Prototyping Self-managed Interdependent Networks
Self-healing Synergies against Cascading Failures

Evangelos Pournaras, Mark Ballandies, Dinesh Achatya, Manish Thapa, Ben-Elias Brandt

www.sfina-net.org

Scope & Challenges

Repeatability of results is often impossible

Large **fragmentation** of research communities

Inconsistent results is possible - we have shown this [2]

Modeling & Simulation of Interdependent (Flow) Networks

Social network analysis, power grid reliability, traffic network congestion, water/gas networks, airline networks, disease spread, financial markets etc.

No interoperability of experimental software tools

Closed software tools

Results: too theoretical or too empirical

Modeling & Simulation Artifact

<u>Write once</u> a model,
<u>test in different</u> domains

High modularity: Plug-in different system dynamics that govern a network
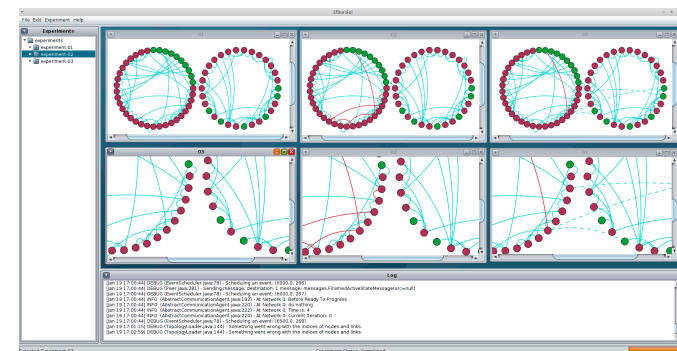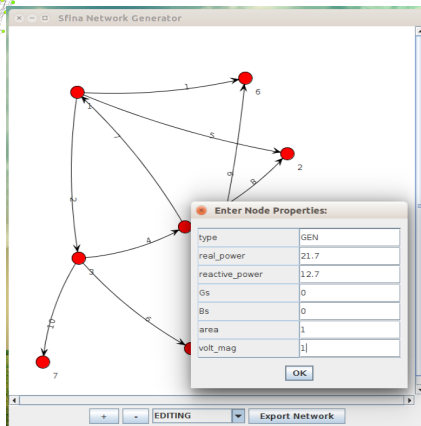
Support **co-simulation** of interdependent networks

Open-source, GLP v.2
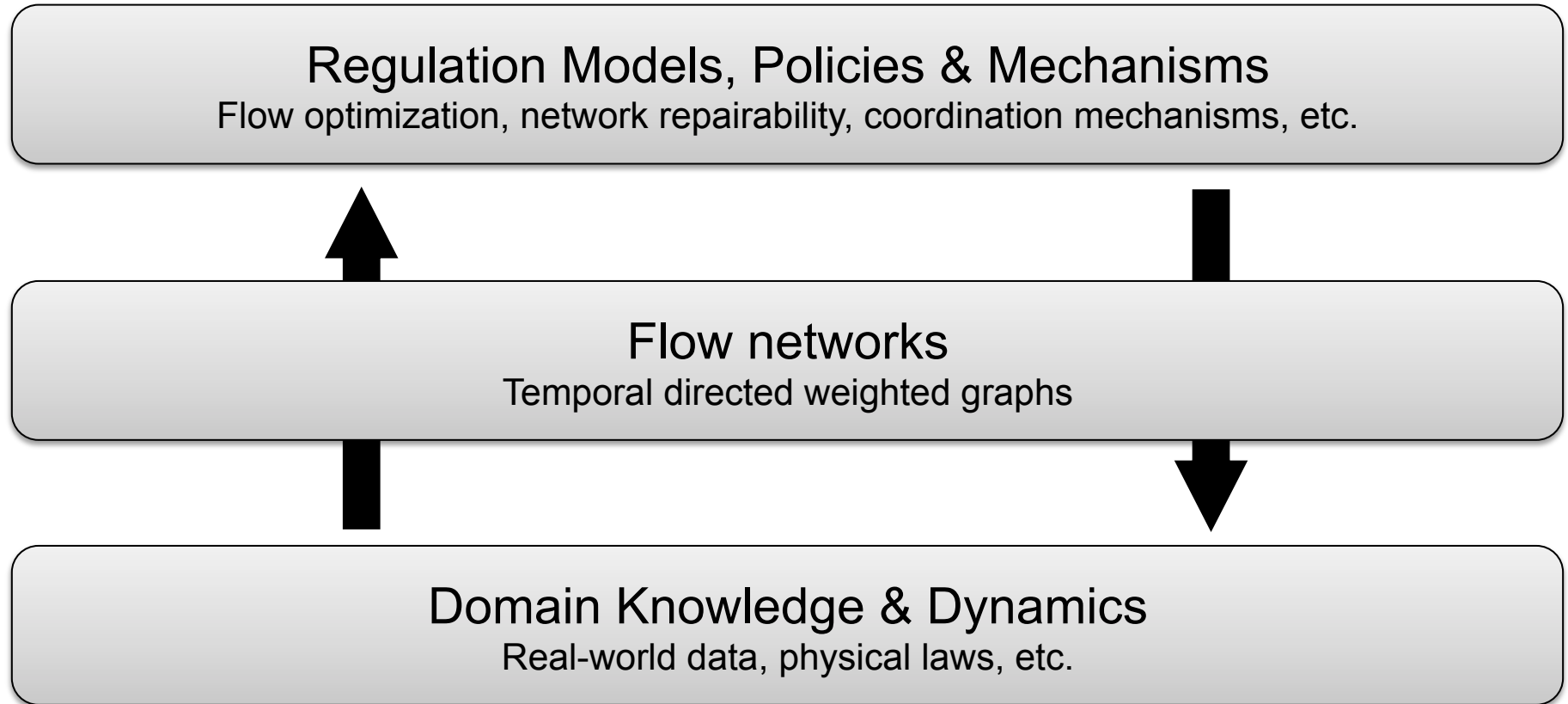Core written in Java but supports domain backends in Matlab, Python, Java, etc

