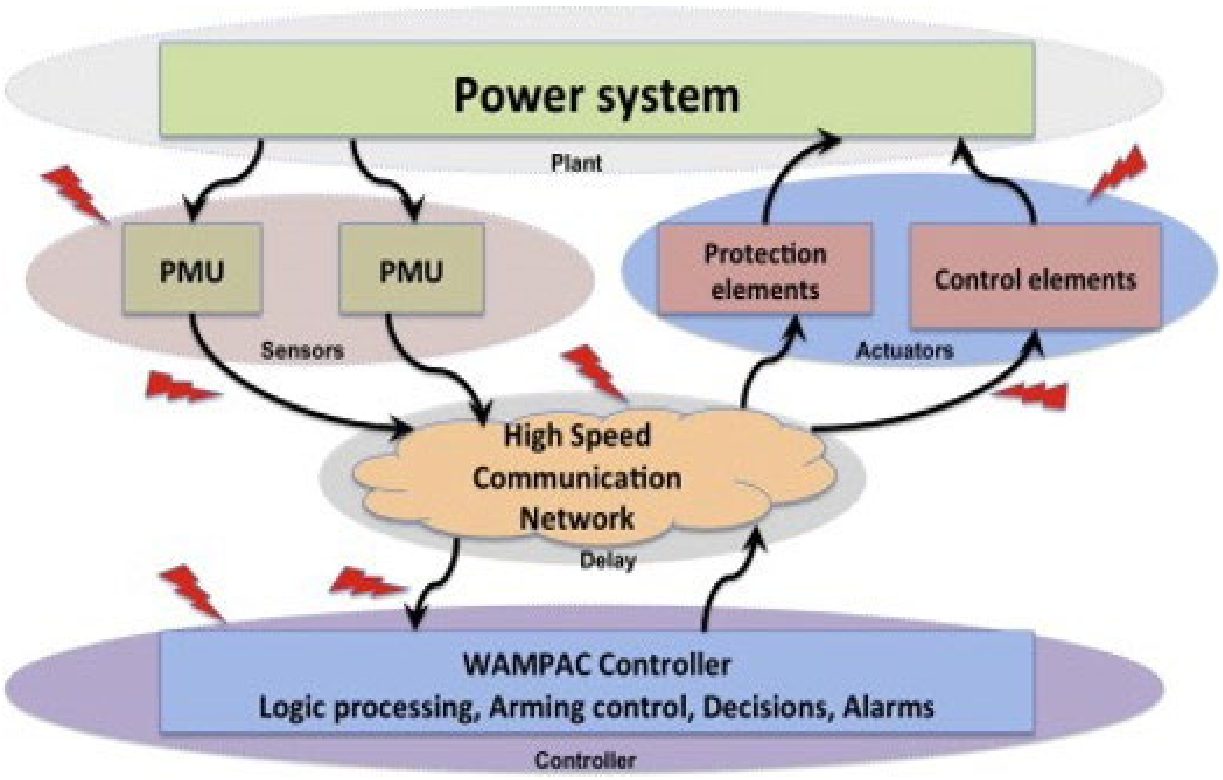
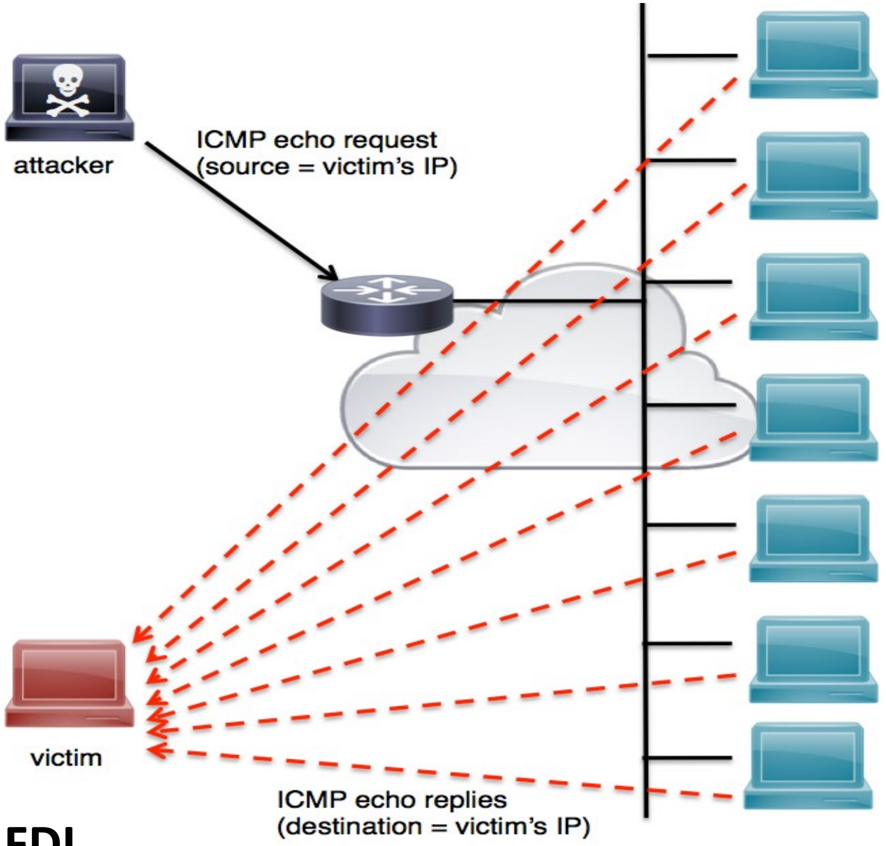
An Integrated Generative Adversarial Network for Identification and Mitigation of Cyber-Attacks in Wide-Area Control

Jishnudeep Kar
PhD Student
North Carolina State University
(jkar@ncsu.edu)

Aranya Chakrabortty
Professor
North Carolina State University
(achakra2@ncsu.edu)

