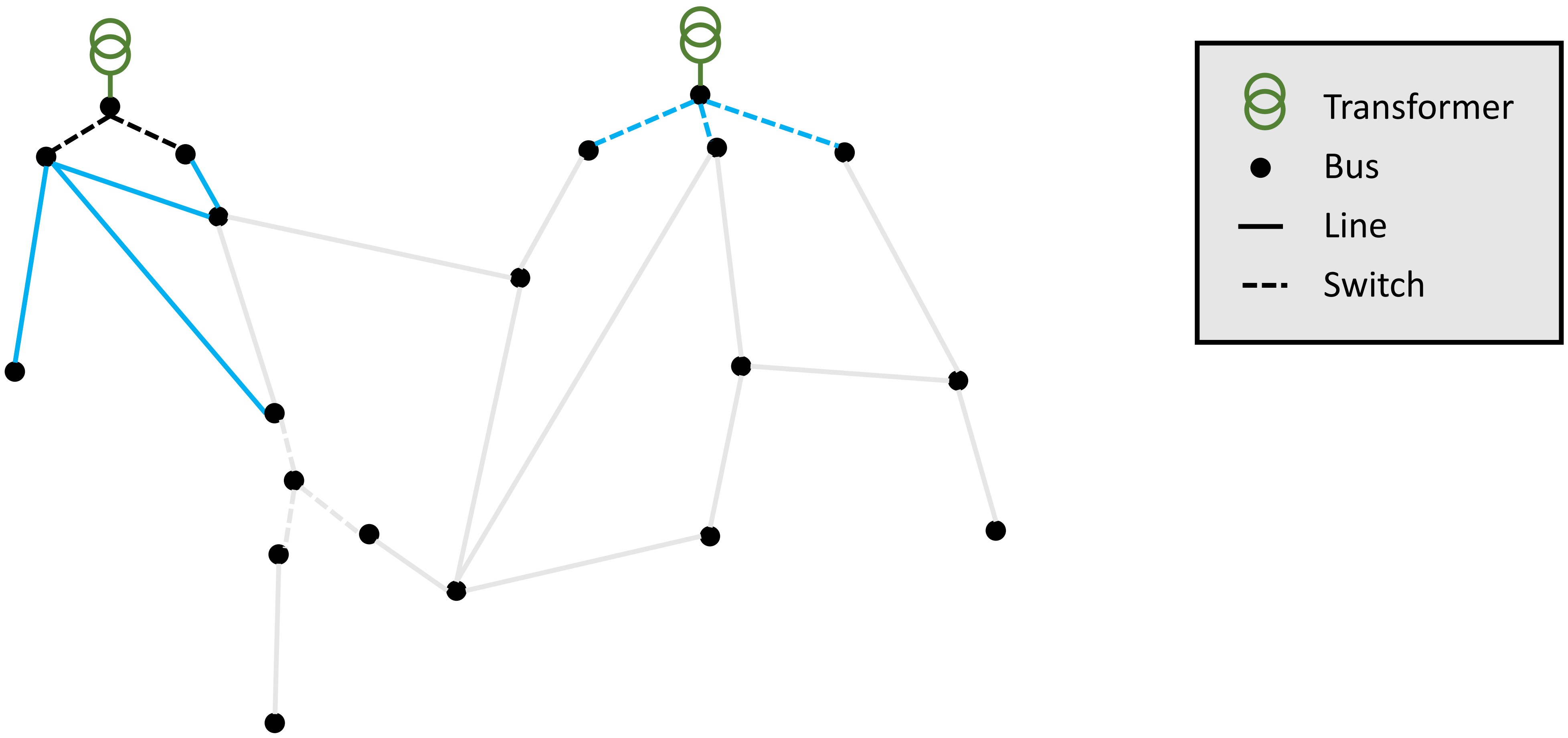
Example: Neighborhood



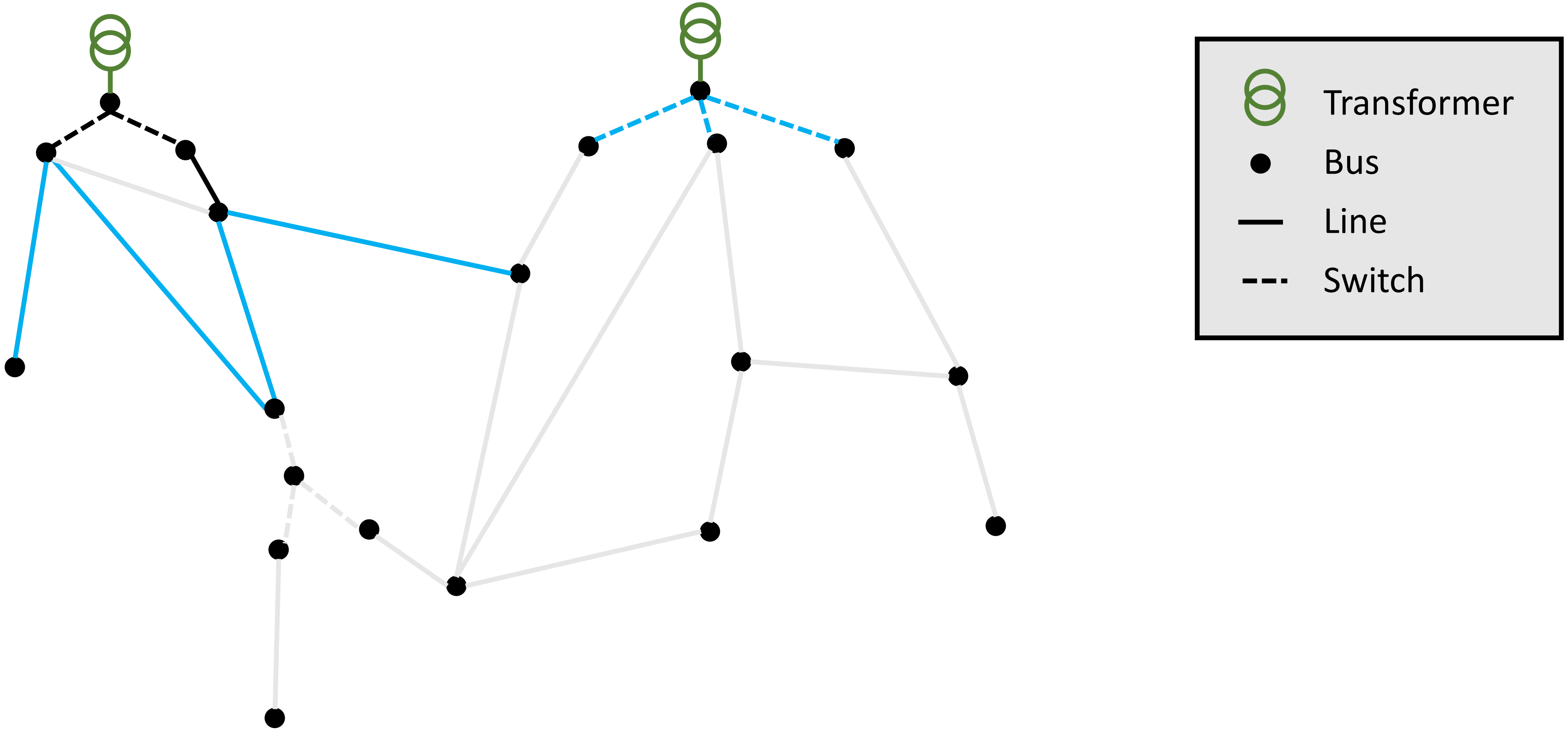
Example: Neighborhood



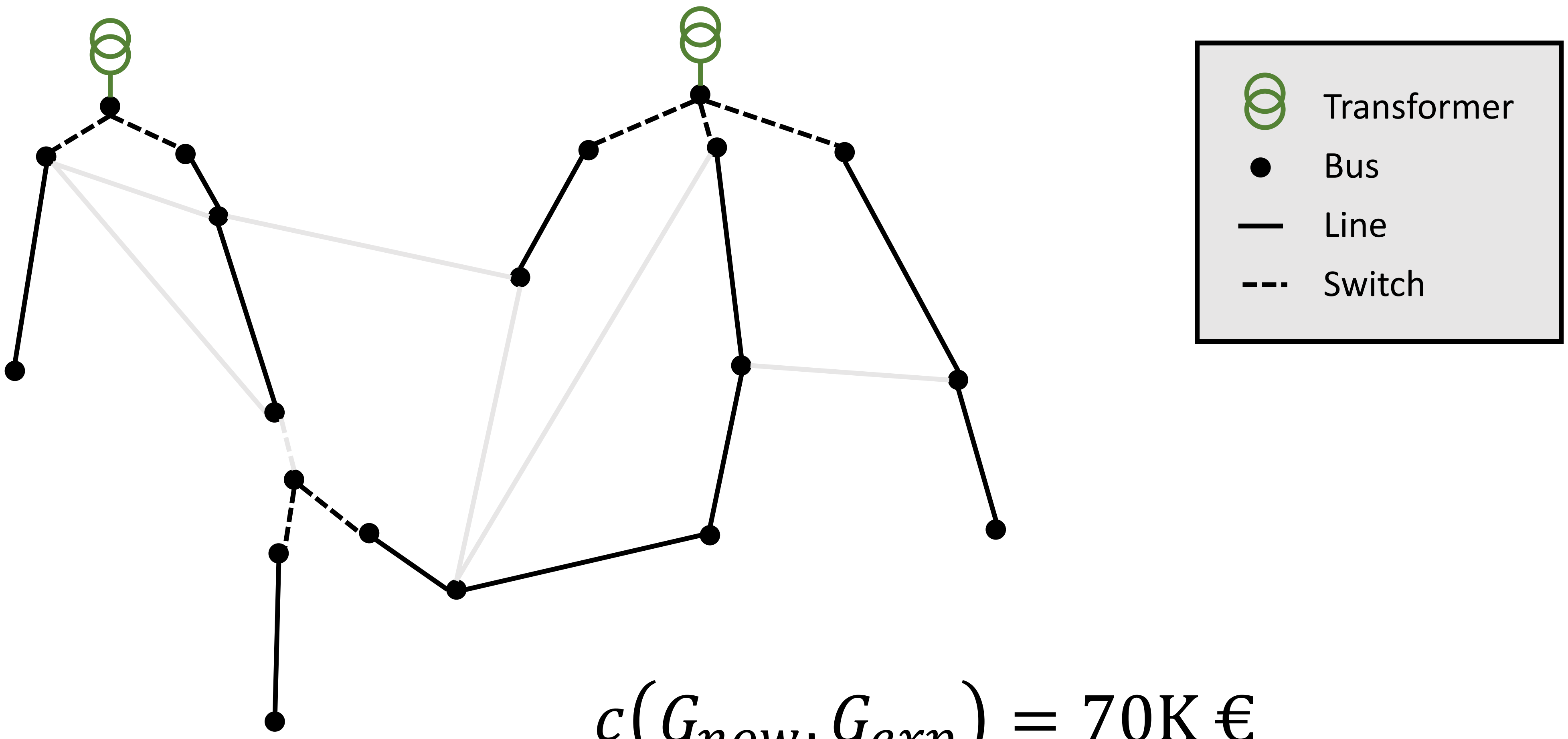
Example: Neighborhood



Example: Neighborhood

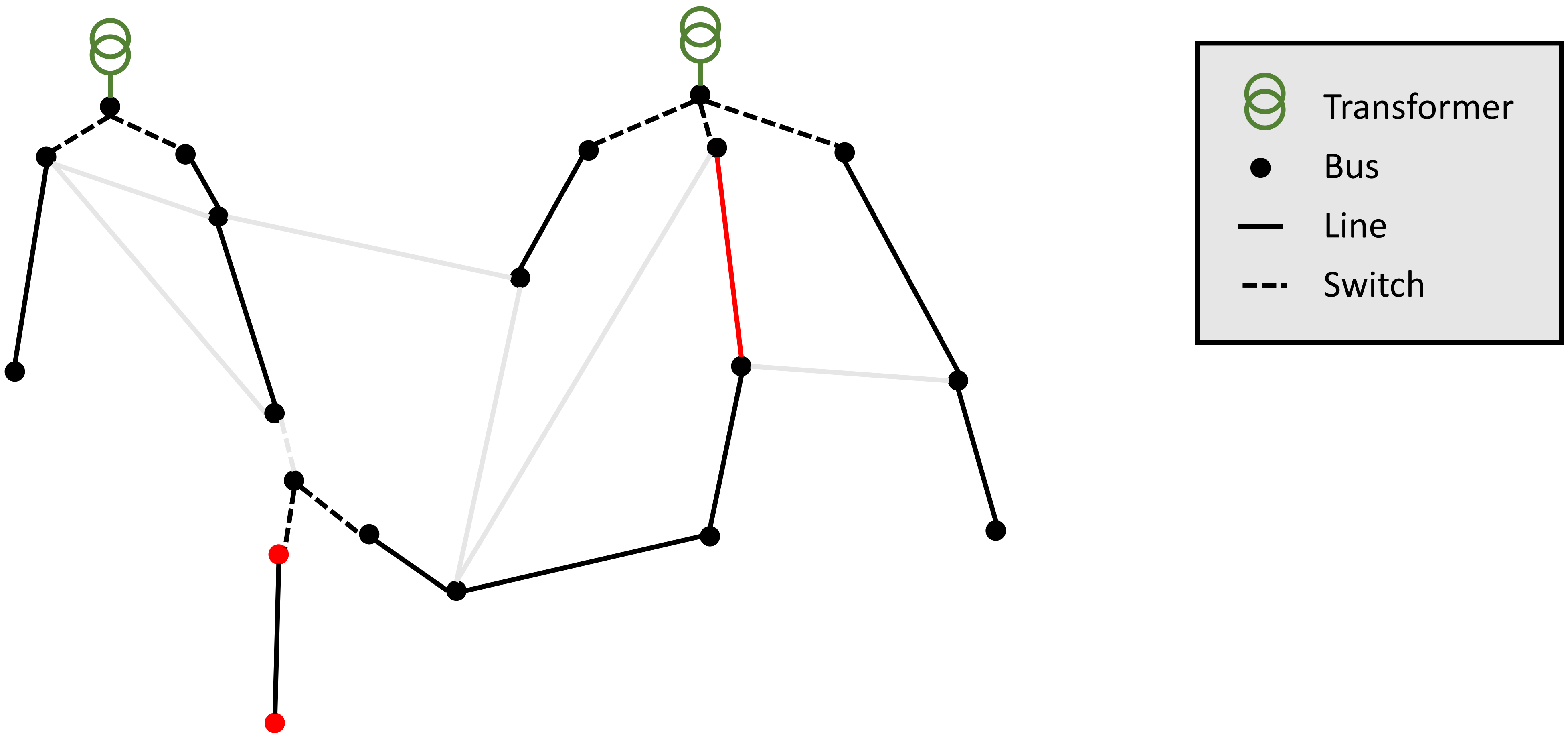


Example: A Solution

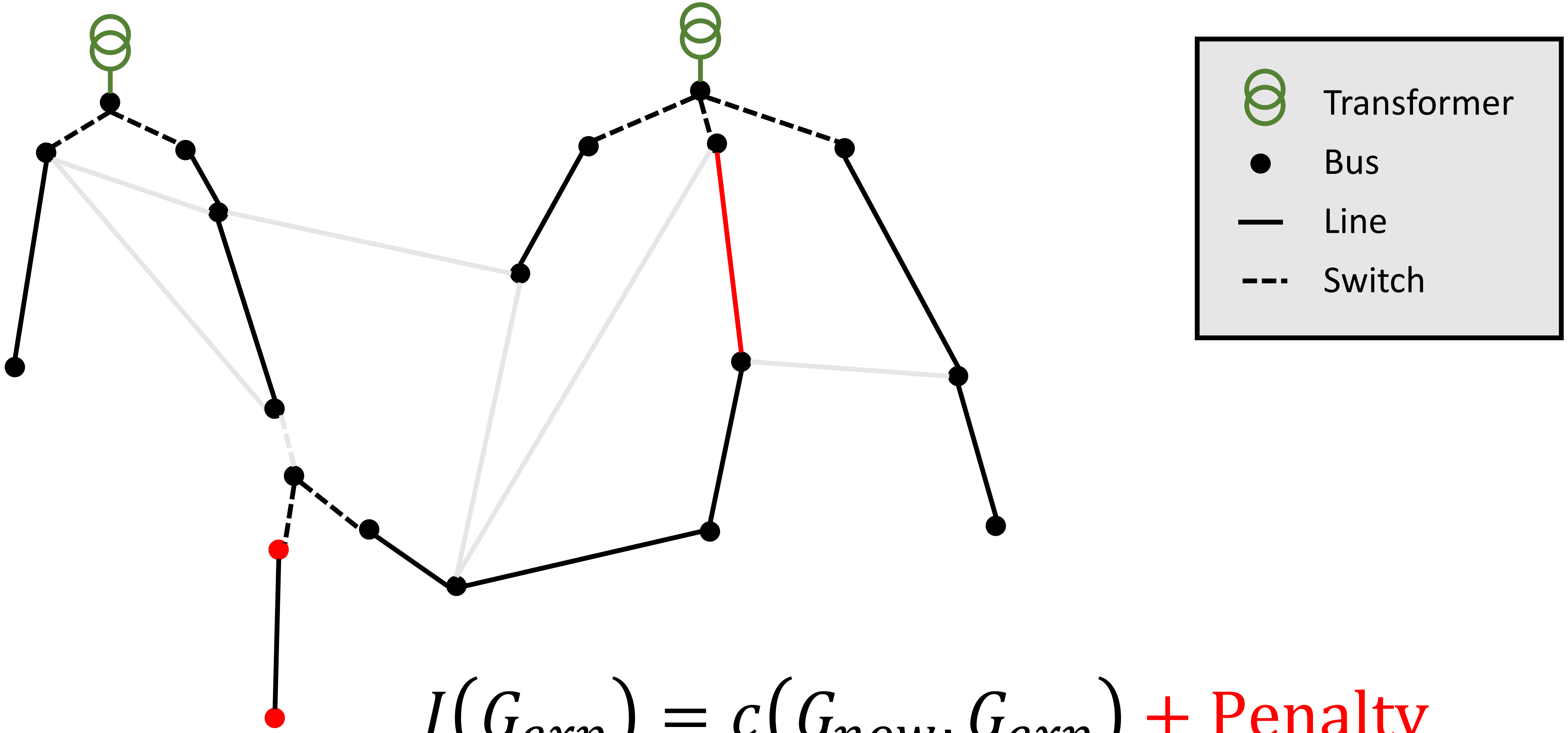


$$c(G_{now}, G_{exp}) = 70\text{K}\,€$$

