The Spire System: Toward an Intrusion-Tolerant Power Grid

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Spread Concepts

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of ENGINEERING

Distributed Systems
and Networks Lab
www.dsn.jhu.edu

Importance of SCADA for the Power Grid

- Supervisory Control and Data Acquisition (SCADA) systems form the backbone of critical infrastructure services
- To preserve control and monitoring capabilities, SCADA systems must be constantly available and run at their expected level of performance (able to react within 100-200ms)
- SCADA system failures and downtime can cause catastrophic consequences, such as equipment damage, blackouts, and human casualties

Emerging Power Grid Threats

- Traditional SCADA systems ran on proprietary networks
  - Created air gap from outside world and attackers
- Cost benefits and ubiquity of IP networks are driving SCADA to use IP networks
  - Exposes SCADA to hostile environments, removing the air gap
- Raises additional concerns because SCADA systems are:
  - In service for decades
  - Running legacy code with well-known exploits

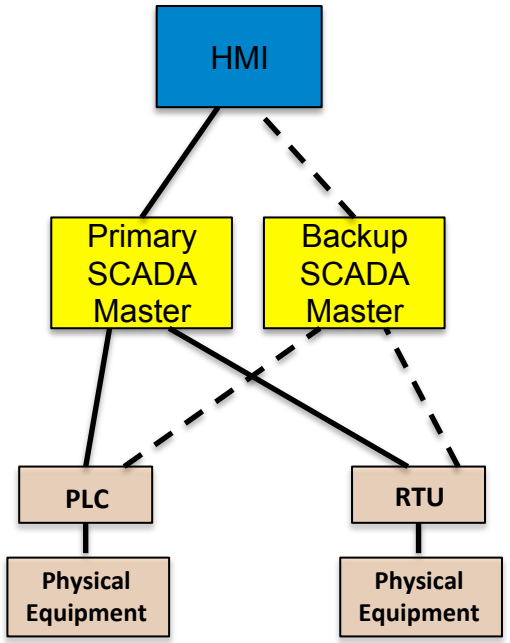
Emerging Power Grid Threats

- Perimeter defenses are not sufficient against determined attackers
  - Stuxnet, Dragonfly/Energetic Bear, Black energy (Ukraine 2015), Crashoverride (Ukraine 2016)
  - Becoming a target for nation-state attackers

SCADA Vulnerability

The move to IP makes SCADA vulnerable on several fronts:

- SCADA system compromises
  - SCADA Master – system-wide damage
  - RTUs, PLCs – limited local effects
  - HMIs
- Network level attacks
  - Routing attacks that disrupt or delay communication
  - Isolating critical components from the rest of the network



Roadmap

- The Spire System
- Red Team Experiment at Pacific Northwest National Labs (PNNL)
- Power Plant Deployment at Hawaiian Electric Company (HECO)
- Toward an Intrusion Tolerant US Power Grid

Spire: Network-Attack Resilient Intrusion-Tolerant SCADA for the Power Grid

The Spire System

- Spire is an intrusion-tolerant SCADA system for the power grid: it continues to work correctly even if some critical components have been compromised
- Intrusion tolerance as the core design principle:
  - Intrusion-tolerant network
  - Intrusion-tolerant consistent state
  - Intrusion-tolerant SCADA Master
- Open Source - http://dsn.jhu.edu/spire

The Spire System: Defense across Space and Time

- Byzantine Fault Tolerant Replication (BFT)
  - Correctly maintains state in the presence of compromises
  - 3f+1 replicas needed to tolerate up to f intrusions
  - 2f+1 connected correct replicas required to make progress
  - Prime protocol – latency guarantees under attack [ACKL11]

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- What prevents an attacker from compromising more than f replicas over time?

