Virtual Integration Platform: Systems – Network "Wind Tunnel"

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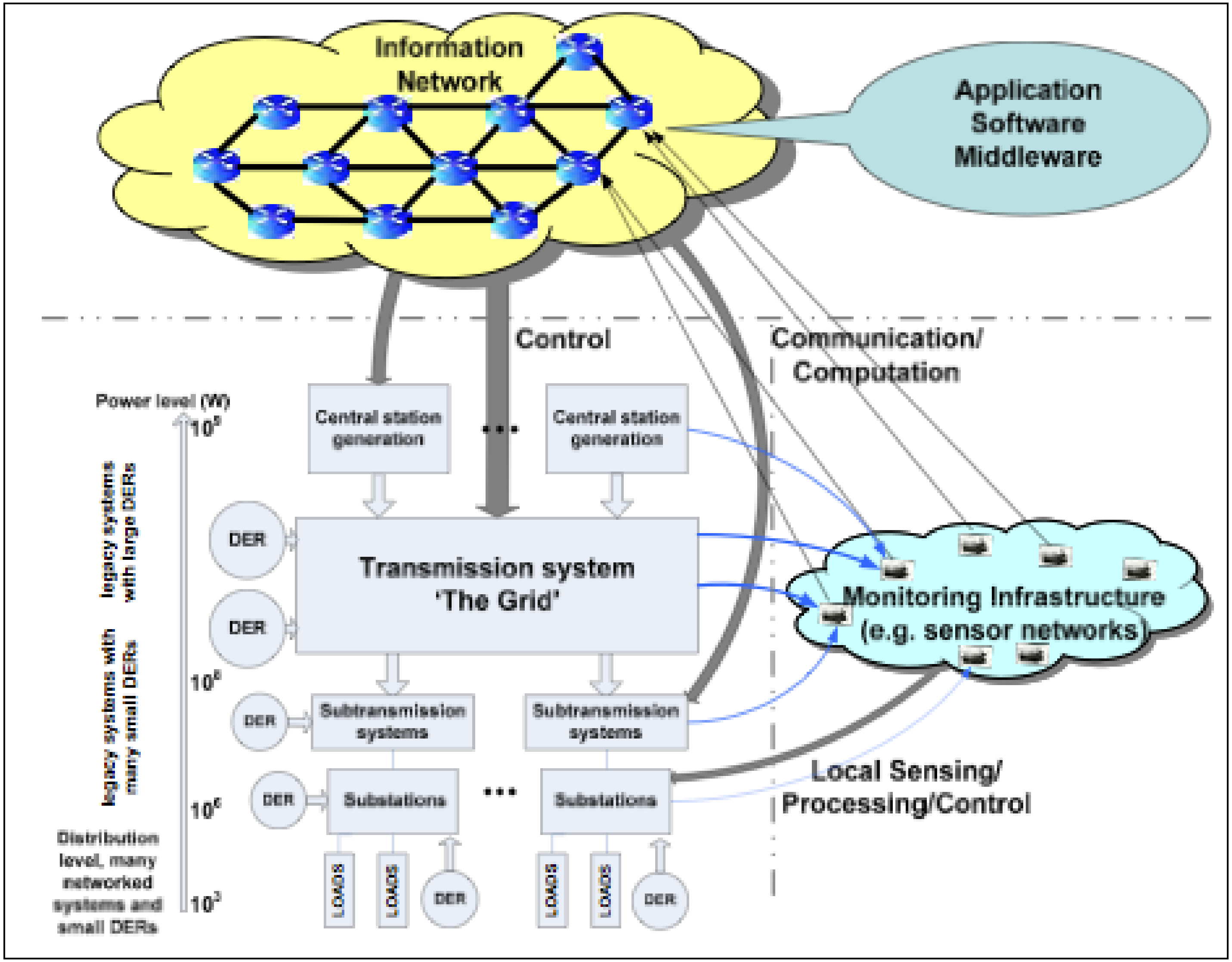
FORCES Kickoff Meeting
April 12, 2013