www.sfina-net.org
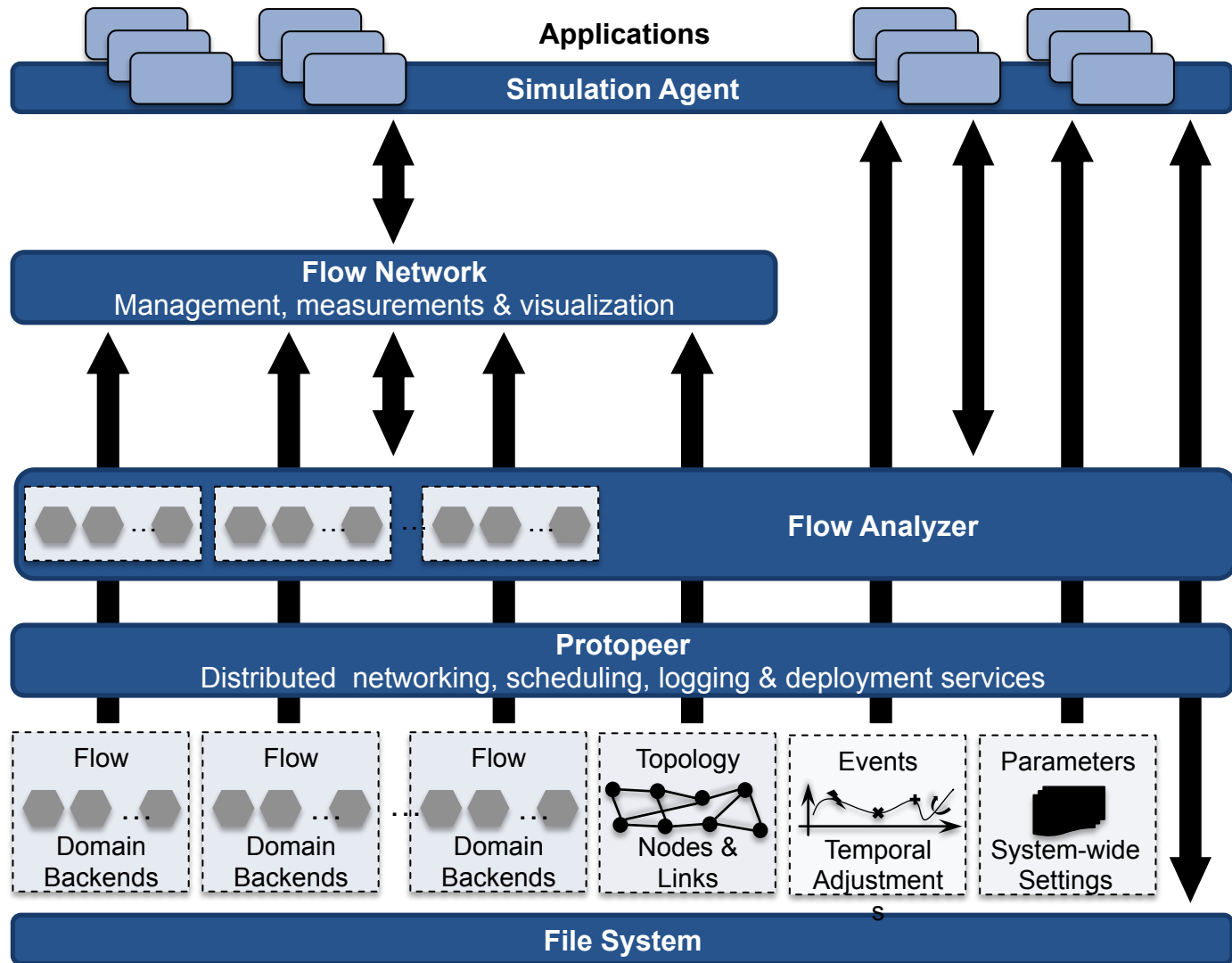
Simulation Framework for Intelligent Network Adaptations

Supports
Graphical user interface
network drawer
distributed simulation
tutorial/documentation
and more...

High-level Design Approach

Regulation Models, Policies & Mechanisms
Flow optimization, network repairability, coordination mechanisms, etc.

Flow networks
Temporal directed weighted graphs

Domain Knowledge & Dynamics
Real-world data, physical laws, etc.

Architecture

Status

SFINA
sfina-net.org

Applications

Self-healing Interdependent Power Networks
https://github.com/SFINA/Self-healing-Networks

