Modeling Methodologies for Power Grid Control System Evaluation

Overview and Problem Statement

Research on various smart grid technologies requires high-fidelity experiments in realistic, large-scale settings. In this project, we are creating a high-fidelity, highly scalable simulation and emulation platform for security evaluation in power grid control networks. The testbed deploys virtual machine-based network emulation and parallel network simulation technologies to achieve that goal, and is designed to efficiently connect various virtual and real systems in the TCIPG lab as a testing and evaluation platform for other smart grid projects.

Research Objectives

- To create a backbone at the core of the Smart Grid testbed at Illinois that connects various components.
- To create models that support security assessment in a realistic large-scale setting.
- To create experimental designs and output analysis.
- **Smart Grid Application Area:** Testbed of power grid control systems.

Technical Description and Solution Approach

- Our testbed uses virtual-machine-based emulation and parallel network simulation technologies.

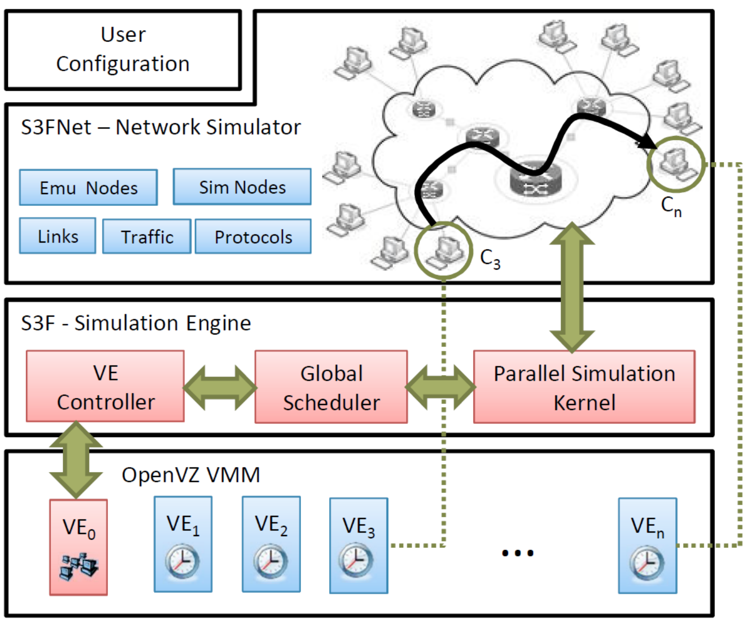

Figure 1: System Design Architecture

- Virtual-machine-based implementation of network emulation.
  - Because of the use of virtual machines, we allow unmodified application code to run in our testbed directly. This yields high functional fidelity.
  - Each virtual machine has its own virtual clock, and it perceives time as if it were running independently and concurrently with other machines in the physical world.
  - We currently have a virtual time system based on OpenVZ virtualization technologies, whose light weight provides good scalability. We are able to run 320 VEs on a single commodity server.

  - The achievable temporal accuracy of our system is subject to scheduler granularities, which are tunable in our system. We can explore the trade-off between execution speed and temporal accuracy (up to 30 μs).

- Parallel network simulation: S3F/S3FNet.
  - S3F simulation engine supports modular construction of simulation models that easily exploits parallelism.
  - The new engine design enables interactive communication with emulation.
  - It is flexible enough to create/explore various testing scenarios in a large-scale setting.
  - S3FNet provides sophisticated, low-level network layers and background traffic simulation.

- Integration of virtualization platforms to S3F/S3FNet.
  - Simulation is for modeling an extensive ensemble of background computation and communication.
  - Emulation is for representing execution of critical software.
  - Design of a global synchronization algorithm that integrates simulation and emulation.

Results and Benefits

- Developed our large-scale, high-fidelity network testbed.
  - S3F/S3FNet parallel network simulation.
  - OpenVZ emulation with virtual time system.
- Validated our testbed (S3F/S3FNet + OpenVZ).
  - System temporal error is bounded by one timeslice (100us).
  - Evaluation of application behavior:
    - Network-intensive (e.g., FTP, web browser) and CPU-intensive applications.
    - The error introduced by a virtual time system is often smaller than that introduced by the OpenVZ platform.
- Publications
  - Zheng and Nicol. “A Virtual Time System for OpenVZ-Based Network Emulations,” PADS’11.
  - Nicol, Jin, and Zheng. “S3F: The Scalable Simulation Framework Revisited,” WSC’11.
  - Zheng, Nicol, Jin, and Tanaka. “A Virtual Time System for Virtualization-Based Network Emulations and Simulations,” JOS’11.
  - Jin, Zheng, Zhu, Nicol, and Winterrowd. “Virtual Time Integration of Emulation and Parallel Simulation,” PADS’12. (Best paper award)
  - Zheng, Jin, and Nicol. “Validation of Application Behavior on a Virtual Time Integrated Network Emulation Testbed,” WSC’12, to appear.

- **Technology Readiness Level:** ongoing

Researchers

- David Nicol, dmnicol@illinois.edu
- Dong (Kevin) Jin, dongjin2@illinois.edu
- Yuhao Zheng, zheng7@illinois.edu
- Huaiyu Zhu, hzhu10@illinois.edu
- Lenhard Winterrowd, winterr2@illinois.edu

Industry Collaborators

- Boeing Corporation
- IBM Research

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