TCIPG

State-Aware Decentralized Database Systems for Smart Grid

Robust State Estimation for Power Systems under Asynchronous Sampling

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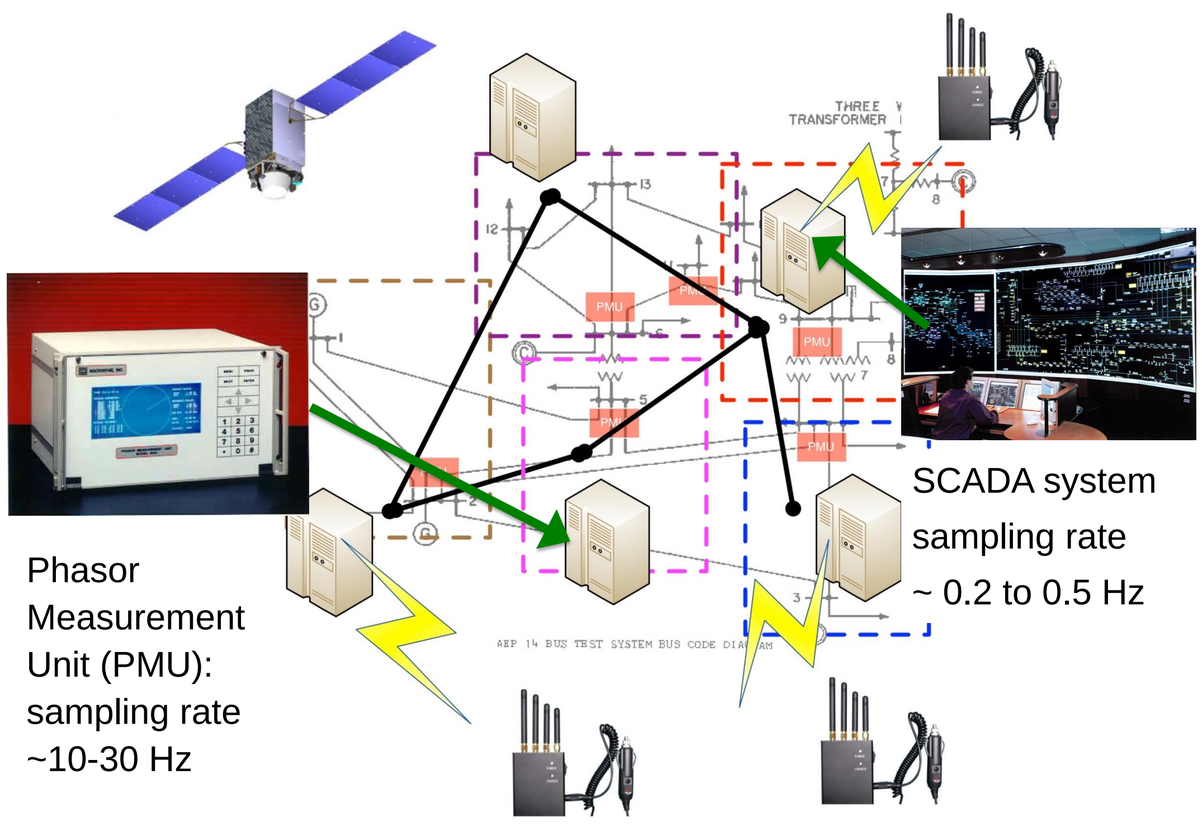
GOAL

- Wide Area Measurement Systems (WAMS) are vulnerable to errors from asynchronous sampling.
- **Design of robust and efficient hybrid PMU and SCADA measurement systems.**
  - Robust to timing attack (e.g., GPS spoofing, replay attack).
  - Combining data from PMU and SCADA systems that operate at different sampling rates.
  - Allows decentralized implementation via gossiping.