Coordinated Smart Transformers
https://github.com/SFINA/Smart-Transformers

Cascade
https://github.com/SFINA/Cascade

Flow Monitor
https://github.com/SFINA/Flow-Monitor

Core

SFINA
https://github.com/SFINA/SFINA

Domain Backends

Disaster Spread
https://github.com/SFINA/Disaster-Spread

Theoretical Spreading Models

Power Network Flow Calculations

InterPSS
http://www.interpss.com

MATPOWER
http://www.pserc.cornell.edu/matpower/

MATSim
https://github.com/SFINA/Transport

Transport Network Flow Calculations

Interdependent Networks

water/gas power airline transport communication

Interdependent & Multiplex Networks

System Operator

System Operator

1. Self-* Mechanisms

2. Topology

Interlinks

1. Self-* Mechanisms

2. Topology

3. Flow Computations

Distributed Coordination Network

3. Flow Computations
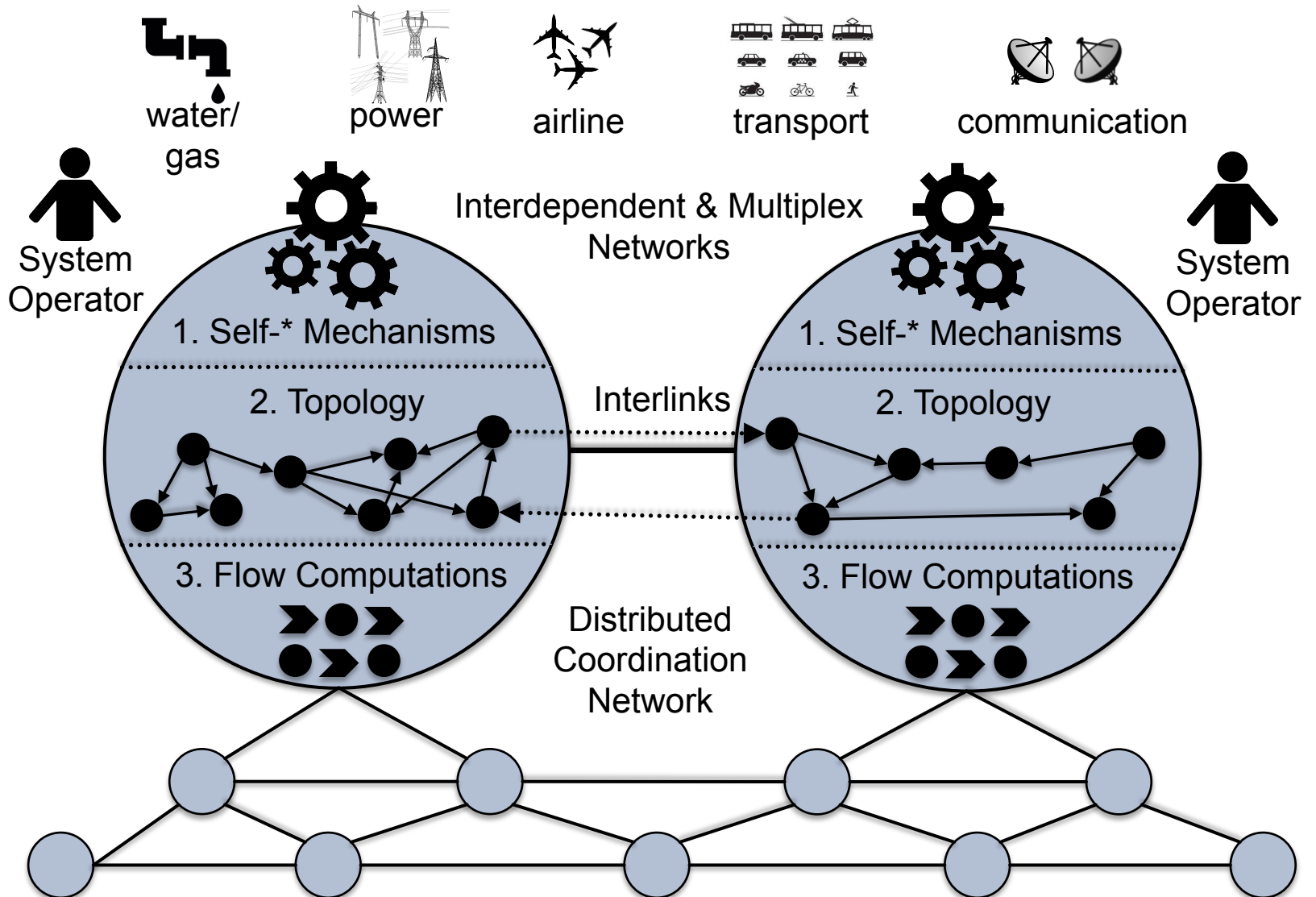
Architecture
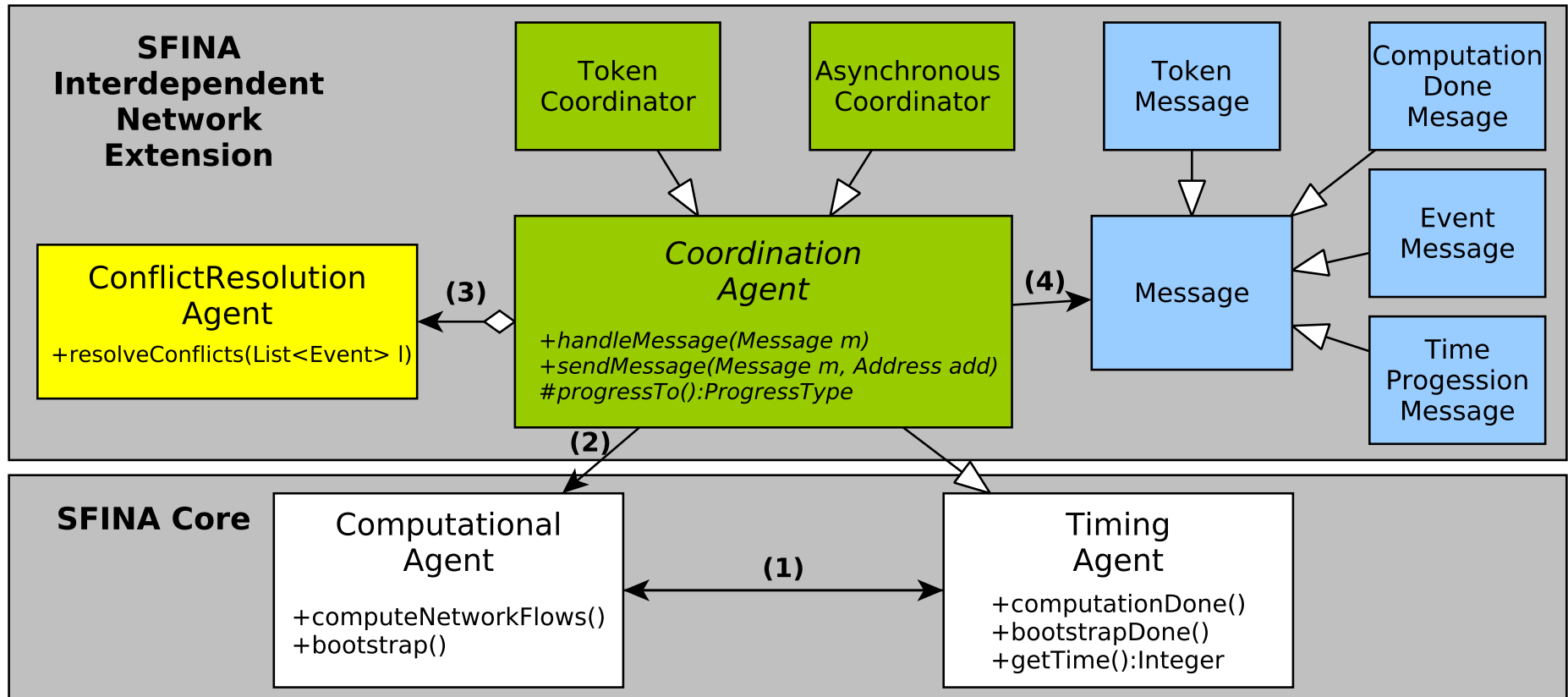
Case Study