VANDERBILT UNIVERSITY

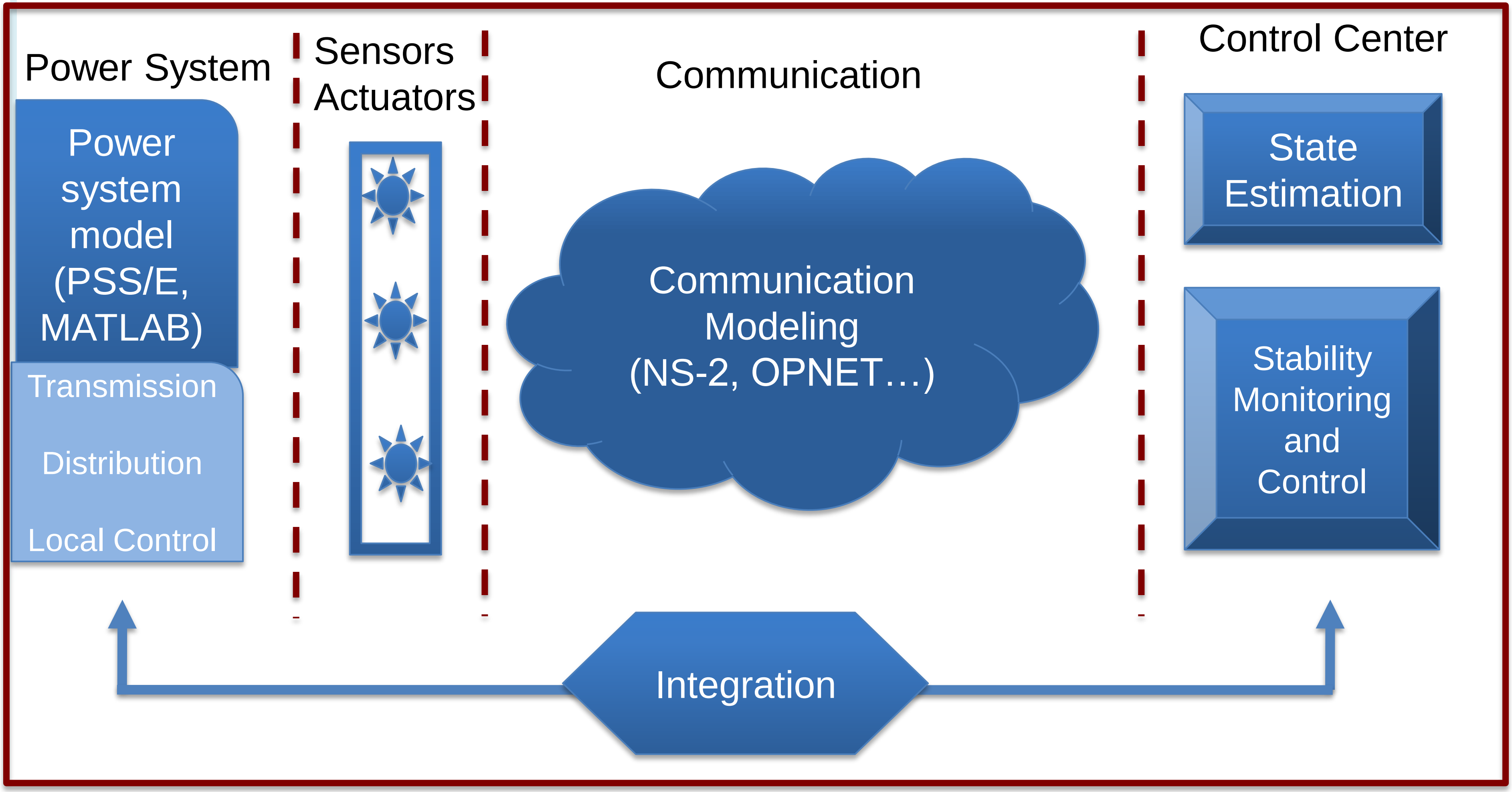
History

- Sastry/Sztipanovits AFRL Study on Virtual Prototyping of C2 Systems (2005)
- Human-Centric Design of C2 Systems: The C2 Wind Tunnel AFOSR project, 2006-2009, (Vanderbilt/Berkeley/George Mason)
- C2 Wind Tunnel Applications/Extensions
  - AFRL project on resilient C2 architectures (cyber attacks impact on mission performance), (2010-2011)
  - BAE Systems National Cyber Range, DARPA, (2009-2010)
  - Cyber C2 – Course of Action evaluation, AFRL, (2010-2012)
  - TRUST SCADA simulation platform, NSF, (2010-2011)
  - C2 Wind Tunnel/DETER integration, ARO, (2009-2012)
  - Experiments with smart grid simulation (with WSU) (2011)
  - Other users – USA, S. Korea, EU