Example: Electrical Constraints



Example: Objective Function



$$J(G_{exp}) = c(G_{now}, G_{exp}) + \text{Penalty}$$

Search Strategy

Adopted from *Ant Colony System* [2]

[2] Dorigo & Gambardella, 1997

Search Strategy

Adopted from *Ant Colony System* [2]

Transition rule:

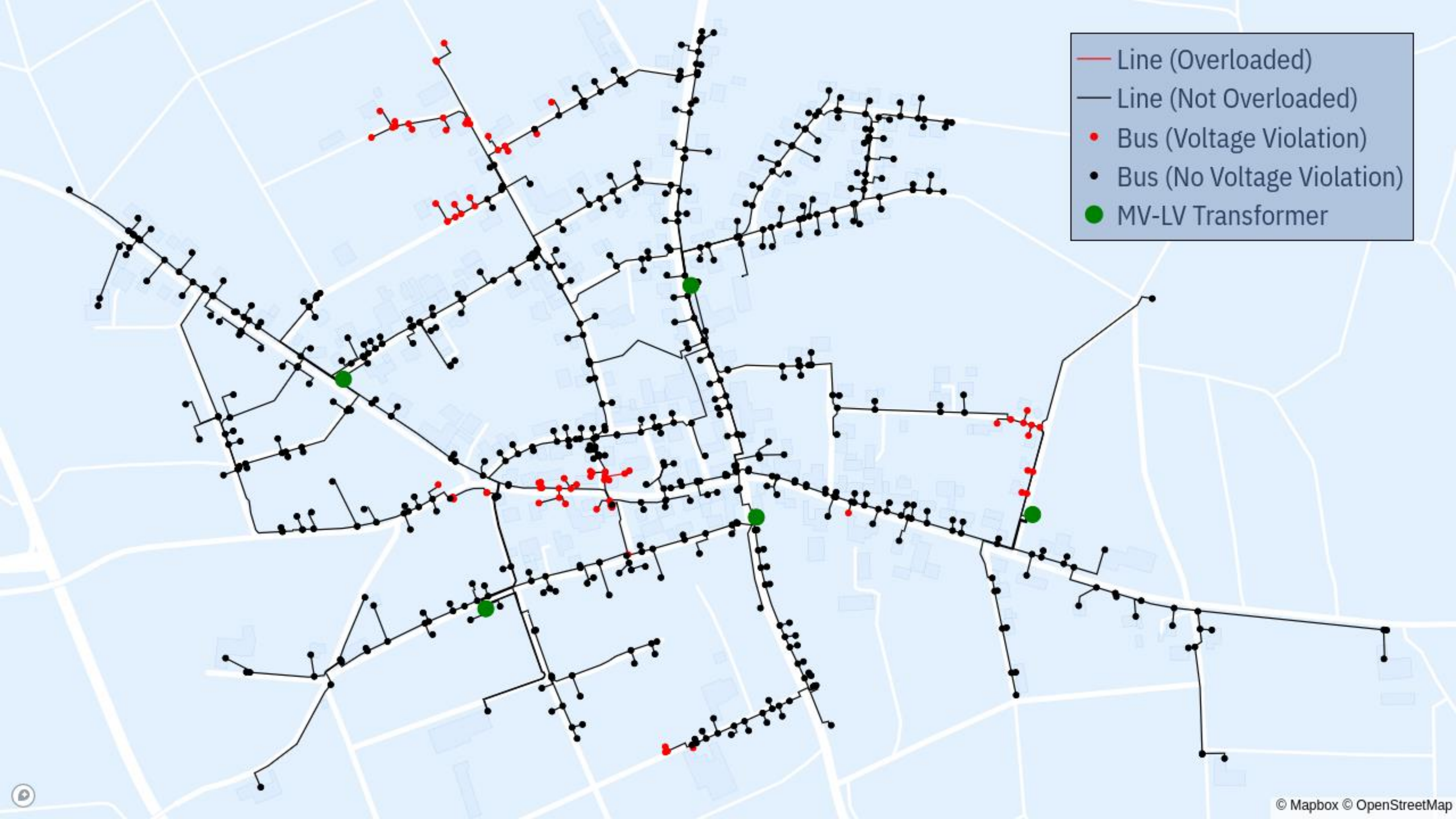
- Probabilistic
- Exploration vs. exploitation

