Mapping Low Voltage Networks Using AMI Data

MONASH University

Powercor AUSTRALIA

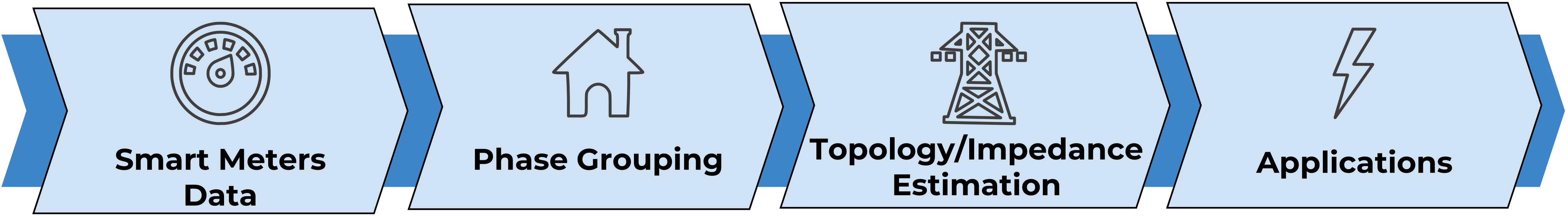
AusNet services

THE UNIVERSITY OF MELBOURNE

C4NET Centre for New Energy Technologies

united energy

Project Overview



Research Team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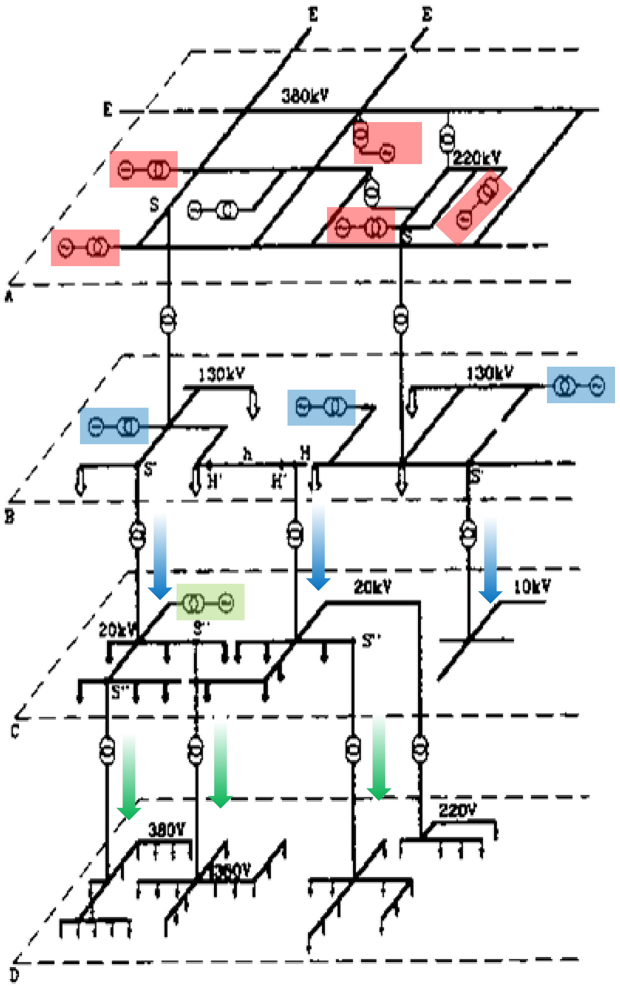
Challenge- Visibility of LV Networks

Transmission

Sub-transmission

Distribution (HV)

Distribution (LV)



In traditional power systems, the main sources of uncertainties are represented by the loads.

Majority of the control and operational problems are solved in the planning or dispatching stages.

LV Network visibility was not necessary

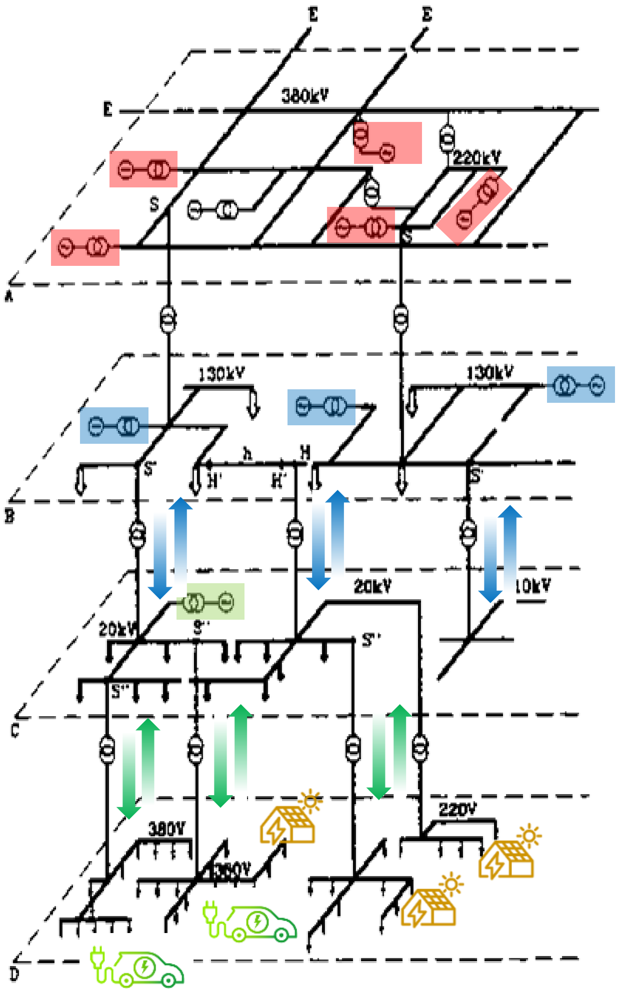
Challenge- Visibility of LV Networks

Transmission

Sub-transmission

Distribution (HV)

Distribution (LV)



Distributed energy resources (DER)

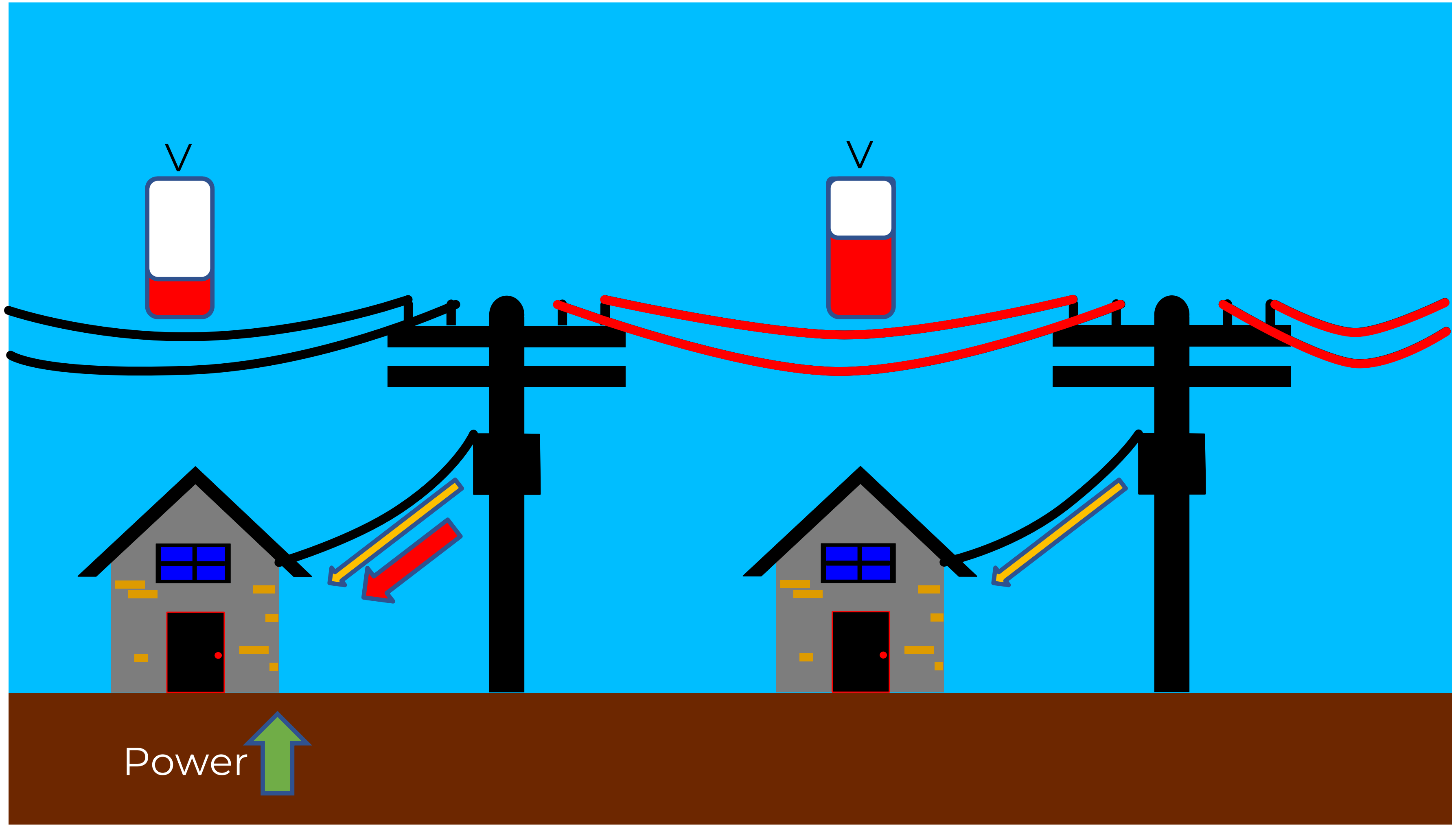
DER management and orchestration

Visibility and accurate models are needed

Challenges – Electrical Models of LV Networks

1. Incomplete assignment of customers to phases
2. Inaccurate location of customers on LV circuits
3. Incomplete records of network topology
4. Incomplete electrical parameters of LV lines