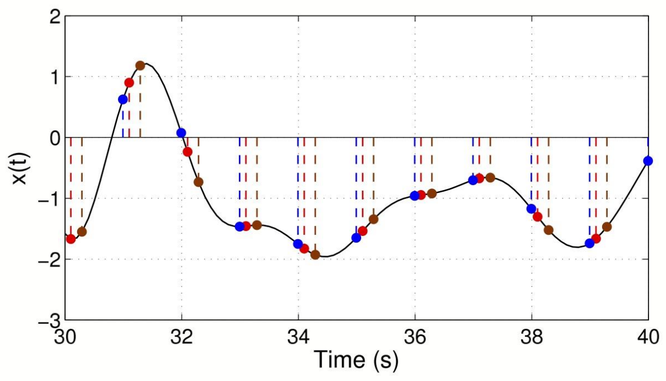


Phasor Measurement Unit (PMU): sampling rate ~10-30 Hz

SCADA system sampling rate ~ 0.2 to 0.5 Hz

CHALLENGES

- Samples of power system states are taken at different time instances.
- A naïve scheme for combining them using conventional technique may result in error.



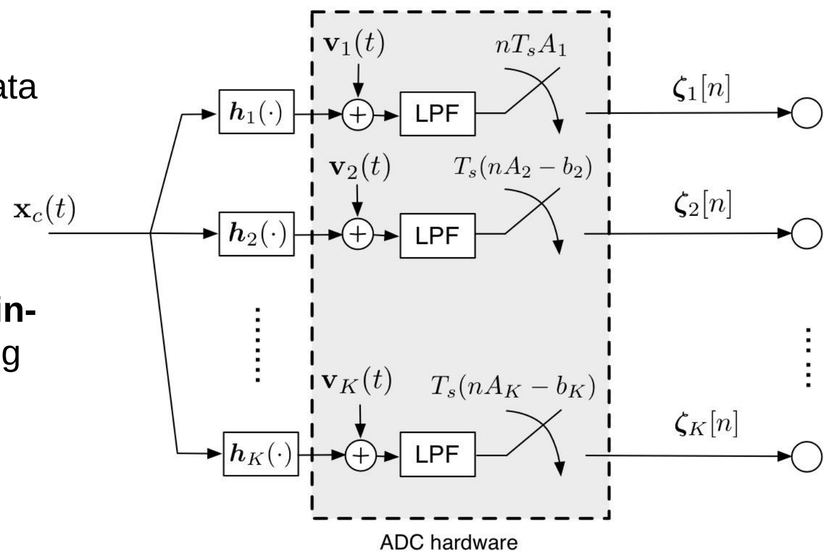
- Both the **power system states** and **timing offsets** are unknown to the measurement system.
- The power sensors (PMU/SCADA) are placed far apart → decentralized algorithm is necessary.

RESEARCH PLAN

- Implement both **state estimation** and the **timing offset estimation** simultaneously.
  ➔ "Realign" the asynchronously sampled data.
- Develop the algorithm via **network diffusion/gossiping**.
  ➔ Flexible communication topology robust to the physical topology.

INSIGHT/APPROACH

- The misaligned data are describing the **same** set of voltage/current.
- We employ a **frequency-domain-based** model using sampling theory.



RESEARCH RESULTS

- A gossip-based alternating optimization for joint estimation problem.

$$\min_{\substack{\mathbf{x}[n],\forall n \\ b_p,\forall p}} \sum_{p=1}^{K} \gamma_p \sum_{f=-Q_pF}^{Q_pF-1} \left\| \boldsymbol{f}_{p,f}\left(\{\mathbf{x}^{(k)}[n]\}_{n=0}^{AL-1}, b_p\right) \right\|_2^2,$$

$$\boldsymbol{f}_{p,f}\left(\{\mathbf{x}^{(k)}[n]\}_{n=0}^{AL-1}, b_p^{(k)}\right) \triangleq \mathbf{Z}_p[f] - \frac{1}{A_p} \sum_{a=0}^{A_p-1} e^{-jb_p^{(k)}\Omega_A(\omega_{p,f},a)} \sum_{n=0}^{AL-1} \mathcal{F}_{p,f}^{a}[n] \boldsymbol{h}_p(\mathbf{x}^{(k)}[n]).$$

Gossip-based decentralized algorithm is possible!

We've modeled the situation with asynchronous sampling AND sub-Nyquist sampling.

Algorithm 1 Alternating optimization heuristic for (35).