Pheromone update:

- Local update: *“I was here, go somewhere else”*
- Global update: *“Let’s focus on the best we found so far”*

[2] Dorigo & Gambardella, 1997

Q&A


Line (Overloaded)
Line (Not Overloaded)
Bus (Voltage Violation)
Bus (No Voltage Violation)
MV-LV Transformer
© Mapbox © OpenStreetMap

Degrees of Freedom

1. Installation of 5 line segments
2. Reinforcement 369 line segments
3. Dismantling of 369 line segments
4. Opening of 102 closed switches
5. Closing of 11 open switches

Baselines

Manual method

Heuristic procedure based on expert knowledge

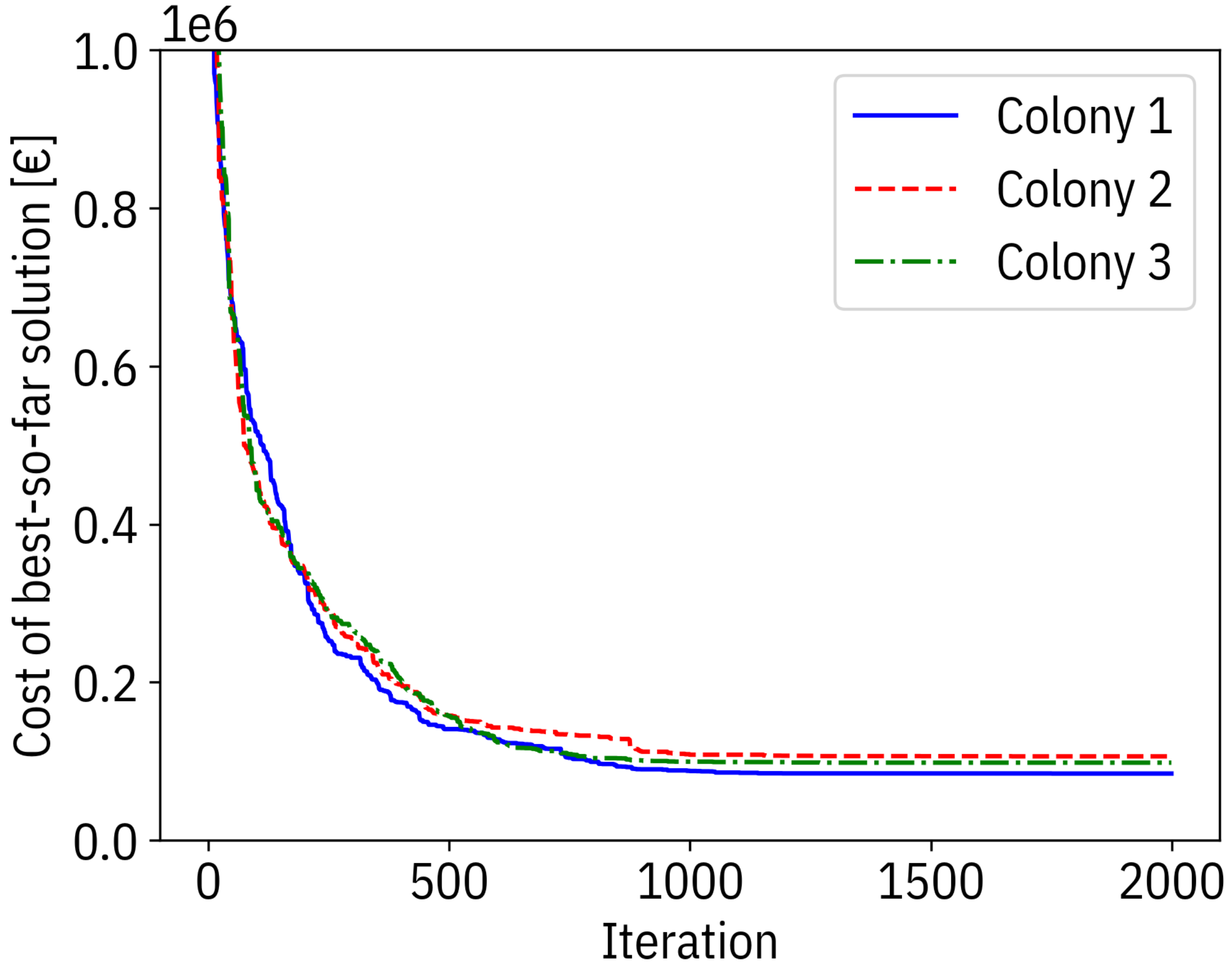
Local search method

Simple, greedy search

Results: Overview

	Manual method	Local search	AntPower
Valid Topology?	✓	✓	✓
Overloaded lines	**0**	**0**	**0**
Voltage violations	**0**	**0**	**0**
Expansion cost	**210K €**	**231K €**	**84K €**

Results: Convergence of AntPower



Conclusion & Future Work

- Ant Colony Optimization can cut costs tremendously

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- Further evaluation needed
  - More problem instances
  - Stronger baselines

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- Ant Colony Optimization can cut costs tremendously
- Further evaluation needed
  - More problem instances
  - Stronger baselines
- Promising: Add support for
  - Installation of switches, transformers
  - Different topologies

Q&A

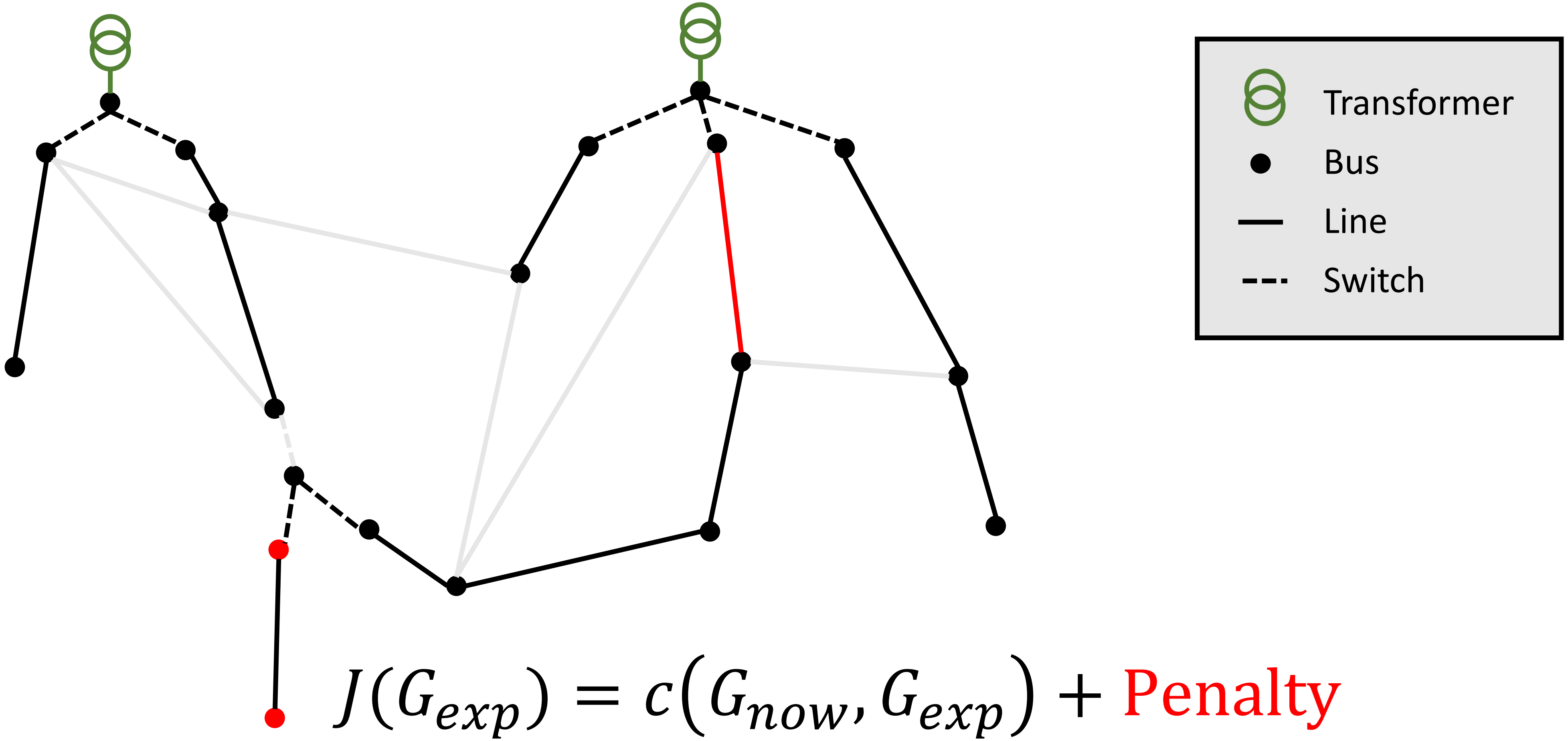
References

[1] M. Dorigo. “Optimization, Learning and Natural Algorithms”. Dissertation. Milan, Italy: Politechnico di Milano, 1992.