Voltage Sensitivity Coefficients



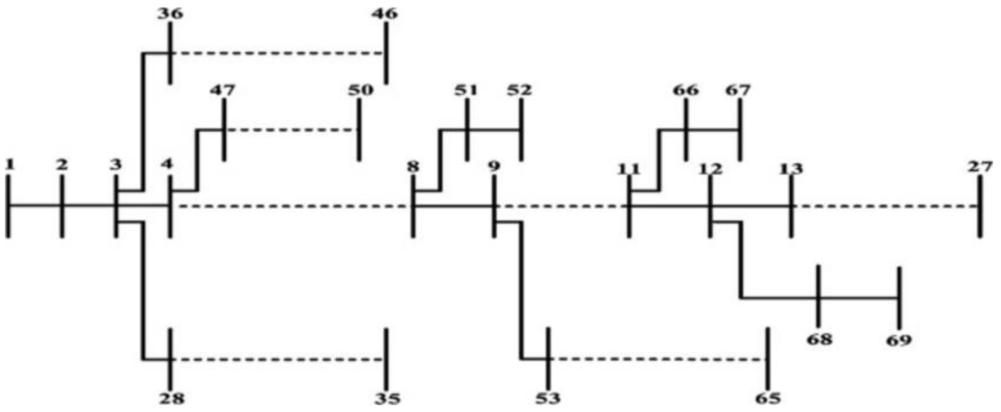
Algorithm Outline

Voltage & current Measurements → Estimate 'voltage sensitivity coefficients' → Line impedance → Estimate a radial network matching those lengths → Topology

Ohm's law

Noisy data -- non-physical solutions

Want the "best" estimate satisfying physical constraints



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Algorithm Outline

Voltage & current Measurements

Estimate 'voltage sensitivity coefficients'

Line impedance

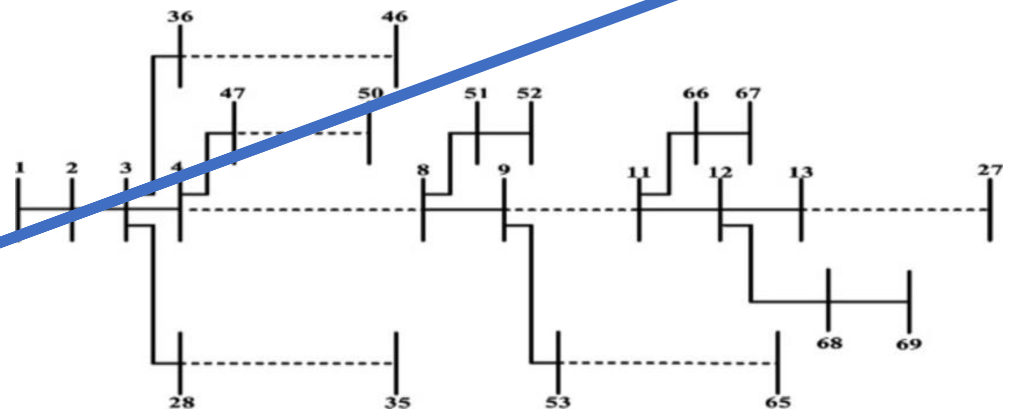
Estimate a radial network matching those lengths

Topology

min mismatch from Ohm's law and transformer voltage + complicated objectives

subject to Symmetry
Positive resistance values
~~Matches a radial network~~

Simpler approximations



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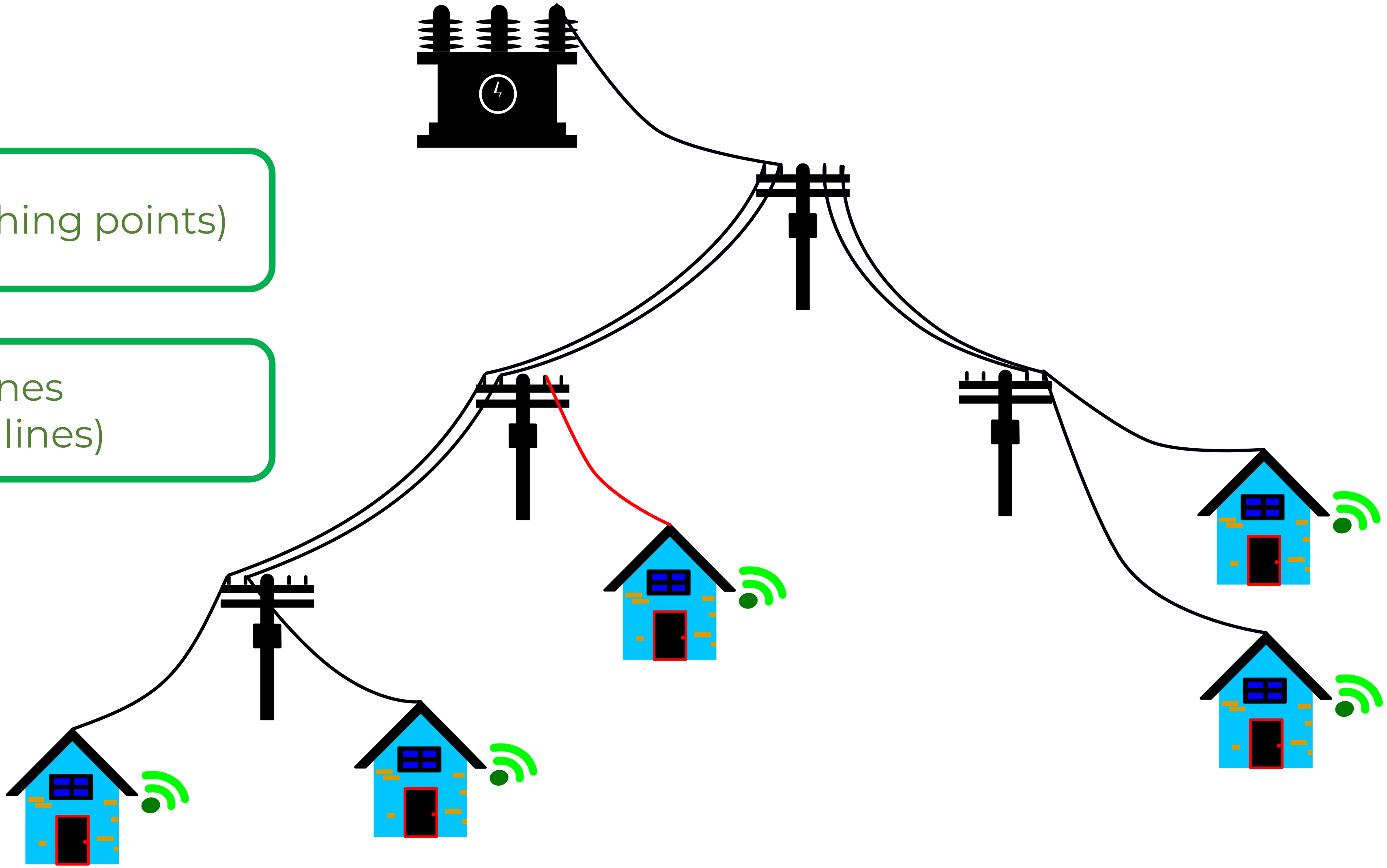
Topology Learning Algorithm

1. Location of poles (branching points)

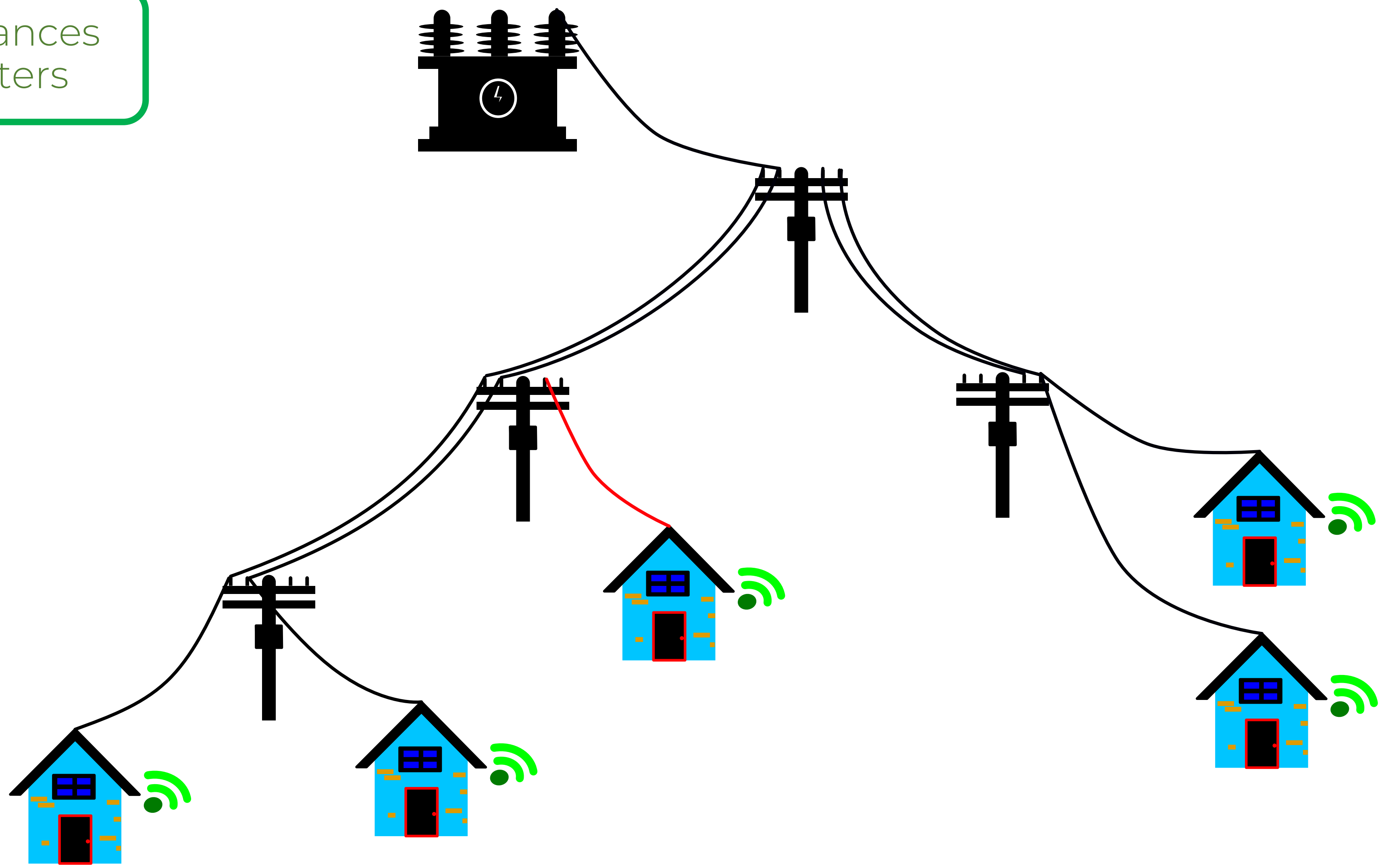
2. Impedance of lines (including service lines)



