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Statistical Structure Learning of Smart Grid for Detection of False Data Injection

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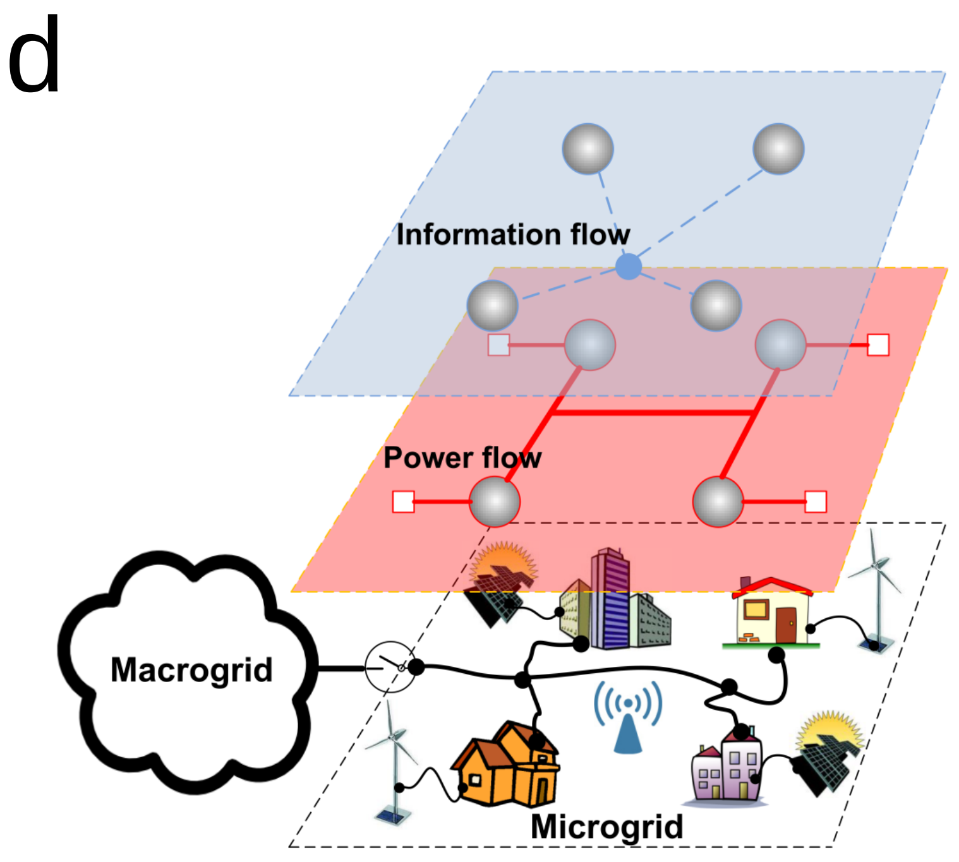
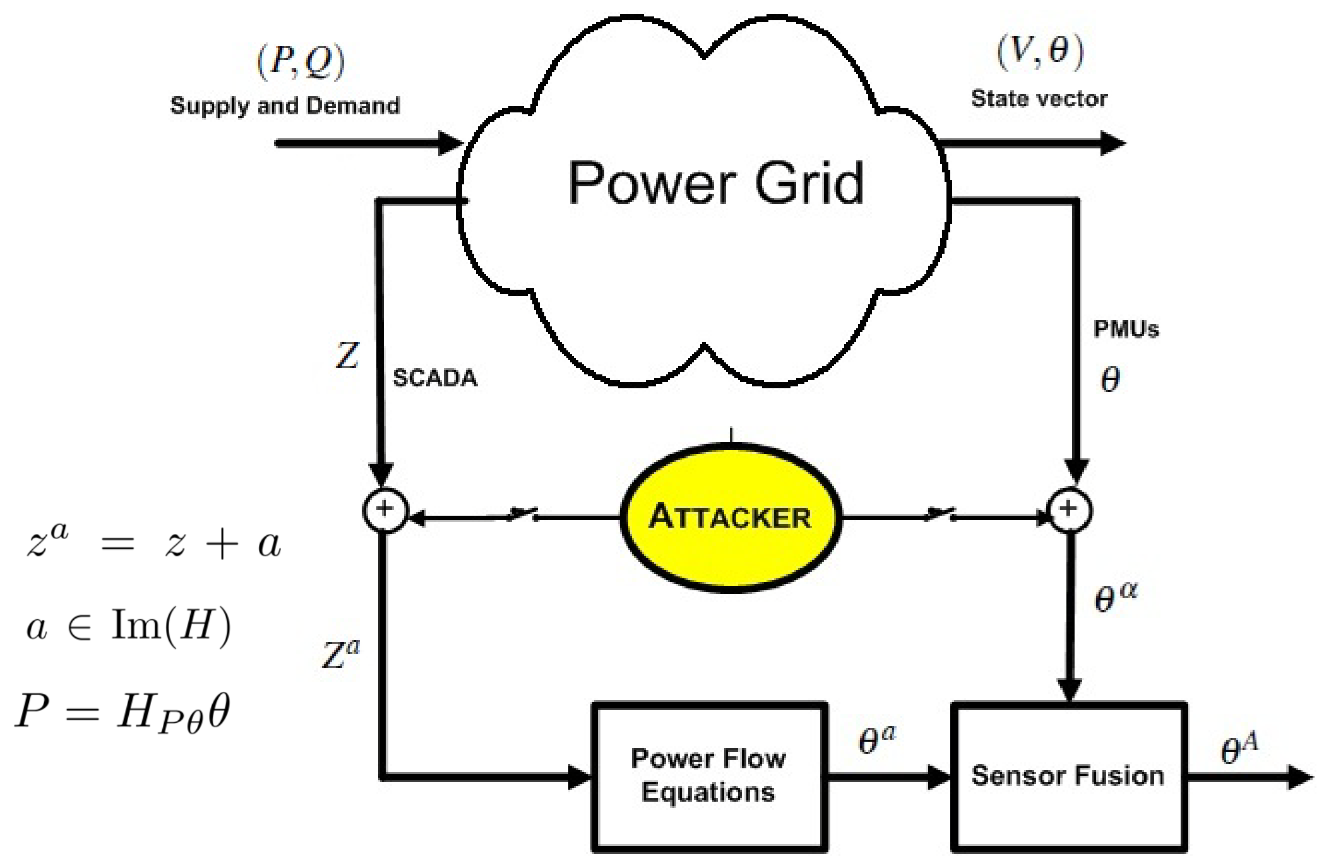
Motivation and Introduction

