The Virtual Power System Testbed (VPST) and Inter-Testbed Integration

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Information Trust Institute

Providing World-Wide Excellence in Information Trust and Security

Institute Vision:

Trust in Society

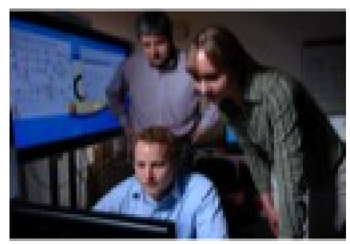
Institute Personnel:

Core faculty from CS and ECE

95+ faculty and senior researchers from 21 Dept's.

Institute Themes:

- Critical Applications, Infrastructures, and Homeland Defense
- Embedded and Enterprise Computing
- Multimedia and Distributed Systems



Institute Highlights

- Established, rapidly growing effort
- Large, diverse community of researchers
- Societal and industrial problems
- Major corporate partnerships
- Led by the College of Engineering at UIUC

Institute Centers

- Boeing Trusted Software Center
- CAESAR: the Center for Autonomous Engineering Systems and Robotics
- Center for Information Forensics
- NCASSR: the National Center for Advanced Secure Systems
- NSA Center for Information Assurance Education
- TCIP: Trustworthy Cyber Infrastructure for the Power Grid
- Trusted ILLIAC Center

TCIP Center: Trustworthy Cyber Infrastructure for Power

TCIP secures the devices, communications, and data systems that make up the power grid, to ensure trustworthy operation during normal conditions, cyber attacks and/or power emergencies.

William H. Sanders, Director

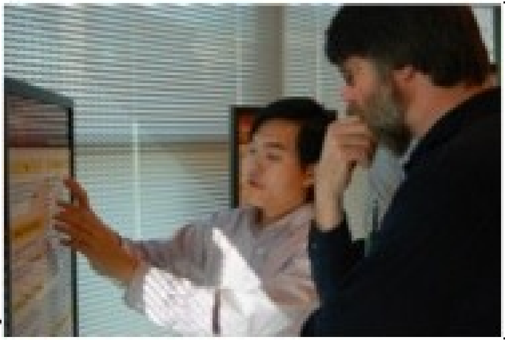
Organization -- 19 Faculty and Senior Staff; 30 Graduate Research Assistants from Univ. of Illinois, Dartmouth, Cornell, and Washington State University

Focus Research Areas

- Developing a secure and reliable computing base and providing foundations for system-wide security and reliability.
- Designing, implementing and integrating communications and control protocols that provide secure, timely and reliable data collection and control.
- Providing evaluative methodologies and tools for modeling, simulation, emulation and experimentation for security technologies for the power grid.
- Providing education, outreach and training at the K-12, undergraduate, and graduate levels and to prepare the next generation workforce.

TCIP Industry Advisory Board

Comprises over 30 industry organizations, representing the entire spectrum of the power industry.