Topology Learning Algorithm

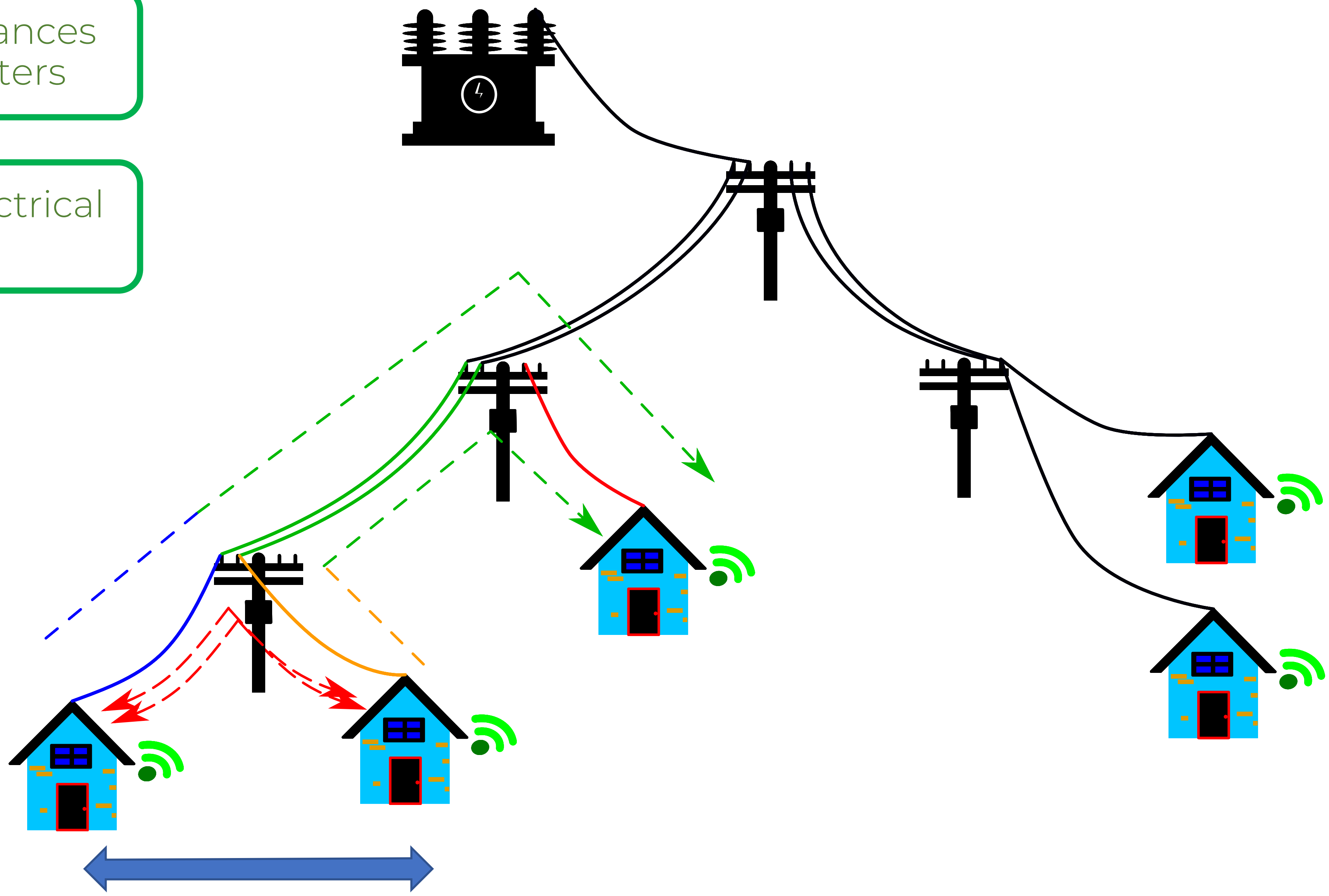
1

Estimated electrical distances between customer meters



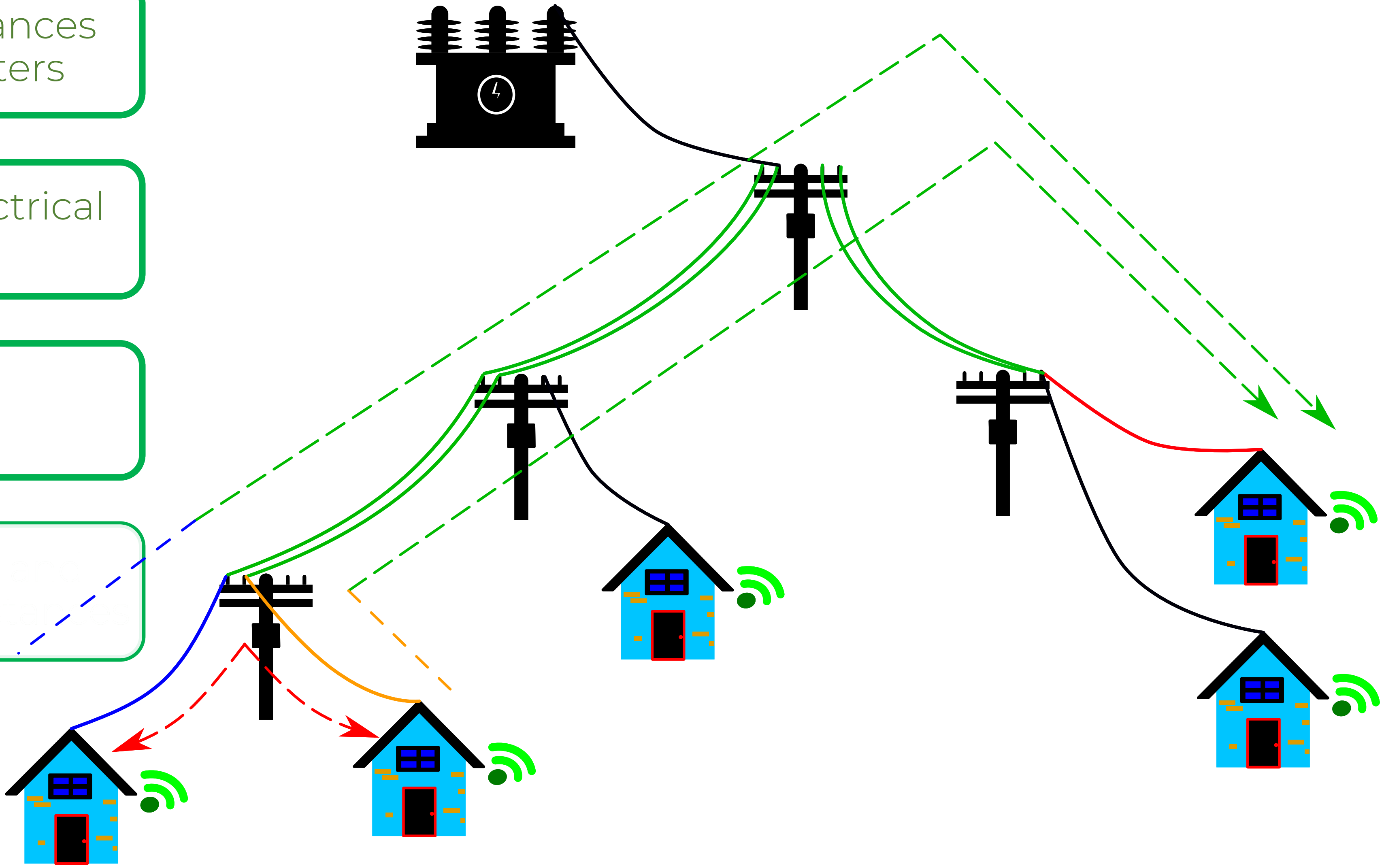
Topology Learning Algorithm

1. Estimated electrical distances between customer meters
2. Differences between electrical distances



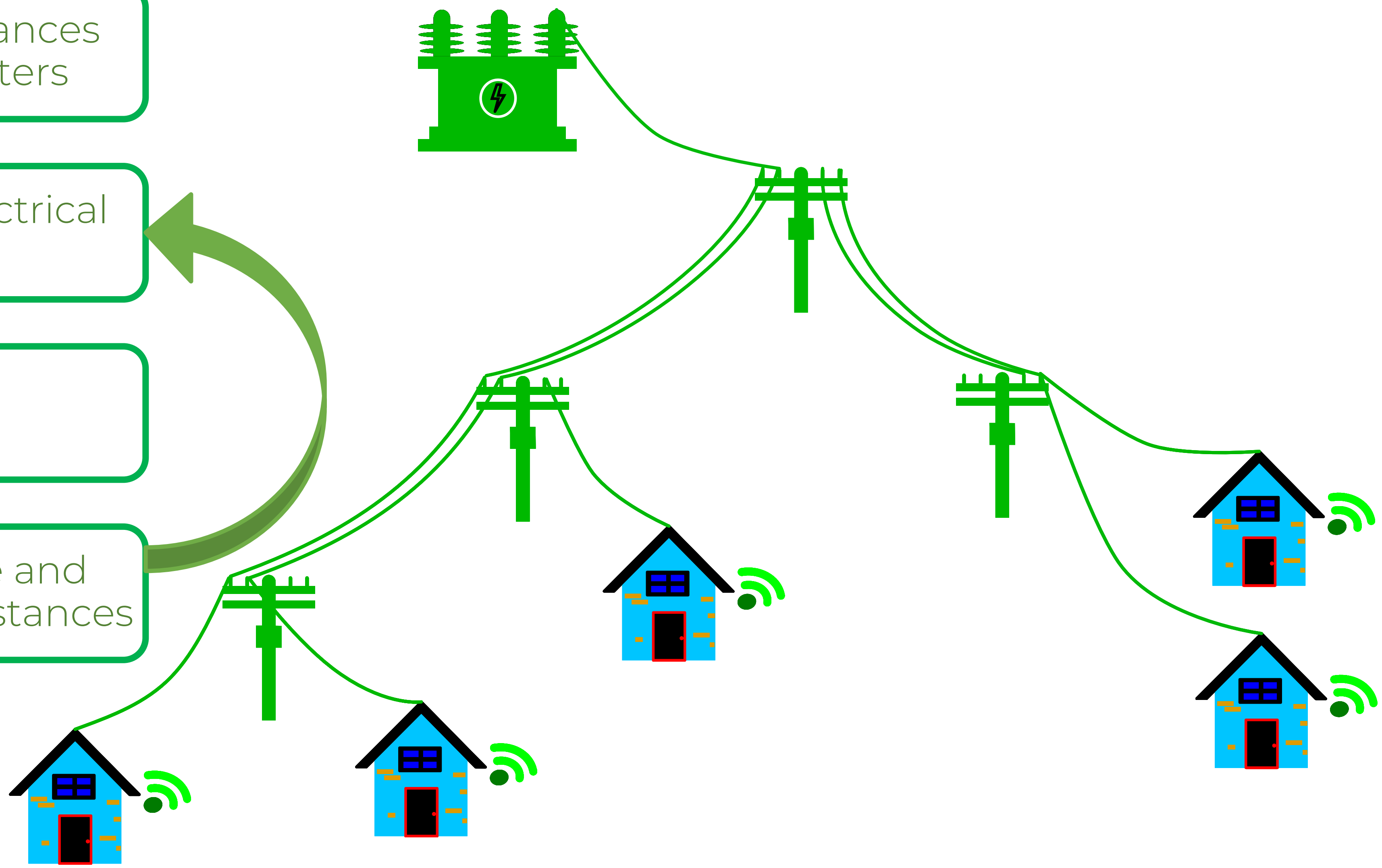
Topology Learning Algorithm

1. Estimated electrical distances between customer meters
2. Differences between electrical distances
3. Trends in differences
4.