- ➢ Future grid vs. current grid



- ➢ Phasor Measurement Units (PMUs)
- • Synchronous with GPS stamp
- • Various applications
- • Will be placed partially along with State Estimators

- ➢ False Data Injection



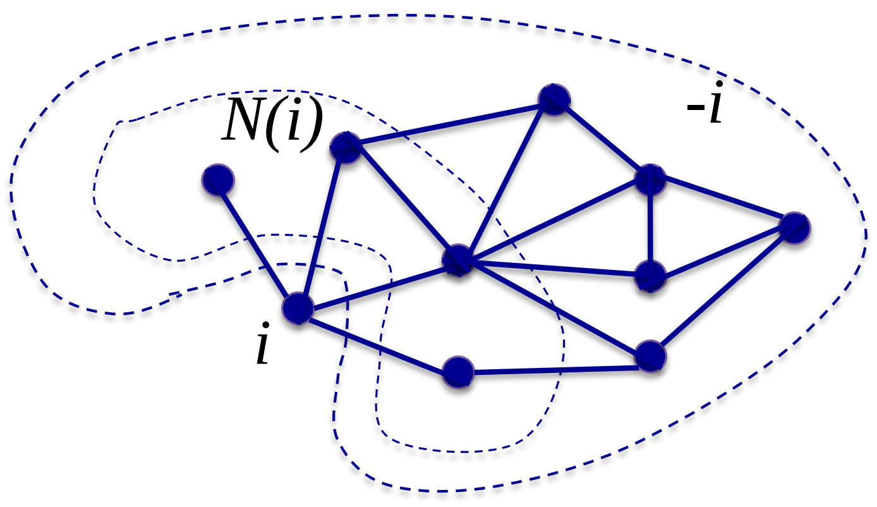
Problem Formulation

Gaussian Markov Random Field

$$f_X(x) \propto exp[-\frac{1}{2}x^T Jx + h^T x]$$

$$J(i,j) = 0 \iff (i,j) \notin E$$

$$E\left(X_i \mid X_{N(i)}\right) = E\left(X_i \mid X_{-i}\right)$$



DC power flow equations

$$P_{ij} = b_{ij}(X_i - X_j) \Rightarrow X_i = \sum_{j \neq i}\{\frac{b_{ij}}{\sum_{i \neq j} b_{ij}}\}X_j + \frac{1}{\sum_{j \neq i} b_{ij}}P_i$$

Structure Learning

Conditional Covariance Test (Anandkumar et.al. 2012)

Estimates the structure of underlying graphical model given i.i.d. samples of the r.v.s