Self-healing Interdependent Power Networks

Flowgates

Transmission system power exchanges

SPP, MISO Move Ahead on Flowgate Rules

January 26, 2015

By Chris O'Malley

The Federal Energy Regulatory Commission last week approved SPP's market-to-market coordination rules with MISO, after the two RTOs resolved an earlier dispute over the creation of flowgates (*ER13-1864*).

SPP had originally proposed restrictions on the right of either RTO to designate a new M2M flowgate — transmission lines or transformers monitored for overloads — outside of their mutually agreed-upon scheduling timeframes.

SPP would have allowed the creation of flowgates during extenuating circumstances or when the RTO seeking a new designation compensated the other for any re-dispatch that resulted.

PJM and Exelon filed comments supporting SPP's position, with Exelon noting that MISO created 500 new flowgates between September 2011 and October 2012, while PJM designated only 80. SPP's transmission owners also supported the restrictions, citing the administrative burdens of complicated resettlement processes related to re-dispatches.

MISO and its Independent Market Monitor opposed SPP's proposal, which they said would effectively give one RTO veto power. The Monitor noted that M2M flowgates are dynamic, responding to changes in outages and constraint definitions.
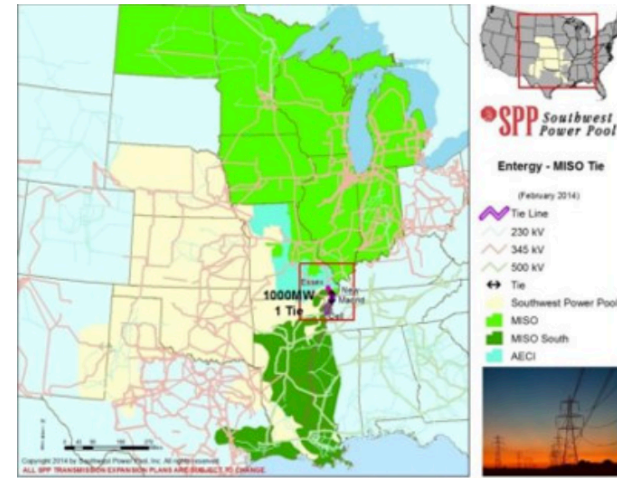
Energy Markets

Microgrid power exchanges by prosumers

Green Power Exchange review: peer-to-peer energy trading via blockchain

May 26, 2018 By Alex Puriy

f Share	Tweet

The Event Horizon 2018 conference drew loads of professionals from energy and blockchain industries. The main objective was to connect developers and startups creating software infrastructure for renewable energy trading via blockchain with investors and venture capital firms looking to support promising projects.

Event Horizon 2018

Future of renewable energy

The interest to renewable energy doesn't arise solely from the promotion of clean energy, but also because the cost of electricity generation from renewables is becoming cheaper than from traditional fossil fuels. This leads to the fact that now there are concerted efforts amongst developed countries to switch from dirty forms of power generation to cleaner and more sustainable energy sources.

According to the International Renewable Energy Agency (IRENA), the current cost spectrum for fossil fuel power generation ranges from $0.05-$0.17 per kilowatt hour (kWh). Global weighted average costs in 2017 for onshore wind and solar PV stand at $0.06 and $0.10 per kWh respectively. Solar PV costs are expected to halve by 2020, so the best onshore wind and solar PV projects could deliver electricity for as little as $0.03 cents per kWh, or less.

Reliability & Security

Challenge: *Interdependencies from cause of instability to opportunity for higher resilience?*

## Is Germany Outsourcing Its Future Energy Security?

By ROMAN KILISEK
on June 12, 2015 at 12:05 PM

💬 Post a Comment

Pylons are seen situated over a residential housing area on June 3, 2005 in Birmingham, England. (Photo by Matt Lewis/Getty Images)

German Federal Minister for Economic Affairs and Energy (BMWI) Sigmar Gabriel recently touted another step towards enhancing EU energy security via regional cooperation. The Minister and 11 of his colleagues from neighboring European countries signed a political declaration meant to ensure the reliable and secure supply of electricity among those countries. Dubbed "12 electrical neighbors" – in essence a "mini energy union' – and the idea itself dating back to July 2014 based on a German initiative, Minister Gabriel was quick to liken this latest development to the "usher[ing] in of a new era of energy policy."