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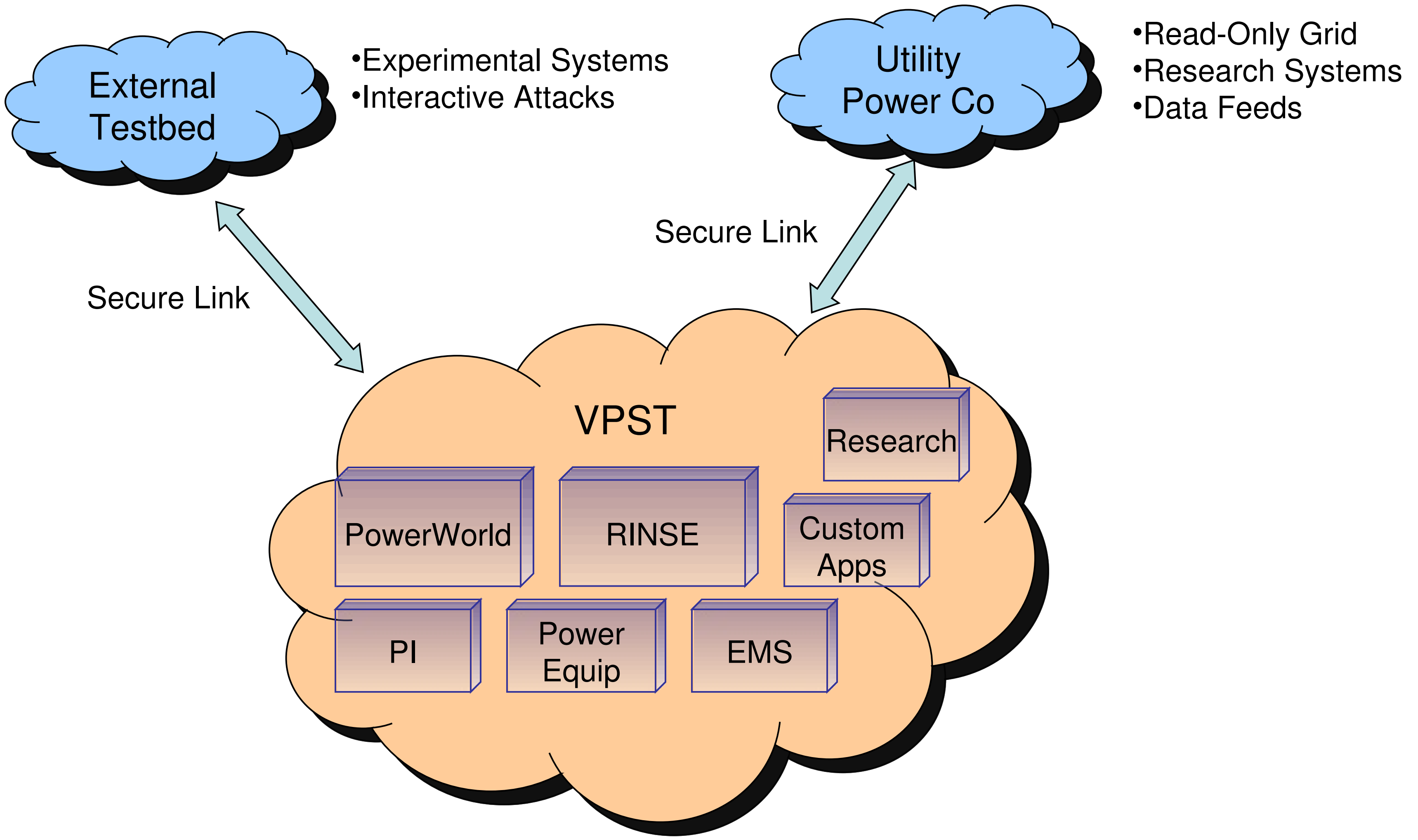
VPST - Introduction

- VPST - Designed to support exploration of security technologies being developed for large scale power grid infrastructure

- Integrates the following
  - Real Power Equipment
  - Electrical Simulations (PowerWorld)
  - Computation/Communication Simulation (RINSE)
  - Secure remote connectivity to other resources

VPST – High Level Overview



RINSE objectives

- Modeling methodologies for high performance / high capability network analysis
  - Model composition to support nearly transparent parallel processing
  - Multi-resolution modeling of traffic
    - mixed/fluid models of transport protocols, routers, links
    - immersive faster-than-real-time simulation for exercises
    - very fast net-wide background bandwidth use computation
    - x1000s speedup over optimized full-resolution model
  - Multi-resolution modeling of network topology