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Algorithm 1 Algorithm CCT($\mathbf{x}^n; \xi_{n,p}, \eta$) for structure learning using samples $\mathbf{x}^n$.
  Initialize $\widehat{G}_p^n = (V, \emptyset)$.
  For each $i, j \in V$, if
      $\min_{S \subset V \setminus \{i,j\}, |S| \leq \eta} |\widehat{\Sigma}(i,j|S)| > \xi_{n,p}$,
  then add $(i,j)$ to $\widehat{G}_p^n$.
  Output: $\widehat{G}_p^n$.
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Detection Scheme

- ➢ Decentralized scheme
- ➢ Online calculations
- ➢ Markov graph changes under attack
- ➢ Mismatch ⇒ alarm

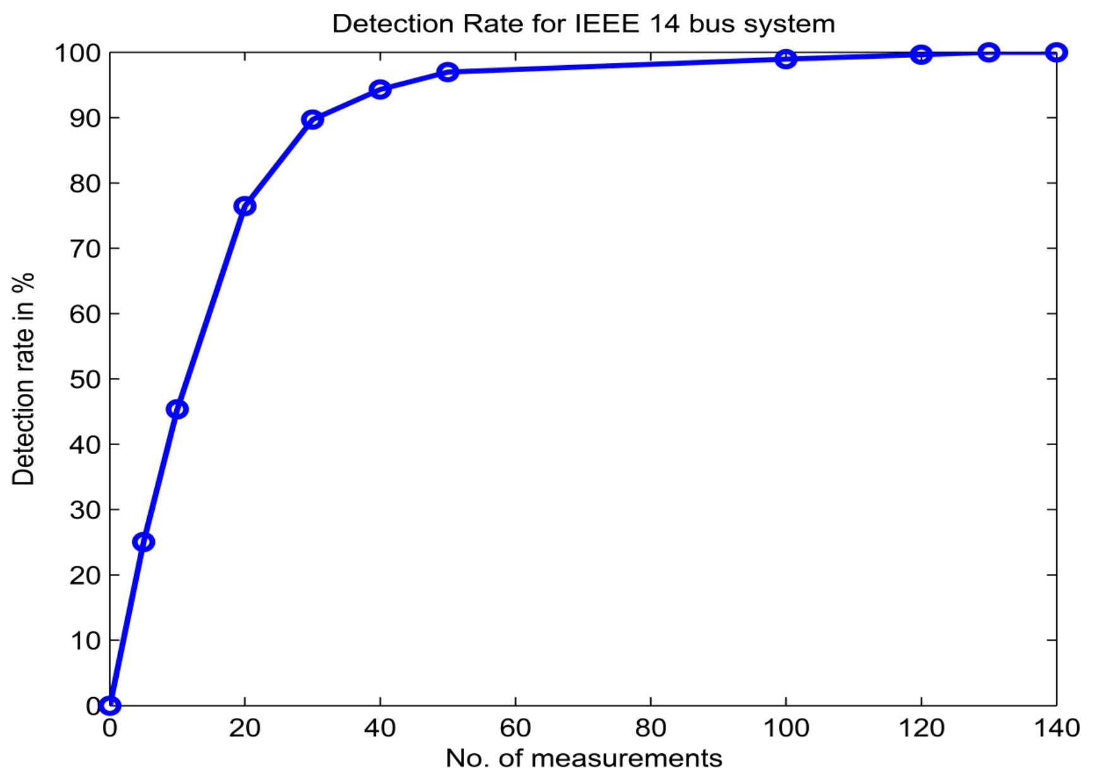
$$z^a = z + a = H(X + d) = HX^a$$

$$\Sigma(X^a, X^a) = H^{-1}[\Sigma(P,P) + \Sigma(a,a)]H^{-1^T}$$

$$\Sigma(X^a, X^a) \neq \Sigma(X, X)$$

- ➢ All attack scenarios
- ➢ MATPOWER for running DC power flow
- ➢ IEEE 14-bus system & IEEE 30-bus system
- ➢ 100% detection rate, min corrupted samples = 130 for IEEE-14 and 50 for IEEE-30.

Reason: sparsity



Detection rate is 90% for just 30 corrupted samples

Considering current sampling rate these values are pretty good.

Discussion & Future Work

- ➢ The first detection scheme for this sophisticated attack
- ➢ Computational complexity $O(p^{\eta+2})$
- ➢ Sample complexity $\Omega(J_{min}^{-2} \log p)$

- ➢ Apply to bigger networks
- ➢ Readily detects other types of attack
- ➢ Causality approach with time series analysis

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