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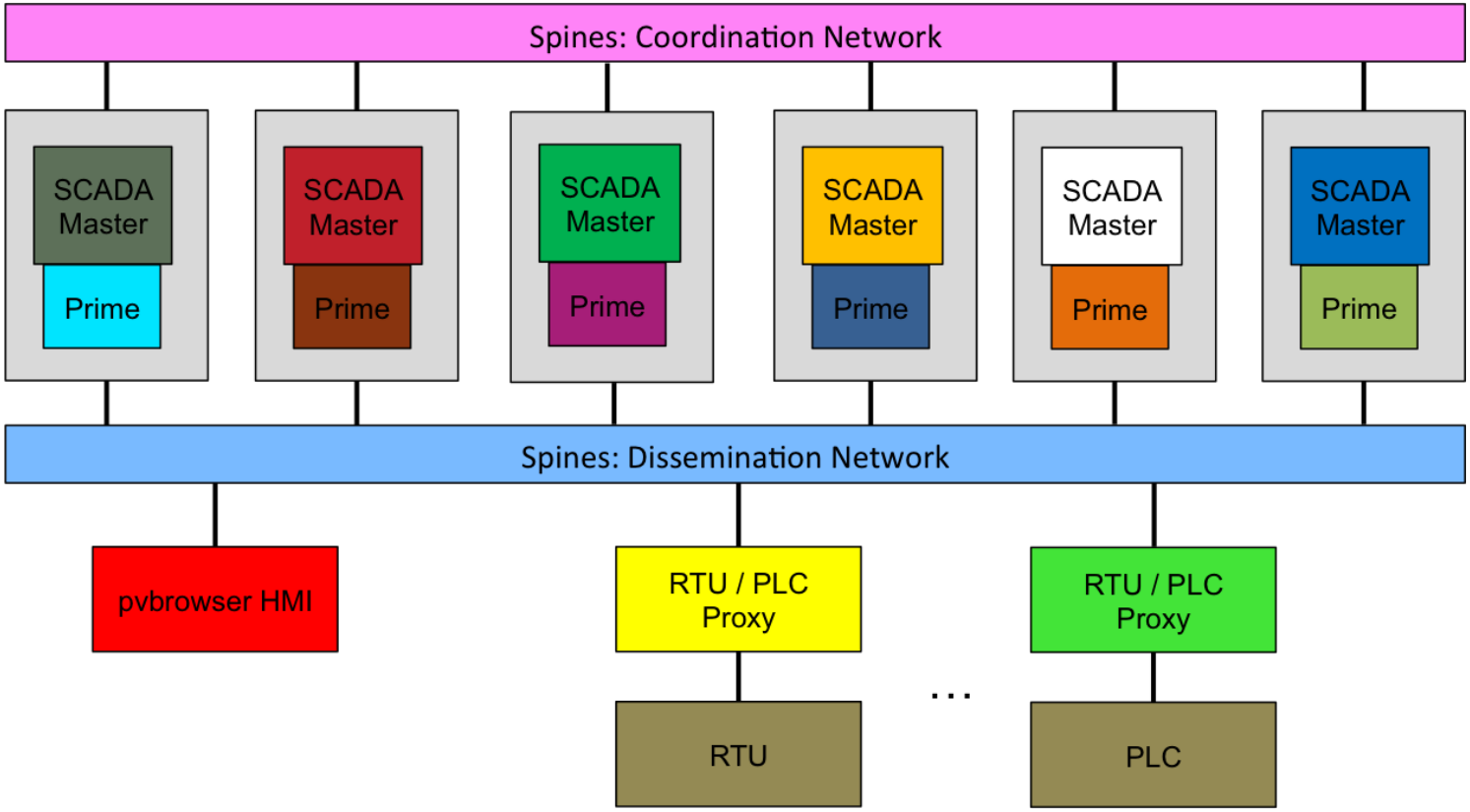
- Proactive Recovery
  - Periodically rejuvenate replicas to a known good state to cleanse any potentially undetected intrusions
  - 3f+2k+1 replicas needed to simultaneously tolerate up to f intrusions and k recovering replicas [SBCNV10]
  - 2f+k+1 connected correct replicas required to make progress