1: **Initialize:** $\{\mathbf{x}^{(0)}[n]\}_{n=1}^{AL}$, $\{b_p^{(0)}\}_{p=1}^{K}$ and $k = 1$;
2: **repeat**
3: Let $\mathbf{d}^{(k)}[n]$ be the Gauss-Newton step taken at $(\{\mathbf{x}^{(k-1)}[n]\}_{n=1}^{AL}, \{b_p^{(k-1)}\}_{p=1}^{K})$ w.r.t. $\mathbf{x}[n]$ (cf. (39)), update:

$$\mathbf{x}^{(k)}[n] \leftarrow \mathbf{x}^{(k-1)}[n] + \mathbf{d}^{(k)}[n], \ \forall\, n. \qquad (37)$$

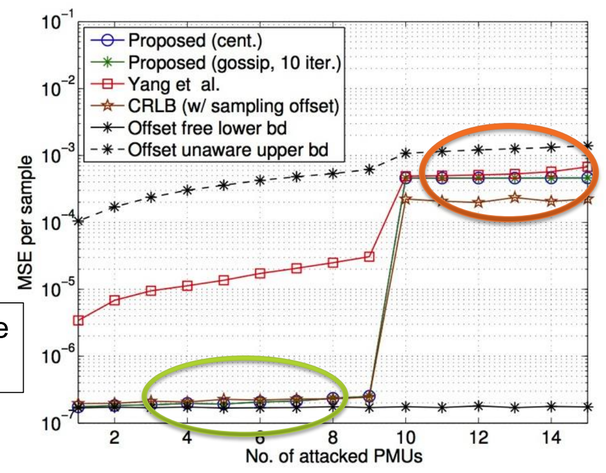
4: Let $g_p^{(k)}$ be the Newton step taken at $(\{\mathbf{x}^{(k)}[n]\}_n, \{b_p^{(k-1)}\}_{p=1}^{K})$ w.r.t. b_p, update:

$$b_p^{(k)} \leftarrow b_p^{(k-1)} + g_p^{(k)}, \ \forall\, p \neq 1. \qquad (38)$$

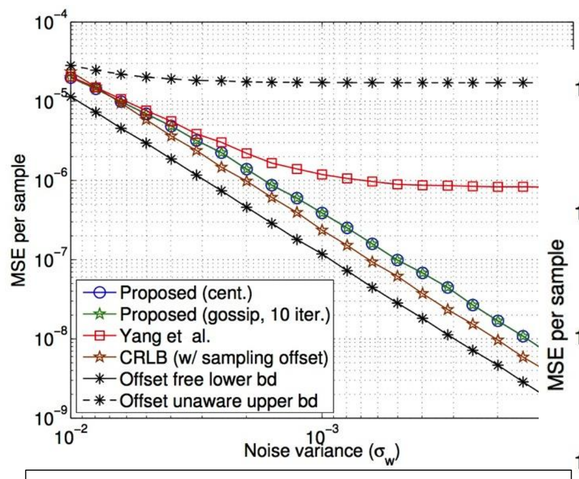
A closed form expression for $g_p^{(k)}$ can be found in Appendix A.
5: $k \leftarrow k + 1$;
6: **until** *some stopping criterion is satisfied.*
7: **Return:** $\{\mathbf{x}^{(k)}[n]\}_{n=1}^{AL}$, $\{b_p^{(k)}\}_{p=1}^{K}$.

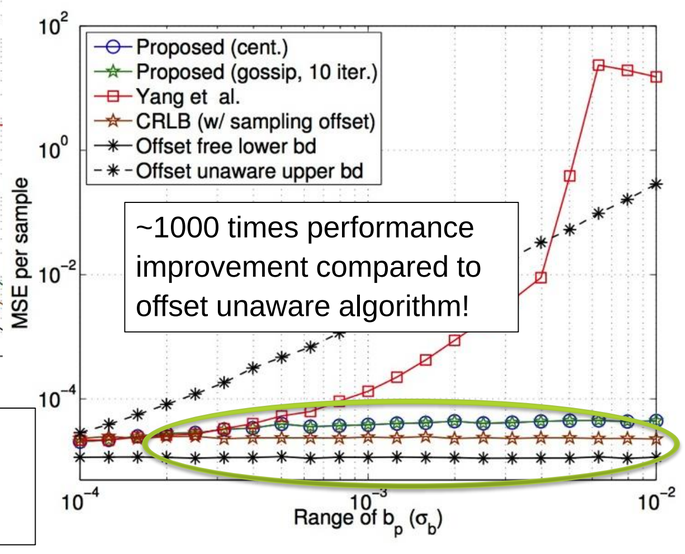
- GPS spoofing on IEEE-30 system.
- **Analysis** gives explicit expression of the circumstances under which a GPS attack can be successful.