[2] M. Dorigo and L. Gambardella. “Ant Colony System: A Cooperative Learning Approach to the Traveling Salesman Problem”. In: IEEE Transactions on Evolutionary Computation 1.1 (1997).

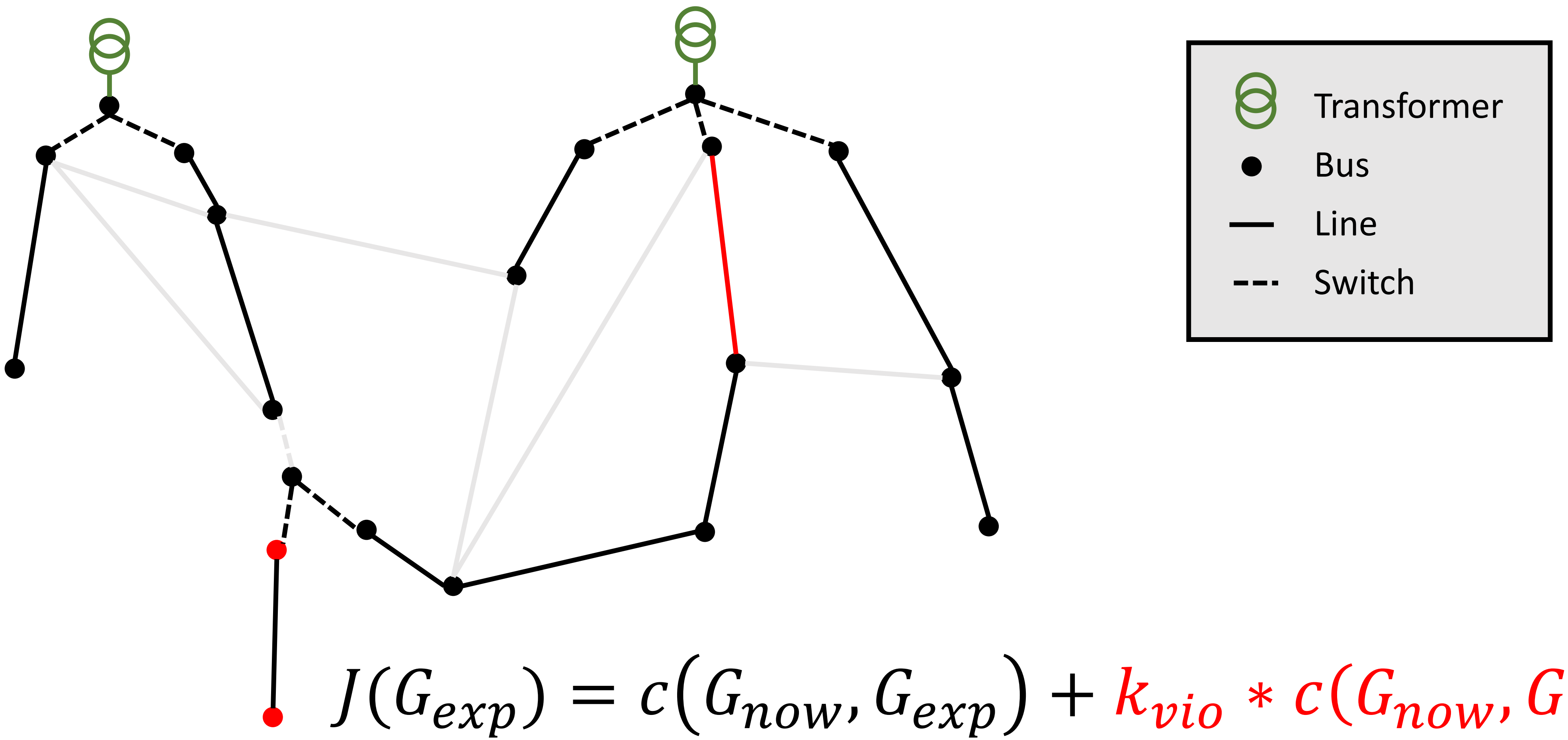
Appendices

Example: Objective Function



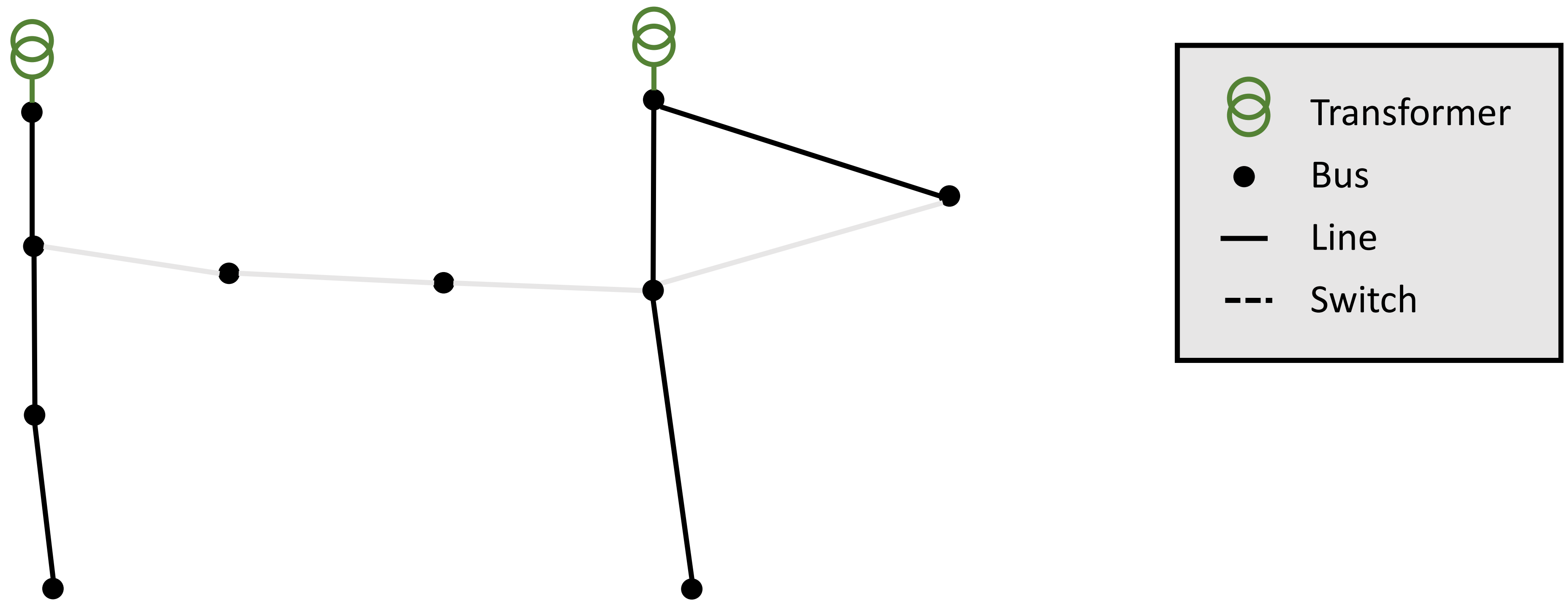
$$J(G_{exp}) = c\left(G_{now}, G_{exp}\right) + \text{Penalty}$$