About DoS/FDI attacks





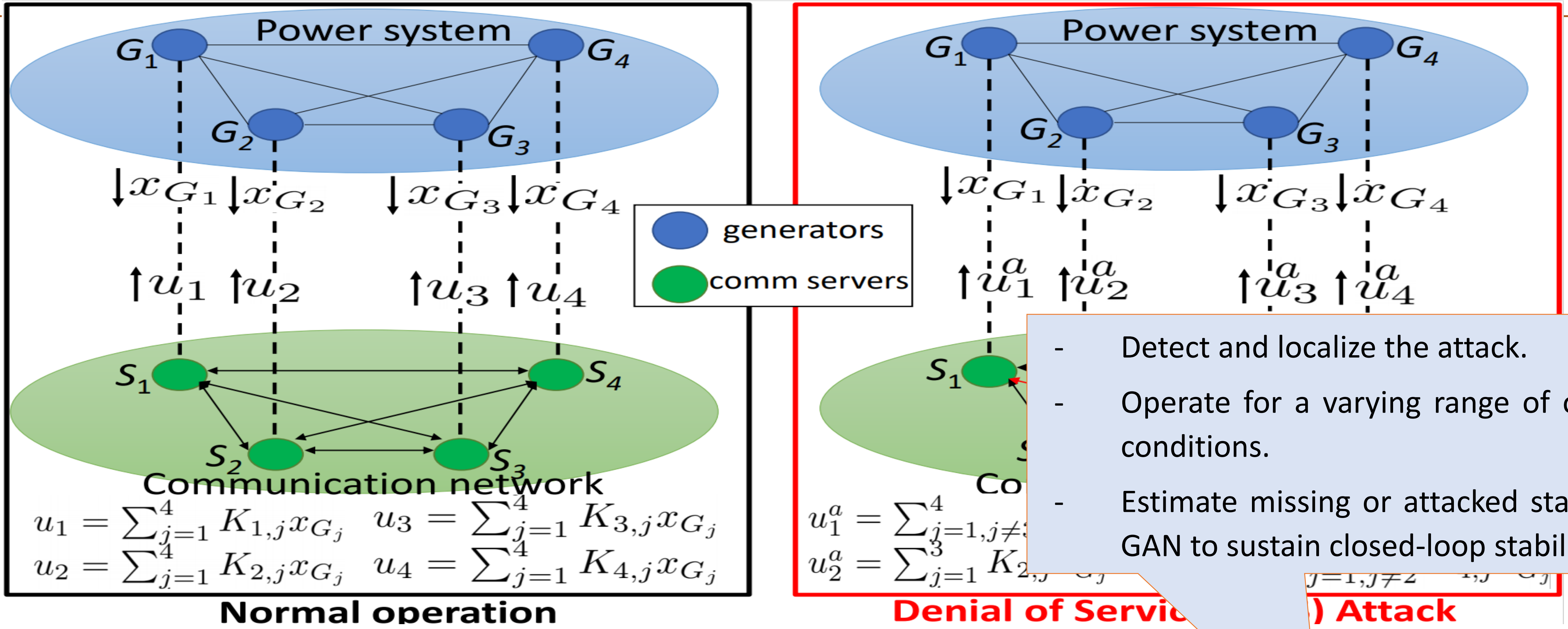
About DoS

- The communicating servers are jammed with malicious request
- Server becomes unable to respond to legitimate requests.

About FDI

- The data shared over the network is corrupted by adding bias.
- This could cause controllers and operators to actuate wrong control actions which may cause closed-loop instability..

About DoS/FDI attacks



- Detect and localize the attack.
- Operate for a varying range of operating conditions.
- Estimate missing or attacked states using GAN to sustain closed-loop stability.

Fig. 2 : Cyber-physical architecture for WAC

$$\Delta \dot{x} = A\Delta x + Bu \qquad u = -K\Delta x$$

$$J = \int_0^\infty (\Delta x^T Q \Delta x + u^T R u)dt\,, \quad Q \geq 0\,,\ R > 0$$

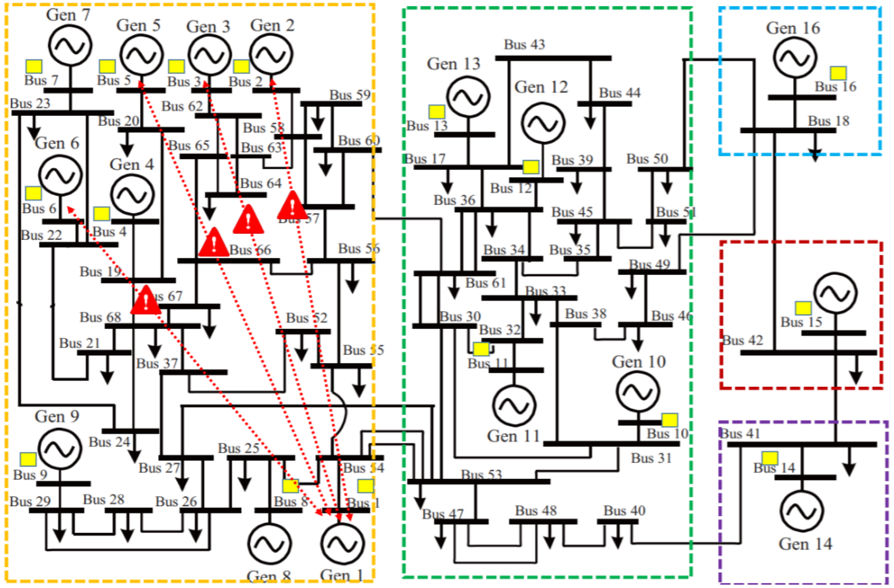
$$\Delta u^a_{G_i}(t) = -\Big(\sum_{G_j \in \mathcal{S}_i} K_{i,j}(x_{G_j}(t) - x_{o,G_j}) + \sum_{G_k \in \mathcal{A}_i} K_{i,j}(x^a_{G_k}(t) - x_{o,G_k}) \Big)$$

Why is resiliency needed ?

Bus (.) : indicates a PMU at bus (.)

Area 1 : $G_{1,..,9}$
Area 2 : $G_{10,..,13}$
Area 3 : G_{14}
Area 4 : G_{15}
Area 5 : G_{16}

