A Cyber-Physical and Agent-Based Defense to False Data Injection Attacks on a SCADA System

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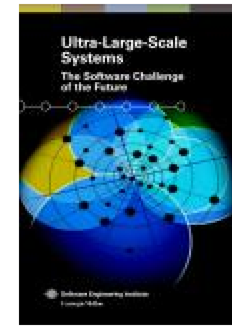

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  - Carol Hawk

Research Problems

1. What is the security threat to the power grid posed by a compromised SCADA (Supervisory Control and Data Acquisition) system?
   - Consequence analysis on power system functions
   - Baseline for understanding how to regain control if attacked
2. Considerations of the architectural components of a SCADA and EMS (Energy Management System):
   - Which components need to be compromised?
   - How must they be compromised to perform an attack?
   - What are the implications for other components of the SCADA / EMS architecture?
3. If a SCADA system is subverted:
   - How can the extent of the subversion be identified and isolated?
   - How can the power system operator regain control?

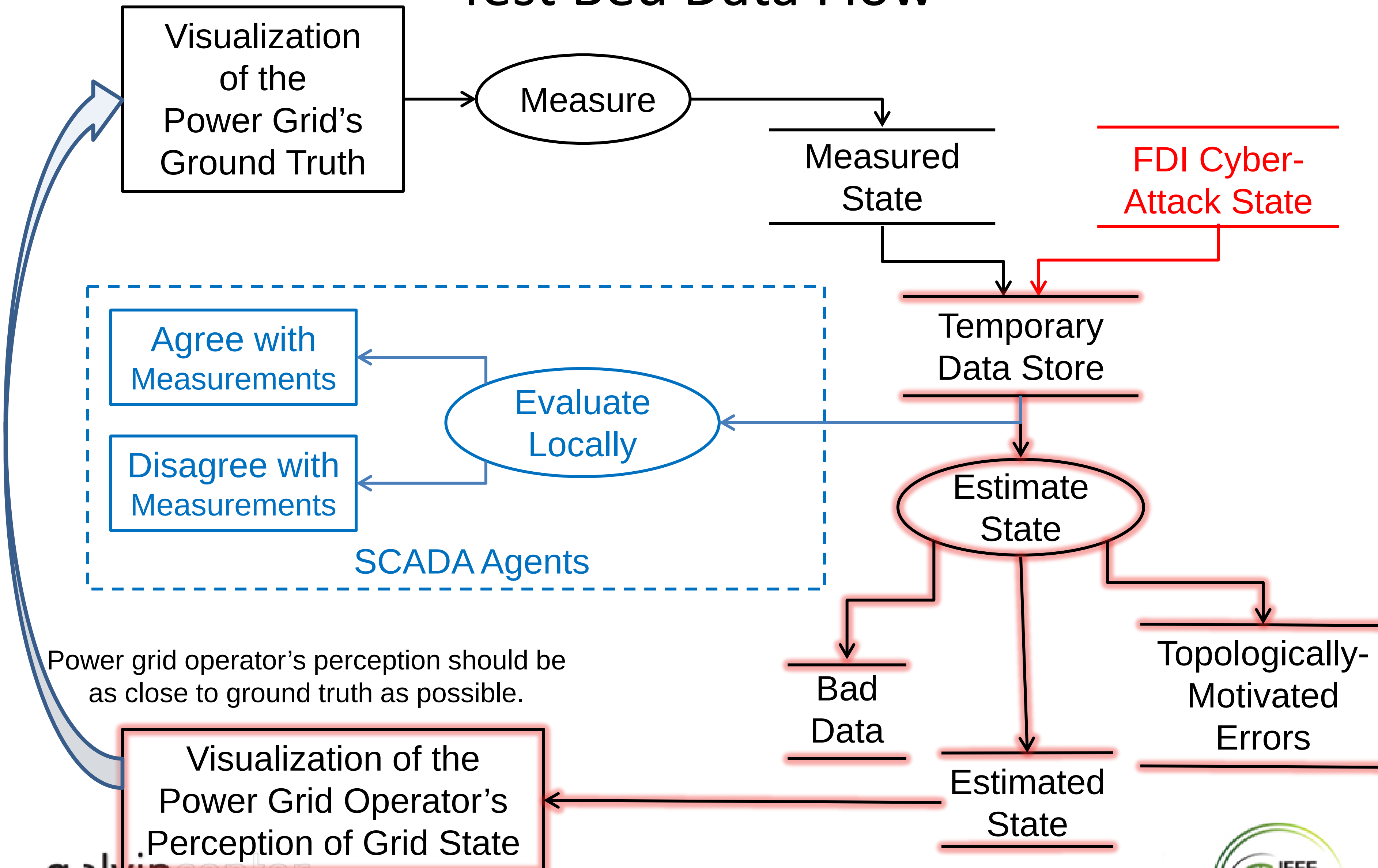
Cyber-Threat: False Data Injection (FDI) Attack