Example: Objective Function

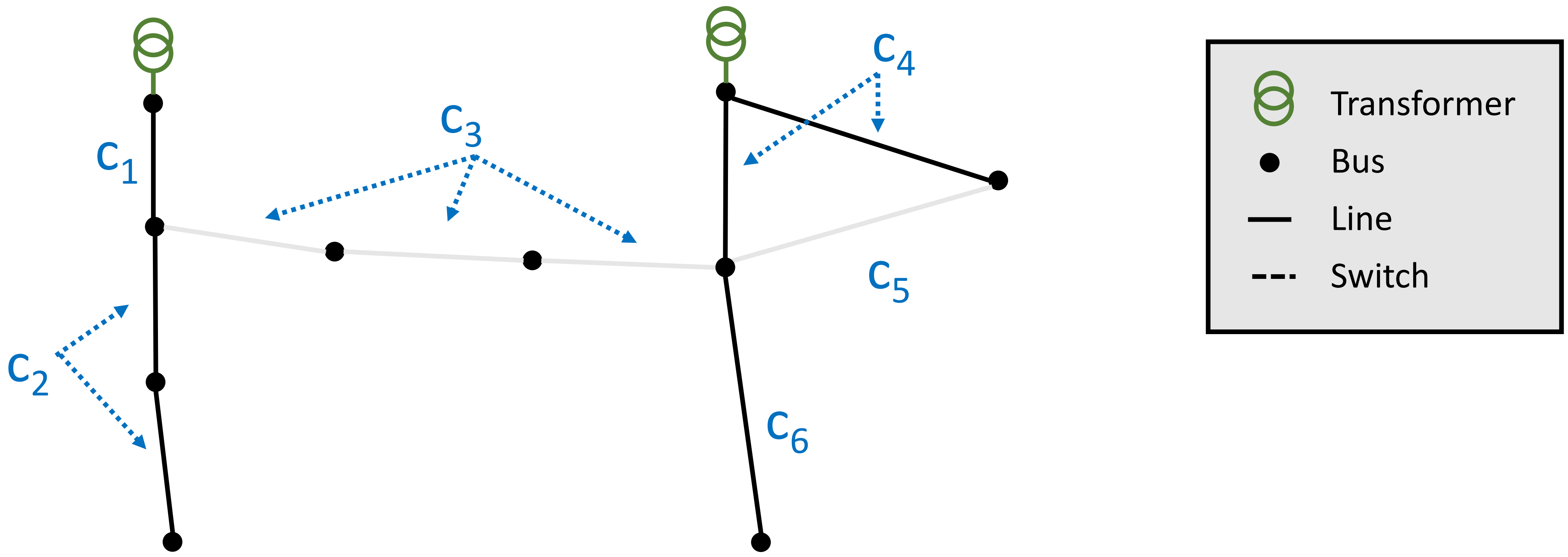


$$J(G_{exp}) = c\left(G_{now}, G_{exp}\right) + k_{vio} * c(G_{now}, G^{*})$$

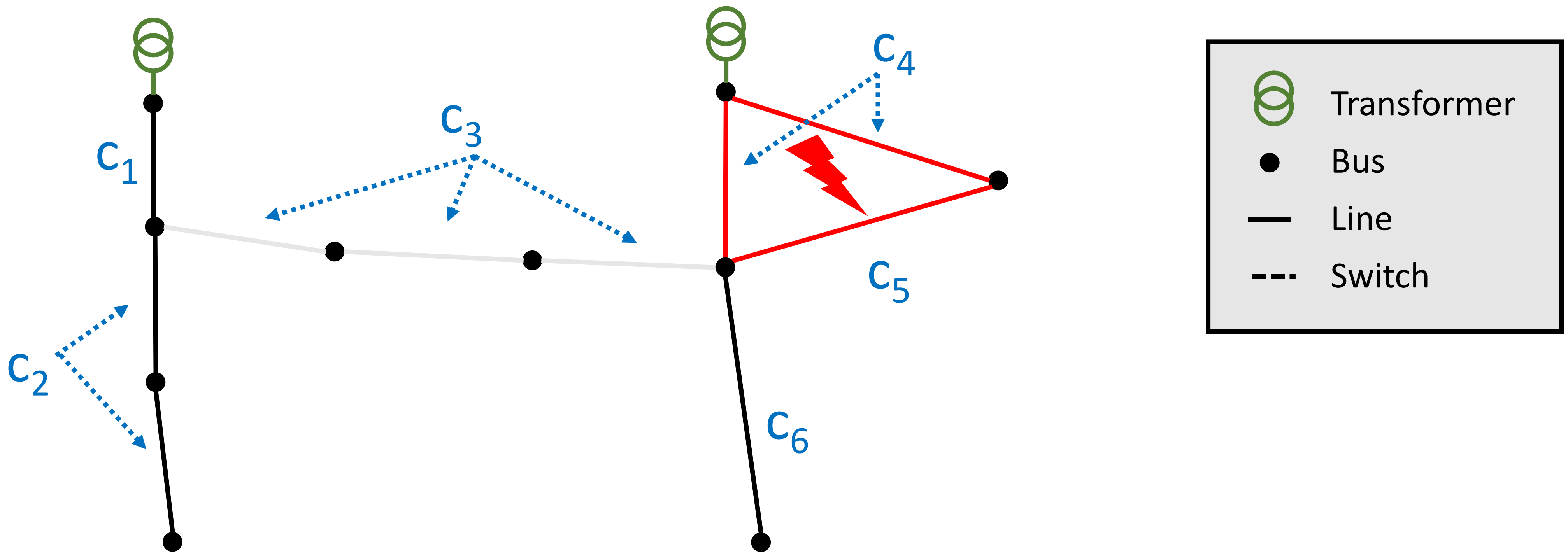
Example: Desegmentation



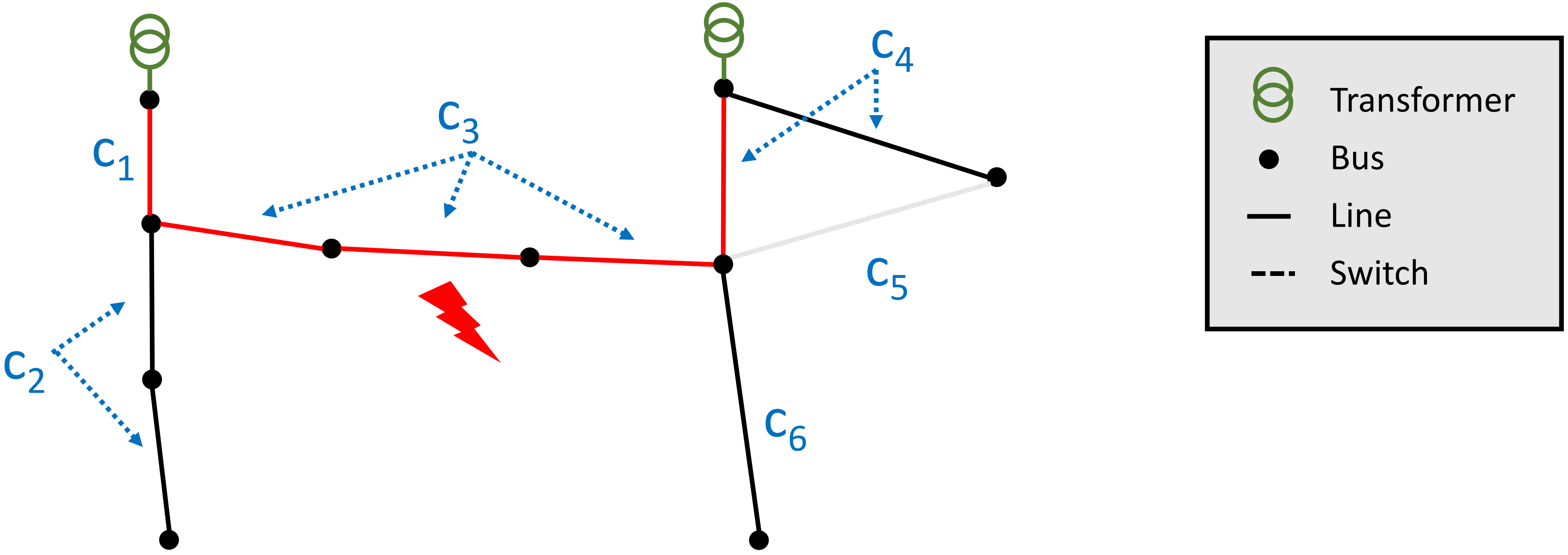
Example: Desegmentation



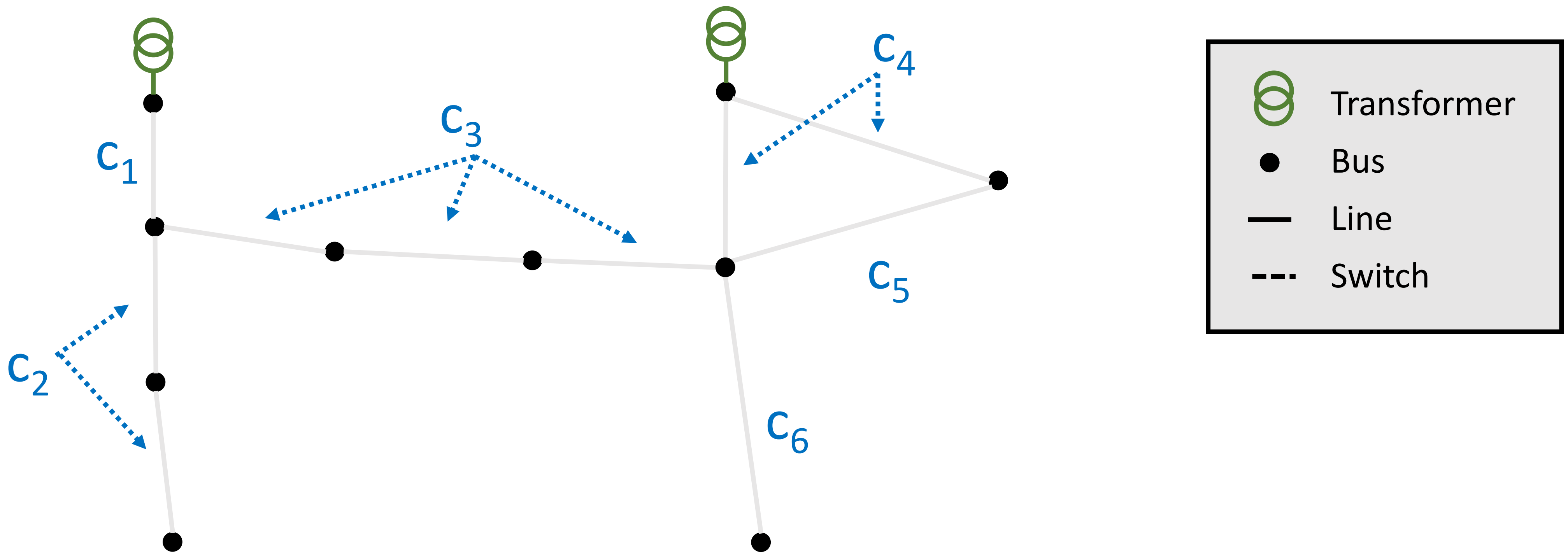
Example: Desegmentation



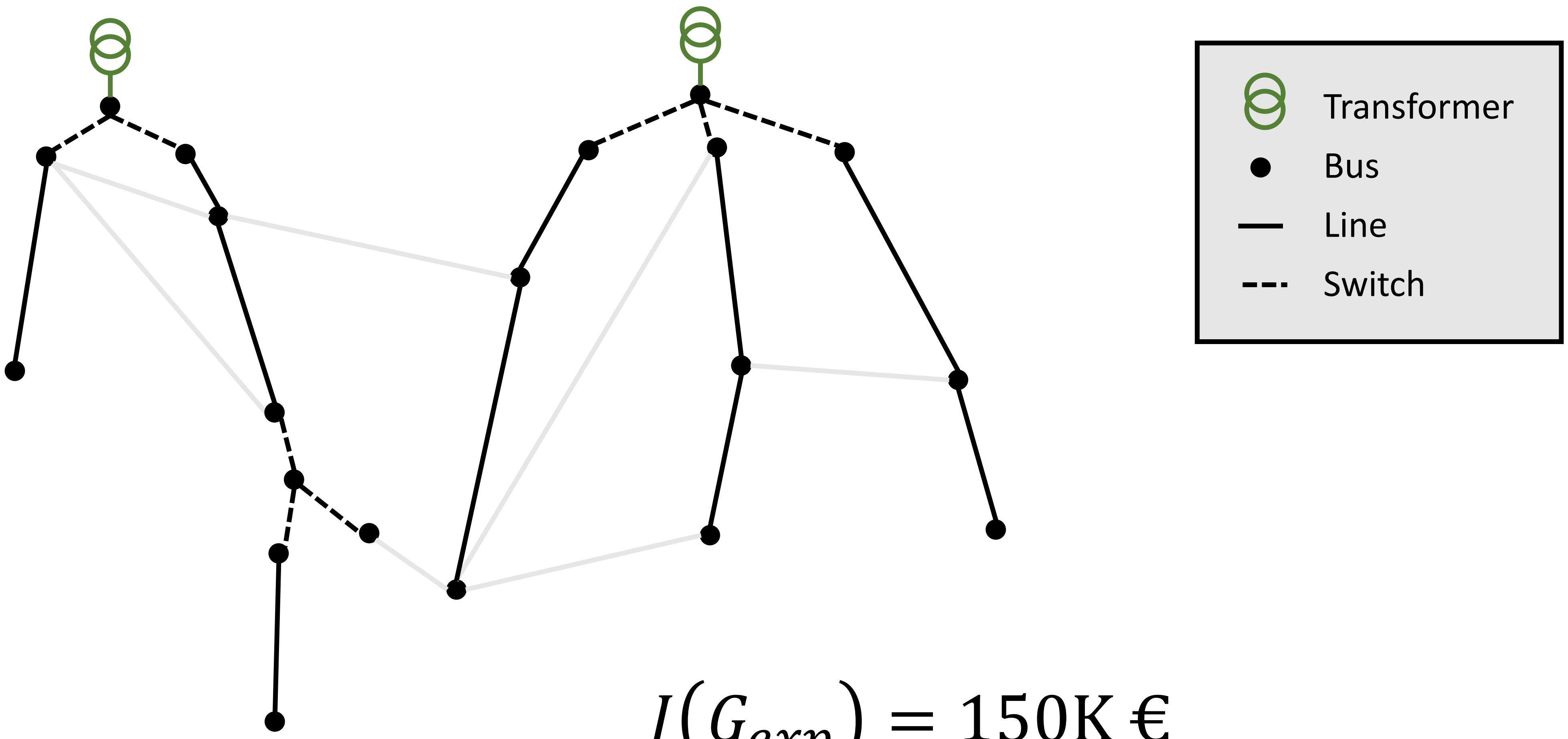
