SmartGridLab+: A Software-Hardware Hybrid Smart Grid Testbed

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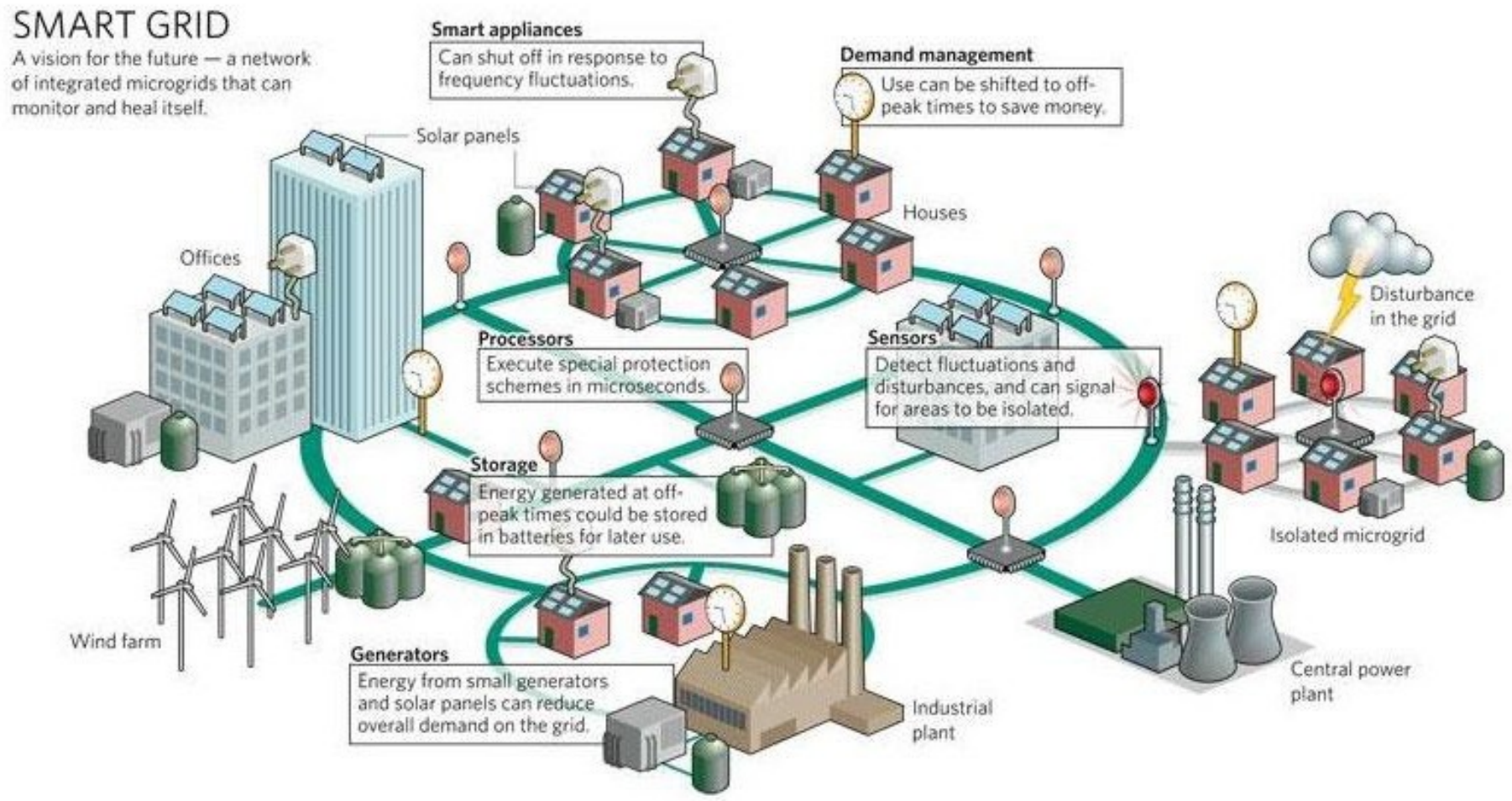
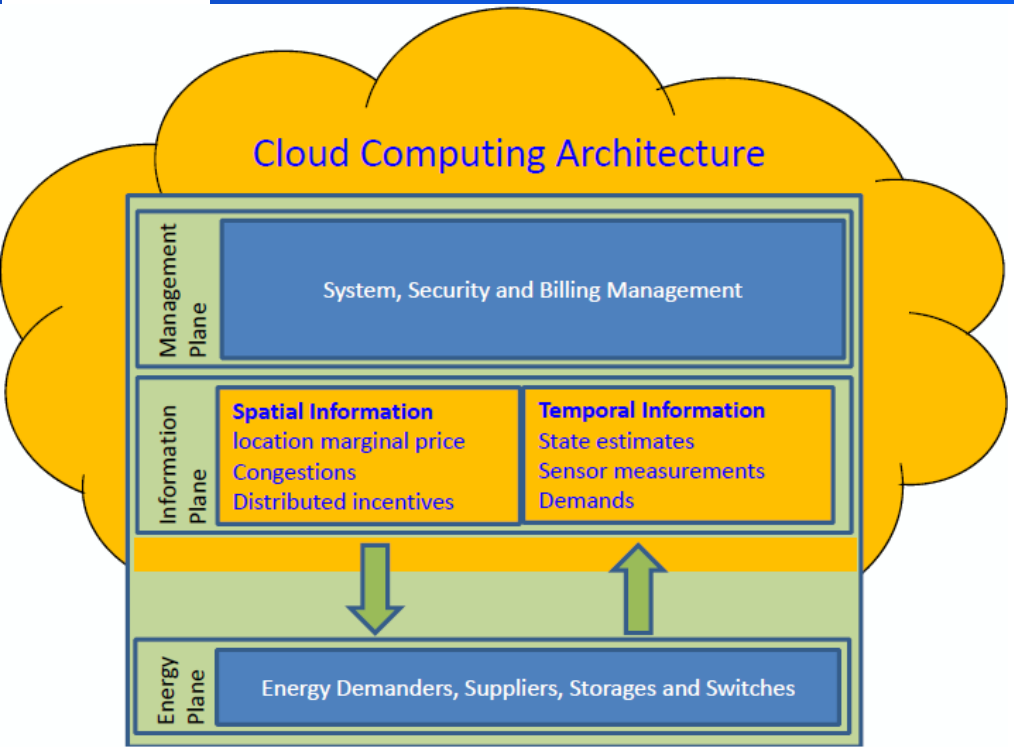
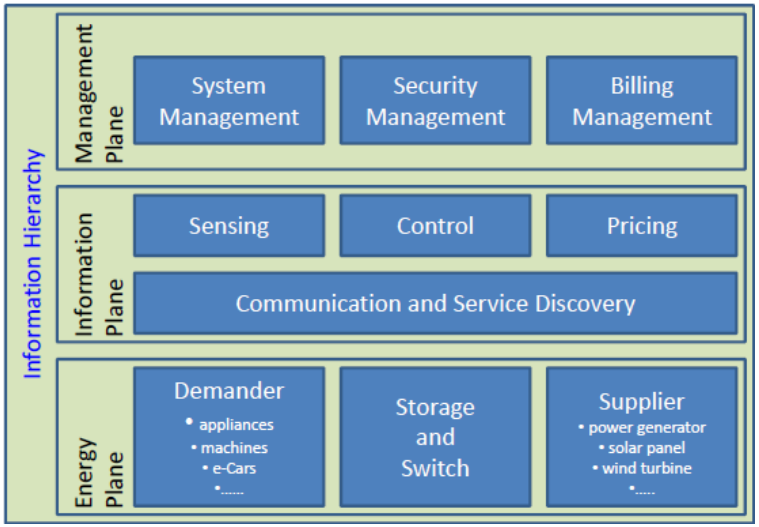
Smart Grid: power grid + information network