Case Study
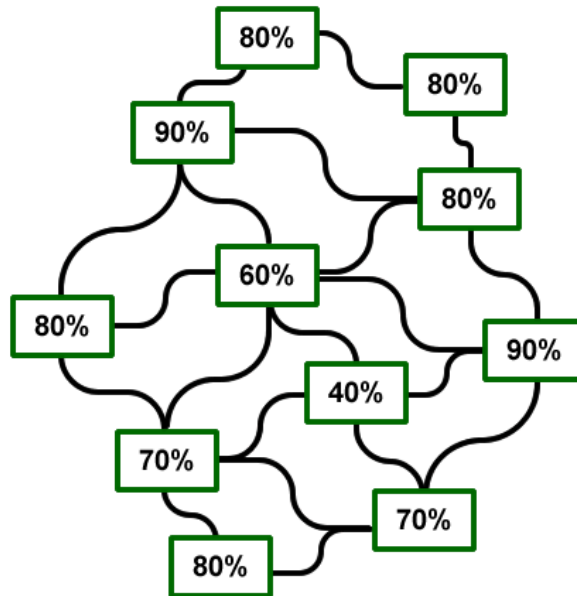
Network running normally

Self-healing Interdependent Power Networks

1. Failure of a power line triggers a cascading failure, network is **damaged**
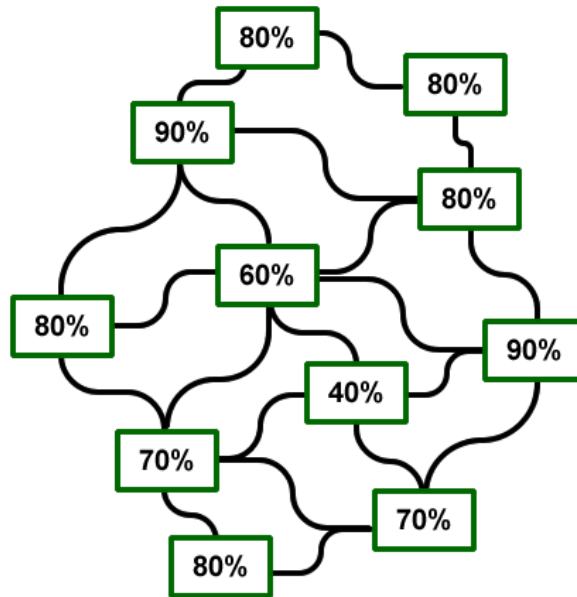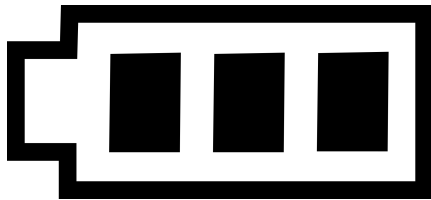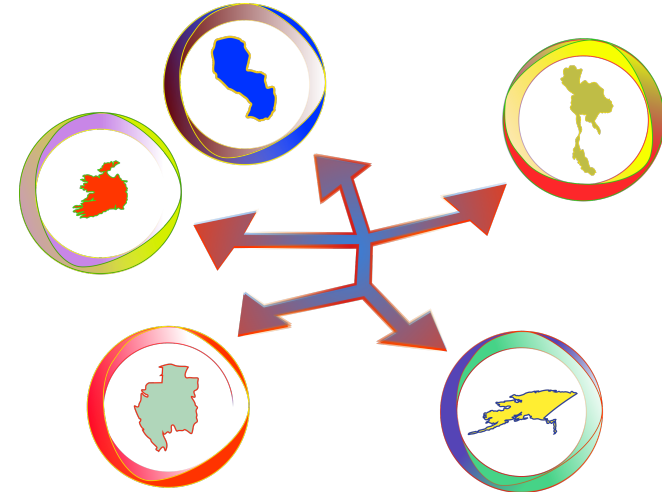
Case Study

Network running normally

Self-healing Interdependent Power Networks

1. Failure of a power line triggers a cascading failure, network is **damaged**
2. Connect the damaged network with a **healer** network (reservoir)
3. Load reduction in the damaged network by **pushing powe**r to the healer network
4. Load increase in the damaged network by **pulling power** from the healer network
5. Evaluation of **reliability improvement**

Experimental Settings

Self-healing: modeled as _particle swarm optimization_

IEEE reference networks
(_topology_+_physical characteristics_+_load profile_)
case-30, case-39, case-57, case 2383

N-1 contingency analysis
1. Remove a link
2. Compute cascading failure
3. Measure disaster
4. Restore network and repeat for all links
5. Probabilistically evaluate reliability