Example: Desegmentation



Example: Desegmentation

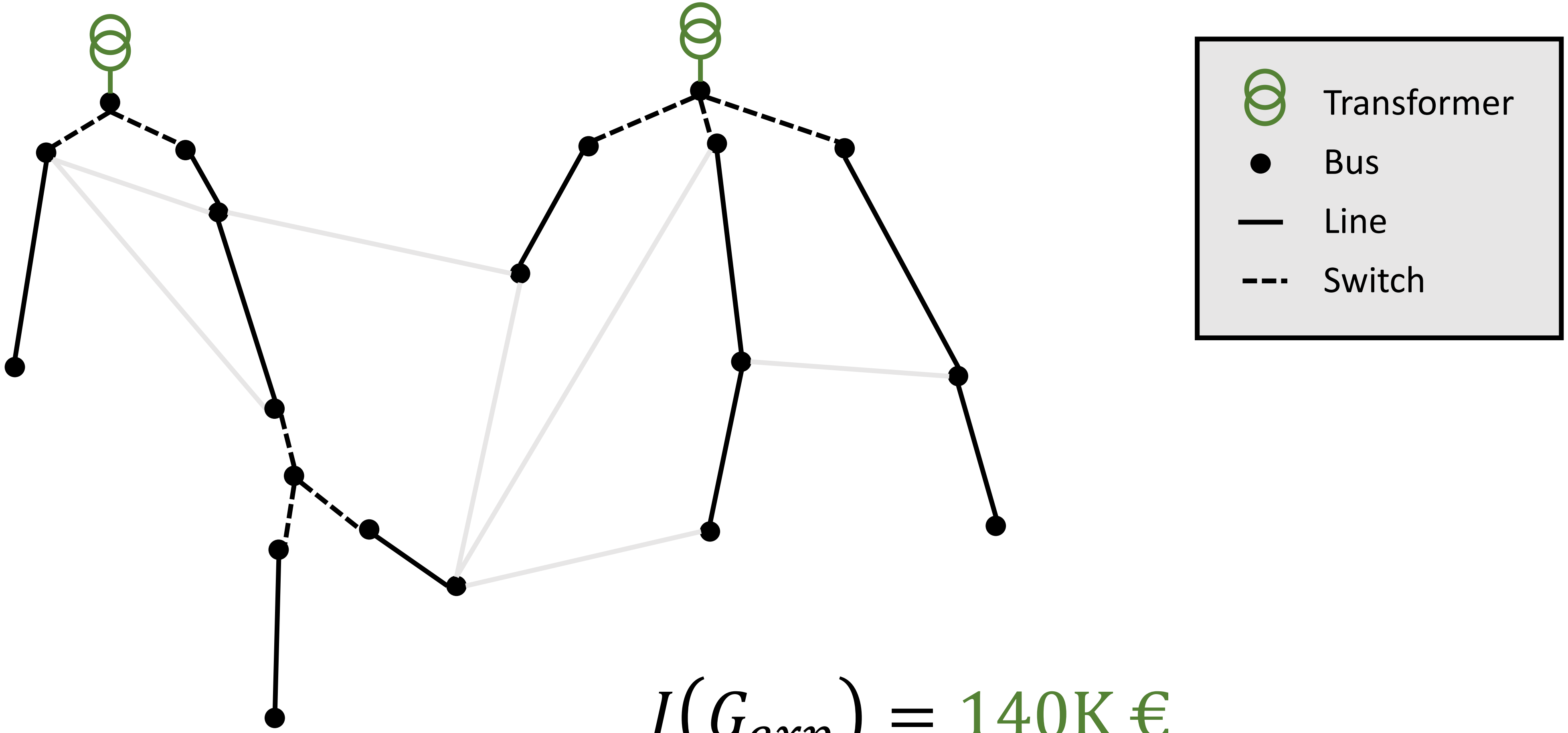


Example: Local search method



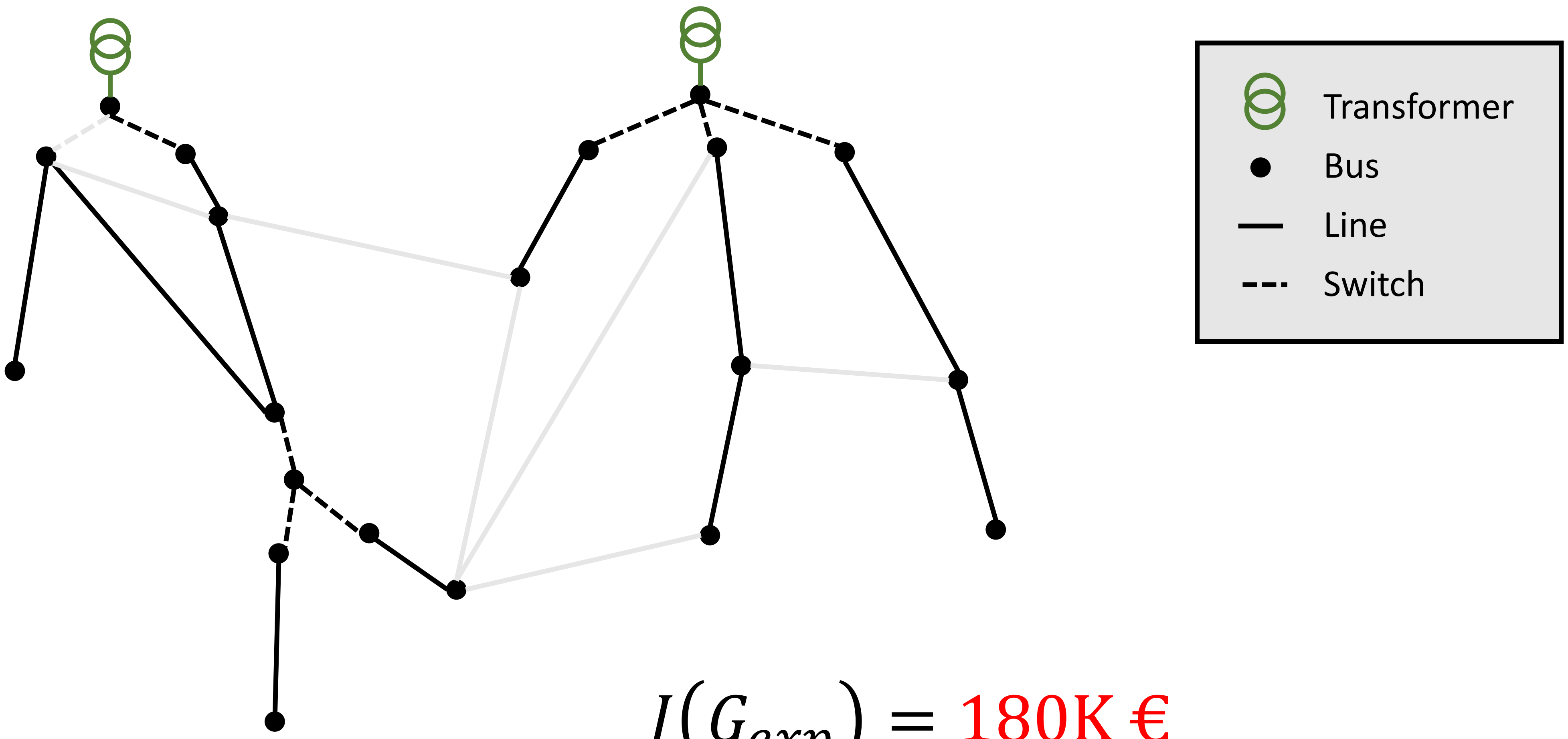
$$J(G_{exp}) = 150\text{K}\,€$$

Example: Local search method



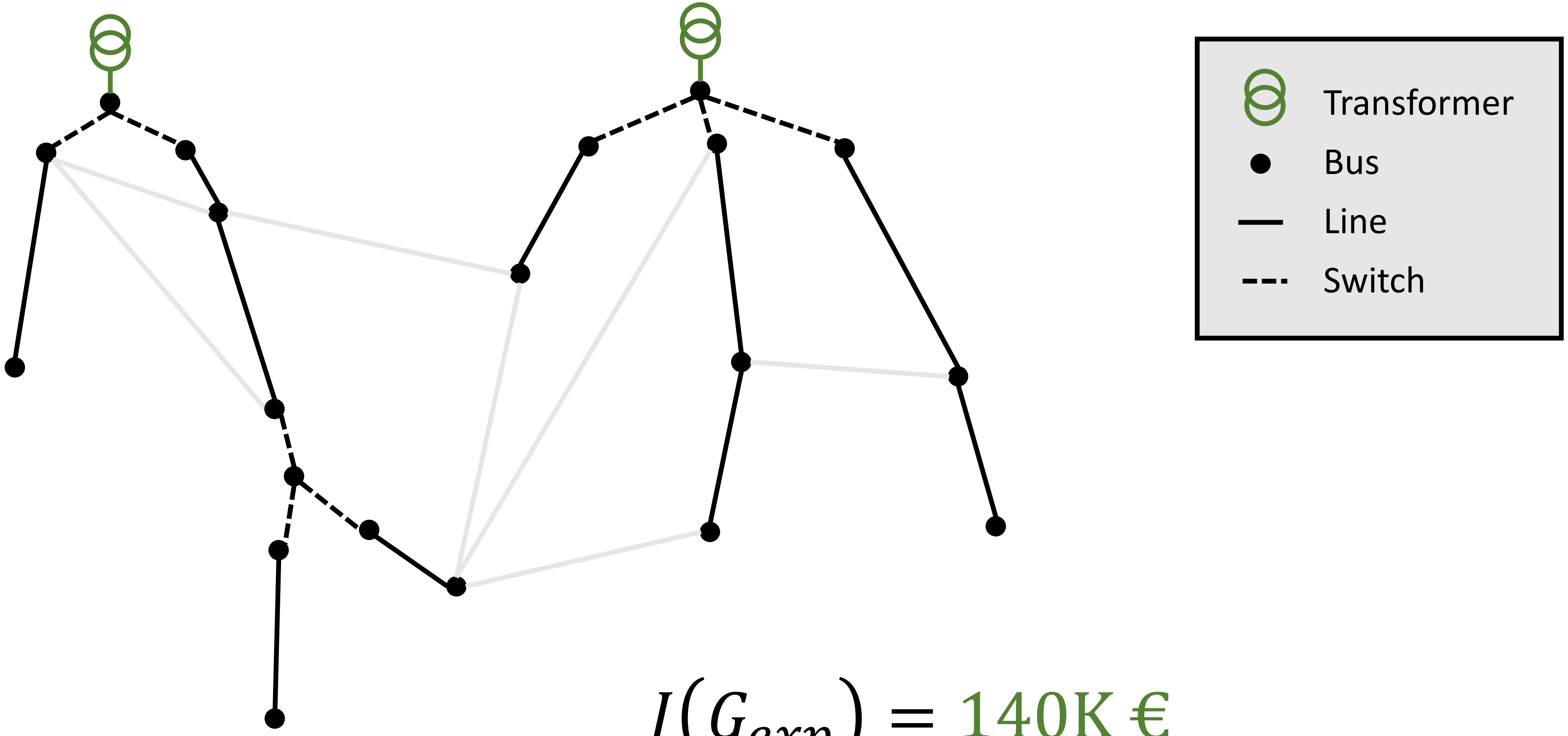
$$J(G_{exp}) = 140\text{K}\,€$$

Example: Local search method