Attacked link



IEEE 68-bus 16 m/c system

Small-signal power grid model

$$\Delta\dot{x} = A\Delta x + Bu$$

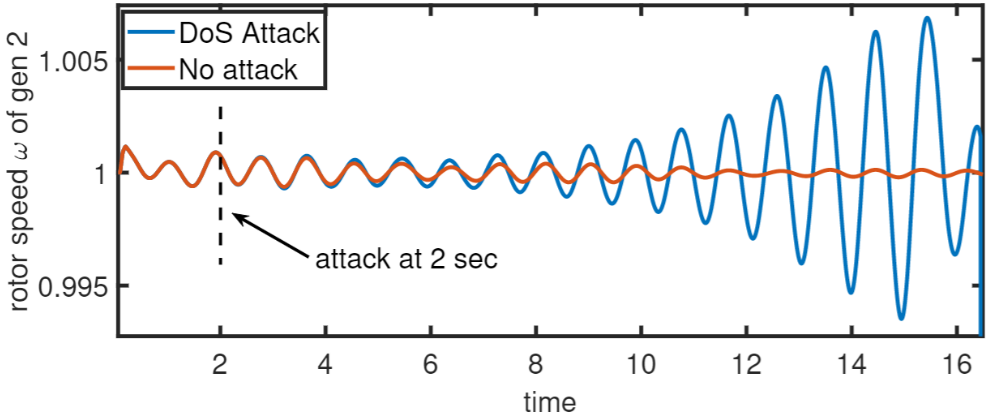
Design a **damping** control input

$$u = -K\Delta x$$

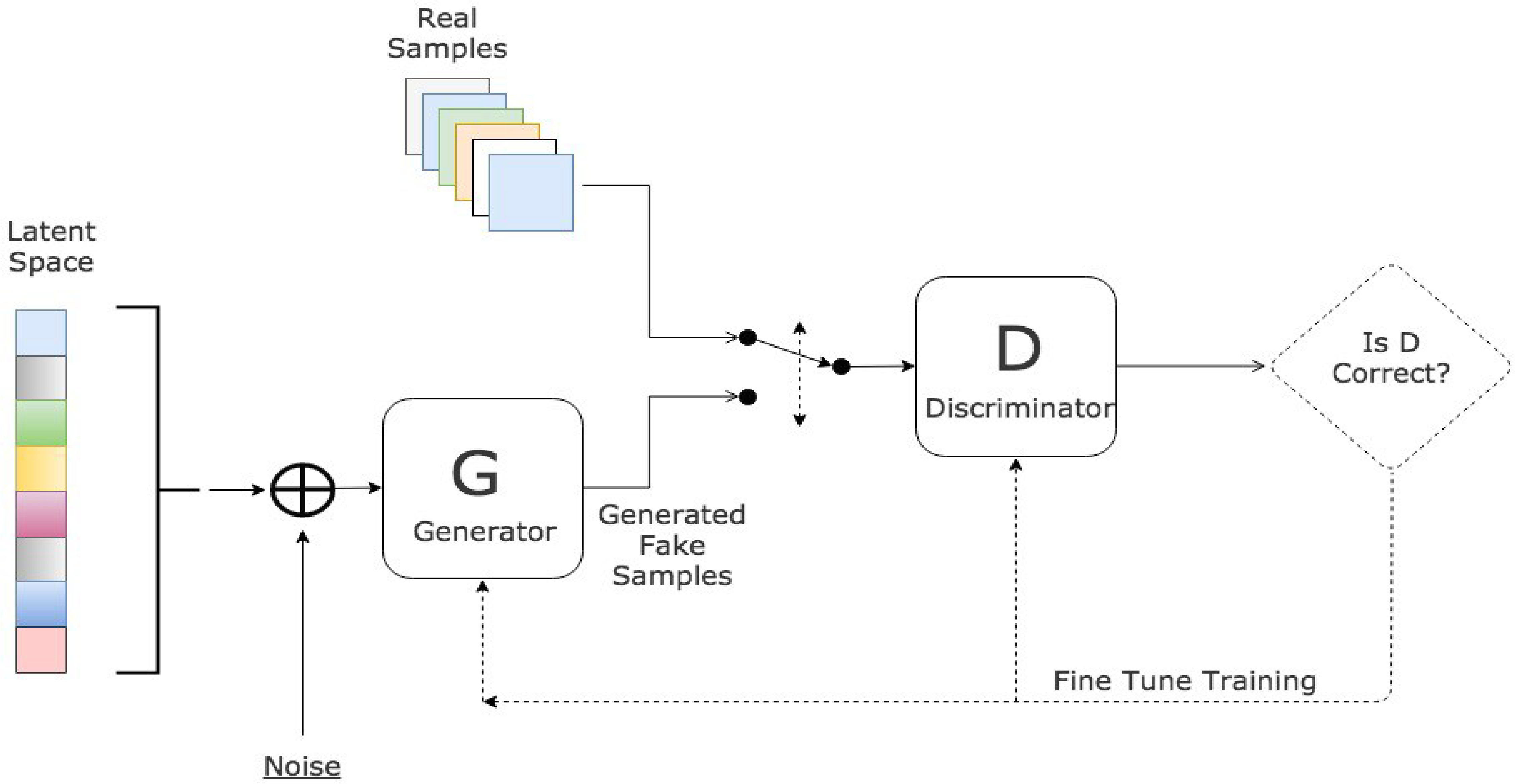
Minimizing LQR cost

$$J = \int_0^{\infty} (\Delta x^T Q \Delta x + u^T R u)dt \ , \ Q \geq 0 \ , \ R > 0$$

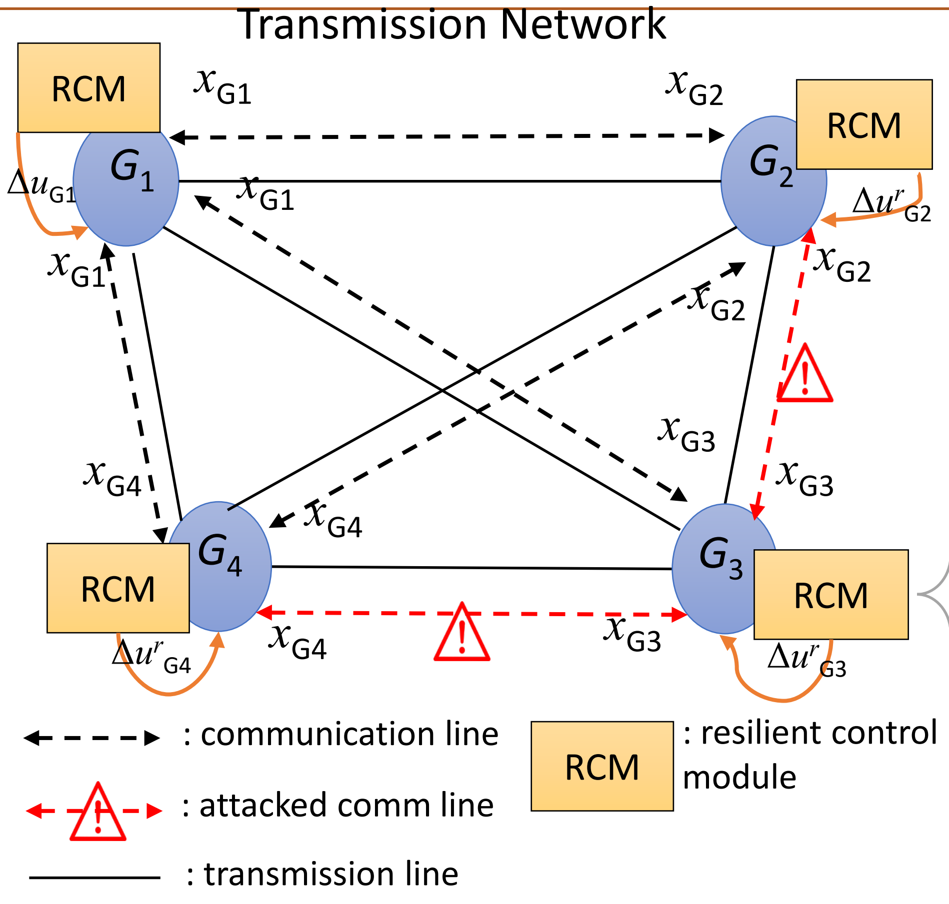
$$K = \begin{bmatrix} K_{1,1} & K_{1,2} & \dots & K_{1,n} \\ \vdots & \vdots & \vdots & \vdots \\ K_{n,1} & K_{n,2} & \dots & K_{n,n} \end{bmatrix}$$