Reliability measures
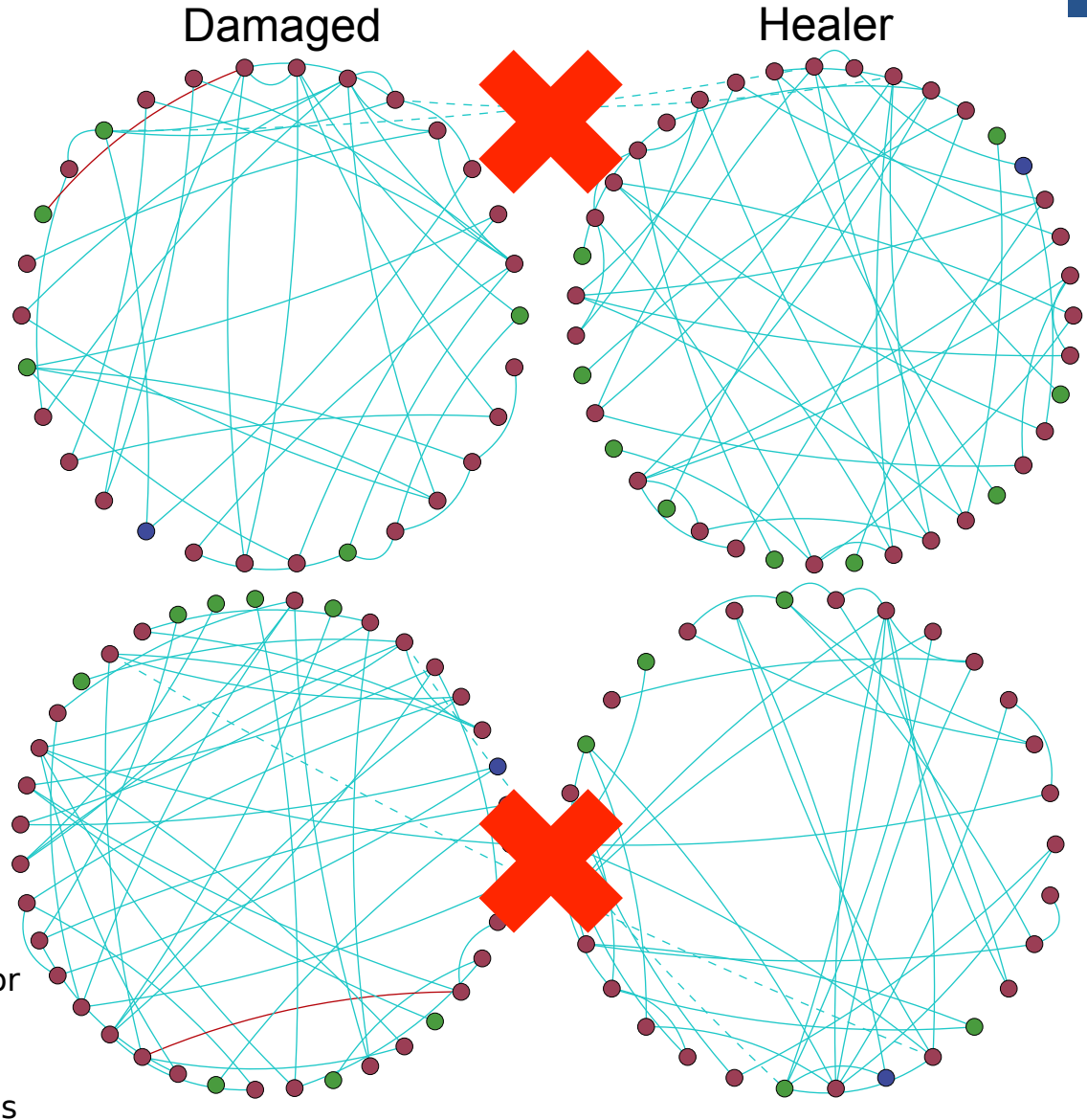_Damage spread_: links survivability+iterations
Relative load served