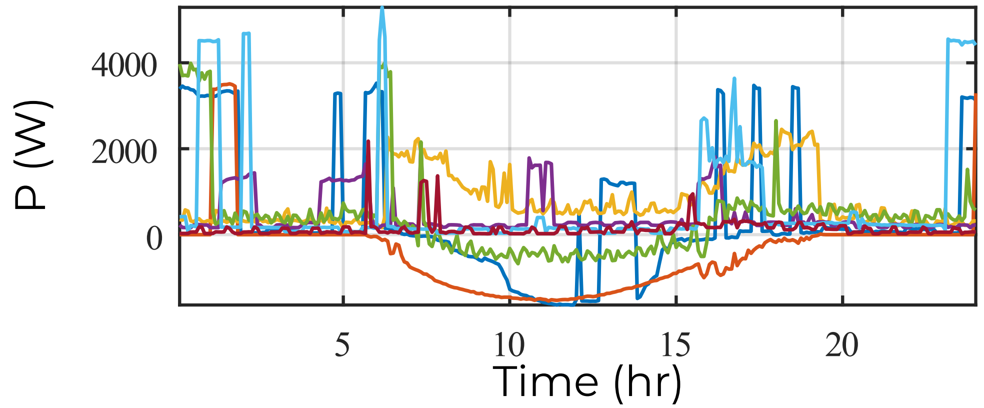
Topology Learning Algorithm

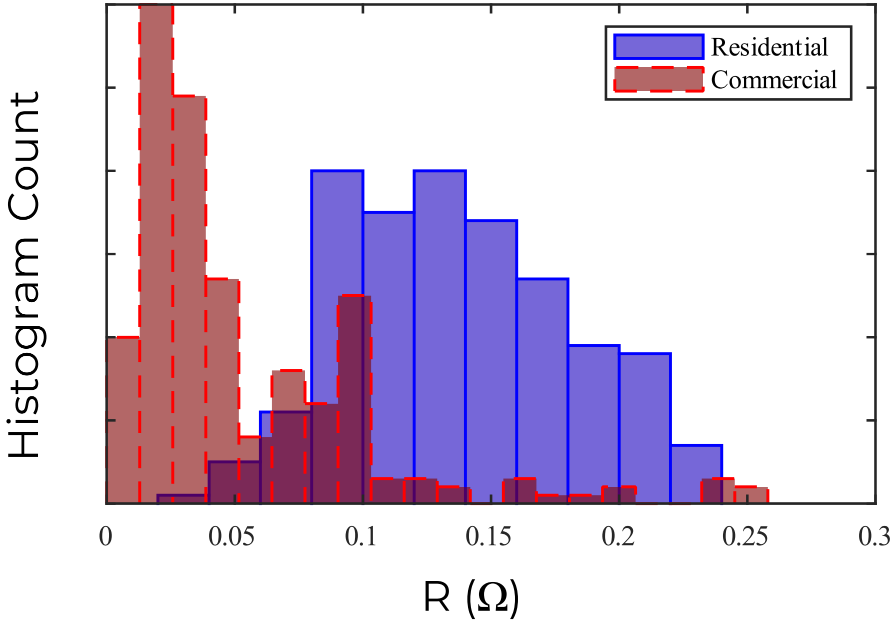
1. Estimated electrical distances between customer meters
2. Differences between electrical distances
3. Trends in differences
4. Estimate location of pole and associated electrical distances



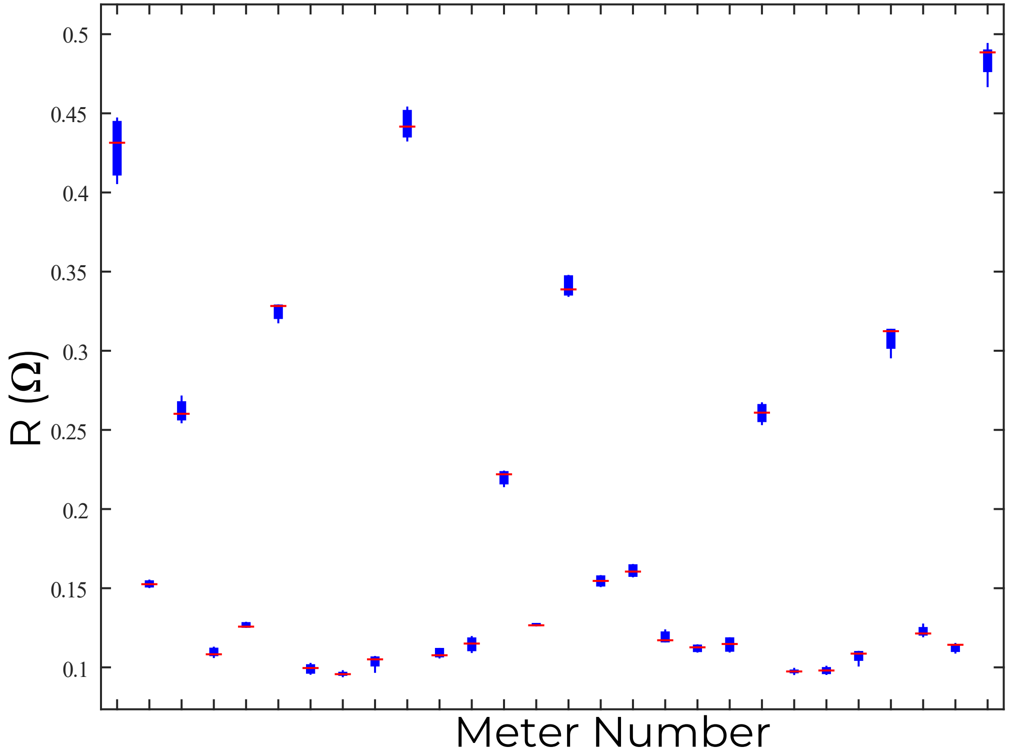
Line Impedance Estimation

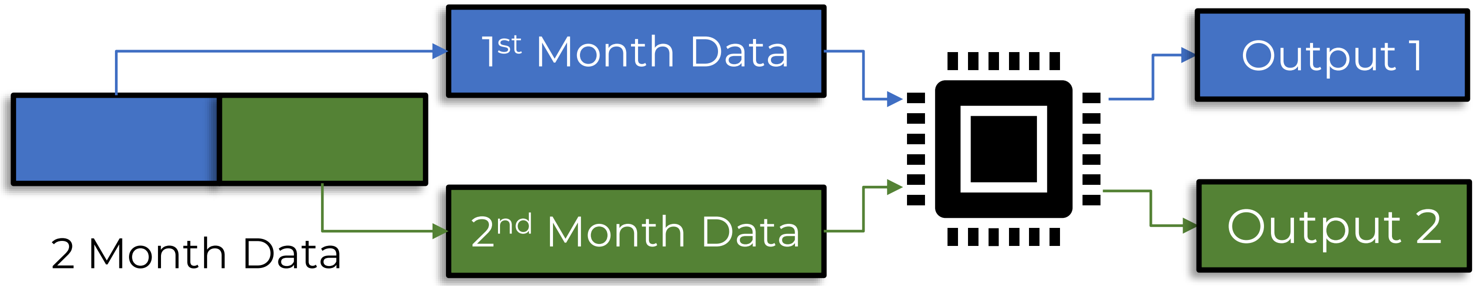
Typical load profile during a day





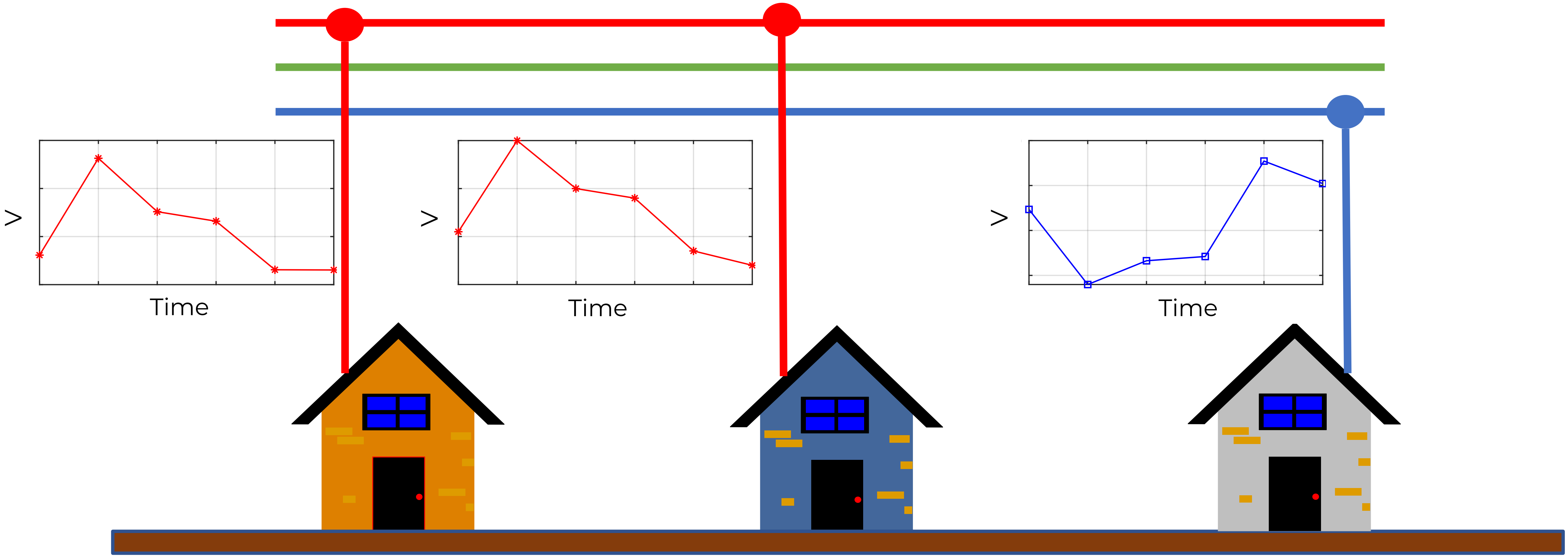
Variation in the estimated impedance using non-overlapping sets of measurements