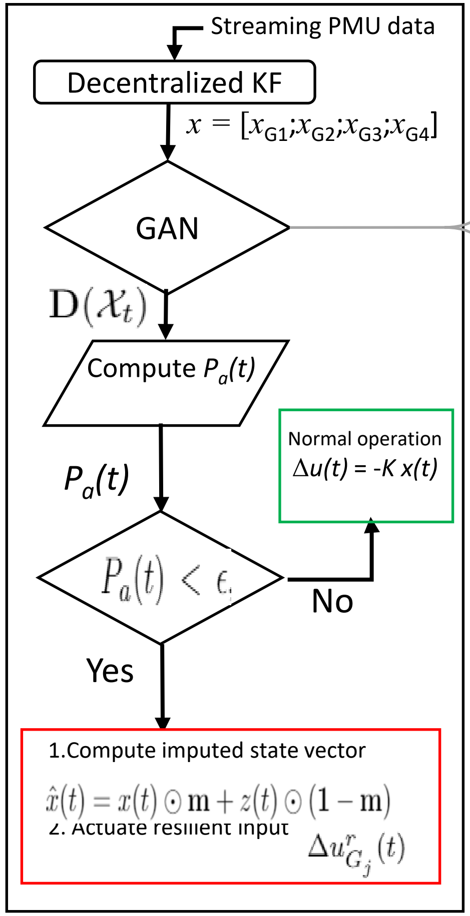


Generative Adversarial Network



Our proposed GAN



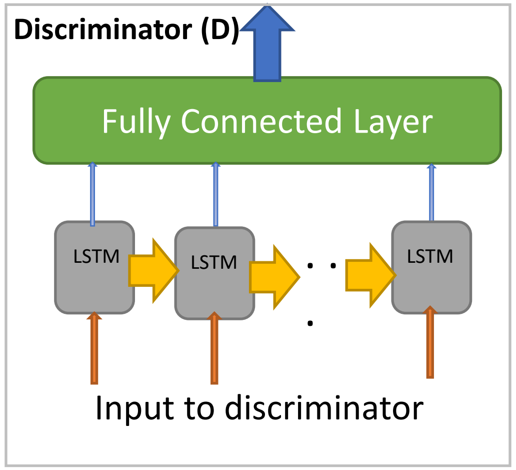


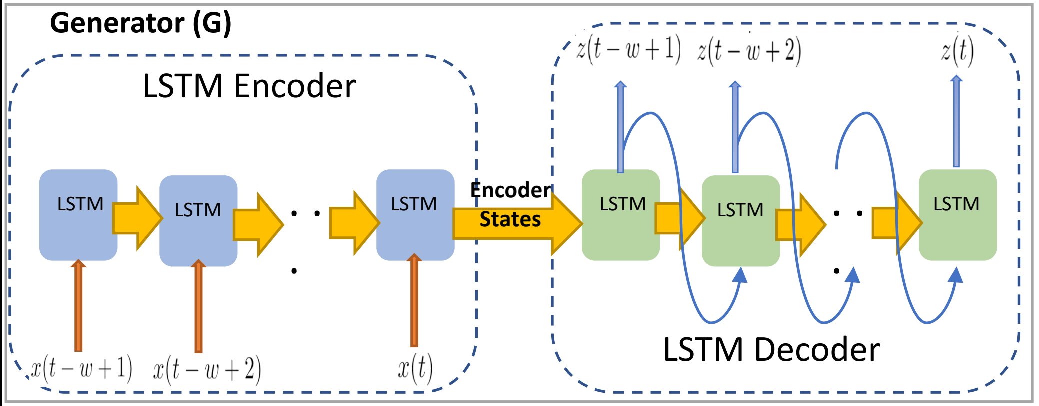
Training

- Input to discriminator is a concatenation of real data and generator output.
- Input to LSTM encoder is attacked state vector from moving data window.

Discrimination

- Input to discriminator is data from moving window for attack detection and identification
- Output of LSTM decoder is imputed healthy states to form augmented state vector.





$$P_a^{G_j}(t) = \left(\mathbf{D}(\mathcal{X}_t^{G_j}) + \mathbf{D}(\mathcal{X}_{t-1}^{G_j}) + \ldots + \mathbf{D}(\mathcal{X}_{t-d+1}^{G_j})\right)/d.$$

Moving average – WHY ?

- GANs cannot be trained to 100% accuracy
- Instances of anomalous scores.
- Averaging removes anomaly.