The Spire System: Single Control Center



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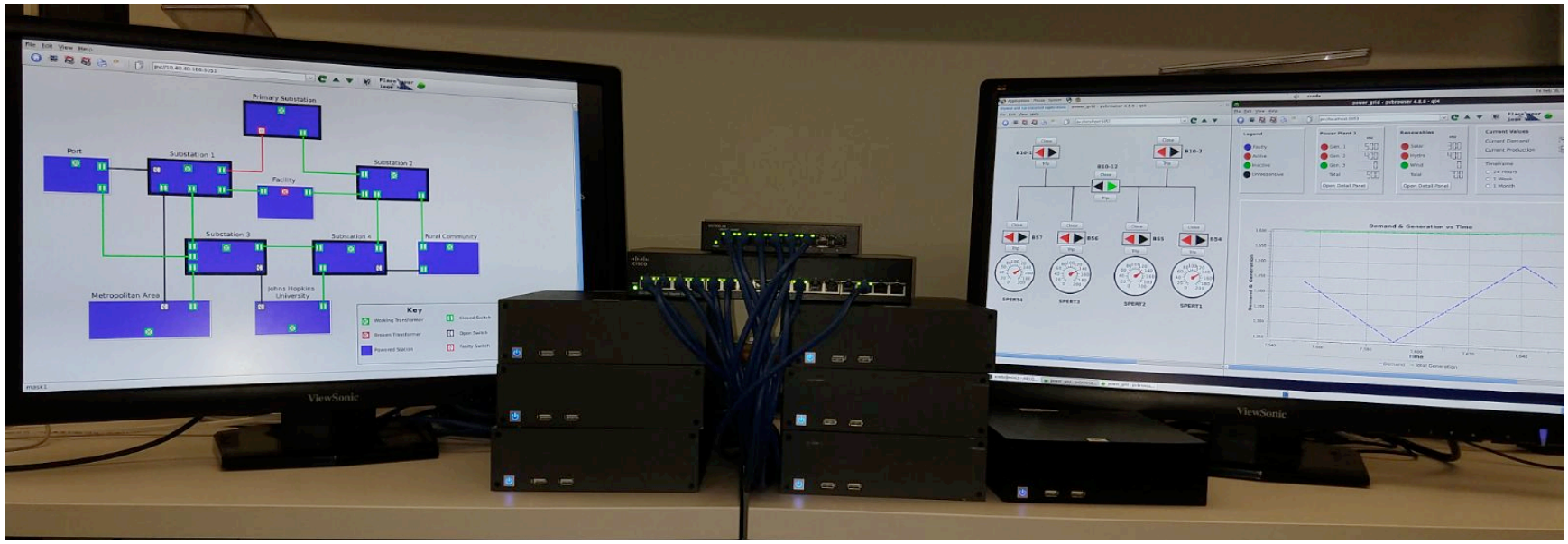


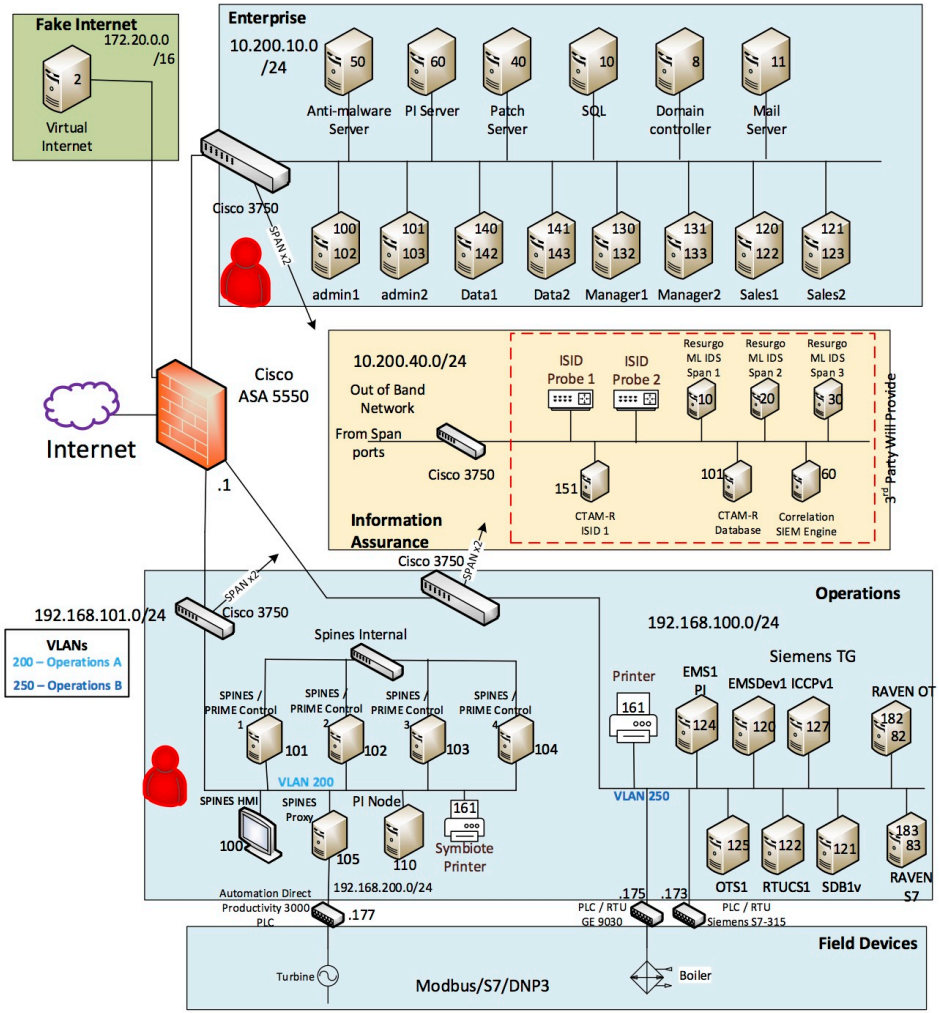
Six Spire replicas, monitoring and controlling three power grid scenarios (two distribution, one generation)