AC power flow analysis (InterPSS): Non-linear power dynamics

Visualization

Damaged

Healer

case-30 <> case 39

Line failure
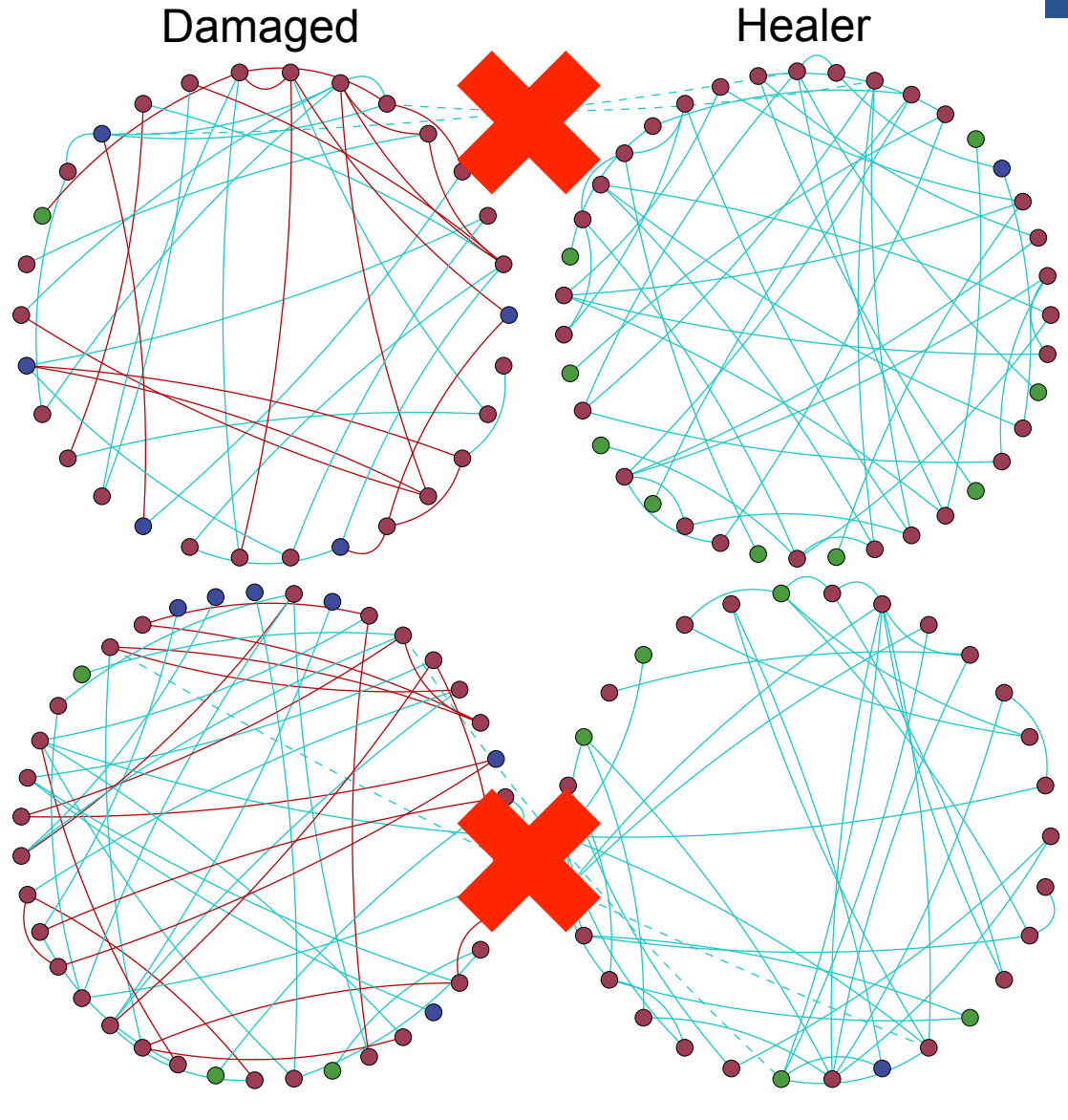
case-39 <> case 30

Active Link
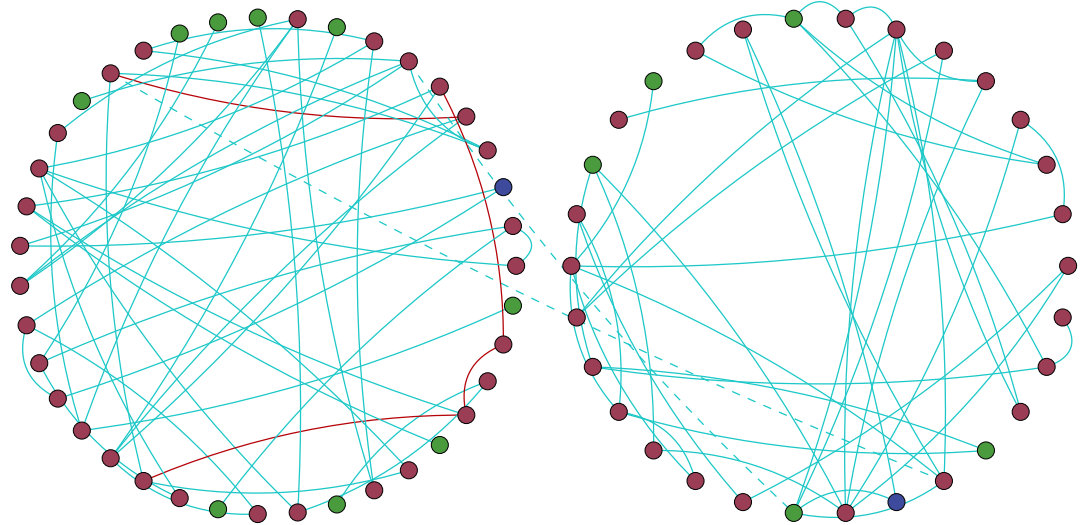
Interdependent Link

Inactive Link

Generator

Bus

Slack Bus

Visualization

Damaged

Healer

case-30 <> case 39

Cascading failure

case-39 <> case 30

— Active Link

-- Interdependent Link