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Simulation

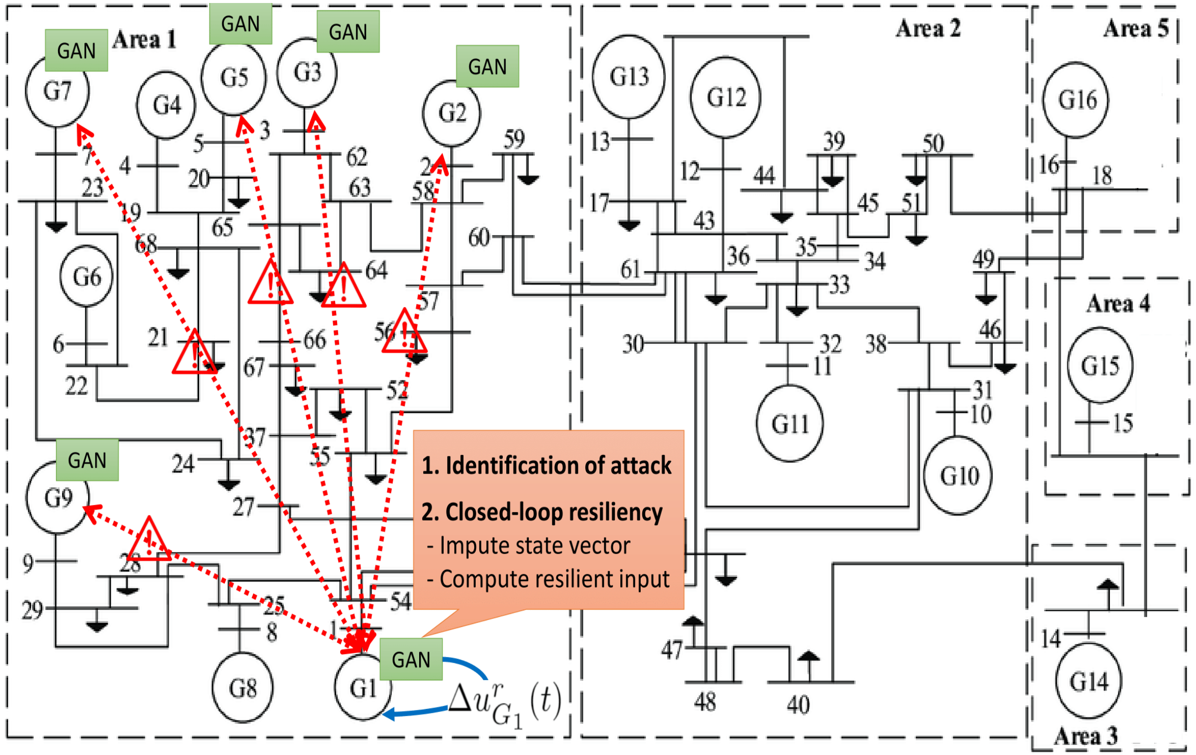
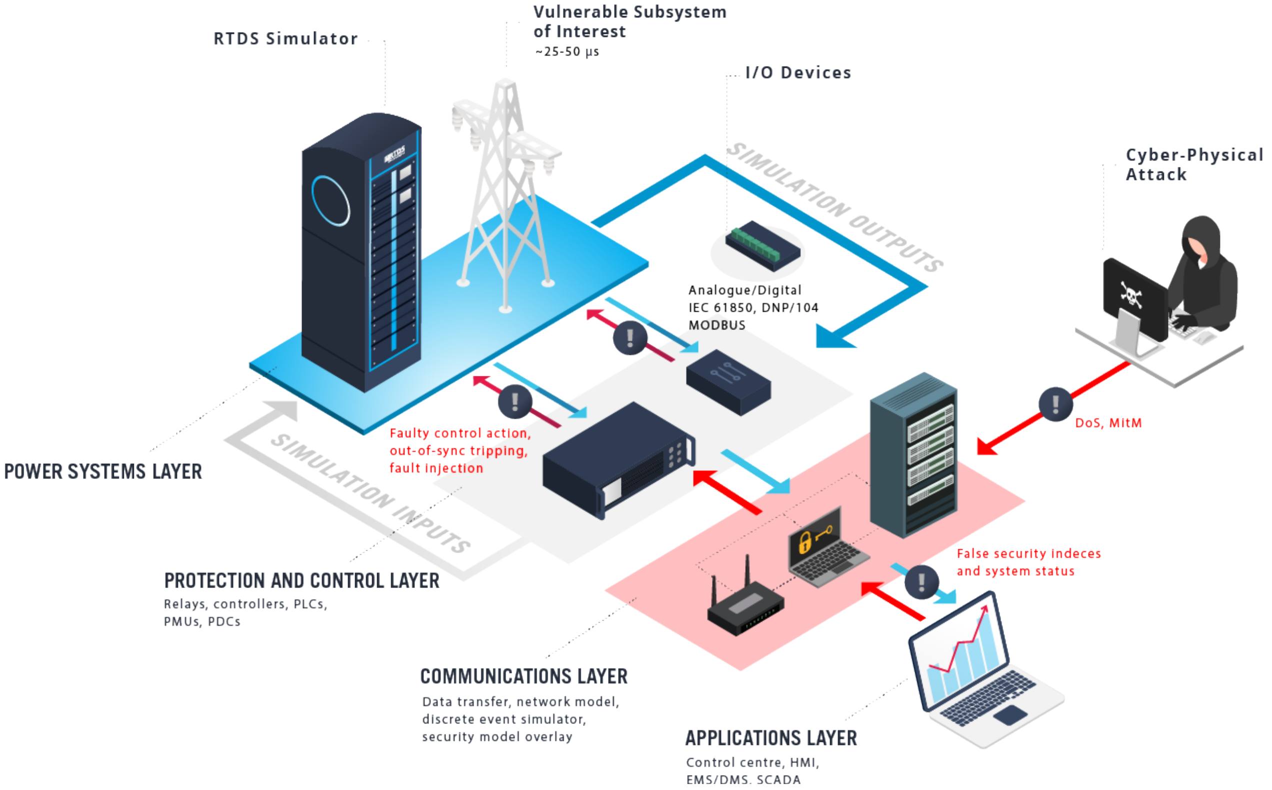