Hierarchy of Smart Grid





2011 NSF CPS Project ($1.87M 2011-2015): Information and Computation Hierarchy for Smart Grids (PI: Tong (Cornell), Co-PI: Birman, Mount, Thomas (Cornell), Varaiya (UC Berkeley), Song (GSU)

The goal is to gain a foundational understanding of how information should be partitioned in time and space; how it should be collected, distributed, compressed, and aggregated.

Related works

- Hardware Testbed:

  Advantages: 1) High fidelity: transient analysis, renewable integration, etc 2) Code can be directly migrated.

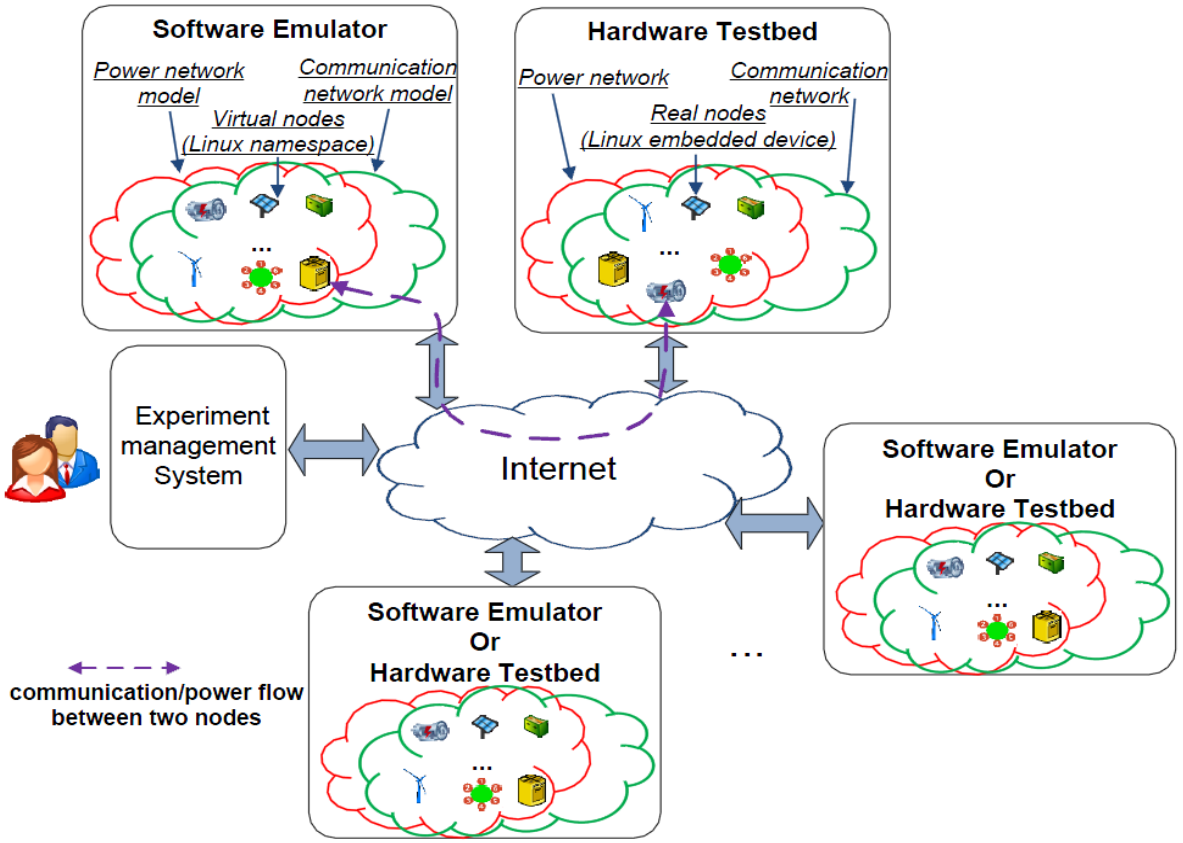
  Disadvantages: 1) No open or remote access 2) Low scalability

- Software Simulator:

  Advantages: 1) High scalability and accessibility. 2) Both real-time and virtual-time.