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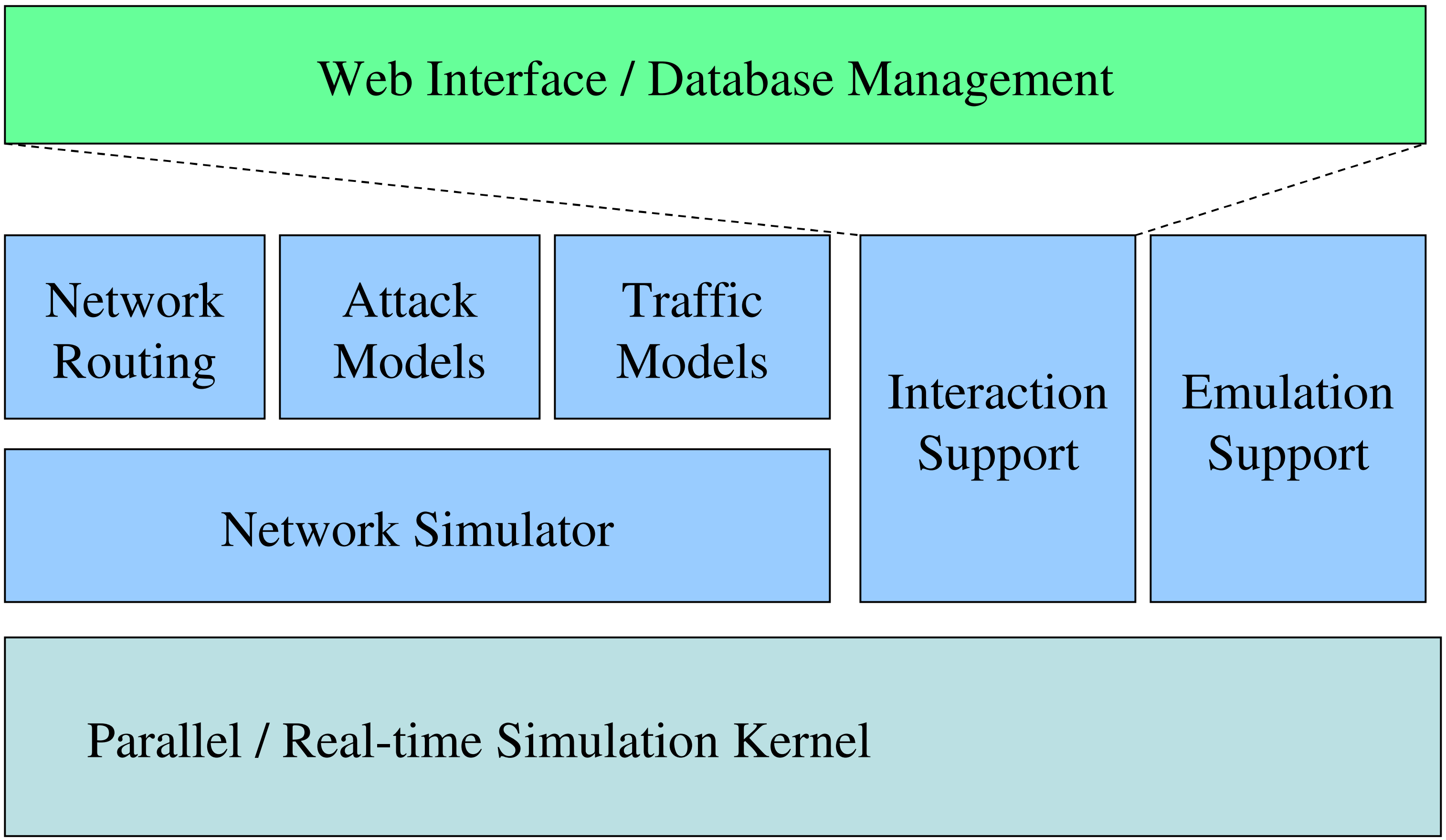
RINSE Host Architecture



VPST Motivation (SCADA context)

- Supervisory Control And Data Acquisition (SCADA)
  - Simplified, a hybrid of physical devices and the software controlling and monitoring them

- SCADA systems have a rising need for security
- Scale and operational context makes using actual equipment infeasible in the long run
- SCADA resources have a relatively high barrier to entry
- Emulation alleviates part of this concern, but accurate models are needed

- Other testbeds have valuable resources as well, and we’d like to leverage that

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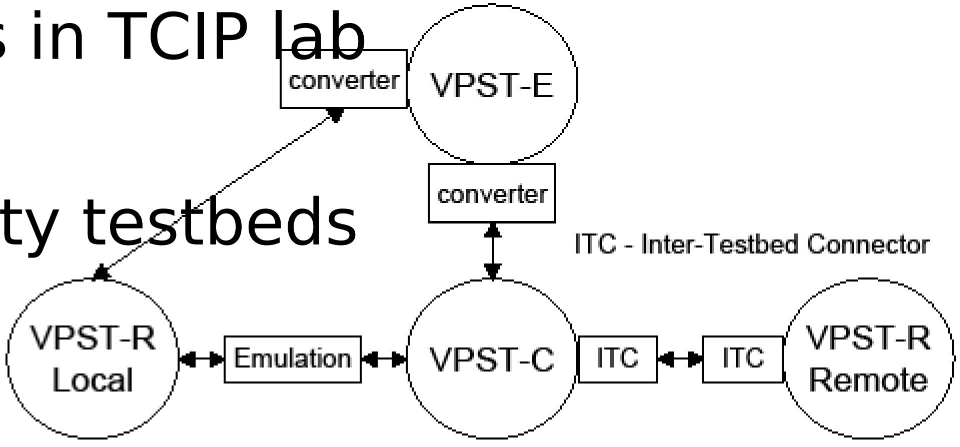
VPST Architecture

- VPST-E
  - Electrical powergrid simulation
  - PowerWorld (can simulate over 100,000 buses)
- VPST-C
  - RINSE-based network simulator
  - Trusted ILLIAC (can simulate over 1 million devices)
- VPST-R-local
  - Real SCADA devices in TCIP lab
- VPST-R-Remote
  - Other SCADA/security testbeds
  - DETER, NSTB, VCSE
  - “Super node”



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Interconnection Requirements