- Single-most critical EMS function is ***state estimation***
  - Process is ***central*** to a grid control center
  - Receives noisy remote sensor data
  - Identifies and discards ***bad data***
  - Determines ***state variables*** of the grid for power flow calculations
  - Based on this data, power grid operations are determined
- False Data Injection
  - Falsifies data that is input to state estimation
  - Has two potential impacts on operator's perception of grid state:
    - Loss of ***observability*** of power grid state $(m < 2N - 1)$
    - Perceived ***observability*** $(m \geq 2N - 1)$, but
      - ➢ Incorrect and unsafe adjustments can be made
      - ➢ Based on misperceptions of system state due to FDI data

Technical Approach

- Focus on FDI attacks that create false sense of *observable* transmission grid state ($m \geq 2N - 1$)
  - There are at least as many *perceived usable* measurements as state variables
  - *Unobservability* ($m < 2N - 1$) will be addressed in the future
- Introduce autonomous software agents to model cyber-physical properties of the grid / EMS at their cyber-physical location
- Theoretically prove that for any and all vectors of FDI cyber-attack
  - The agents can autonomously detect it
  - Even if the agents may be compromised
- Validate proof by modeling and simulation
- Implement proof-of-concept on SCADA devices

Test Bed Data Flow



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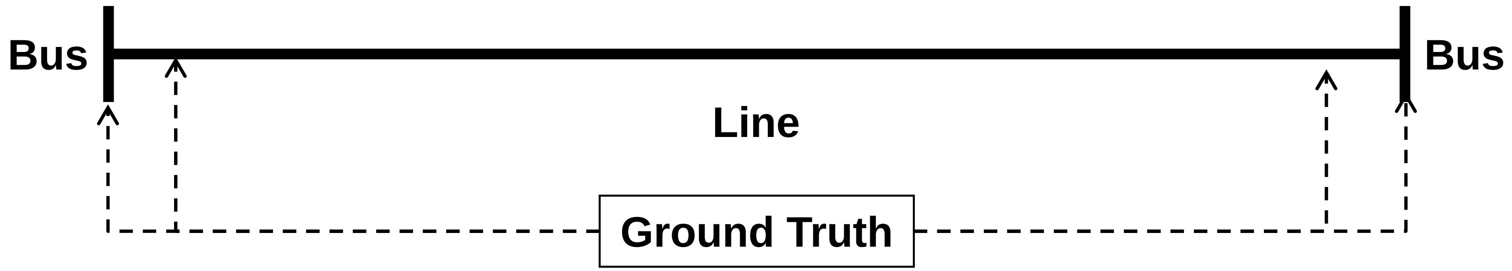
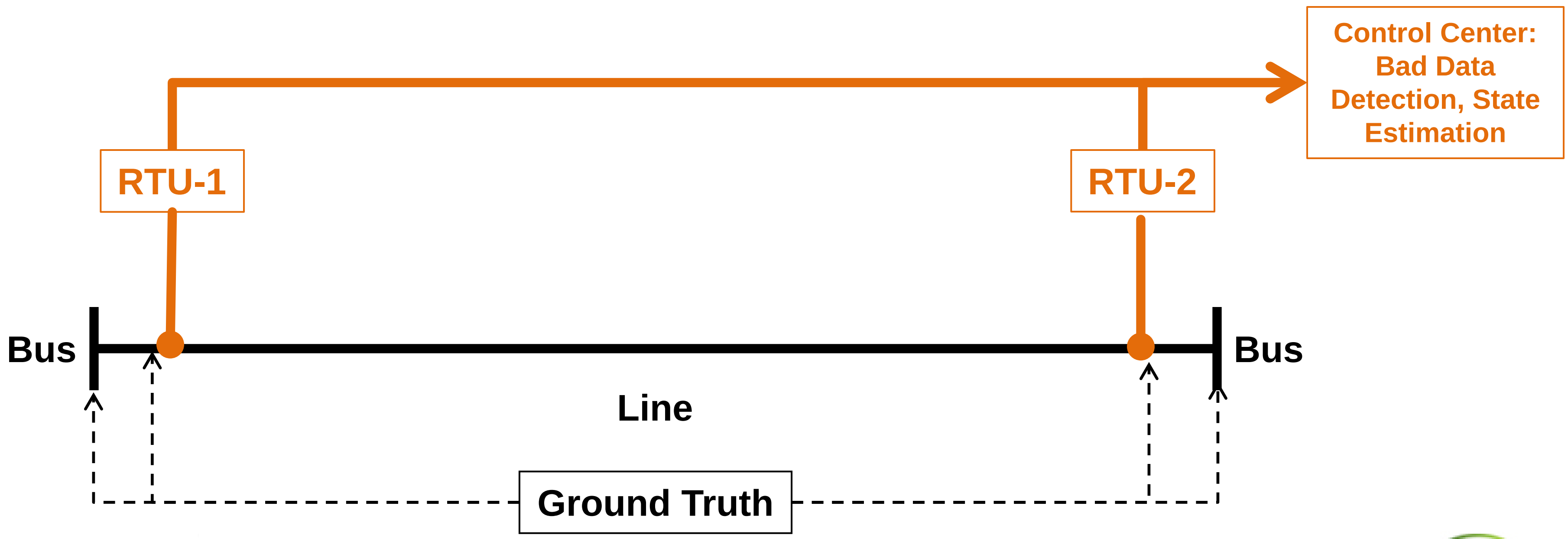
Five Models Studied in the Proposed SCADA Agent Protection System