Red Team Experiment

March 27 – April 7, 2017

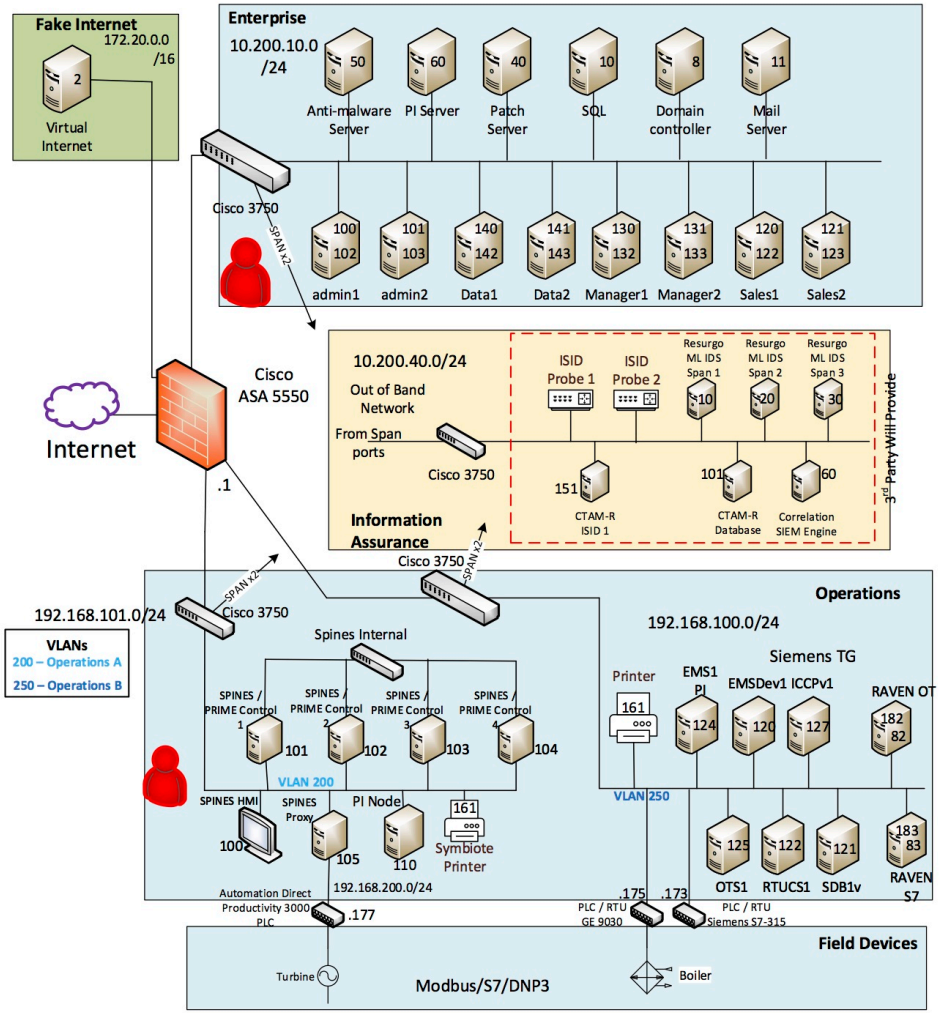
DoD ESTCP Red Team Experiment

- DoD ESTCP experiment at Pacific Northwest National Labs
  - Conducted by Resurgo with JHU DSN lab and Spread Concepts LLC participation
- Evaluated NIST-compliant commercial SCADA architecture and Spire
  - Each attacked by Sandia National Labs red team