- Secure Connectivity
  - May face threats from external cyber-attack and internal malicious code
  - Several layers of protection similar to OPSAID
    - Transmission security (IPSec and SSL)
    - Authentication and access control at all accessing points (IPSec)
    - Traffic isolation (private network)
    - Intrusion detection if necessary (Snort)

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Performance Requirements

- Performance
  - Overcome latency across multiple testbeds
    - Inter-Testbed Connector (ITC), single point of contact and then distributes the workload
    - Two connections between each testbed
      - Control channel
      - Aggregated data channel
    - Use lookahead algorithms to keep the simulation at least as fast as real time (emulated devices)
  - Must use highly scalable simulation environment
    - VPST-C (RINSE network simulator)
    - VPST-E (PowerWorld simulator)

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Resource Requirements

- Resource Allocation
  - Flexible configuration
  - Accurate resource mapping that can balance customizability and speed
  - Design of ITC takes decentralized approach and is decomposed into modules
  - VPST must intelligently partition simulation models and expand that to heterogeneous testbeds

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Reproducibility Requirements

- Reproducibility
  - Dynamics of SCADA networks (size of network, type of physical medium, time-varying traffic patterns) requires precise experiment reproduction
  - VPST-C enhances local reproducibility with fully configurable and controllable parameter space
  - Human-in-the-loop interaction necessitates that parameters can be changed online and recorded for later reproduction (VPST uses tcpdump/libpcap files for network traffic capture)

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Fidelity Requirements

- Fidelity
  - VPST must be as transparent as possible to real devices
    - Realistic data patterns and interactions
    - Latency
    - Accurate simulated hosts
  - Counterpoint to performance, must be addressed carefully

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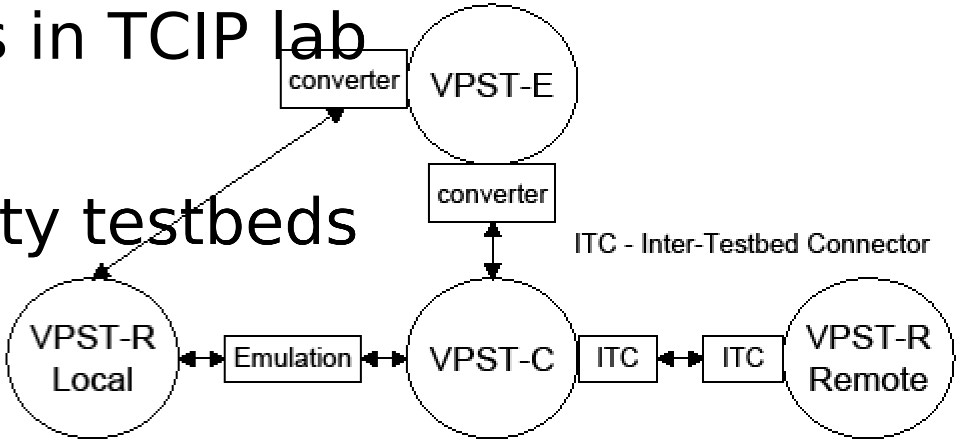
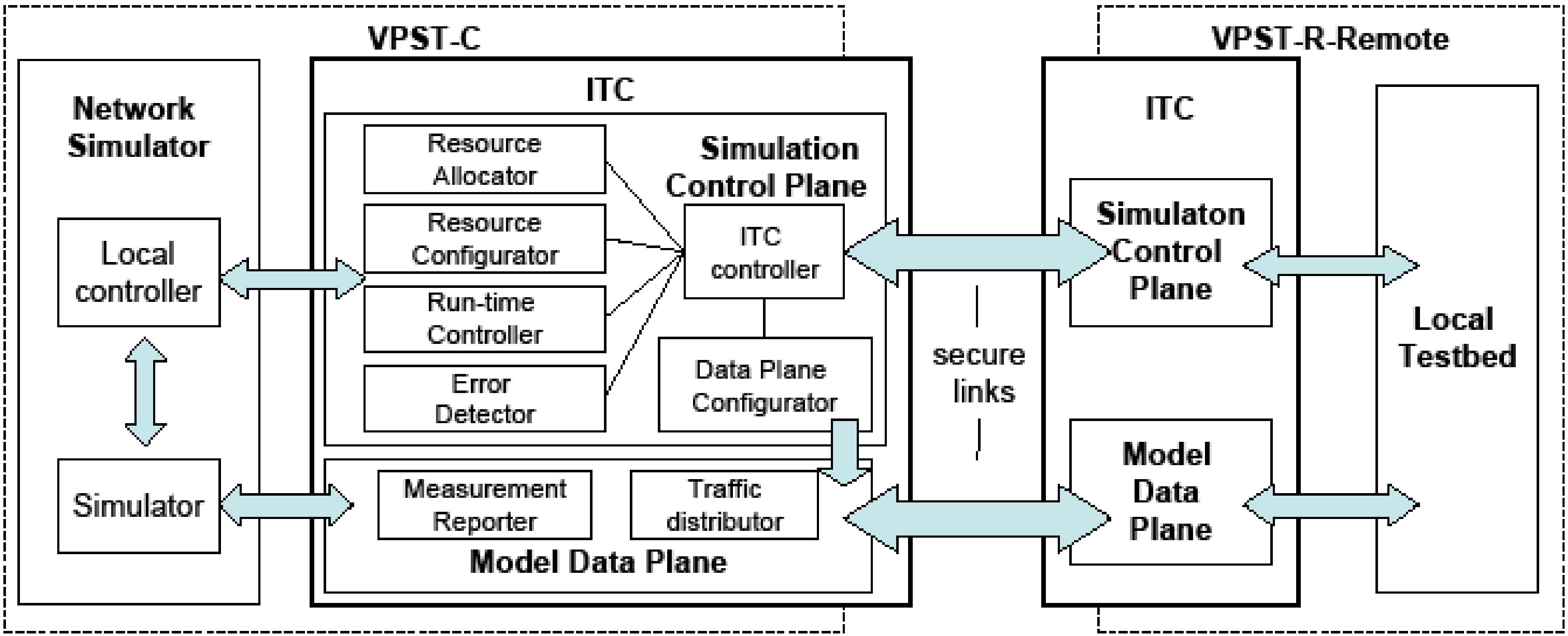