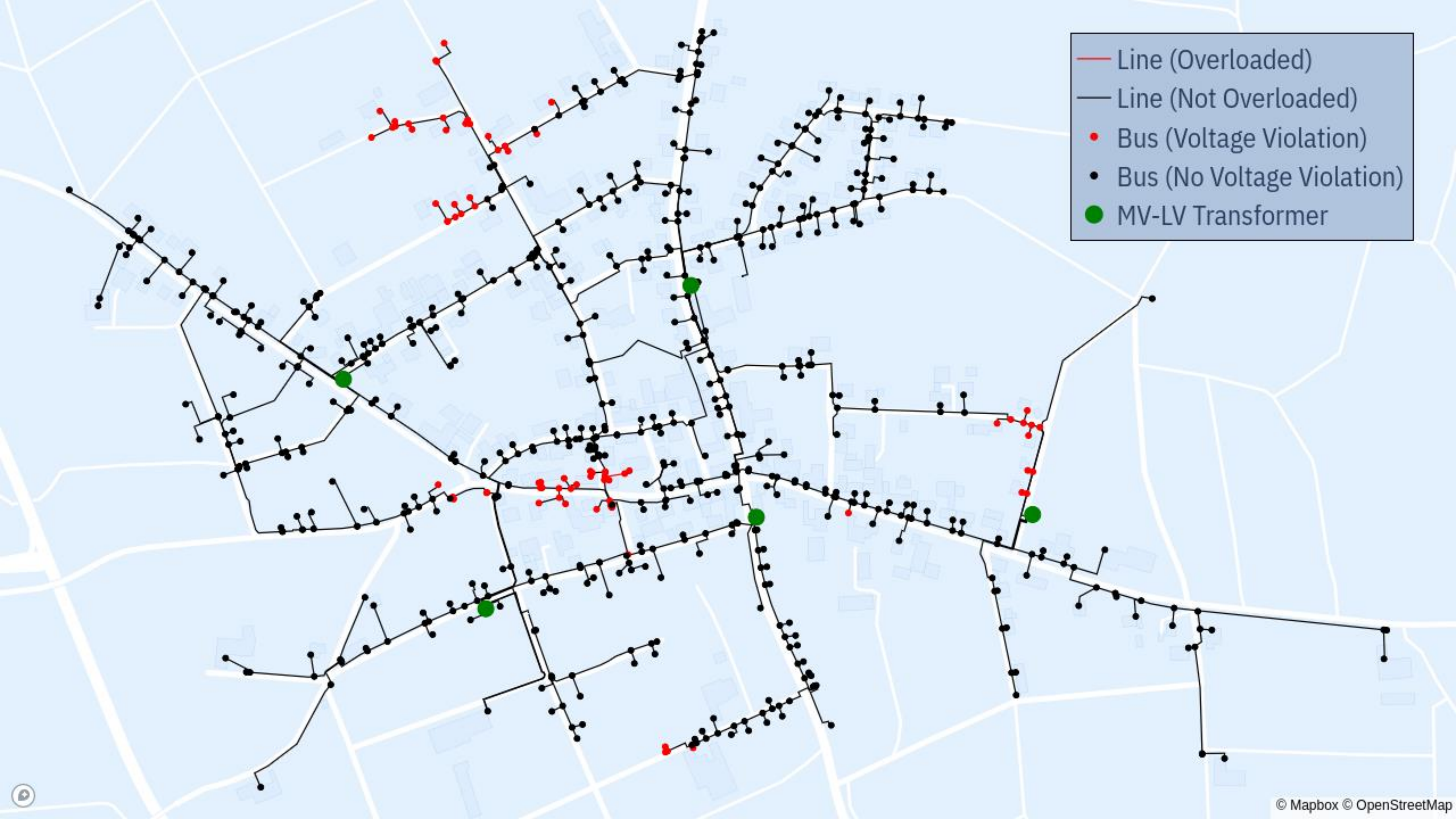


$$J(G_{exp}) = 180\text{K €}$$

Example: Local search method



$$J\left(G_{exp}\right) = 140\text{K €}$$


Line (Overloaded)
Line (Not Overloaded)
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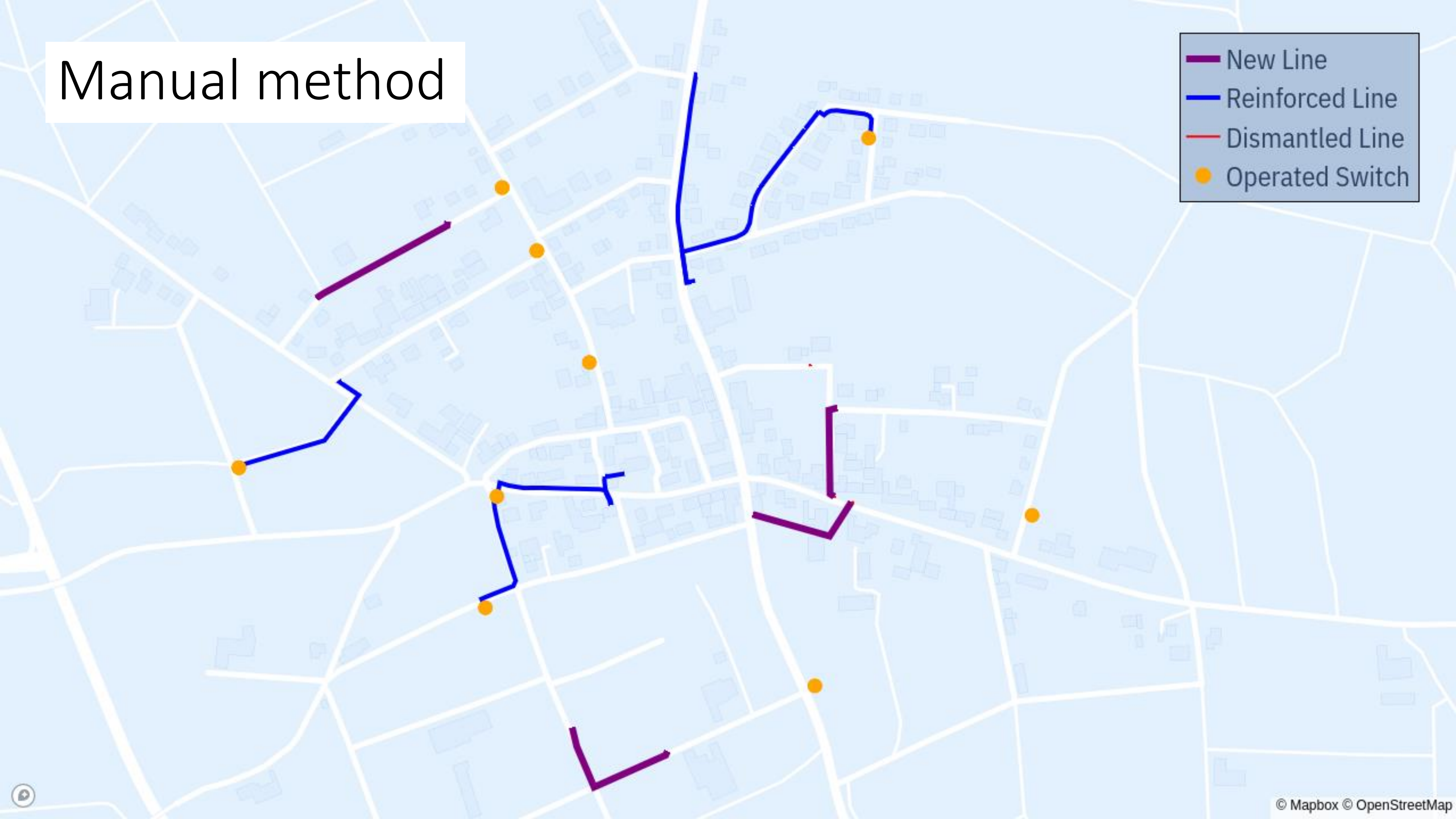
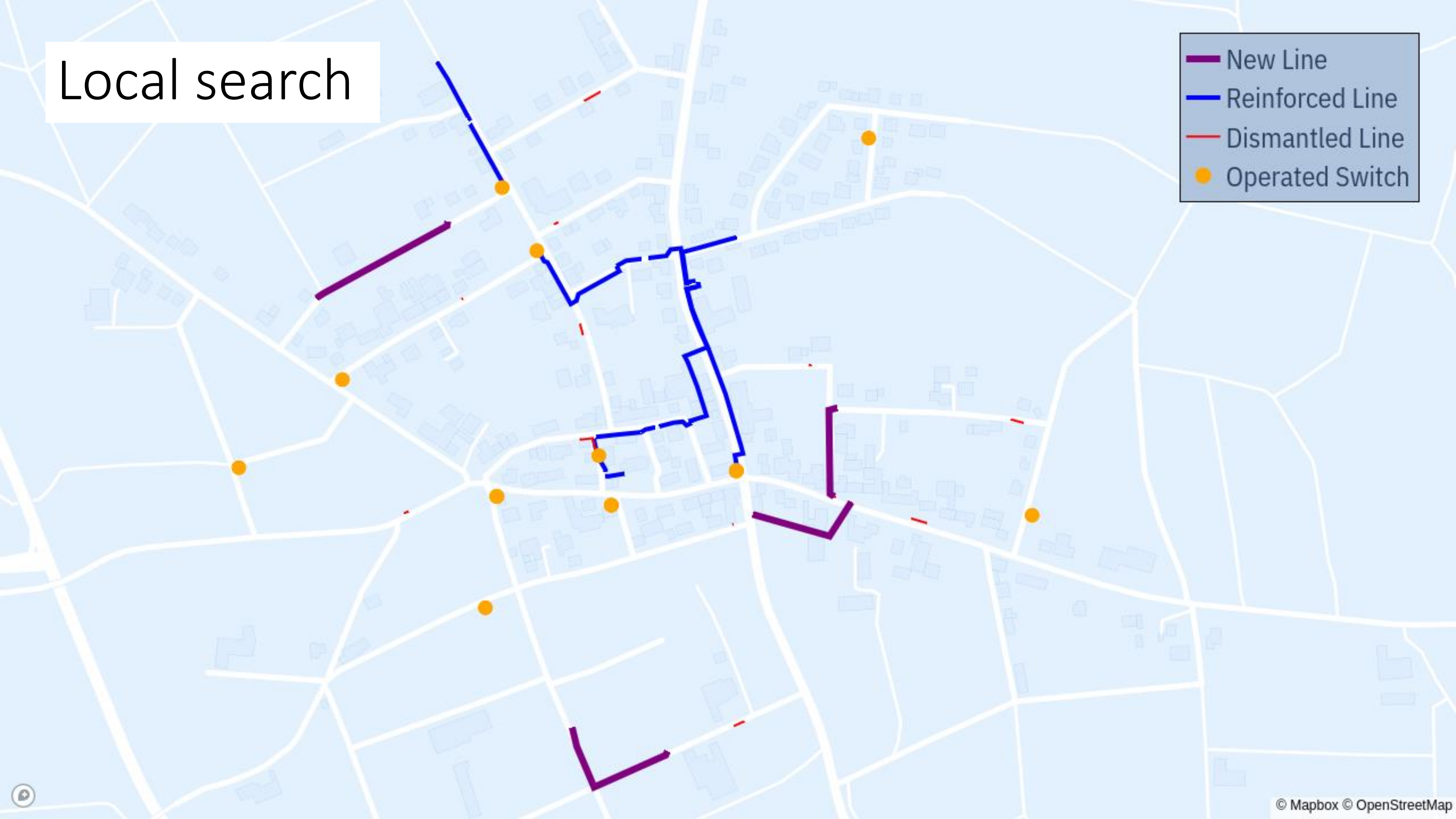
Bus (No Voltage Violation)
MV-LV Transformer
© Mapbox © OpenStreetMap

