Subspace-based Detection Of Outage Events With Multiple Sources In Power Grids

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Introduction

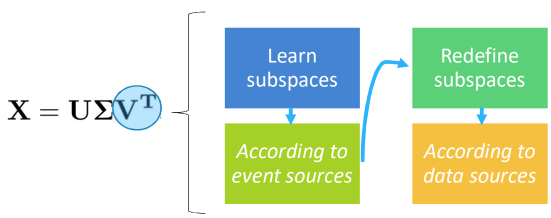
- Modern sensors that deliver fine-grained data are becoming increasingly available to assist power engineering applications.
- Power outage detection and estimation, arguably the most critical application, can benefit from insights drawn from such data.
- The grid is a highly complex system where several cyber-physical features define an exponentially large number of grid states for which there might not be data available to learn all possible outage scenarios.

Detection Problem

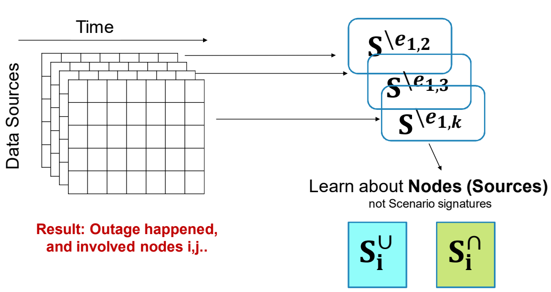
- **GOAL**: Identify and localize power line failures (edge disconnections) using PMU data collected at power buses (nodes).
- No direct edge status is available.
- Not all possible failures have been seen in the past.
- Learning all possible failures would be too expensive.

Methodology

- Normal operations data lie on a low-dimensional subspace:



- Under a specific failure scenario data points also lie in a low-dimensional space.
- Failure subspaces are formed using historical data.
- Using $\mathbf{V}^{\mathbf{T}}$ subspaces are: $\mathcal{S}^0, \mathcal{S}^{\setminus e_{i,j}}$
- In a graph $\mathcal{P}(\mathcal{N}, \mathcal{E})$ we learn $|\mathcal{E}|$ single-line failure scenarios, i.e. **edge subspaces**, with $|\mathcal{E}| \ll 2^{|\mathcal{E}|}$
- Using edge subspaces we create **node subspaces**.
- Node subspaces represent "any" failure.



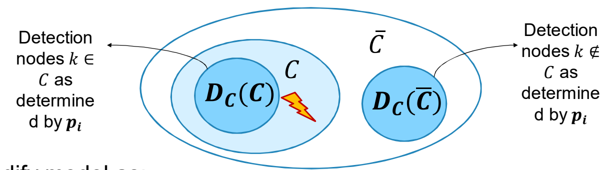
- Data-driven detection adds another cyber-physical dependability
- Data can be missing due to:
  - Equipment malfunction
  - Cyber attacks
  - Communication issues

What about missing data?

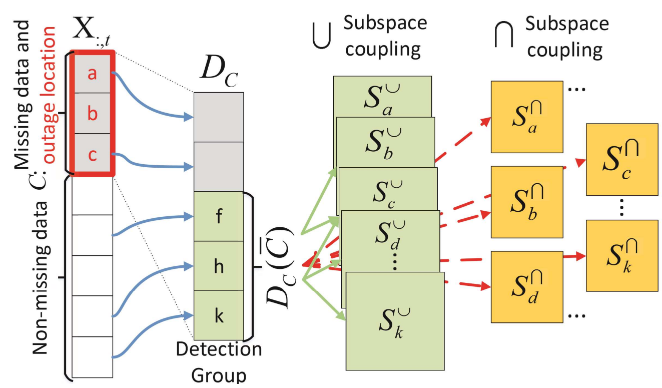
- "Separate" data sources according to their detection performance, identify critical nodes.
- Recommend data redundancy for critical nodes.
- For a data cluster C (with nodes $i \in C$):

  $\boldsymbol{D_C(C)}$ → detection nodes k, for C, belong to C.

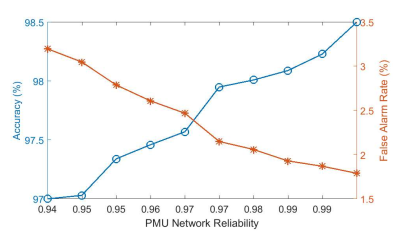
  $\boldsymbol{D_C(\bar{C})}$ → detection nodes k, for $\boldsymbol{C}$, don't belong to $\boldsymbol{C}$.
- Detection nodes: using $\boldsymbol{p_i}$ for all $i \in C$



- Modify model as:



Discussion and Future work



Using a subset of data sources high detection accuracy can be achieved (under realistic data failures).

Extreme cases of missing data lead to higher detection errors.

- Based on distances to (node) subspaces "any" failure can potentially be detected, as more complex failures lie on the union of a subset of the $|\mathcal{E}|$ single-line failure scenarios.

Method	Accuracy
Log Reg (OVR) (Simple)	98.4%
Log Reg (OVR) (Multiple)	23.6%
Subspace (Single)	97.5%
Subspace (Multiple)	73.8%
Subspace (Geo-Correlated)	87.3%

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