Inter-Testbed Connector (ITC) Architecture



Inter-Testbed Connector (ITC) Architecture

- Simulation Control Plane
  - ITC Controller
    - Exchanges control commands with a remote ITC
    - Collects/distributes commands on local control plane
  - Resource Allocator
    - Load balancing and allocation
    - Verify correctness of topology mapping
    - Guarantee IP uniqueness/mapping
  - Resource configurator
    - Uses DML to configure hosts, links, traffic, etc.

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Inter-Testbed Connector (ITC) Architecture

- Simulation Control Plane (continued)
  - Run-time controller
    - Control experiment online
      - E.g. launch DoS attacks, altering data polling behavior
  - Error Detector
    - Detect host failures, asynchronization, out-of-bound parameters, etc.
    - Respond by allocating extra resources, generating alerts, writing to logs or terminating/restarting experiment
  - Data Plane Configurator
    - Issue controls to the data plane at initialization, run-time, and cleanup stages

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Inter-Testbed Connector (ITC) Architecture

- Model Data Plane
  - Traffic Distributor
    - Bridges traffic across interconnected testbeds
    - Minimizes the number of physical links by using a “super node”
  - Measurement Reporter
    - Collects metrics
    - Leverages both local and remote collection

Use Case 1

- Training and Human-in-the-loop Event Analysis
  - Mid-western blackout of 2003
    - Operators need to be trained with full situational awareness
  - Requirements
    - Secure Connectivity for sensitive information
    - Reproducibility for event replay and analysis of the impact of human decisions
    - Scalability for large-scale power systems
    - Fidelity to ensure realistic scenarios

Use Case 2

- Analysis of Incremental Deployment
  - Old and new technologies must co-exist
    - DNP3SA, for instance, must be tested on a large-scale heterogeneous environment before being deployed
  - Requirements
    - Reproducibility for ensuring new technology is the root cause of change
    - High performance for accurate scale models
    - Fidelity to ensure new technology behaves the same as in the wild

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Use Case 3

- Attack Robustness Analysis
  - Simulation & Emulation can combine to test a proposed defense against an attack
  - Goals
    - Leverage something like DETER for cyber-attack capabilities
    - Use National Labs for various SCADA equipment
    - VPST-C is the “master” coordinating and providing the modeling and analysis for the experiment
  - Requirements
    - Secure connectivity to provide containment
    - Reproducibility to allow attack replay against various defenses
    - Fidelity to ensure defense results are real

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Difficult Problems

- Coordinated resource allocation and aggregation
- Time contraction and dilation
- Representative traffic generation and modeling
  - Production SCADA networks are generally very closed
  - Responses can be highly contextual leading to complex models
- Interconnected testbed GOTCHA’s
  - “virtual” attacks become real

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Summary

- Shown the need to integrate multiple testbeds for SCADA networks and requirements/difficulties therein
- Some aspects currently implemented, more to come
- Future work
  - To develop a black-box implementation of the ITC
  - To develop a mechanism to ensure efficient WAN transmission via coordinated control and integration

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Acknowledgments

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