Integrated control, communication, power system



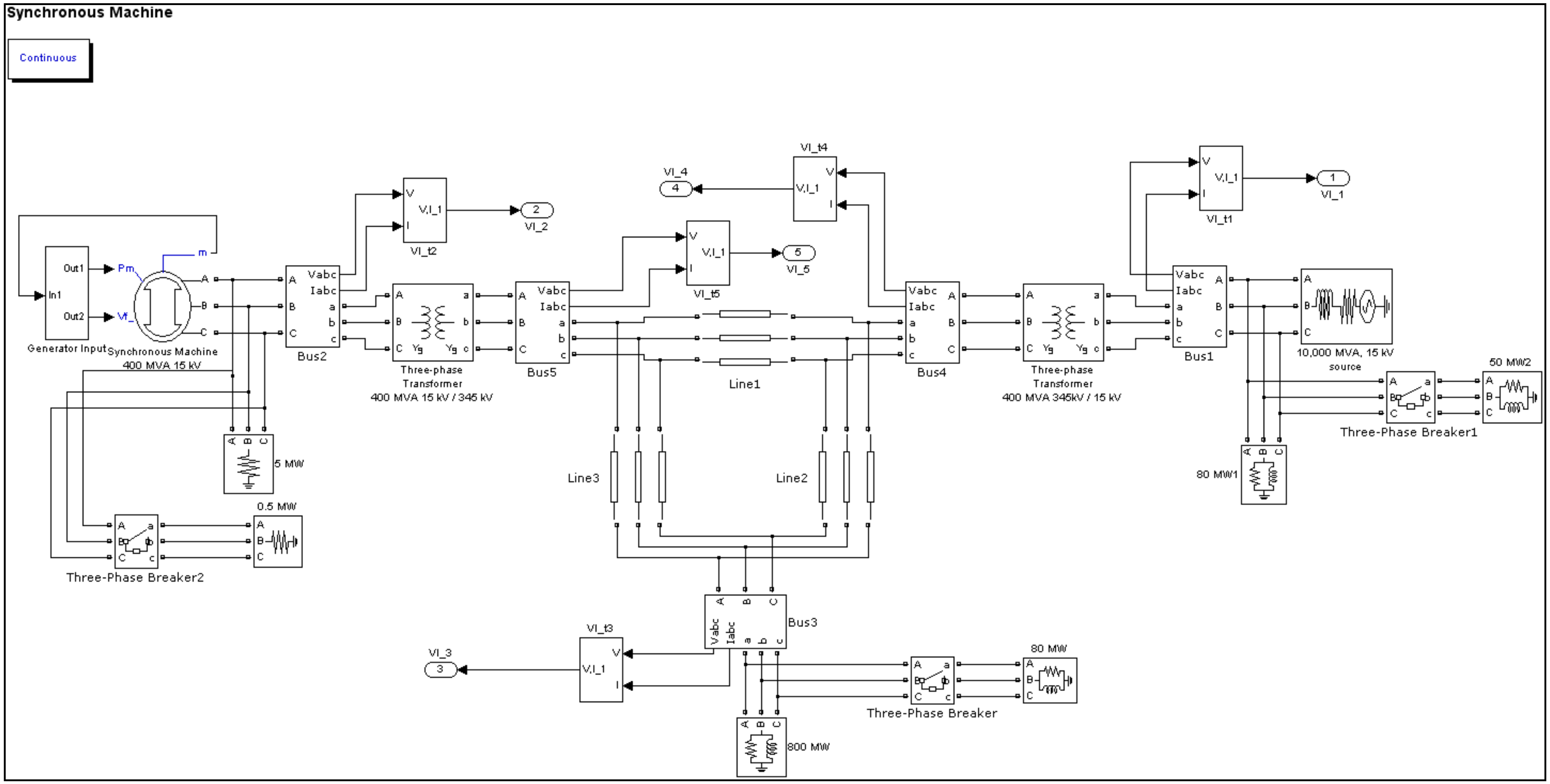
Interfacing Existing Modeling Tools



Electric Grid Modeling and Simulation: Gaps

- Modeling interdependencies of infrastructure accompanying the power grid, including sensors, control, communication network and computational components is challenge.
- No single tool to model power system, communication and control system
- No single tool to model the system at transmission and distribution level with attention to all details
- Tools needed to combine data that is multi-rate, multi-scale, multi-data, multi-use, multi-model from multiple heterogeneous interacting domains
- Solutions:
  - Single integrated tools
  - ***Compose multiple models and simulations: model and simulation integration challenge***