Customer Phase Grouping

Voltage correlation-based techniques for phase grouping



Customer Phase Grouping

Input: Smart meter measurements

↓

Pre-processing

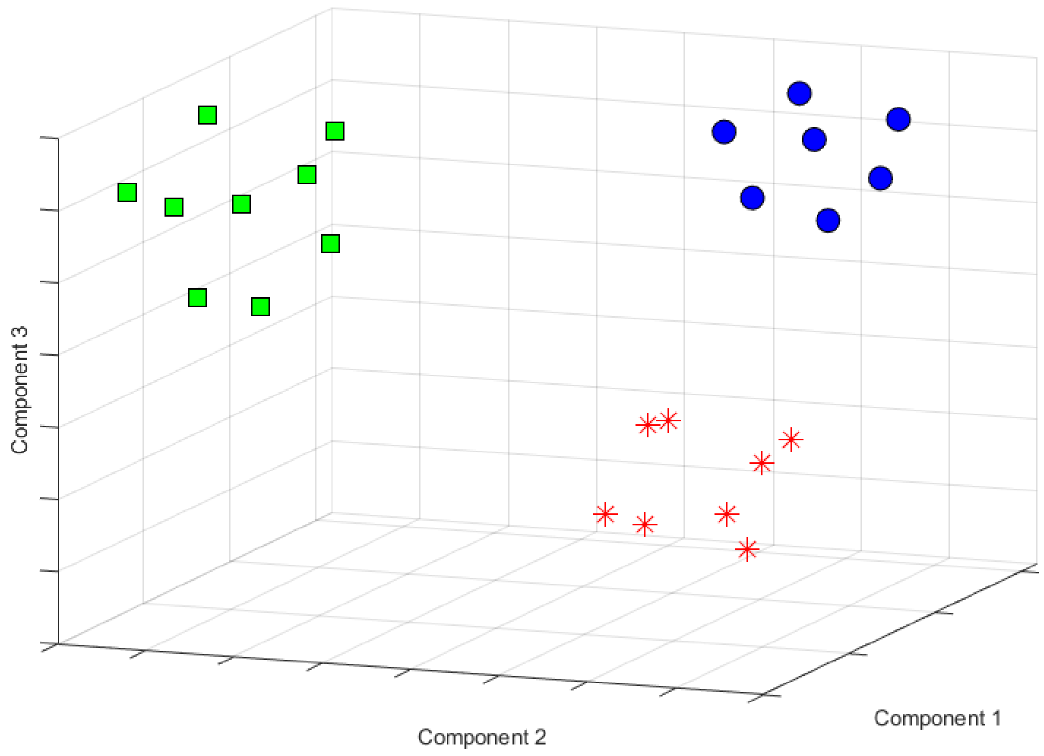
↓

TSNE and *k*-means on load compensated voltages

↓

Separate measurements into 3 clusters

Example of clusters



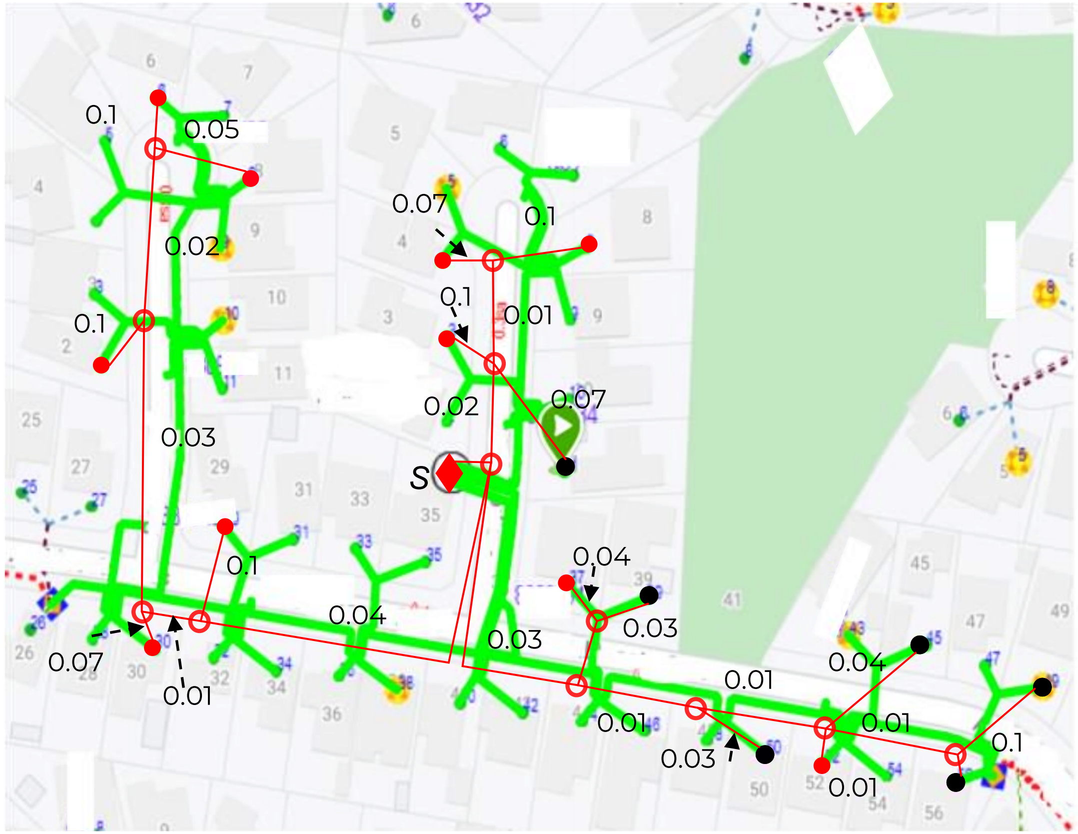
Network Topology Estimation - Performance Evaluation

Tested on various LV networks:

- 6 transformers with residential customers
- 5 transformers with commercial customers

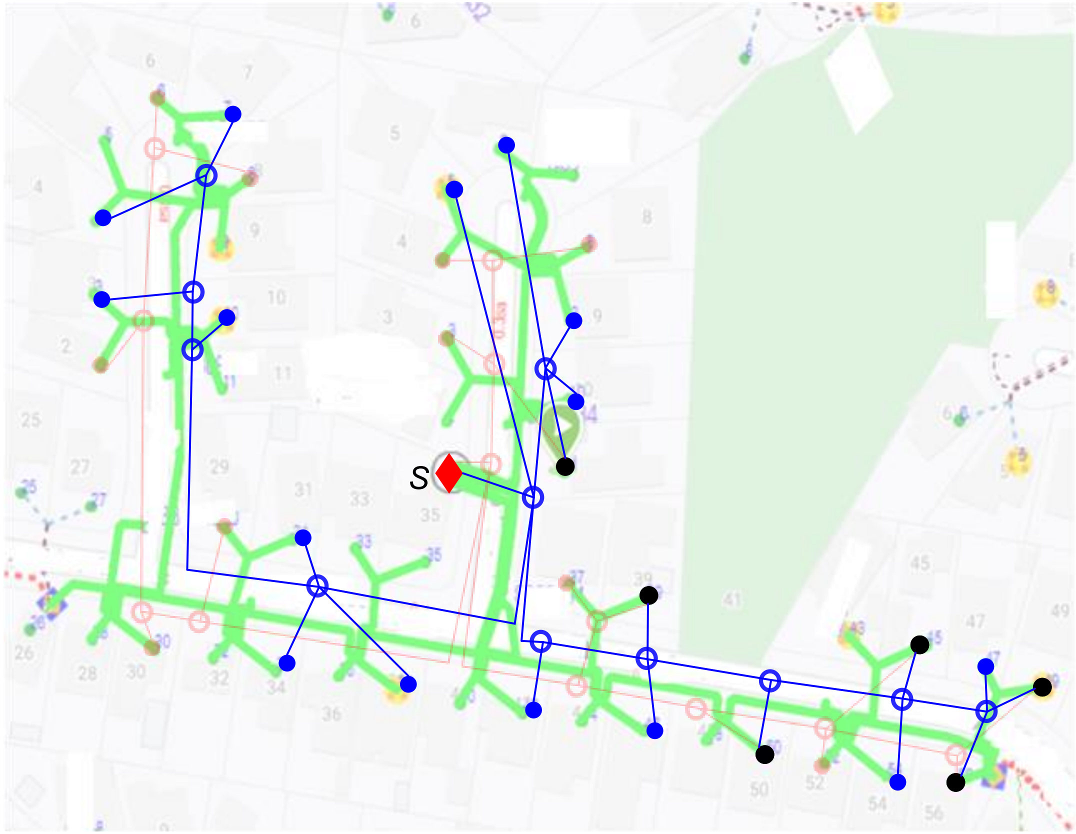
Consistency check using non-overlapping sets of measurements