Manual method



Local search




AntPower
New Line
Reinforced Line
Dismantled Line
Operated Switch
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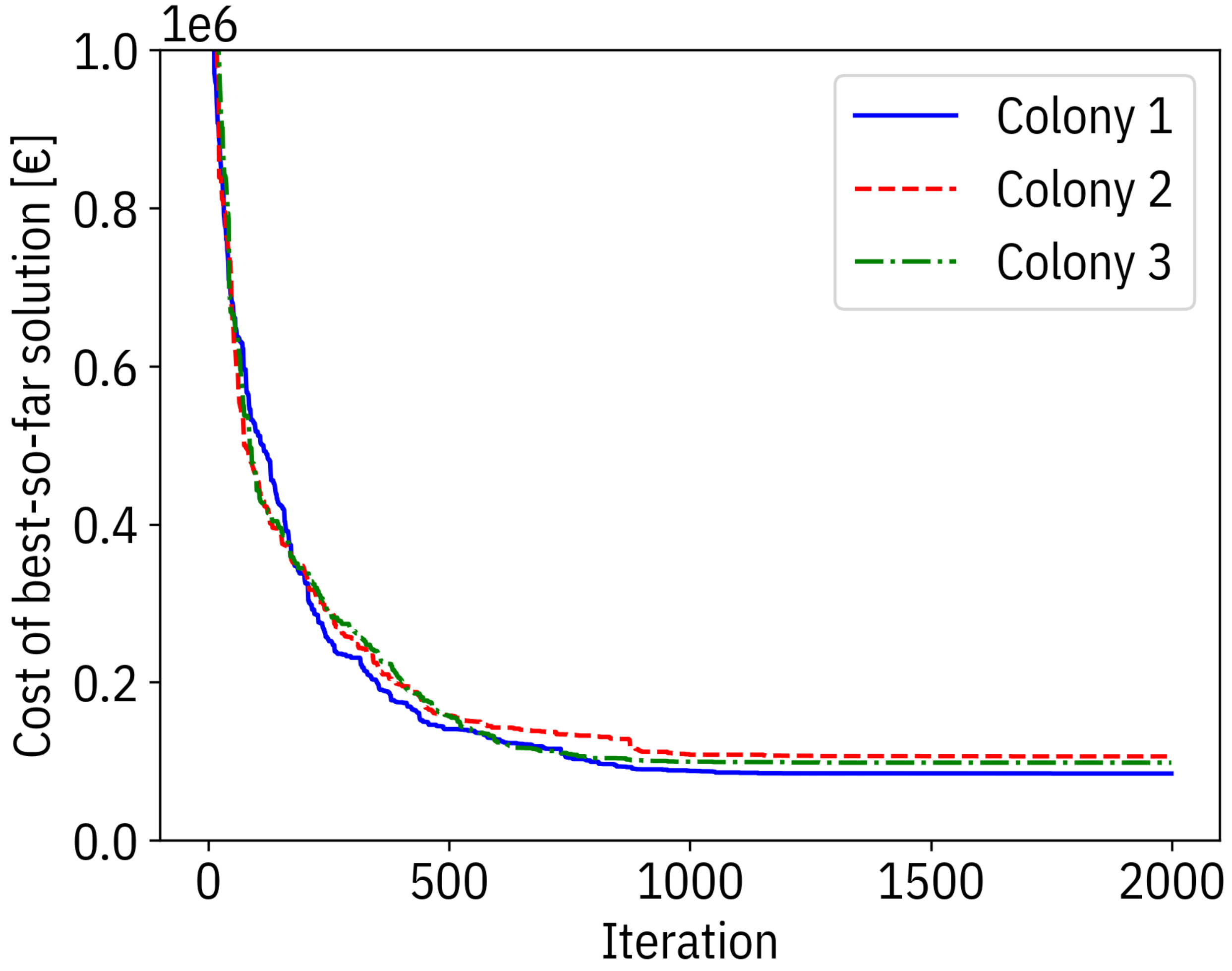
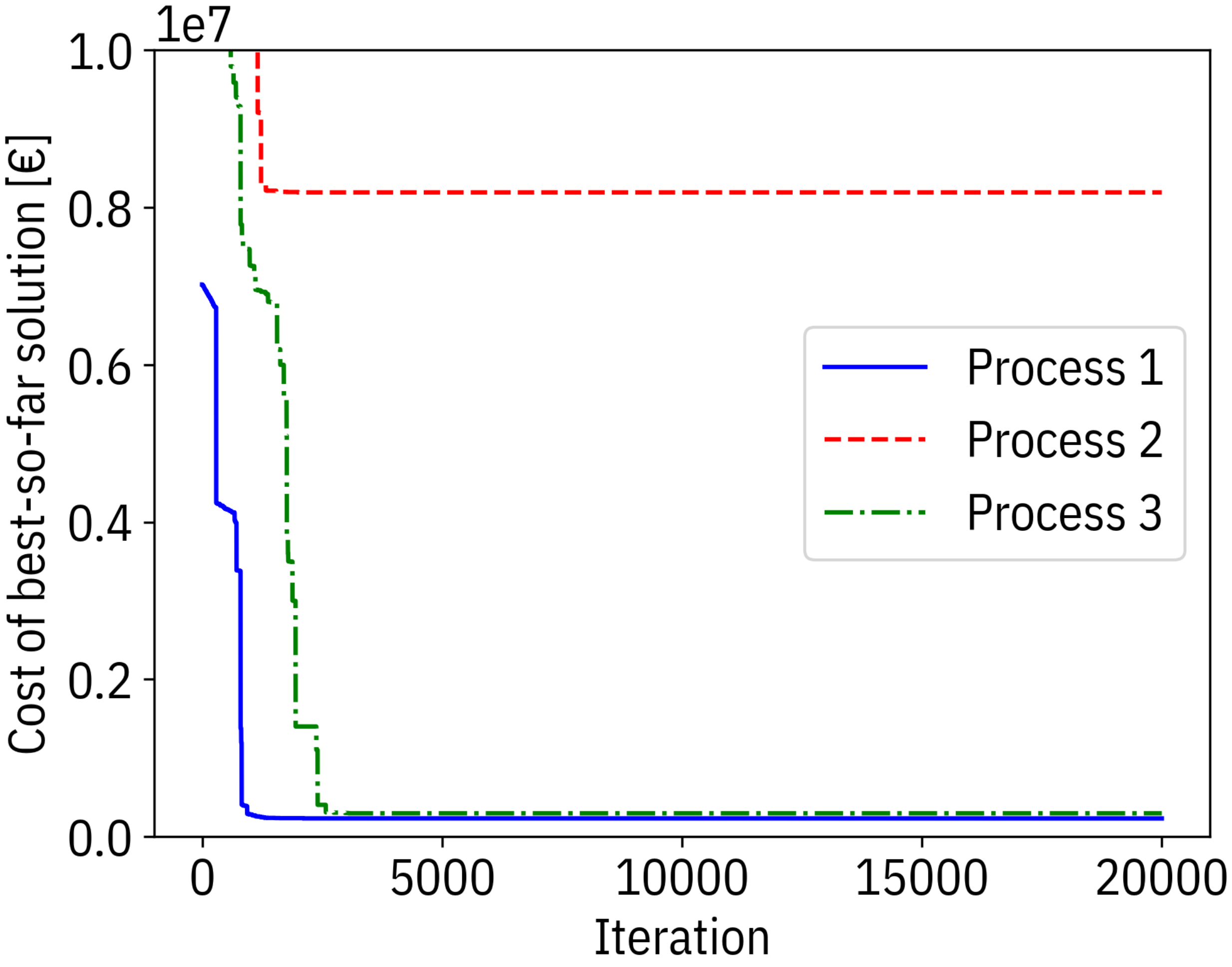
Results: Convergence of AntPower



Results: Convergence of Local Search



Pheromones Across Iterations