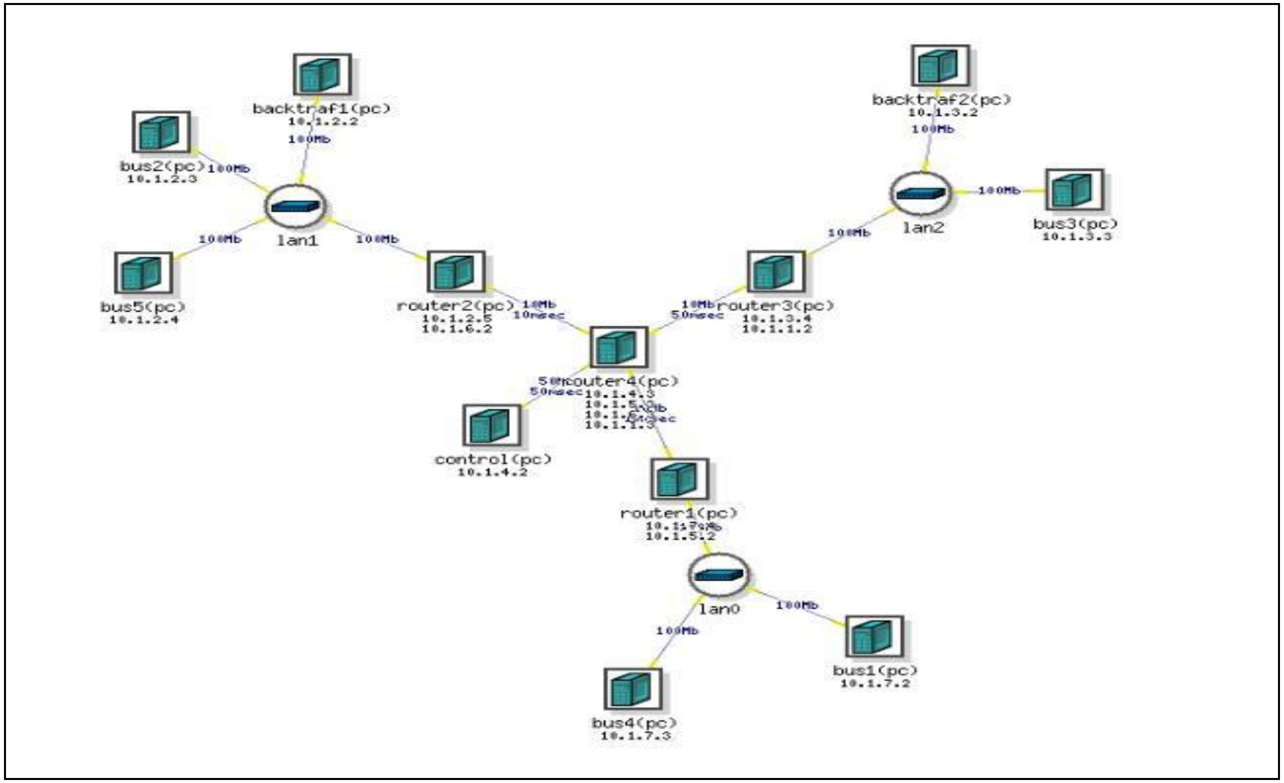
5-Bus Example: Power Grid Model



Tool: SimPower/MATLAB
Modeling Language: Simulink
Semantics: Continuous Time

Other Tools: RTDS
Modeling Language: RSCAD
Semantics: Continuous RT

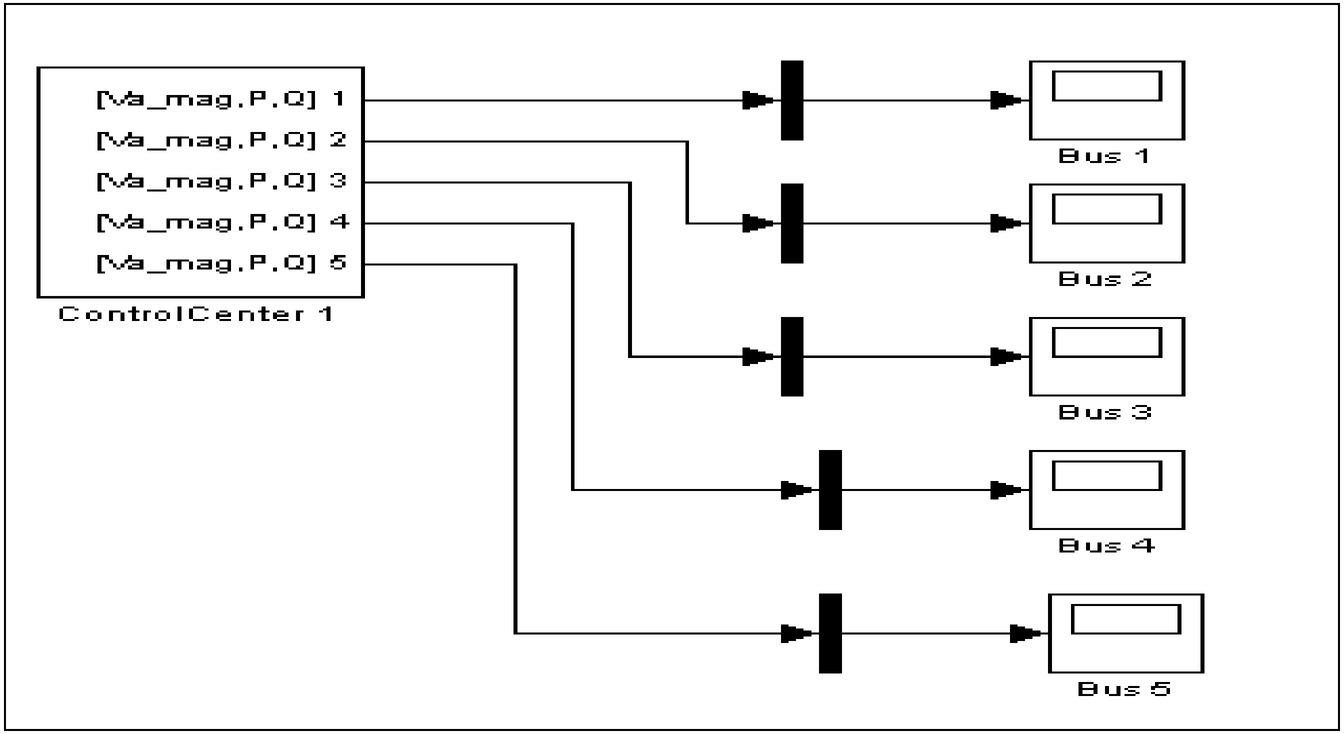
5-Bus Example: Communication Model



Tool: NS-2
Modeling Language: NS-2
Semantics: Discrete Event

Other Tools: OMNeT++
OPNET, TrueTime,..
Semantics: Discrete Event

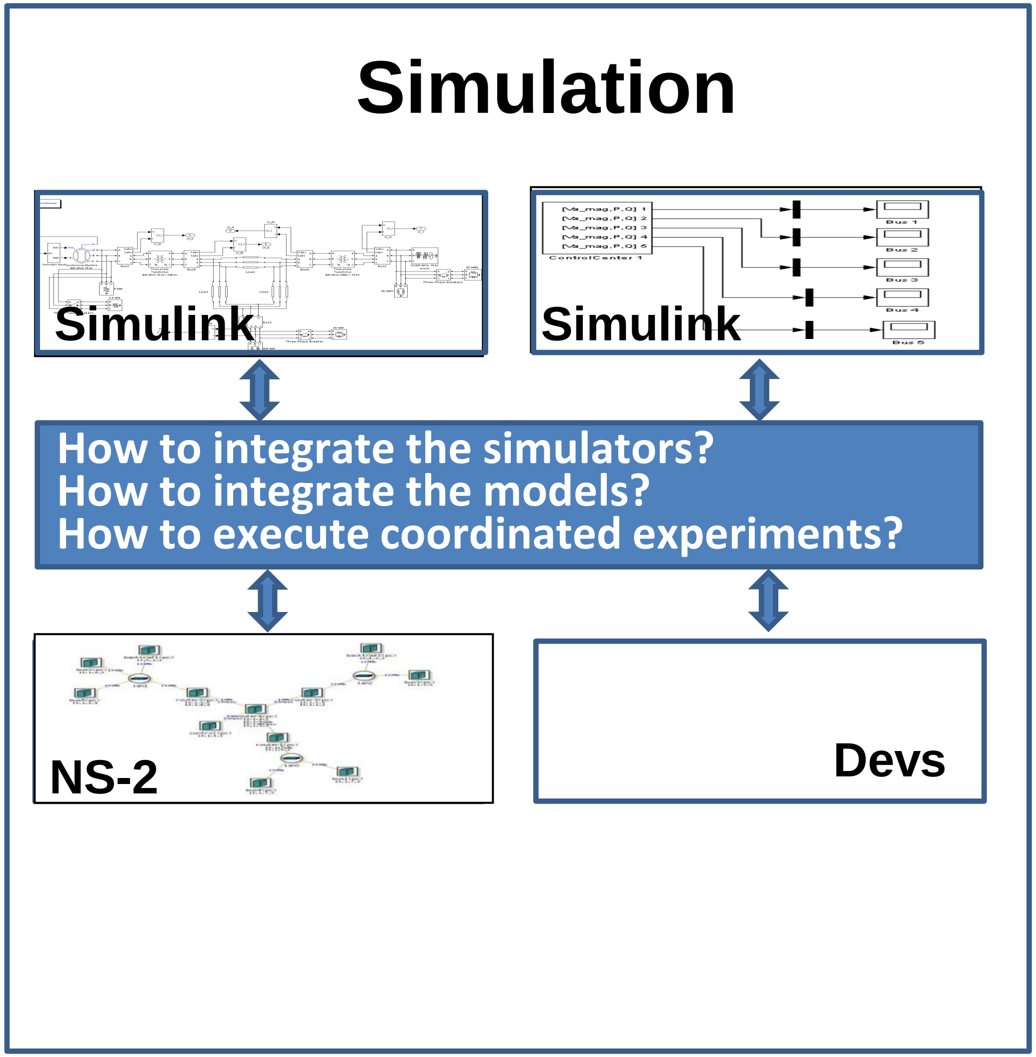
5-Bus Example: Control Center Model



Tool: MATLAB
Modeling Language: Simulink
Semantics: Discrete time

Other Tools: DEVS, LabView,
Semantics: Discrete Event

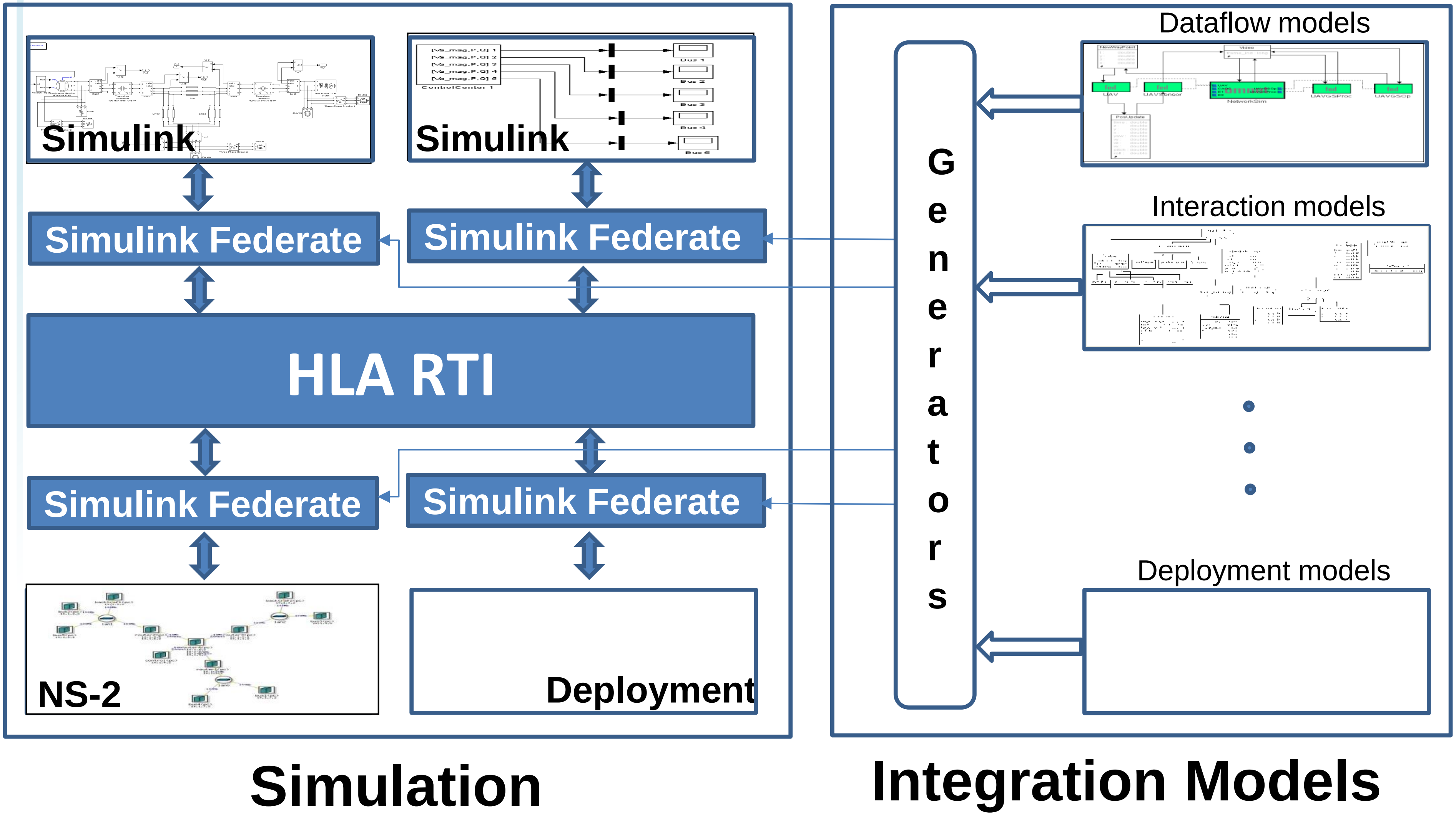
Integration Challenges



- Simulators have different timing models
- Execution needs to be coordinated
- Data needs to be shared
- Different time-scale and resolution
- Logical time v.s. real time
- Different simulation engines

- Modeling languages are different
- Semantics is different:
  - continuous time
  - discrete time
  - discrete event