Network 1- Phase R

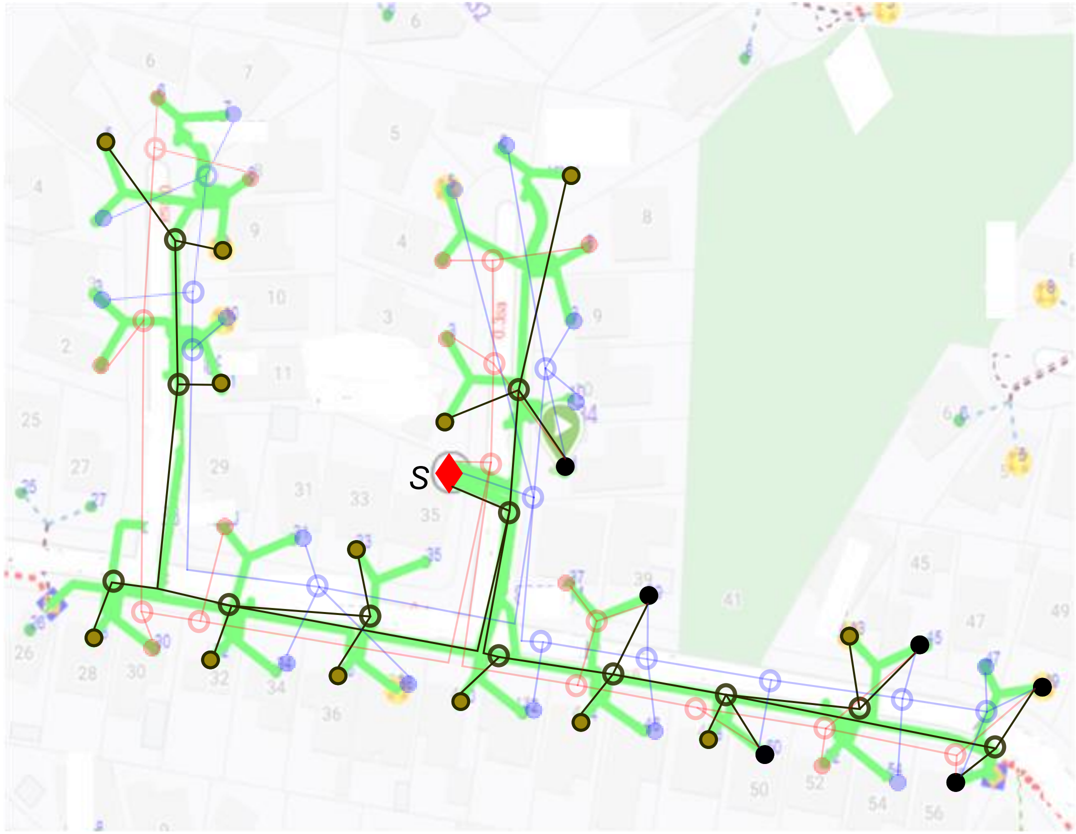


Network Topology Estimation - Performance Evaluation

Network 1- Phase B



Network 1- Phase W



Application 1 - Fault Detection

Challenge:

Faults can occur throughout the network

Can be easy to fix, but require knowledge on where fault has occurred – not always oblivious

Can we **detect** and **locate** these faults in a timely manner?

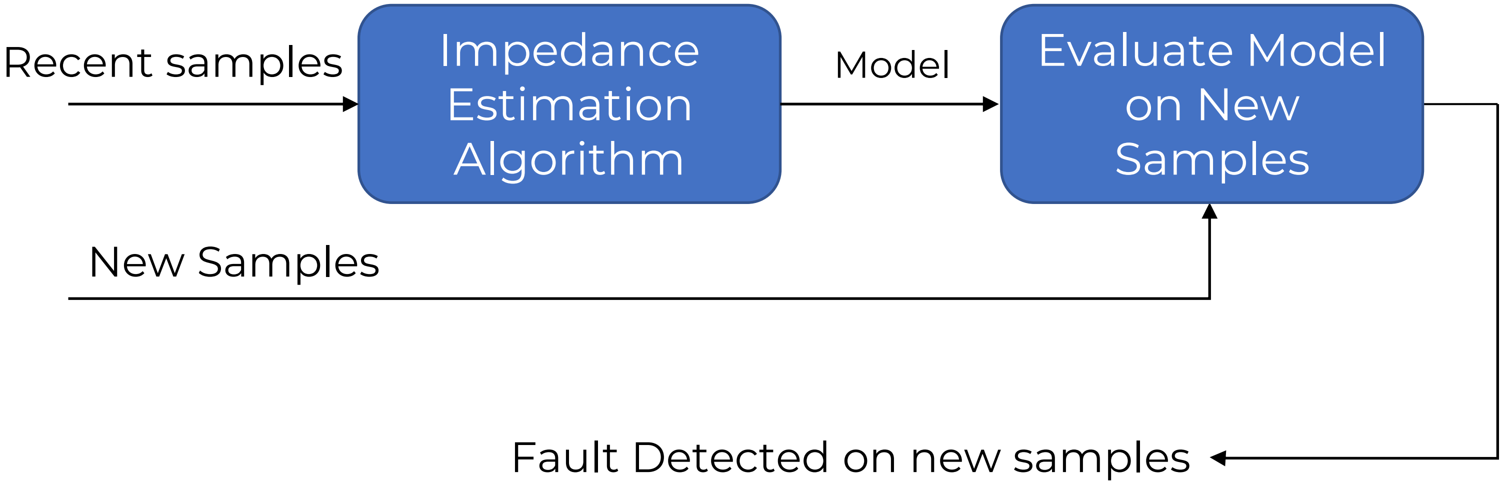
Application 1 - Fault Detection

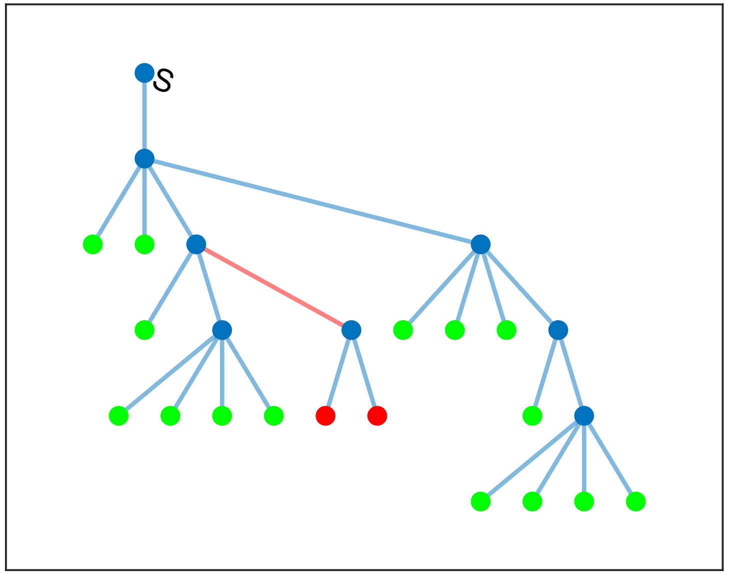
Solution:

Build models of network before faults occur (keep models up to date)

When a fault occurs, observe a deviation from expected customer voltage values

Deviations occur for customers downstream from the fault





Application 1 - Fault Detection

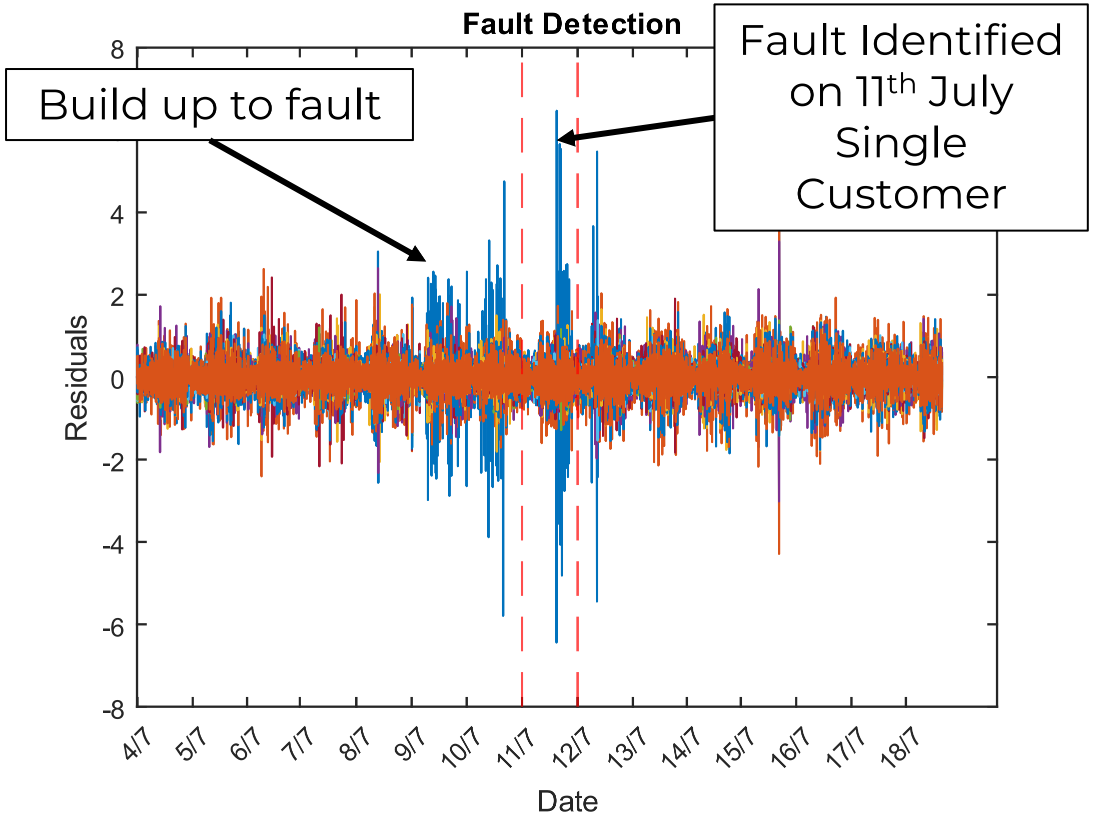
Test Cases:

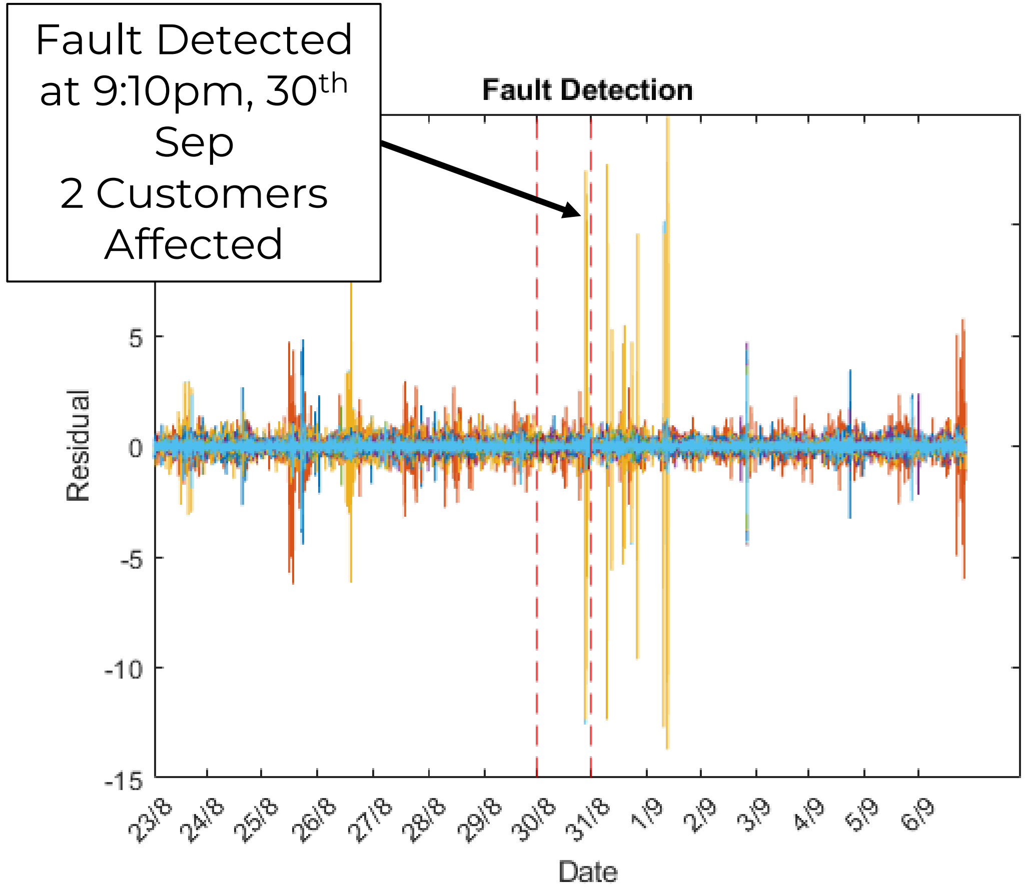
- High impedance fault
- Burned Fuse in pillar
- Rubbing caused by council tree

Summary of Findings:

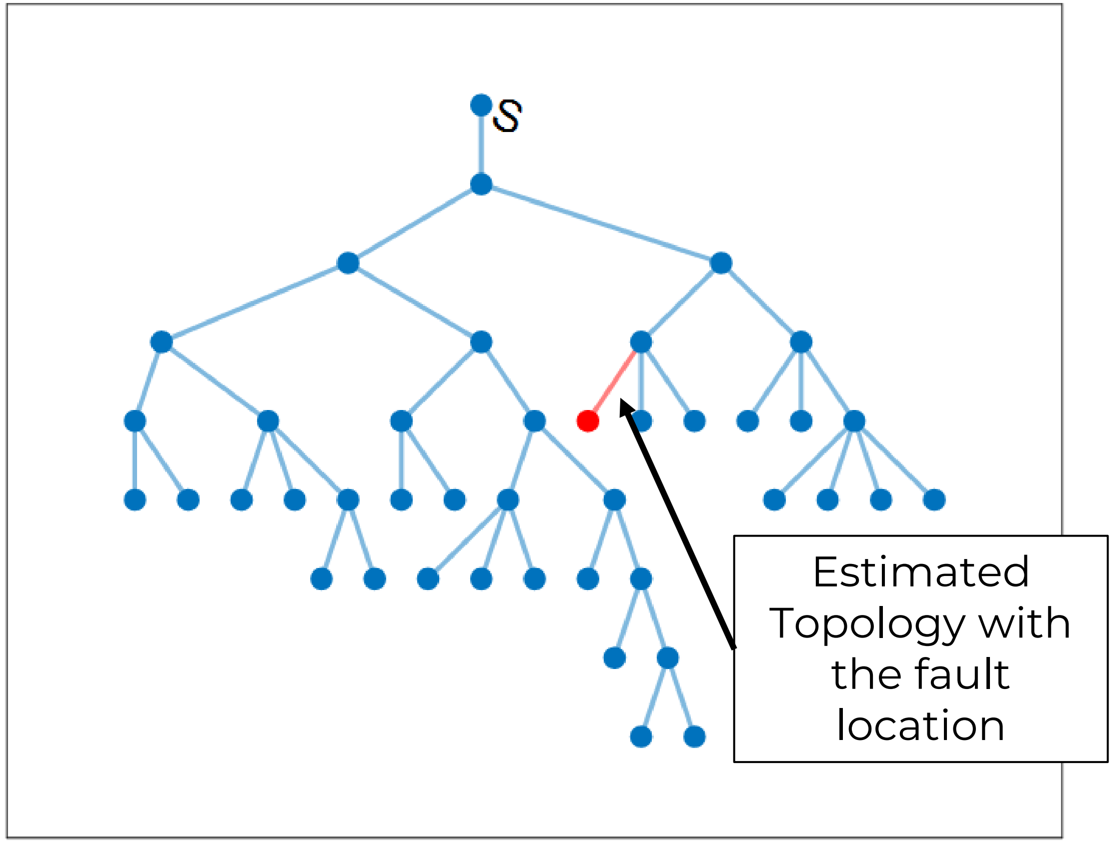
- Faults are identified for all test cases
- Fault signatures can be seen within 2 samples (typical 10 minutes)
  - Longer times will allow for more confidence
- In some cases, able to <u>**detect build up to the fault**</u>

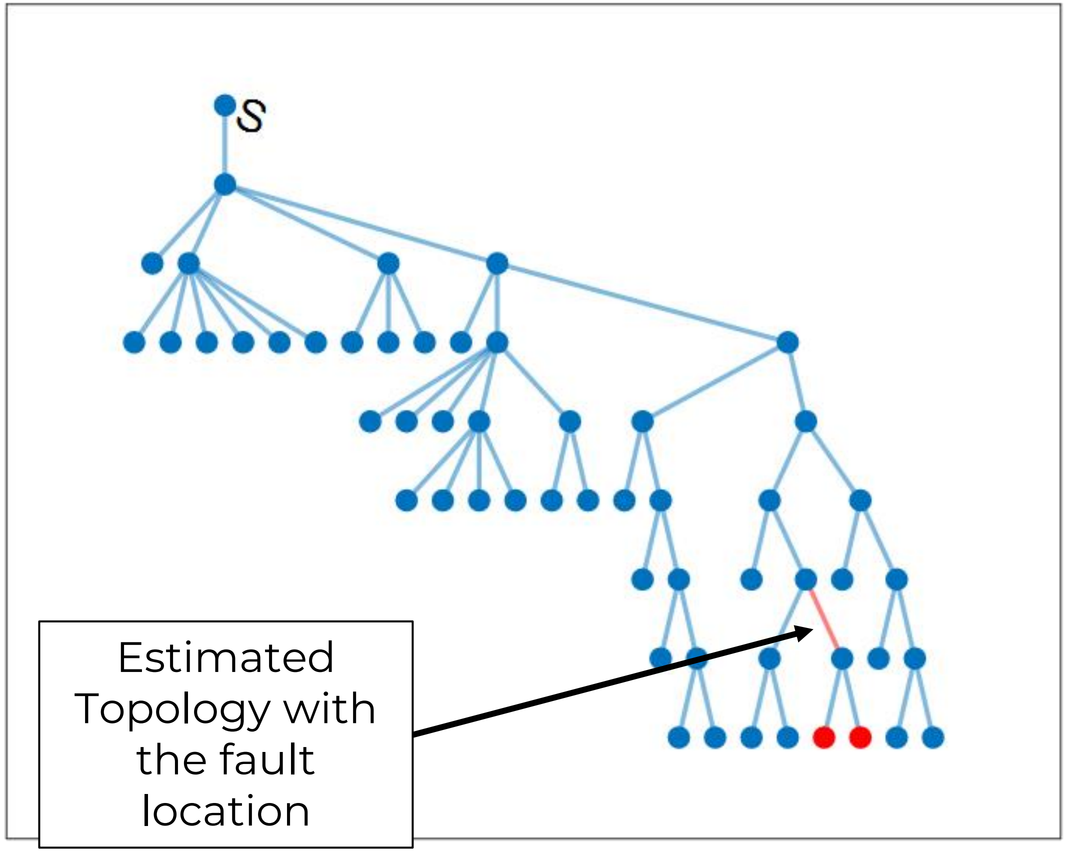
Application 1 - Fault Detection





Application 1 - Fault Detection



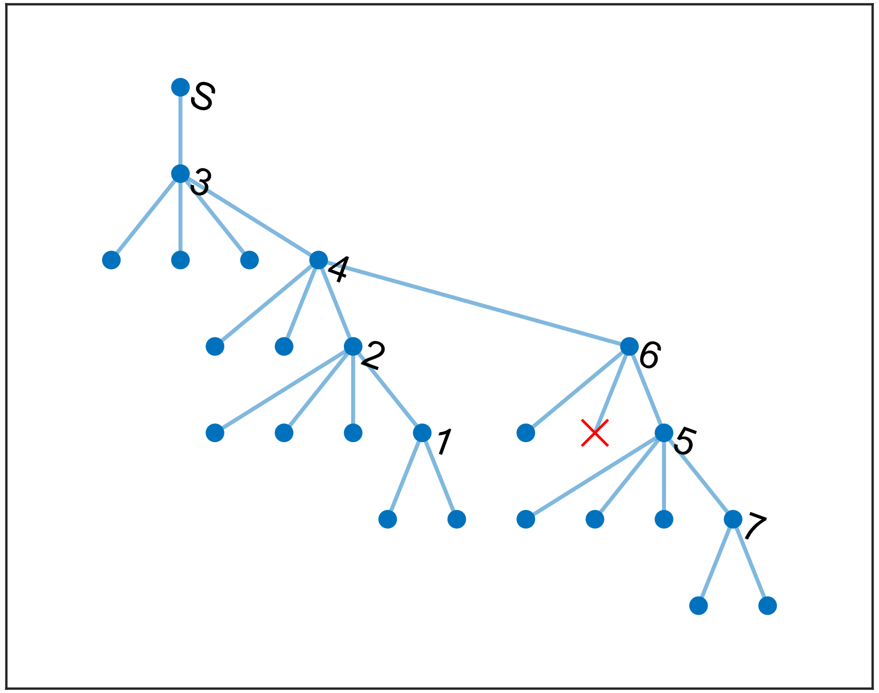


Application 2 - Unmetered Load detection

Source: Ausgrid

Problem:

- Some loads aren't metered (streetlights, theft)
- Assuming high smart meter coverage, with only 1-2 unmetered customers
- **Where are these loads?**