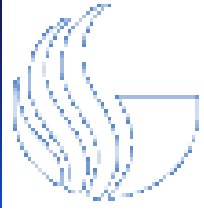
  Disadvantages: 1) Low fidelity. 2) Code cannot be directly migrated (only duplicate the behavior but not the execution environment).

Software Emulator+ Hardware Testbed



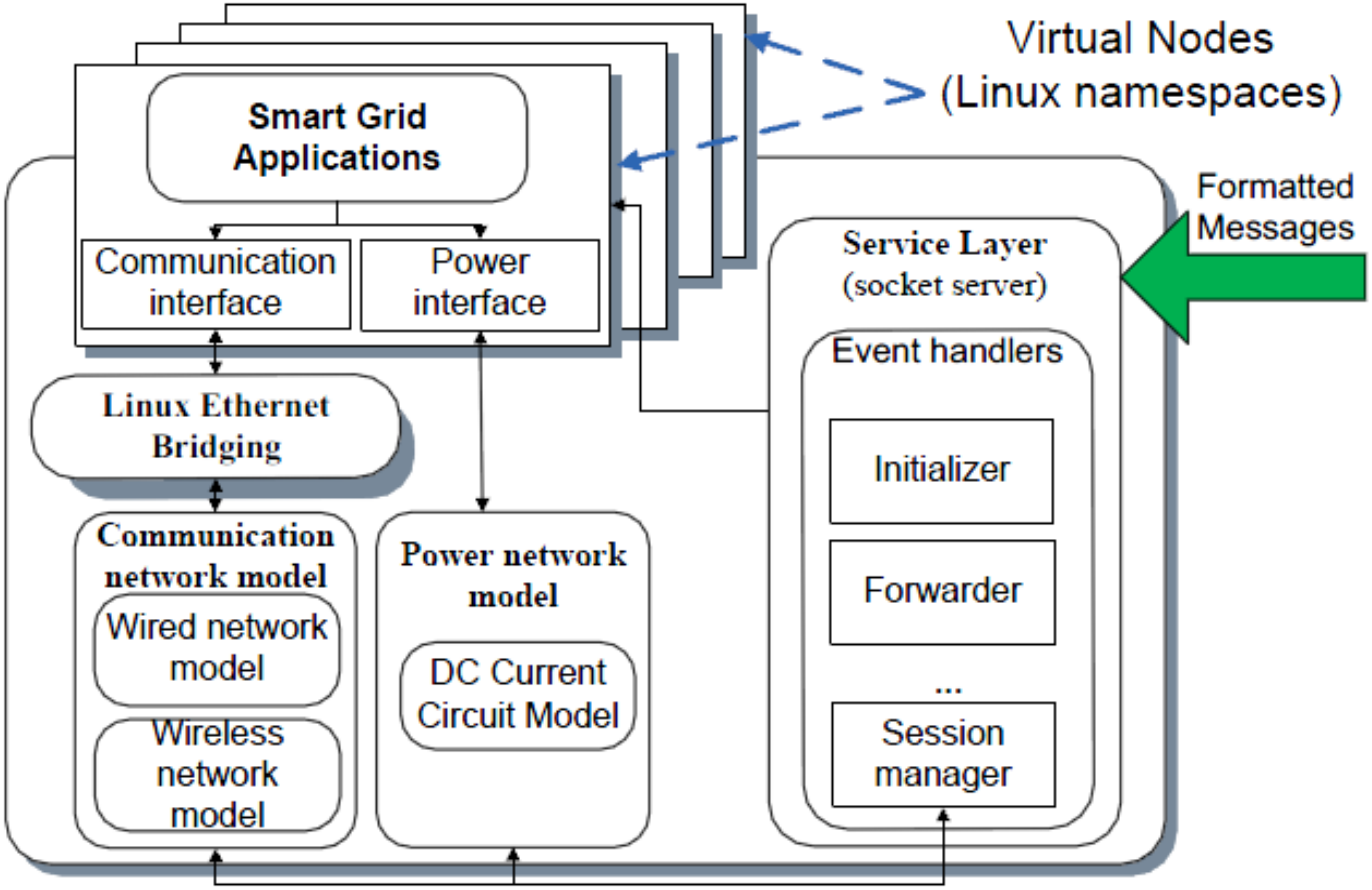
Features: (combine the merits from both hardware and software platforms).

- Exact same code can run on both testbed and emulator.
- Remote access and configuration of hardware testbed.
- Scalable distributed experiment platform, plug-and-play through Internet.
- A virtual node can exchange energy and communicate with a real node.