- Simulated systems are interacting but modeling languages do not have construct to express them
- No support for specifying experiments

Simulation and Model Integration



Technology Needs

Integrating *models*

- Heterogeneous modeling for different domains: power systems, communication networks, control software, command and control organization, scenarios, etc.
- Needed: an overarching *integration model* that **connects** and **relates** the heterogeneous domain models in a logically coherent framework.

Integrating the *system*

- Heterogeneous simulators and emulators for different domains: Colored Petri Nets, OMNET++, NS-2, OPNET, DEVS, Simulink/Stateflow, DSMLs, etc.
- Needed: an underlying *software infrastructure* that **connects** and **relates** the heterogeneous simulators in a logically and temporally coherent framework.

Key idea: Integration is about interactions across system components. Why don't we model the interactions and use these models to facilitate model and system integration?

Simulation Integration Frameworks

Simulation Integration Frameworks:

- SIMNET (DARPA, live training, 80's)
  - incremental updates (dead reckoning)
  - objects and events to communicate changes
  - human-in-the-loop real-time simulation

- DIS (DARPA, large-scale battlefield sims, 90's)
  - time is assumed to be real-time
  - interaction based on UDP broadcast
  - 1278.1a-1998 IEEE standard

- **HLA** (DMSO, mid 90's)

High Level Architecture (HLA)

- An IEEE standard for “interoperable” and “reusable” models and simulations.
  - Most used specification (also used in the demo) is IEEE HLA 1.3 (1998)
  - Most recent specification is IEEE HLA 1516 (2000+)
- Provides a general purpose infrastructure for “distributed” simulation and analysis
  - Interactions are defined via Federation Object Model, Simulation Object Model and Management Object Model
  - Pub/Sub interactions over TCP
  - Complex time management/coordination
- Run Time Infrastructure (RTI)
  - Open source (RTI Portico) and COTS versions
  - Several middleware variants supporting better scaling:
  - Test and Training Enabling Architecture (TENA)
  - TIBCO’s TIB, OMG’s DDS, IBM’s DCS, MS.NET, Cornell’s Quicksilver

Multi-modeling With Existing C2WT

Three levels of modeling & customization:

- **Modeling the modeling tools - Infrastructure**
  - Performed "one-time" when a new simulation platform (model type) is integrated [usually by developers]
  - Metamodeling and metamodel comp.
- **Component Modeling and Integration Modeling – Scenarios**
  - Performed when a new scenario has to be experimented [usually by subject matter experts who can describe scenarios]
  - Requires:
    - Models of model tools used ('federates')
    - Data models
    - Integration models: Interactions among the models
- **Modeling Situations – Experiments**
  - Execution platform, experiment setup, deployment [usually by experimenters who can parameterize experiments and analyze experimental results

Simulink/Stateflow; CPN, C++/Java; DevsJava; OMNeT++; NS-2; Delta-3D; GoogleEarth
HLA-RTI Portico
Experiment design