"Phase transition" behavior with the no. of attacked PMUs!



- **Simulation** on **PMU data.**

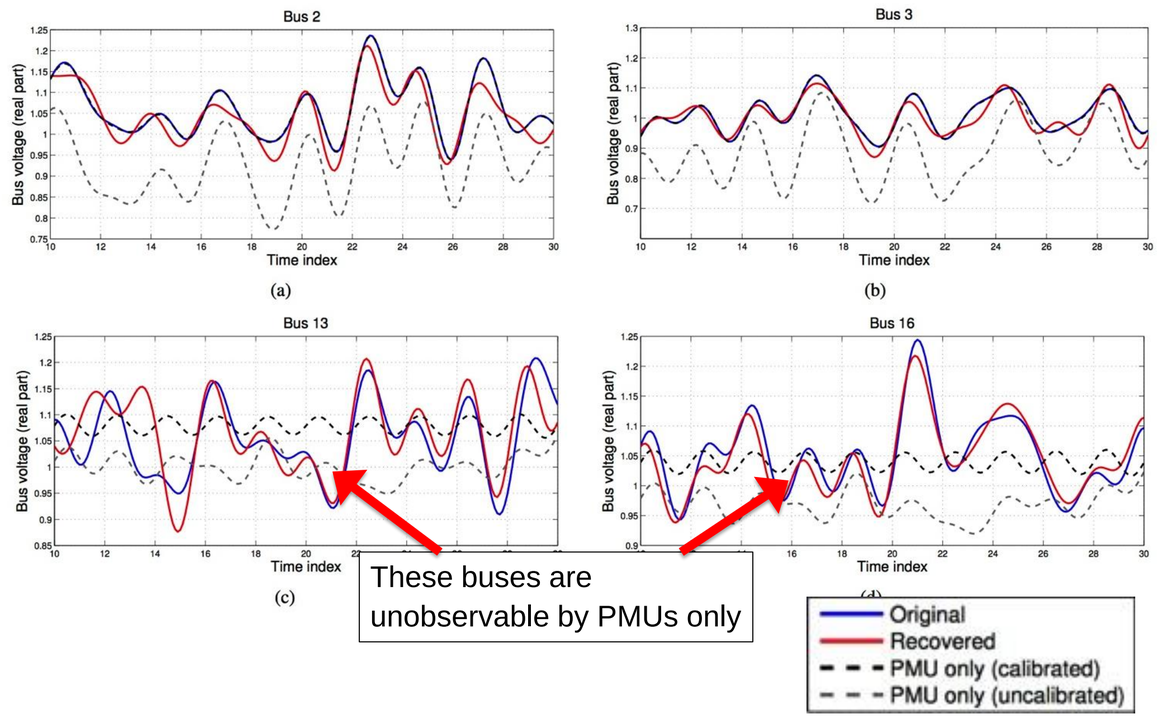




~1000 times performance improvement compared to offset unaware algorithm!

Analysis results:
We need ~double number of PMUs usually required to prevent attacks

- A snapshot of the recovery result under **SCADA/PMU hybrid** measurement (an insufficient no. of PMUs are installed).



These buses are unobservable by PMUs only

BROADER IMPACT

- First step towards a wide area measurement system that is aware of the timing error.

INTERACTION WITH OTHER PROJECTS

- TCIPG activity on "PMU Enhanced Power System Operations."

FUTURE EFFORTS

- Extend the current model to incorporate PMU data.

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