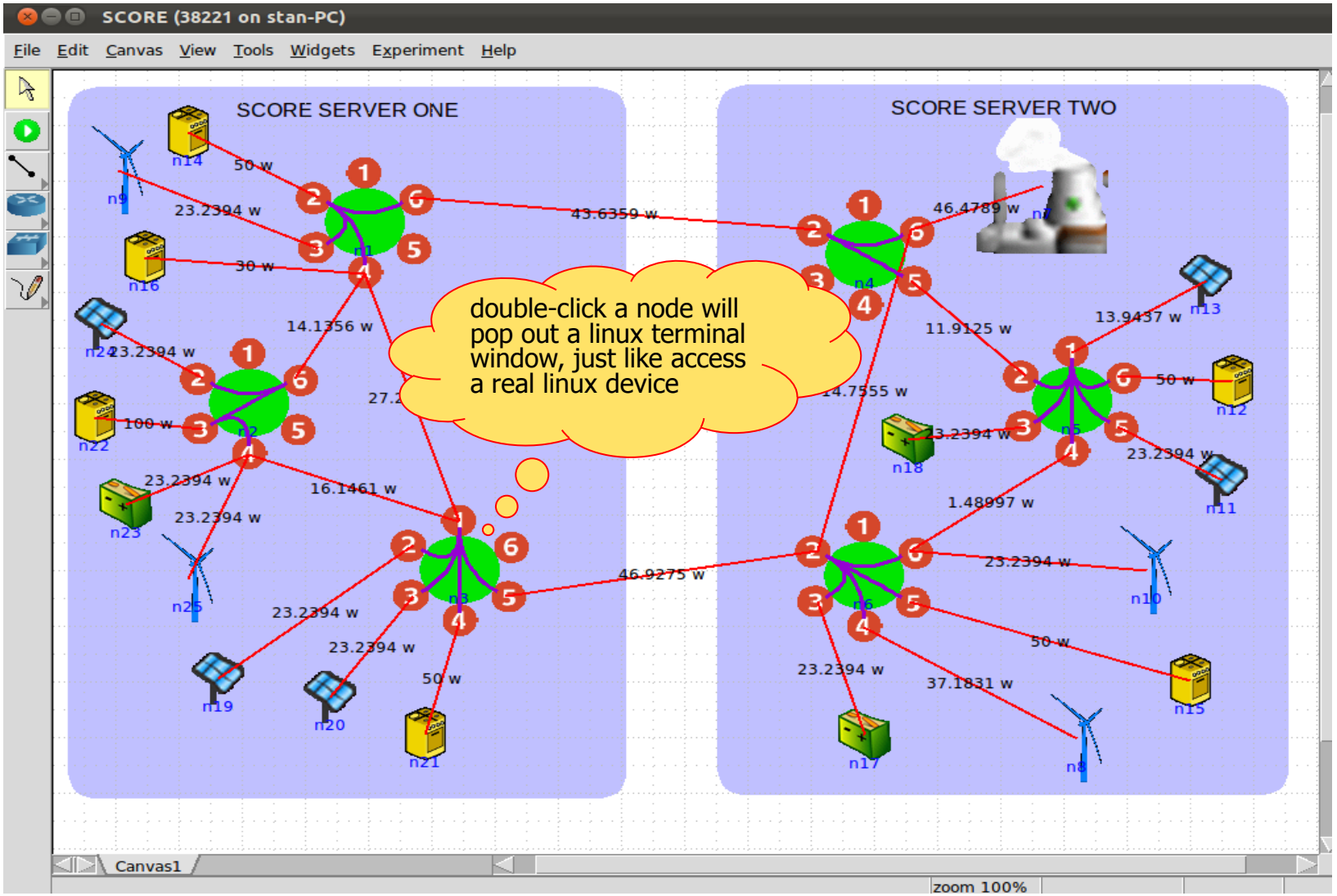
Part I:
Software Emulator

Software Emulator Design



Song Tan, et al , SCORE: Smart-grid Common Research Emulator, IEEE SmartGridComm, 2012

SCORE: Smart-grid Common Open Research Emulator



Open source release at http://sourceforge.net/projects/score-sensorweb/ > 200 downloads