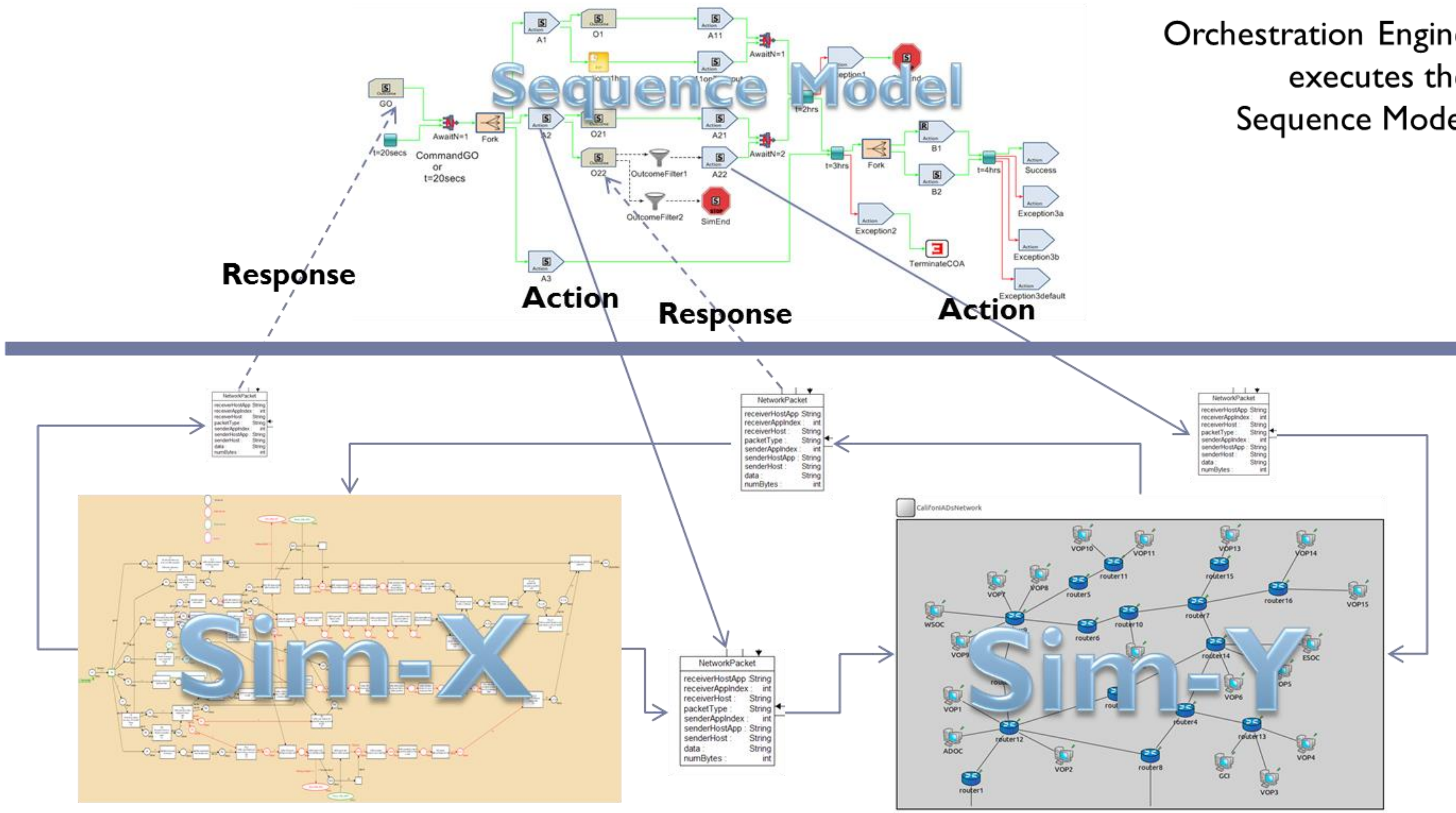
Physical system libraries
Operator utilities
Network models
Network attack models
Scenario models
3D environment models
Data collection in MySQL

Experiment models
"Excursions"
Data analysis scripts
Deployment models

http://wiki.isis.vanderbilt.edu/OpenC2WT

Experimentation:
Sequence model controls execution

Orchestration Engine
executes the
Sequence Model



Simulation engines co-operate via the C2WT

Conclusion

- We need highly scalable modeling and simulation infrastructure that is model-based, cyber-physical, scalable and highly automated.
- Feasibility of the proposed approach largely depends on semantically sound modeling and model integration, heterogeneous multi-model simulation and information management infrastructure.