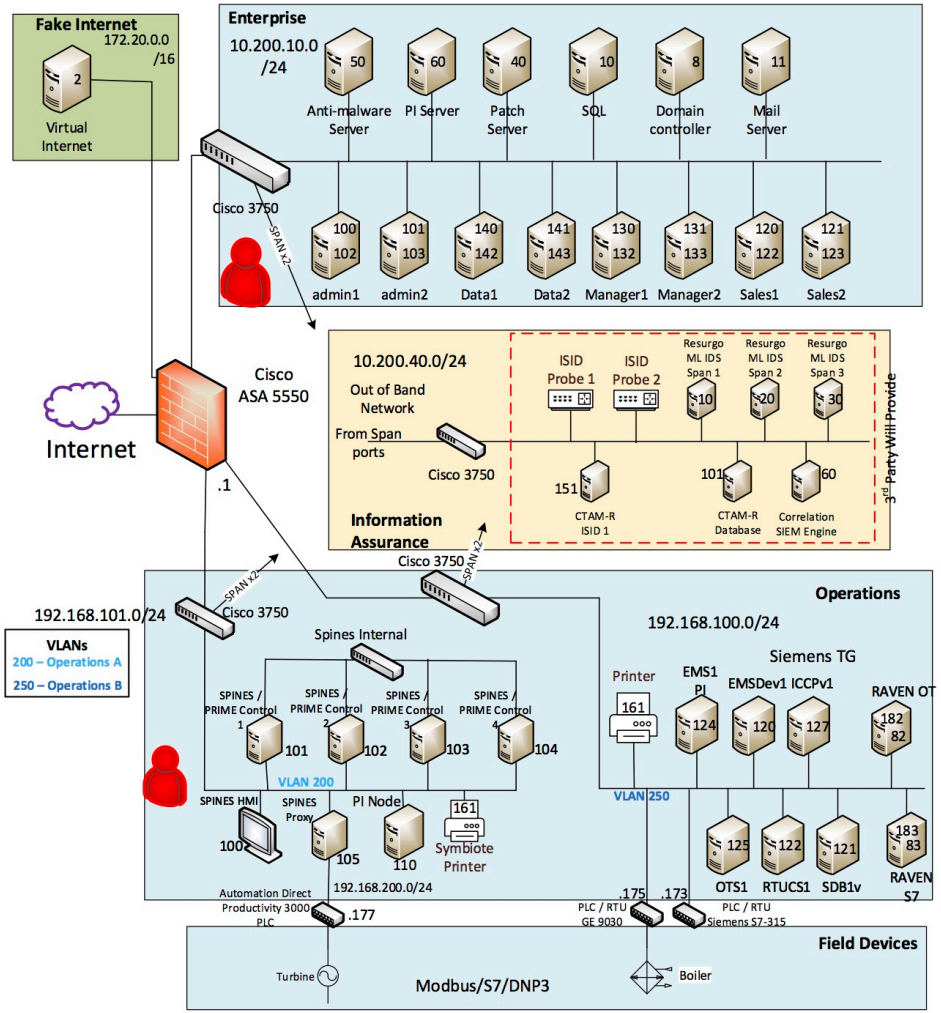
DoD ESTCP Red Team Results

- NIST-compliant system completely taken over
  - MITM attack from corporate network
  - Direct access to PLC from operational network
- Spire completely unaffected
  - Attacks in corporate and operational network
  - Given complete access to a replica and code
  - Red team gave up after several days



DoD ESTCP Red Team Takeaways

- Today's power grid is vulnerable
- There is a difference between current best practices and state-of-the-art research-based solutions
- Secure network setup using cloud expertise (protected the system for two days)
- Customized intrusion-tolerant protocols (defended the system in the presence of an intrusion on the third day)