SCORE: Smart-grid Common Open Research Emulator

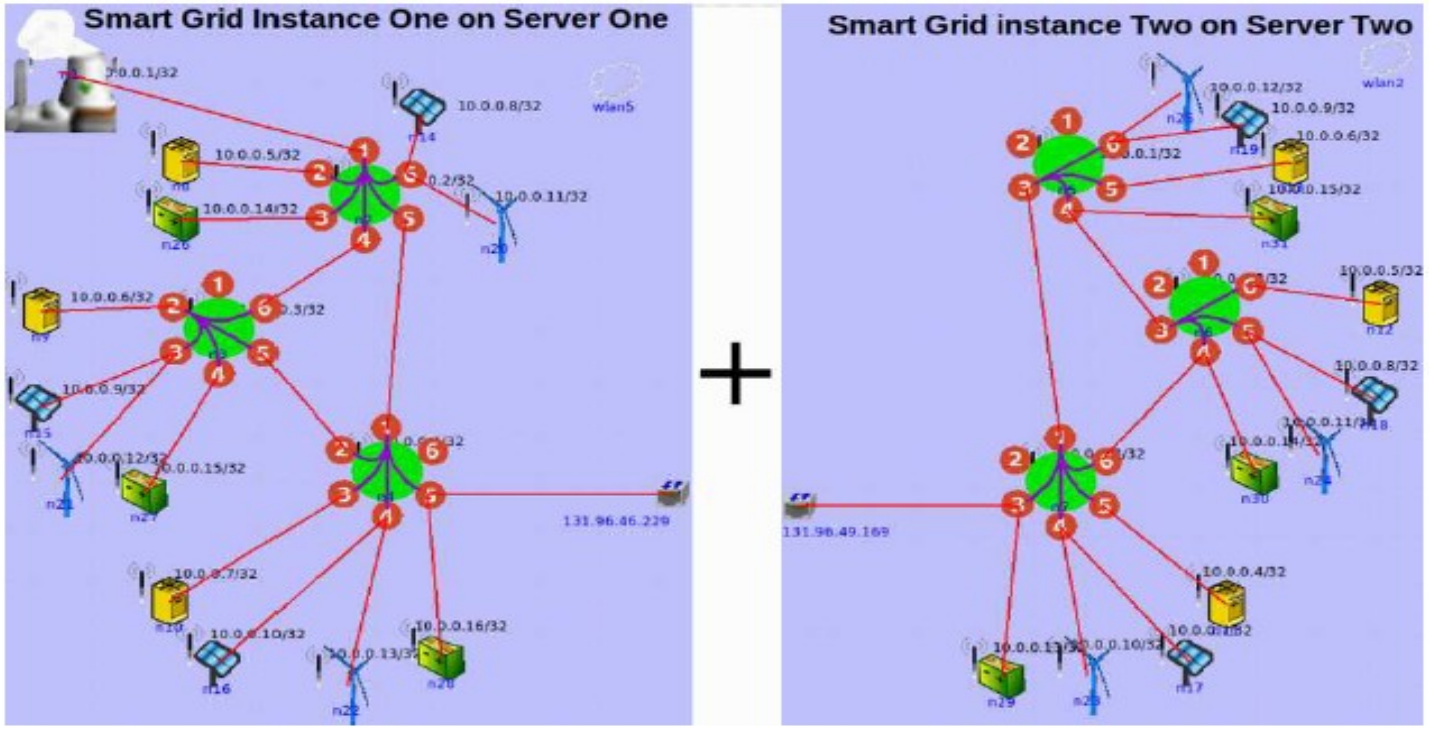
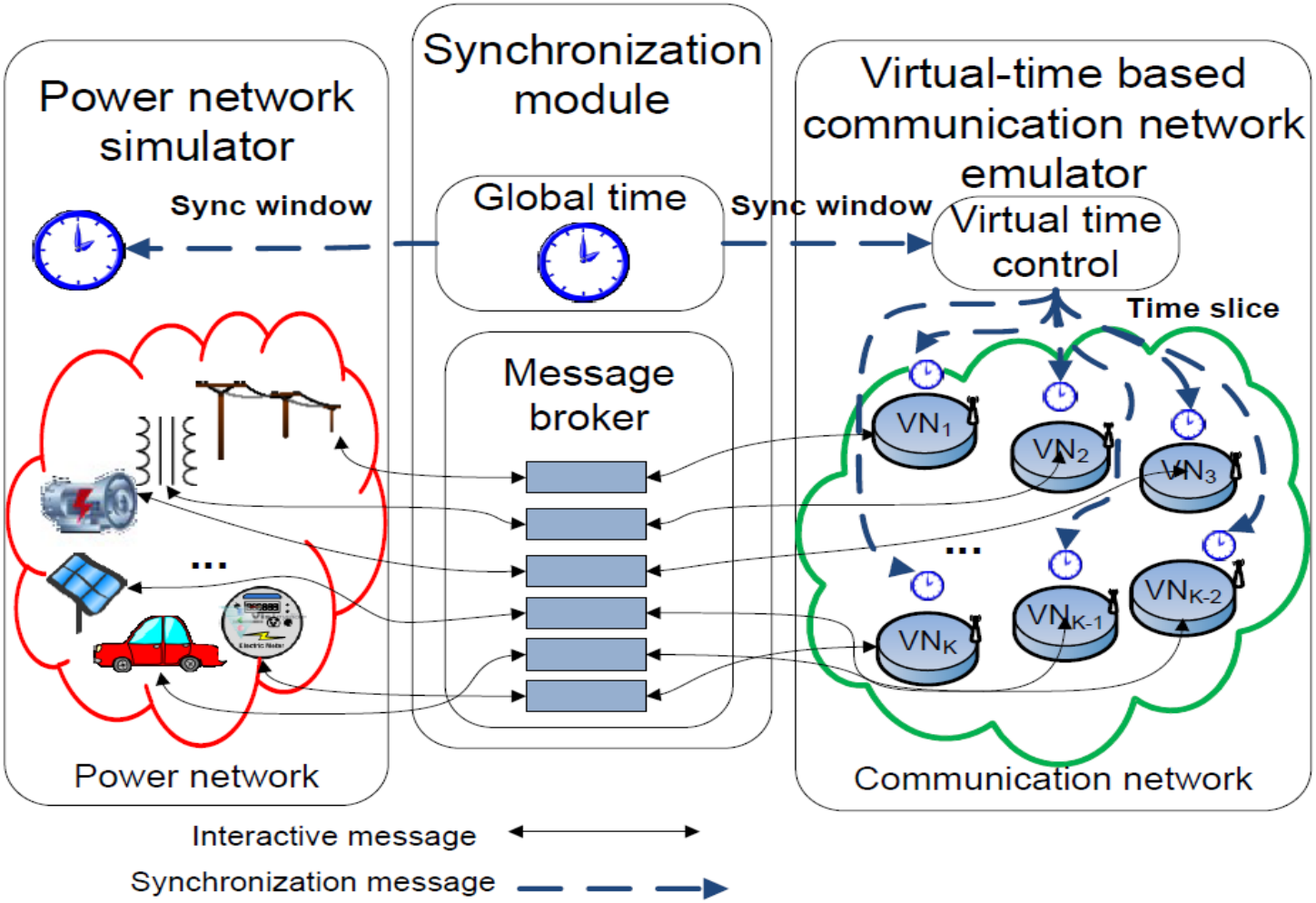


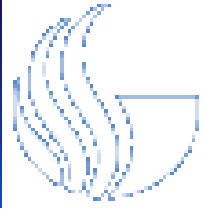
Fig. 11. Dynamic connections of two Smart Grid emulation instances in SCORE

Song Tan, et al , Distributed Software Emulator for Cyber-Physical Analysis in Smart Grid, IEEE Transaction on Emerging Topics in Computing, 2014