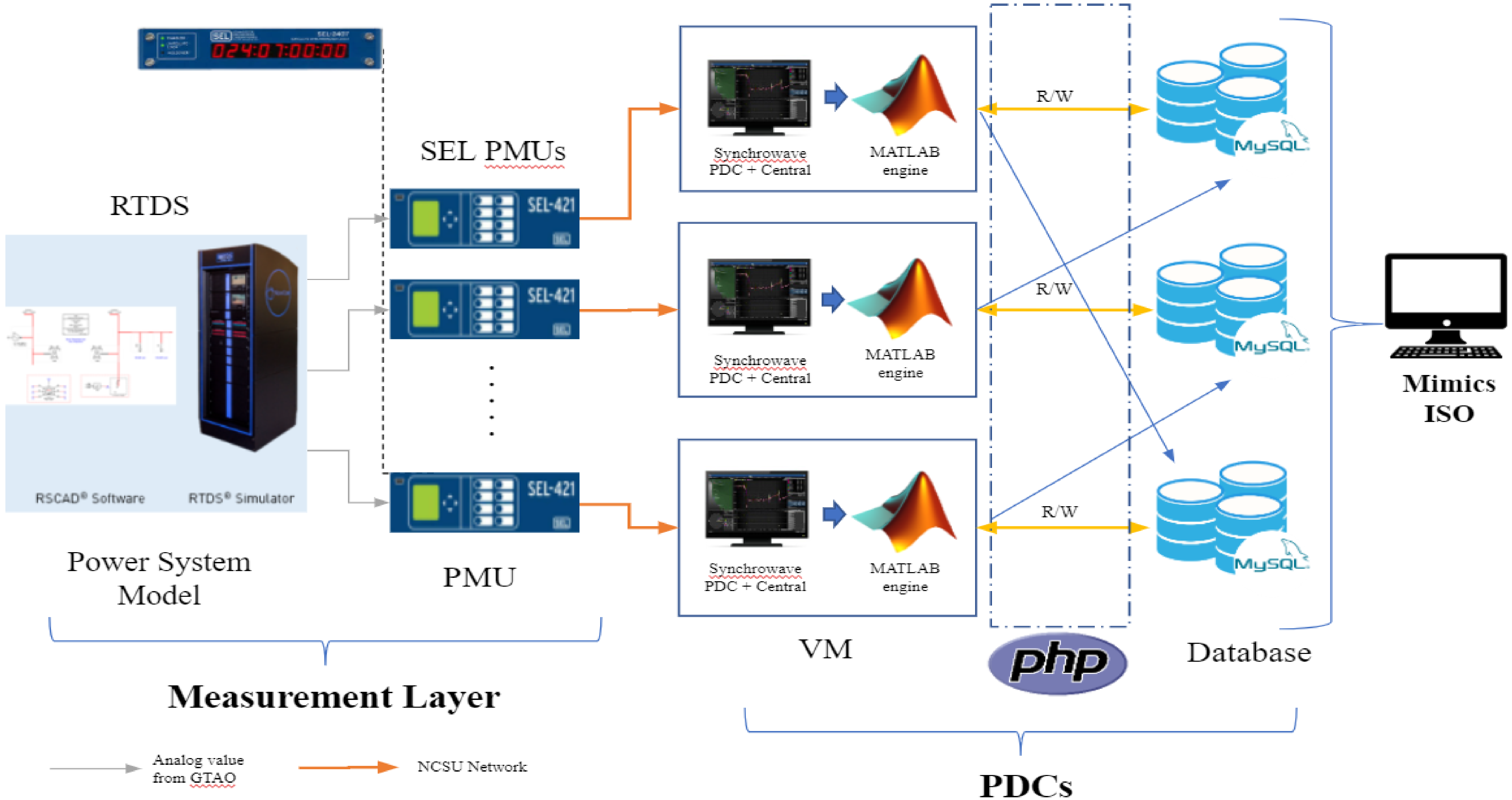
Fig. 4 : IEEE 68-bus system



- Attacked links are shown by red lines.
- Training data consists of 5000 operating points.

- Communication delays are :
  - *Intra-area = 30ms, Inter-area = 60ms.*
  - *Deviation = +/- 10%*

Testbed



SEL PMUs
RTDS
SEL-421
RSCAD® Software
RTDS® Simulator
Power System Model
PMU
Measurement Layer
Synchrowave PDC + Central
MATLAB engine
R/W
MySQL
Mimics ISO
VM
php
Database
PDCs
Analog value from GTAO
NCSU Network

Detection and identification (FDI)