1. Electrical Model
2. SCADA Model
3. SCADA Attack Model
4. SCADA Agent Model
5. SCADA Agent Attack Model

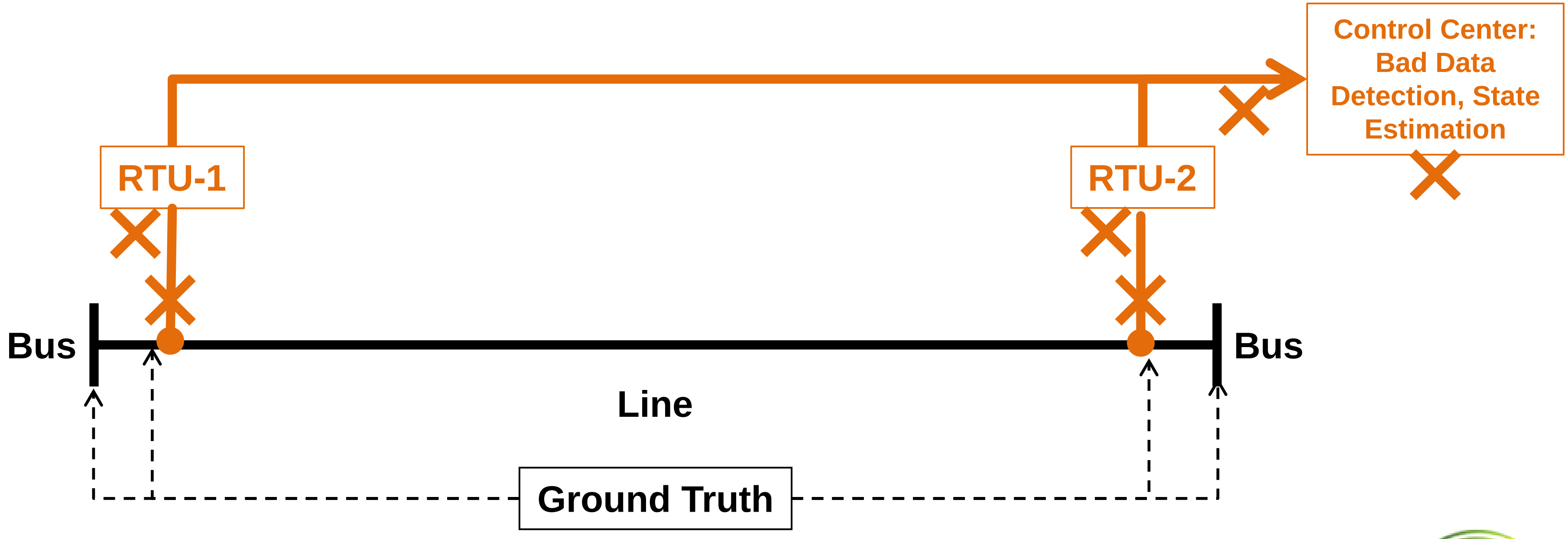
1. Electrical Model



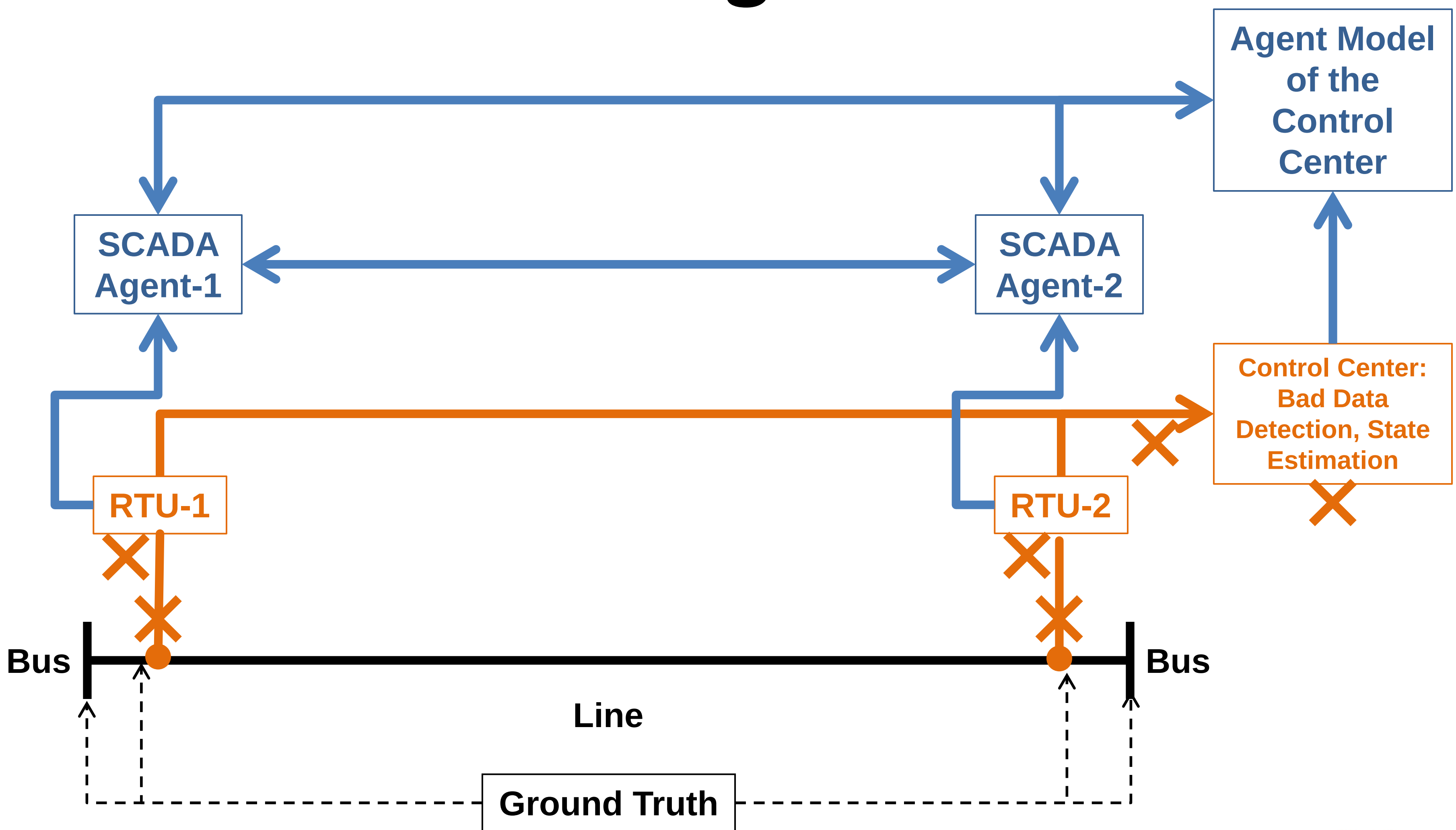
2. SCADA Model



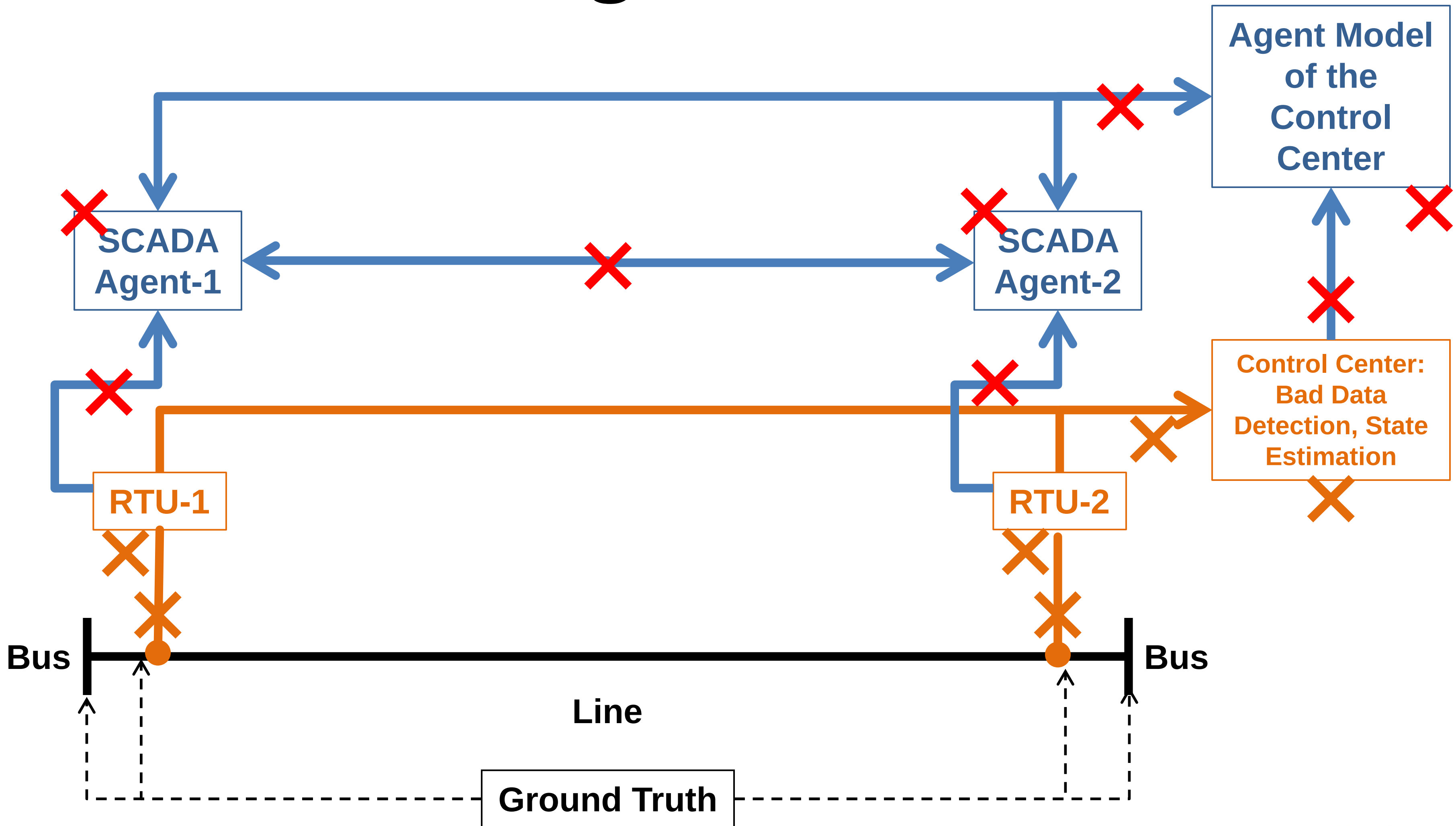
3. SCADA Attack Model



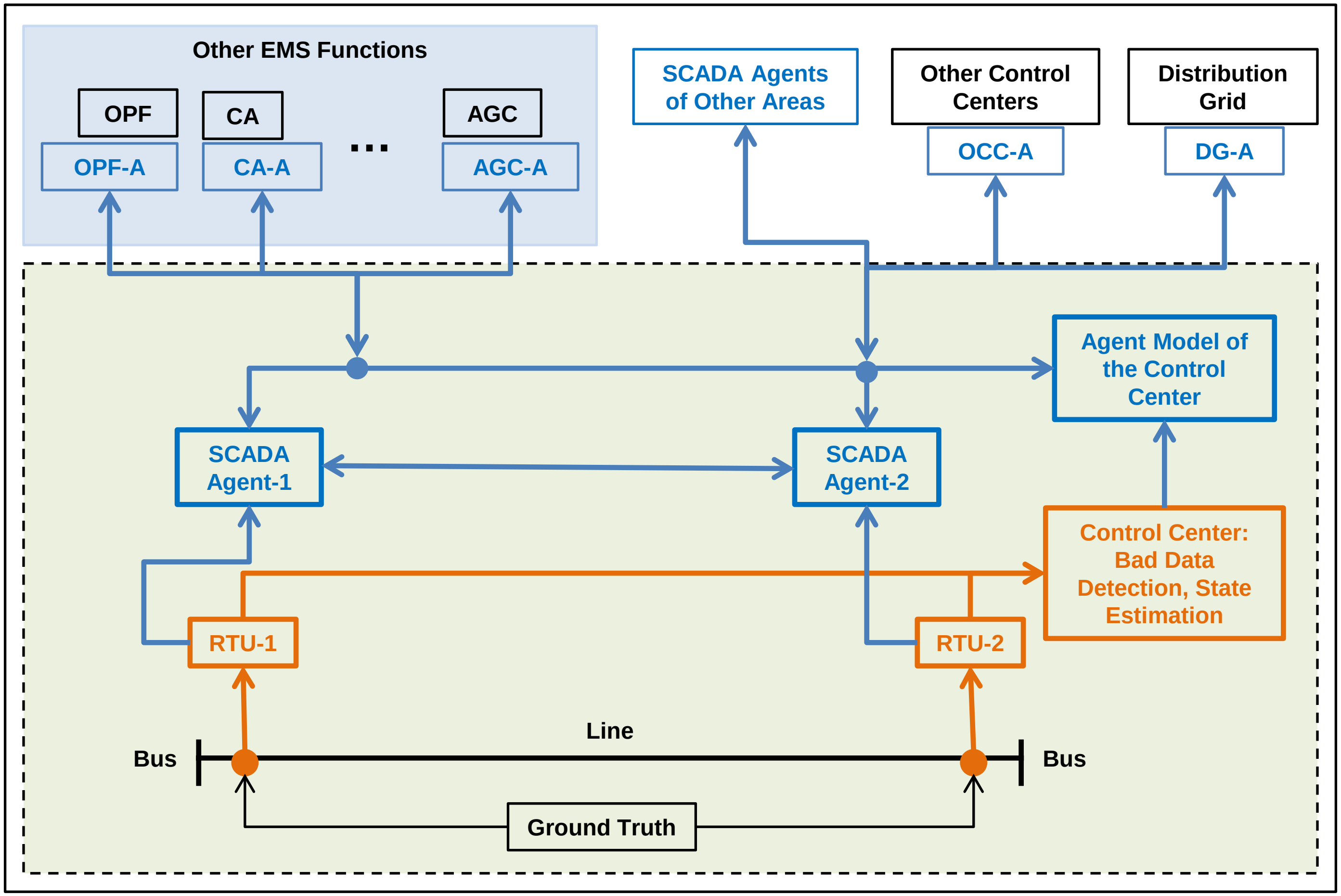
4. SCADA Agent Model



5. SCADA Agent Attack Model



SCADA Agent Architecture



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Architectural Rationale

- Do not modify centralized state estimation functions with security enhancements
  - It is an optimized process for current operations