Integrating GridLAB-D with CORE: real/virtual time

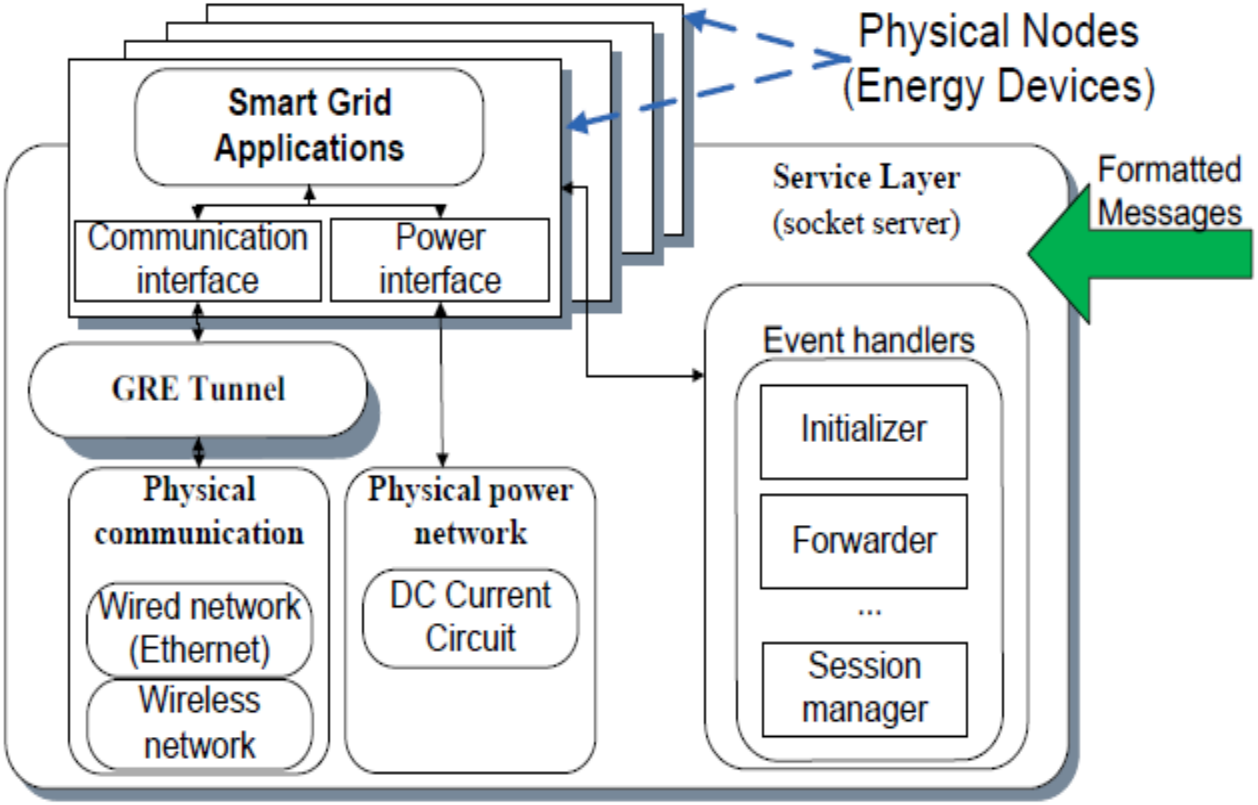


Song Tan, et al , Integrated Software Testbed for Cyber-Physical Analysis in Smart Grid, ISGT 2014.
Open source release at: http://sourceforge.net/projects/scoreplus/ > 60 downloads



Part II:
Hardware Testbed

Hardware Testbed Design



Song Tan, et al , ScorePlus: An Integrated Scalable Cyber-Physical Experiment Environment for Smart Grid, IEEE SECON, 2015