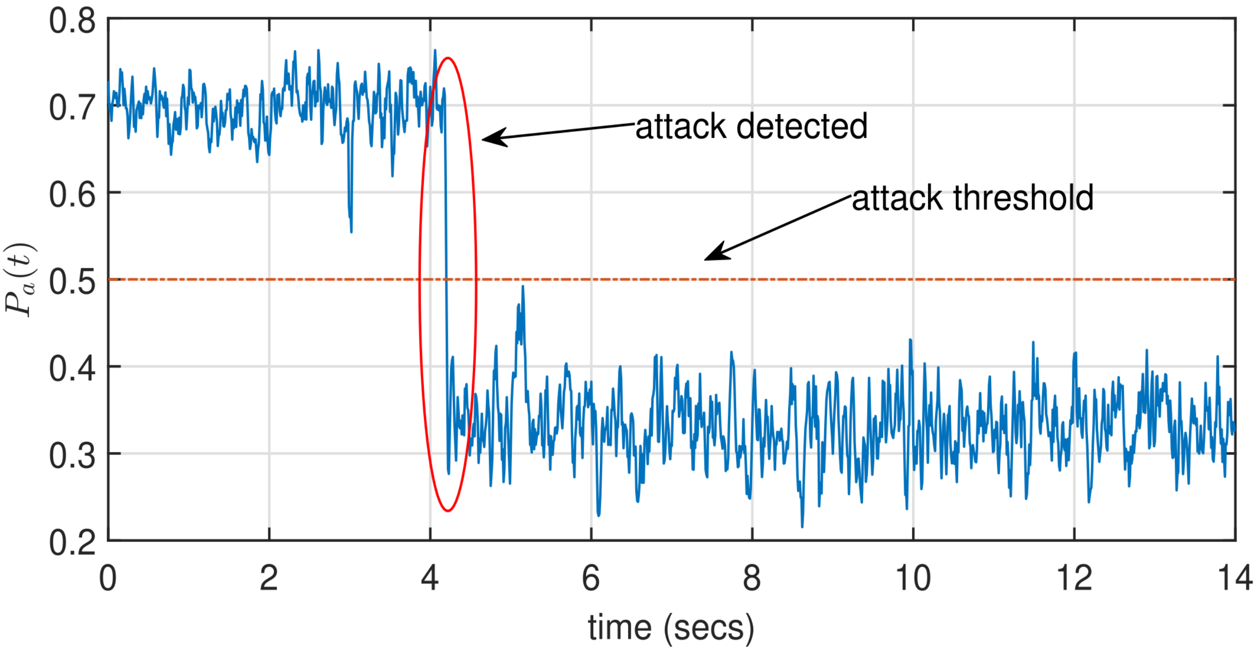


Fig. 5a : Detection of FDI attack

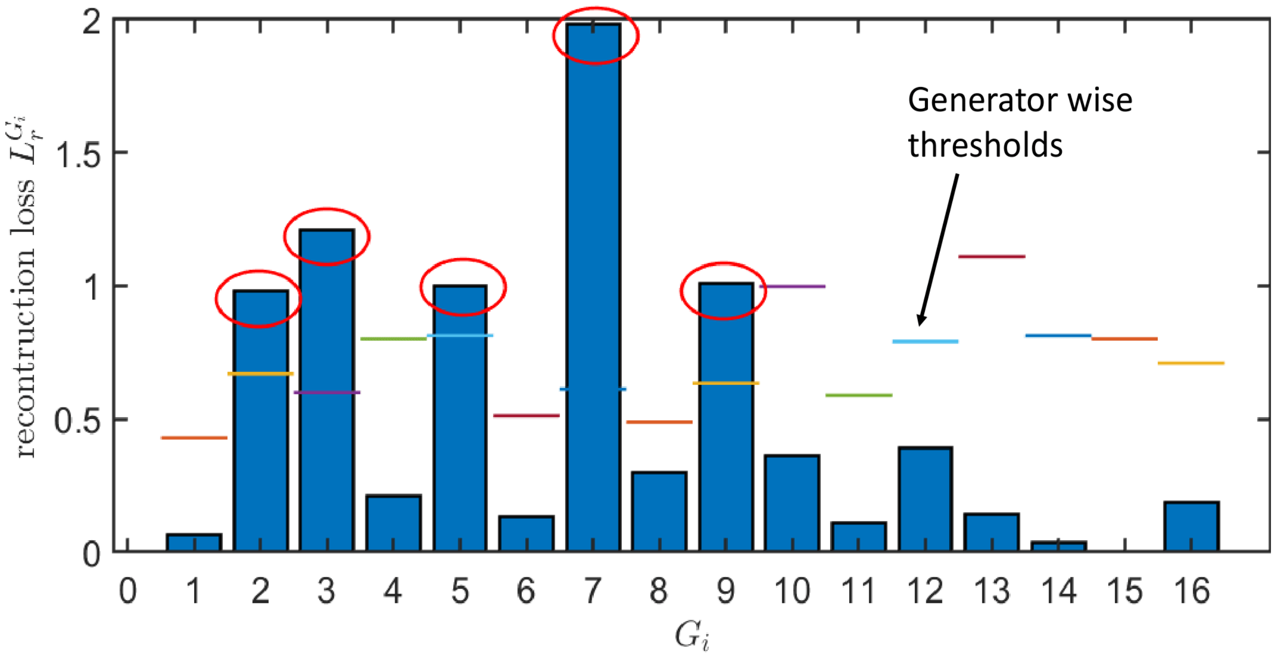


Fig. 5b : Localization of FDI attack

- It is seen that during a FDI attack, the average discriminator Pa shows a sudden drop.
- The threshold can be estimated based on the best score obtained during training phase.
- Generator wise reconstruction error is computed between received and predicted states.

$$L_r^{G_j}(t) = ||(\mathcal{X}_t - \mathbf{G}(\mathcal{X}_t)) \odot \Omega_{G_j}||$$