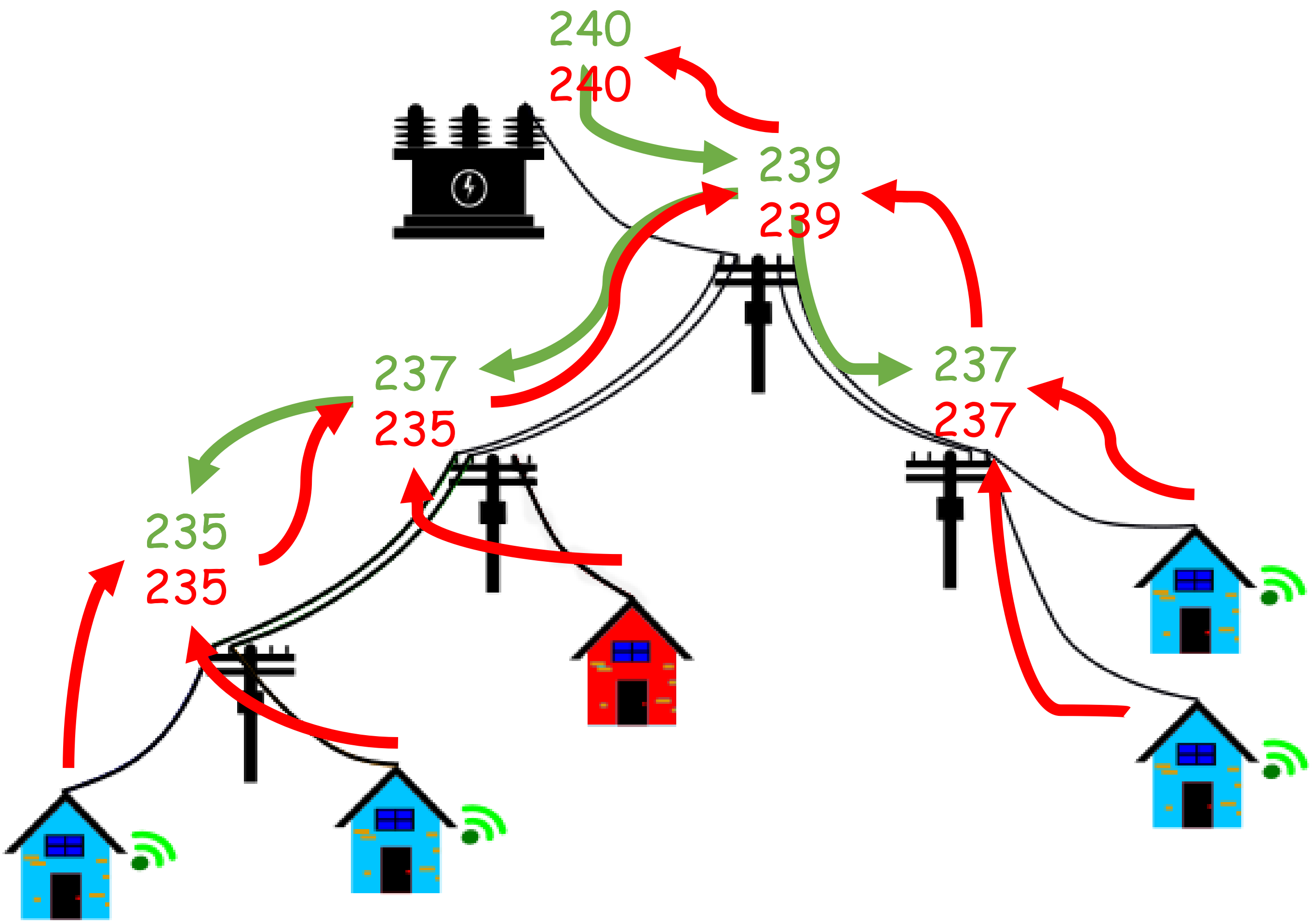
YES
Node 6

Application 2 - Unmetered Load detection

Solution:

- Estimate voltage at poles in 2 ways:
  - From Transformer (Estimated)
  - From Customers (Measured)

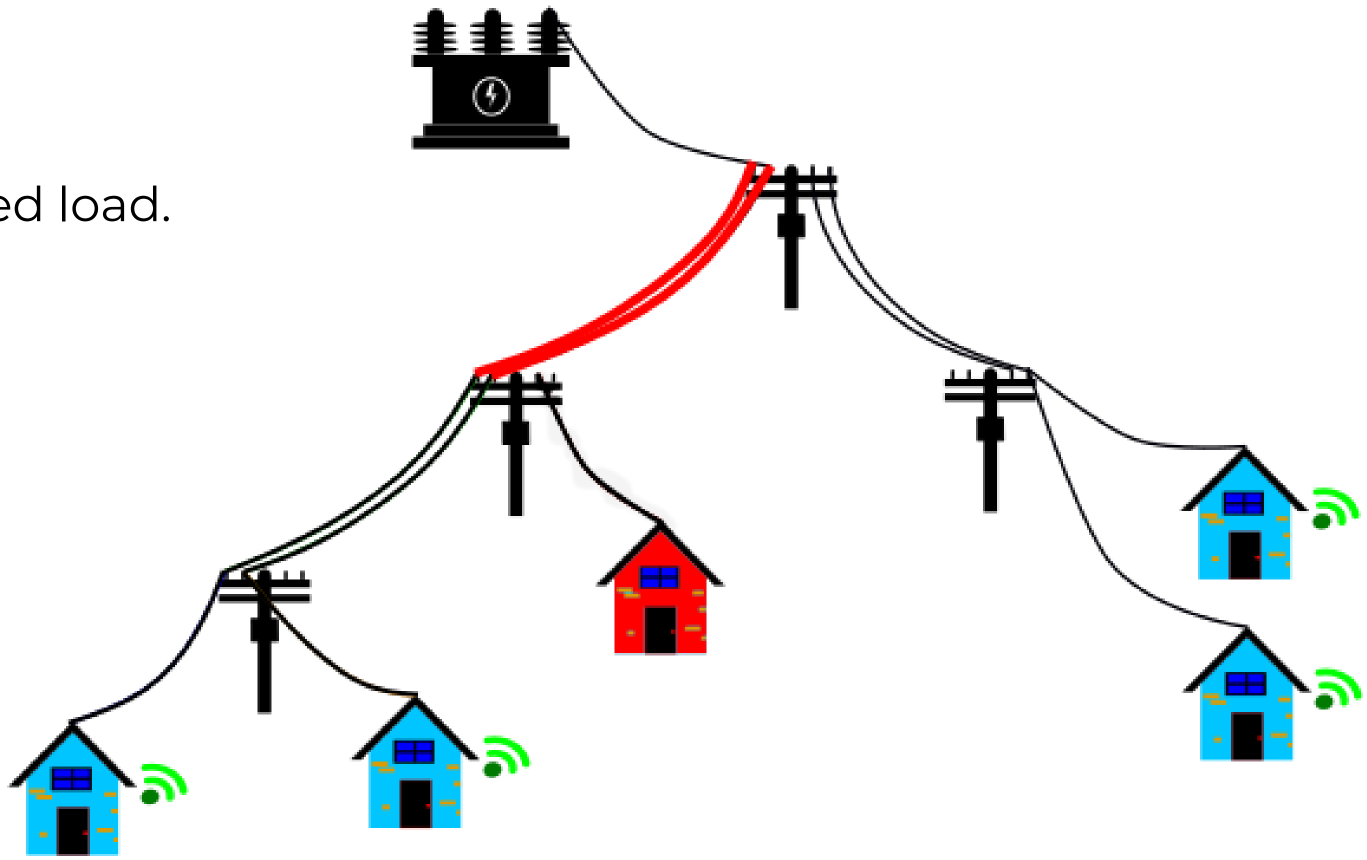
- Difference in voltage estimates can indicate if unmetered load is present and where it is



Application 2 - Unmetered Load detection

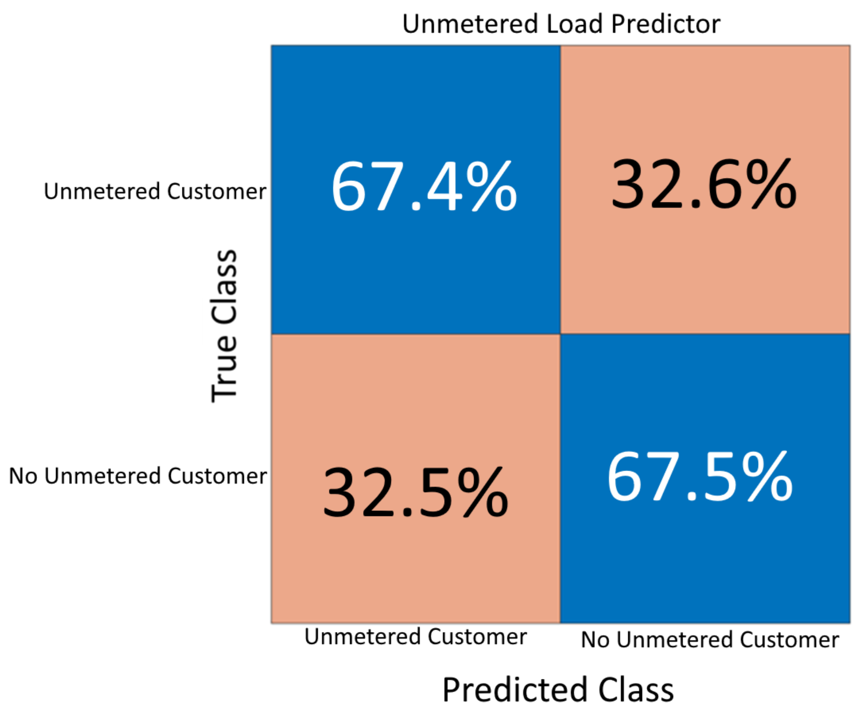
Implementation:

- Utilize peak current draw of unmetered load.
- Topology estimation can disguise the “average” effect of unmetered load.
- Heavy unmetered loads are more pronounced - easier to detect.
- Detect during these times.



Application 2 - Unmetered Load detection

- 67% accuracy for detecting unmetered loads
- 45% accuracy for locating unmetered load (to within nearby area)
- See significant improvement in accuracy for exact location of unmetered customer



	Exact Guess	Nearby Node	Approximate Accuracy
Random Selection	10.0%	19.1%	29.1%
Algorithm	33.3%	11.9%	45.2%

Summary

Algorithms for:

- Clustering algorithms for phase grouping of customers
- Mapping low voltage networks using AMI data
- Estimating impedance values

Applications:

- Fault detection in LV grids
- Unmetered load and electricity theft detection

- Accurate DER hosting capacity assessment
- Better informed regulatory and asset investment decisions

Mapping Low Voltage Networks Using AMI Data

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