Hawaiian Electric Company
Power Plant Deployment

January 22 – February 2, 2018

DoD ESTCP Hawaiian Electric Company Deployment Setup

- Spire test deployment at HECO
  - "Mothballed" Honolulu plant
  - Managed small power topology, controlling 3 physical breakers via a Modbus PLC
- Deployment goals
  - Operate correctly in real environment without adverse effects
  - Meet performance requirements

DoD ESTCP Hawaiian Electric Company Deployment Results

- Ran continuously for 6 days without adverse effects on other plant systems
- Timing experiment using sensor to measure HMI reaction time showed that Spire met latency requirements

Toward an Intrusion-Tolerant Power Grid

Encouraging Adoption through Open Source

- Challenge
  - Legacy, proprietary software is difficult to modernize
  - Strict reliability requirements and result in highly conservative ecosystem
- Open-source ecosystem
  - Educate power companies, SCADA vendors, and regulators about new solutions
  - Prove that new technology is effective before it is adopted/ adapted

Spire

pvb

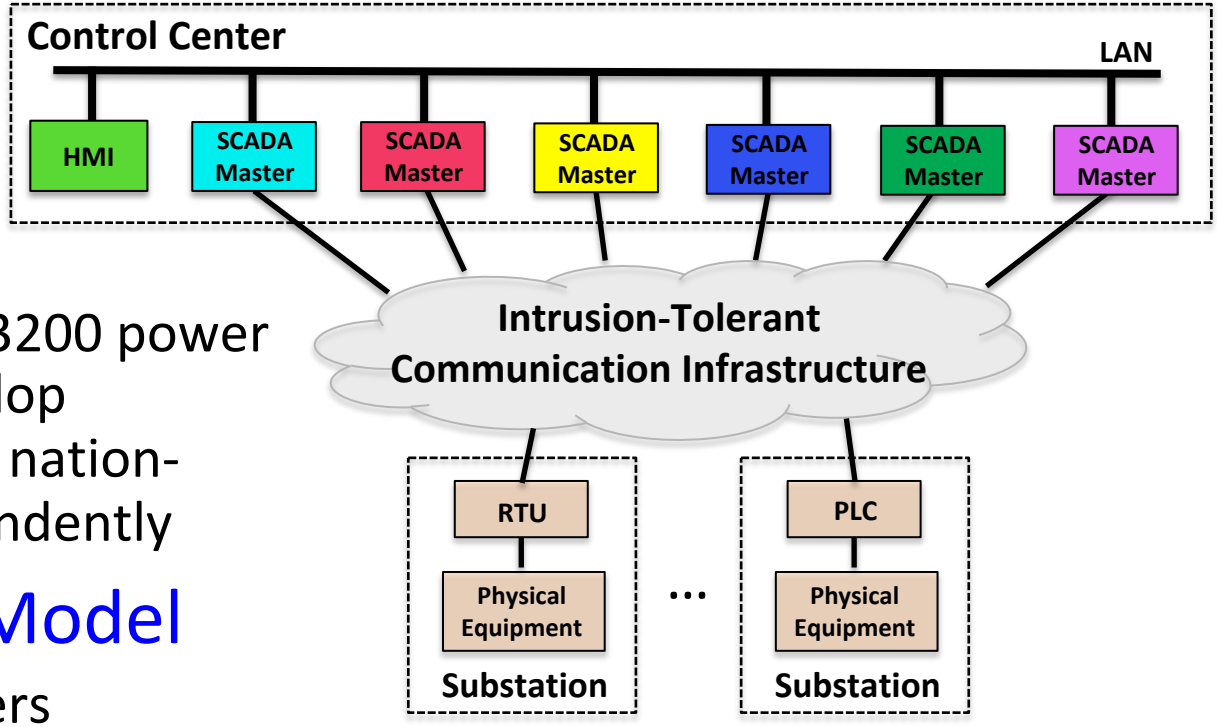
TANGO

GSF

openPLC

Systemic Resilience through a Service Provider Model

- Challenge
  - Interconnection leads to “weakest link” problem
  - Difficult for each of 3200 power installations to develop expertise to counter nation-state attacks independently
- Service Provider Model
  - Service provider offers intrusion-tolerant state maintenance service
  - Power companies customize system and endpoints



Spire: Toward Deployment

- Seeking industry partners / relevant projects
- Spire forum focused on open source intrusion-tolerant control systems for the power grid
- http://dsn.jhu.edu/spire
- http://www.spreadconcepts.com

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