Closed-loop results

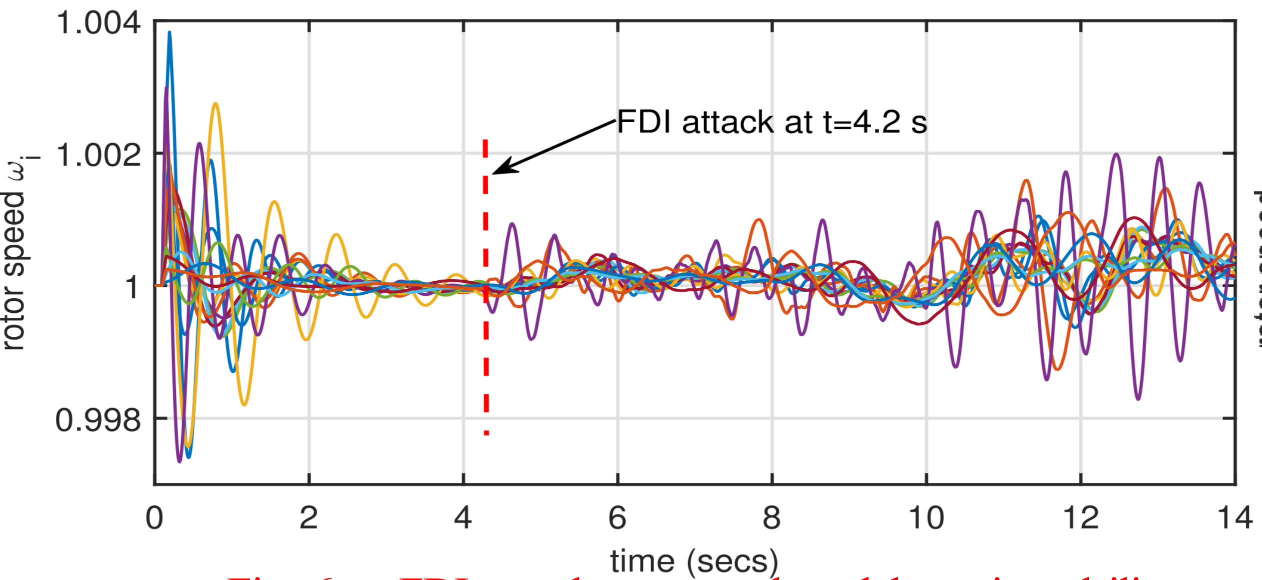


Fig. 6a : FDI attack causes closed-loop instability

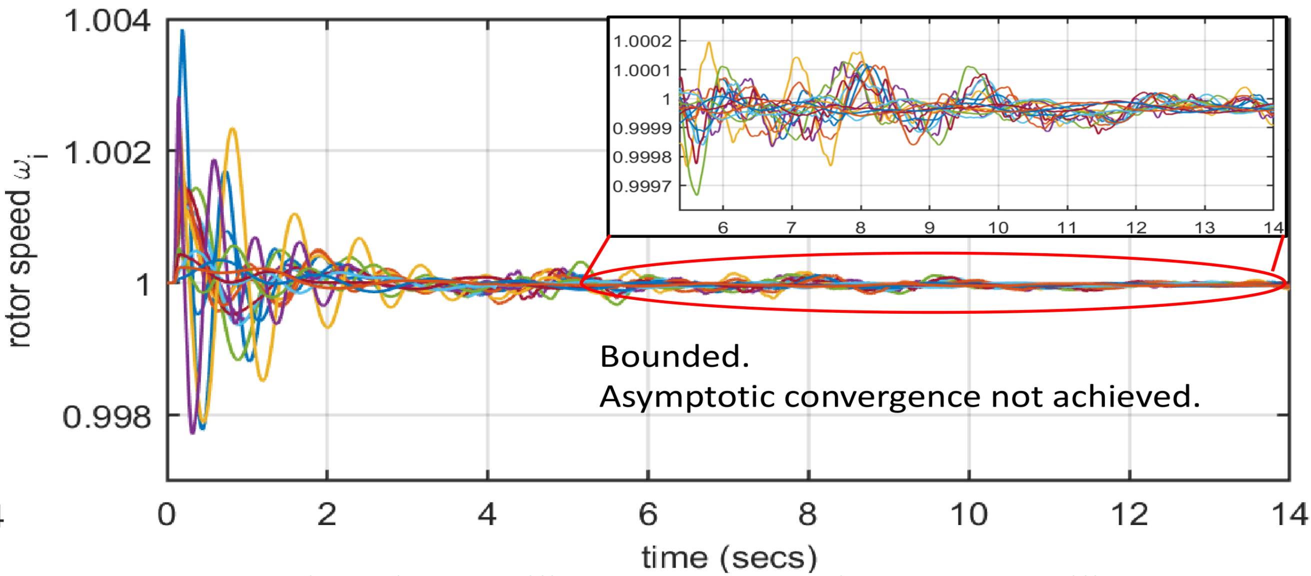


Fig. 6b : Resiliency to FDI using GAN resiliency

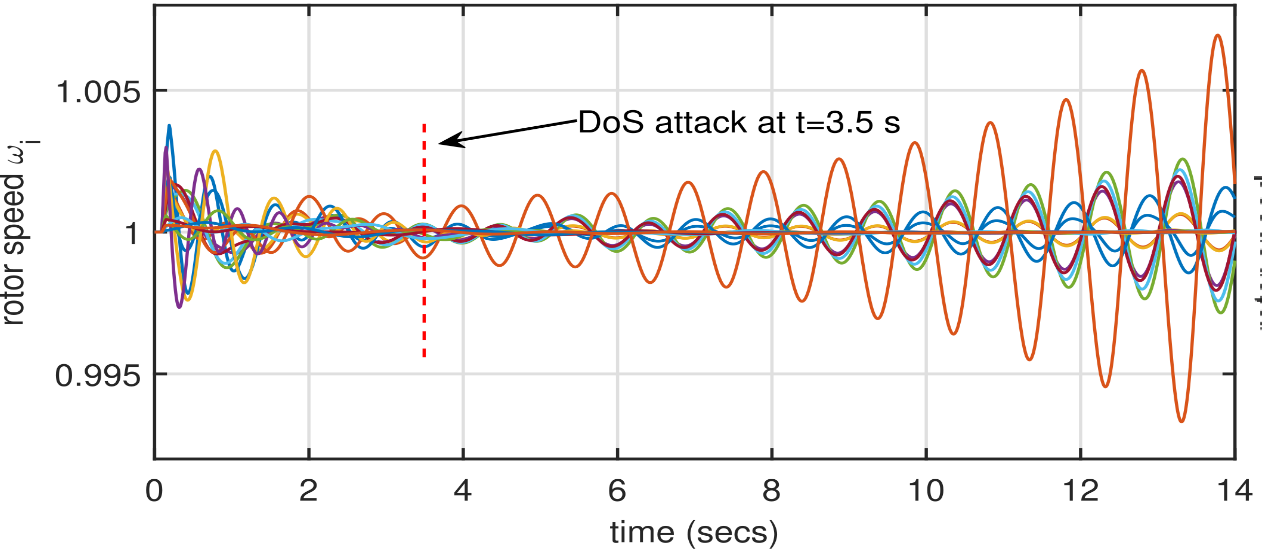


Fig. 7a : DoS causes closed-loop instability

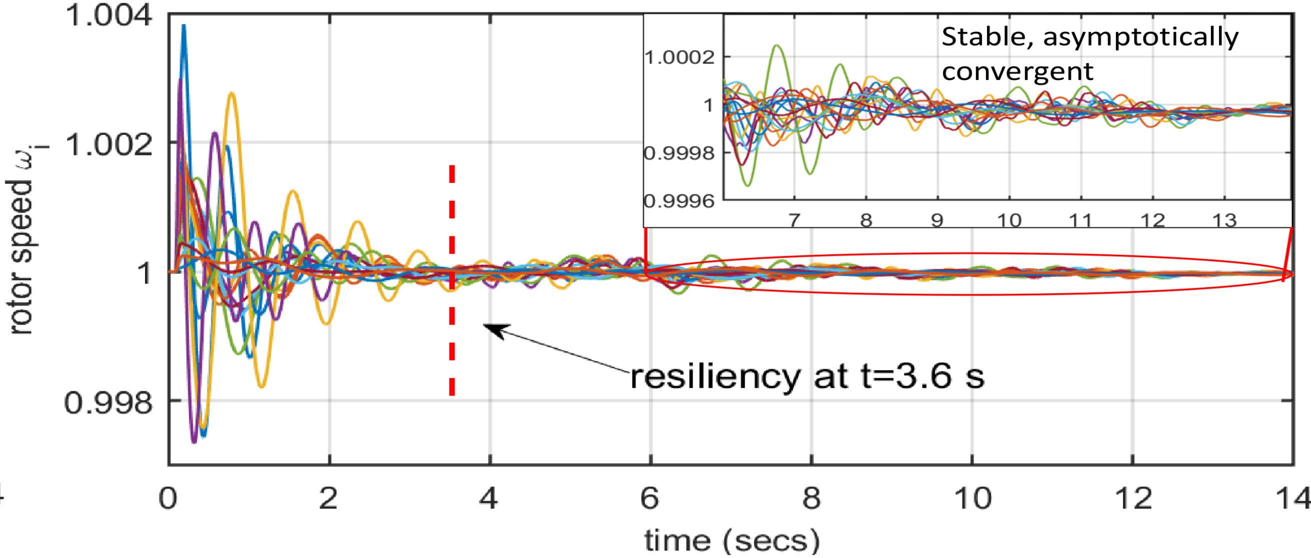


Fig. 7b : Resiliency to DoS using GAN

Conclusions and references

- Neural network-based methods benefit in not requiring the actual model to ensure resiliency during a cyber-attack.
- Can be implemented in a decentralized manner ensuring model privacy.
- Proposed GAN based method work effectively to both localize and mitigate both FDI and DoS cyber-attacks.
- **Future Work** : Large changes in operating points, non-linear controller, IBRs

References

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