  - Early and widespread adoption is desired
    - Interoperability with legacy systems
    - Low-interference with current operations
    - Minimize startup and implementation costs
- Overlay distributed state estimation (DSE) verification for security
  - If DSE can be conducted autonomously by software agents
  - FDI attacks on centralized state estimation can be detected by distributed agents
  - ***Power system is a closed system***
    - ***There is always knowledge elsewhere that can be leveraged***

Results to Date: A Cyber-Attack is Possible

G. Hug-Glanzmann and J.A. Giampapa, "Vulnerability Assessment of AC State Estimation with Respect to False Data Injection Cyber-Attacks," in *IEEE Transactions on Smart Grid*, Vol. 3, No. 3, pp. 1362–1370, September 2012.

- Three techniques for determining which measurements to attack
  - DC Model
    - Common in literature 2009 – present
    - Introduces detectable errors
  - AC Model
    - Based on Jacobian matrix
    - Introduced
  - Graph Theoretic Model
    - Extends AC Model for buses with no injections
    - Introduced

- Two techniques for determining measurement values
  - For an FDI-attack that falsifies observability
  - DC calculations – rapid but introduce detectable errors
  - AC calculations – non-linear, will not be detected

Take-Away Message

- Comprehensive power grid SCADA security requires a cyber-physical systems approach
  - Evaluate the threat with respect to its impact on properties of the power grid, not just the cybernetic infrastructure
  - Remedies should also focus on mitigating the impact of the threat, especially for cost-effective solutions to cyber-security.
- Knowledge to avert threat can be leveraged from multiple perspectives and sub-systems
  - Electrical properties, control theory, cybernetic properties
  - Leverage knowledge from other EMS functions

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