Hardware Testbed modules

(a) Solar Panel Controller

(b) Demander

(c) Storage

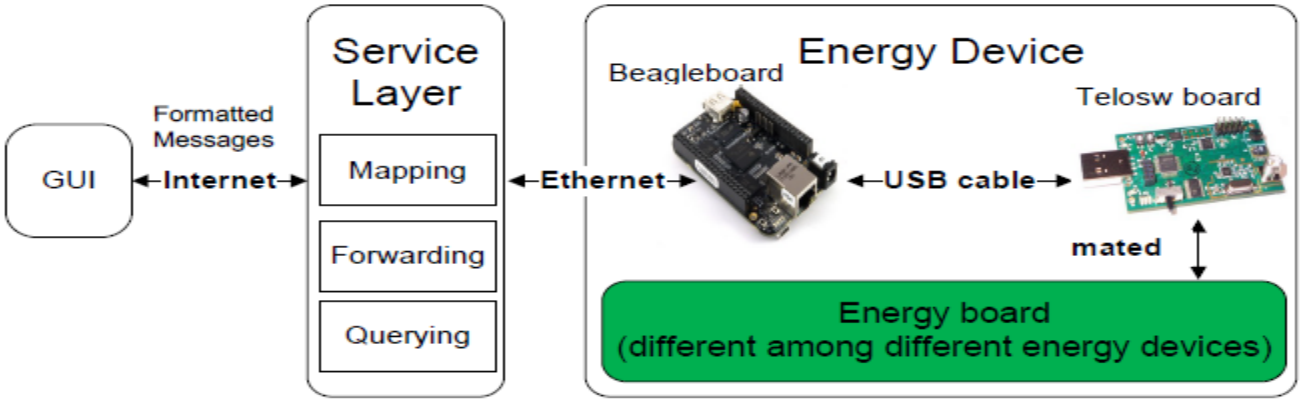
(d) Topology Switch

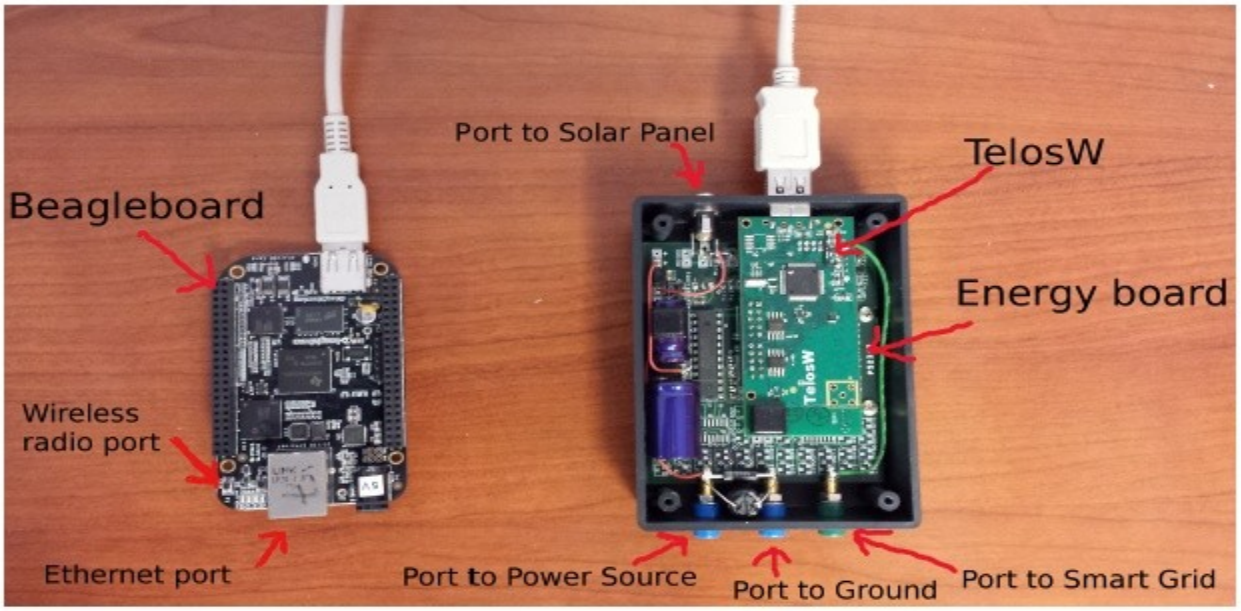
(e) Solar Panel

(f) Wind Turbine

Song Tan, et al , ScorePlus: An Integrated Scalable Cyber-Physical Experiment Environment for Smart Grid, IEEE SECON, 2015

Hardware Testbed Module in Detail





Song Tan, et al , ScorePlus: An Integrated Scalable Cyber-Physical Experiment Environment for Smart Grid, IEEE SECON, 2015

Dynamic Topology configuration

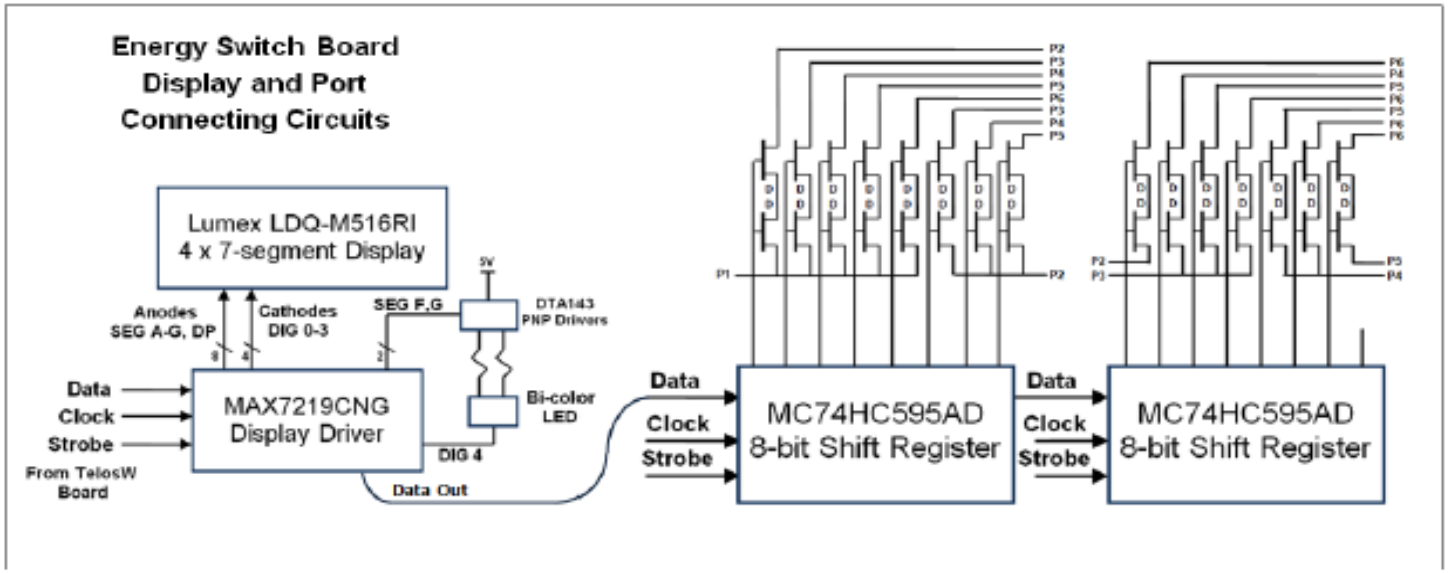
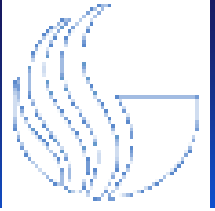


Fig. 11. Design of Energy board for Topology Switch

Song Tan, et al , ScorePlus: An Integrated Scalable Cyber-Physical Experiment Environment for Smart Grid, IEEE SECON, 2015

Testbed setup



Part III:
Integrate Software Emulator with Hardware Testbed

Integrating Communication Network

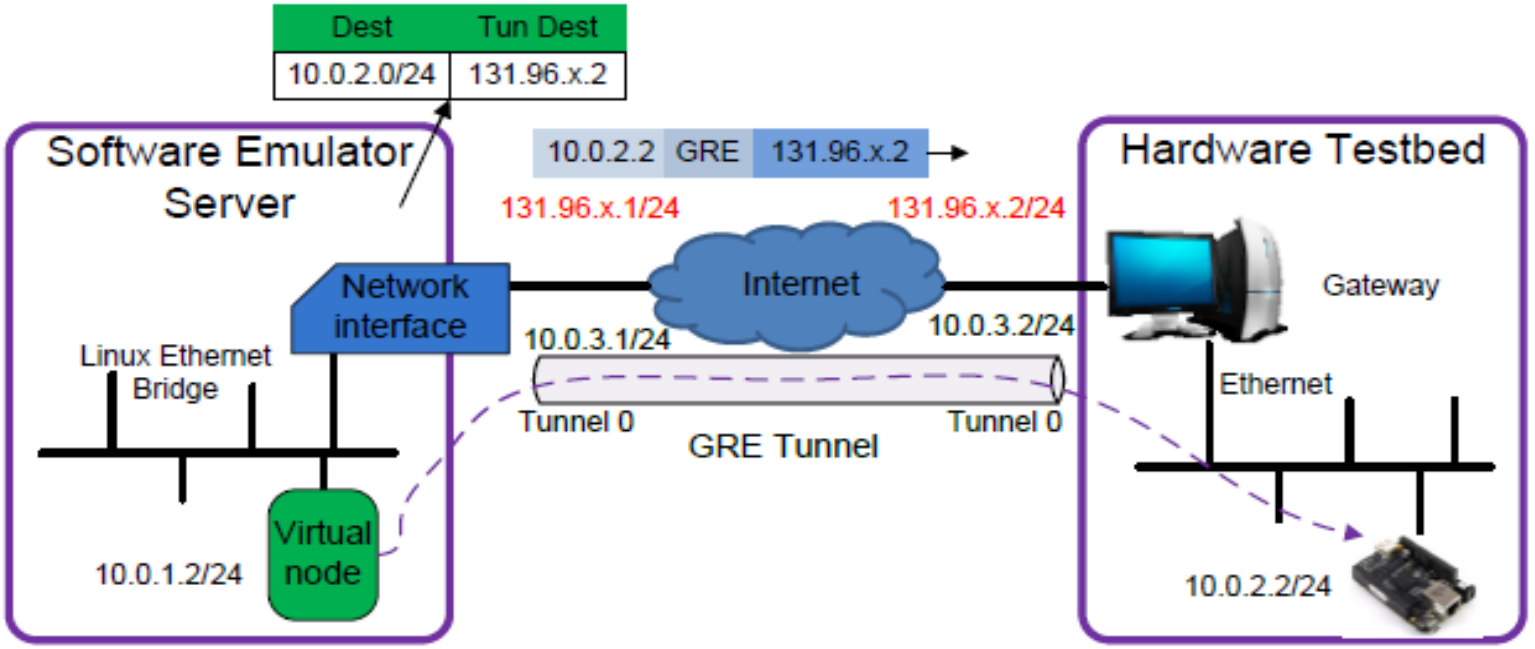


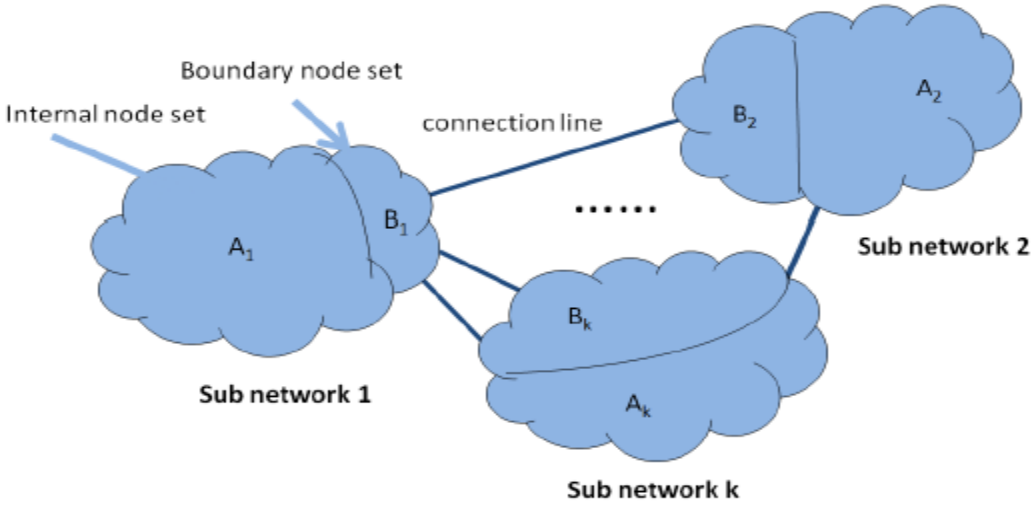
Fig. 12. Communication between virtual node and real node through GRE tunneling

Song Tan, et al , ScorePlus: An Integrated Scalable Cyber-Physical Experiment Environment for Smart Grid, IEEE SECON, 2015

Integrating Power Network

- Domain Decomposition:

  Calculate the boundary node voltages and then set the interface module in hardware testbed, which is essentially a supplier and demander with large capacity!!



$$\begin{bmatrix} Y_{A_1A_1} & 0 & \cdots & 0 & Y_{A_1B} \\ 0 & Y_{A_2A_2} & \cdots & 0 & Y_{A_2B} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & Y_{A_kA_k} & Y_{A_kB} \\ Y_{BA_1} & Y_{BA_2} & \cdots & Y_{BA_k} & Y_{BB} \end{bmatrix} \begin{bmatrix} V_{A_1} \\ V_{A_2} \\ \vdots \\ V_{A_k} \\ V_B \end{bmatrix} = \begin{bmatrix} I_{A_1} \\ I_{A_2} \\ \vdots \\ I_{A_k} \\ I_B \end{bmatrix}$$

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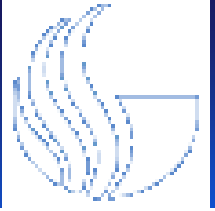
Conclusion

- In Summary:
  - Exact same code can run on both testbed and emulator.
  - Remote access and configuration of hardware testbed.
  - Scalable distributed experiment platform, plug-and-play through Internet.
  - A virtual node can exchange energy and communicate with a real node.

Future Works

- Employ cloud computing with web portal.
- Current model still DC circuit model, upgrade to AC model.
- Allow seamless integration with real power grid;
  - Include yet beyond injecting data from real power grid to emulate



Questions?