— Inactive Link

● Generator

● Bus

● Slack Bus

Visualization

Damaged   Healer
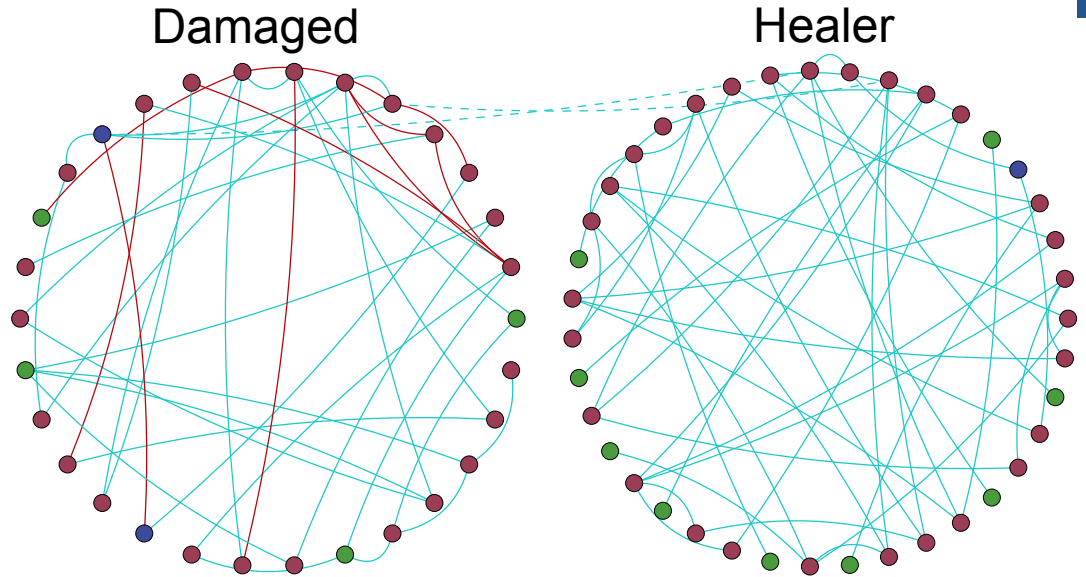
case-30 <> case 39

Self-healing

case-39 <> case 30

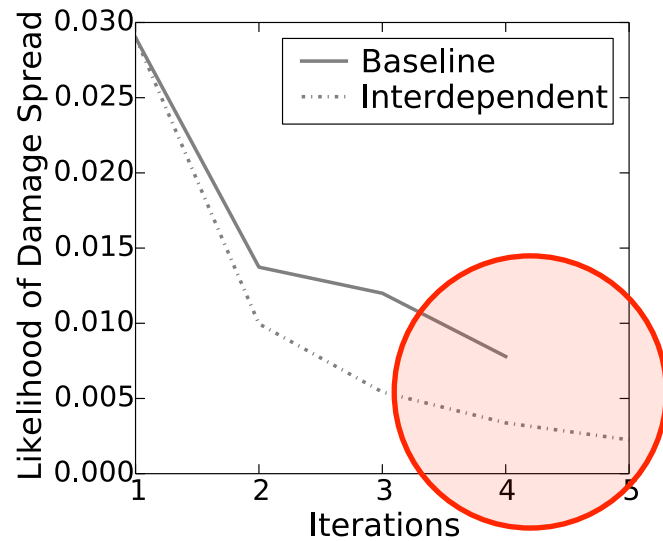—— Active Link   🟢 Generator

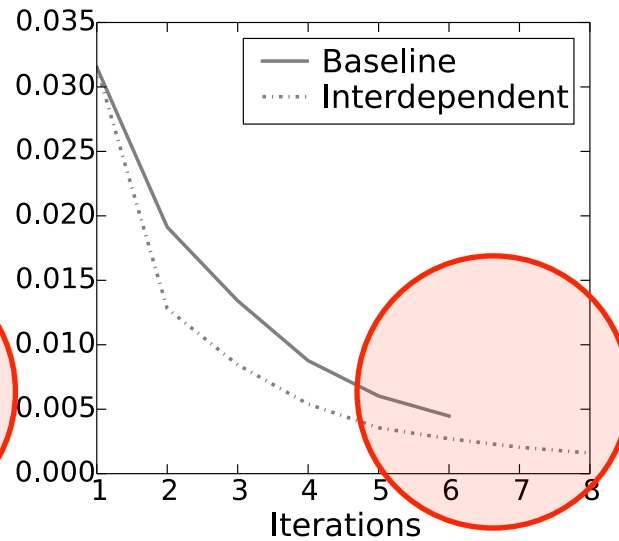- - - Interdependent Link   🔴 Bus

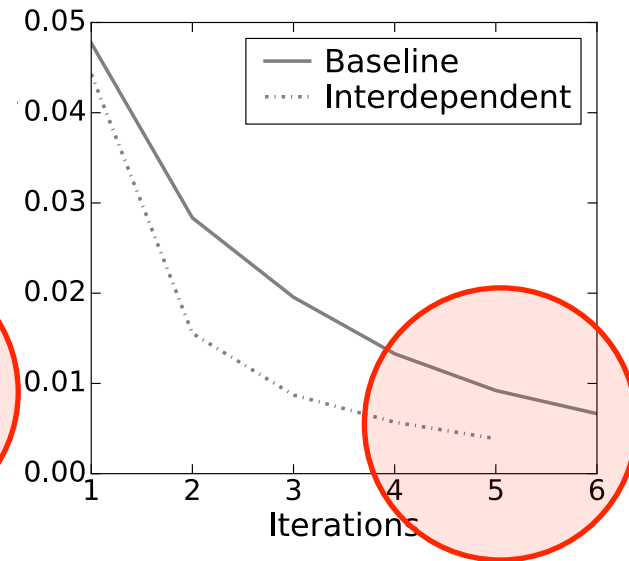—— Inactive Link   🔵 Slack Bus

Damage Spread

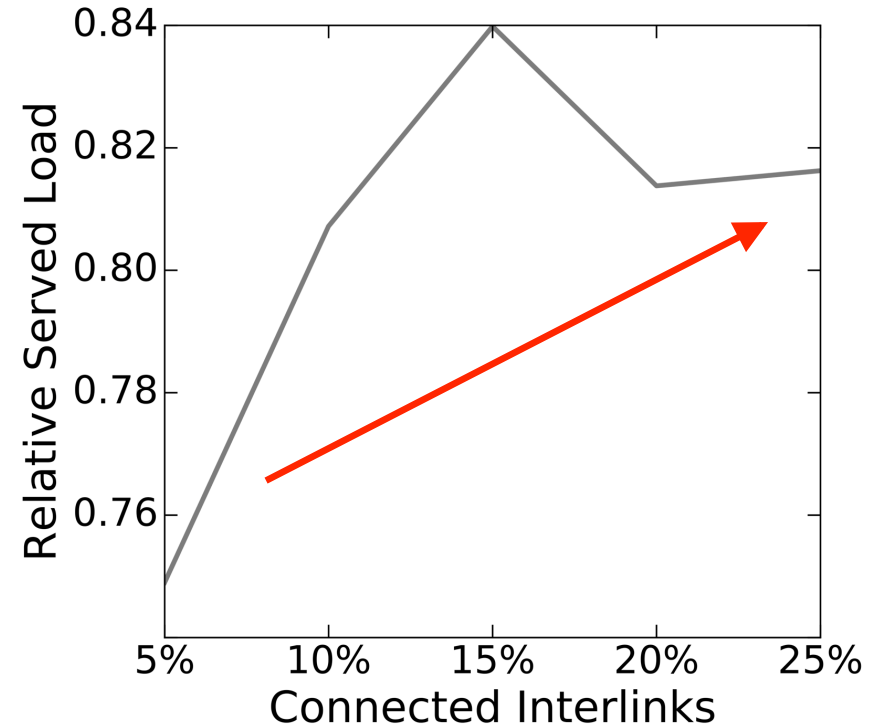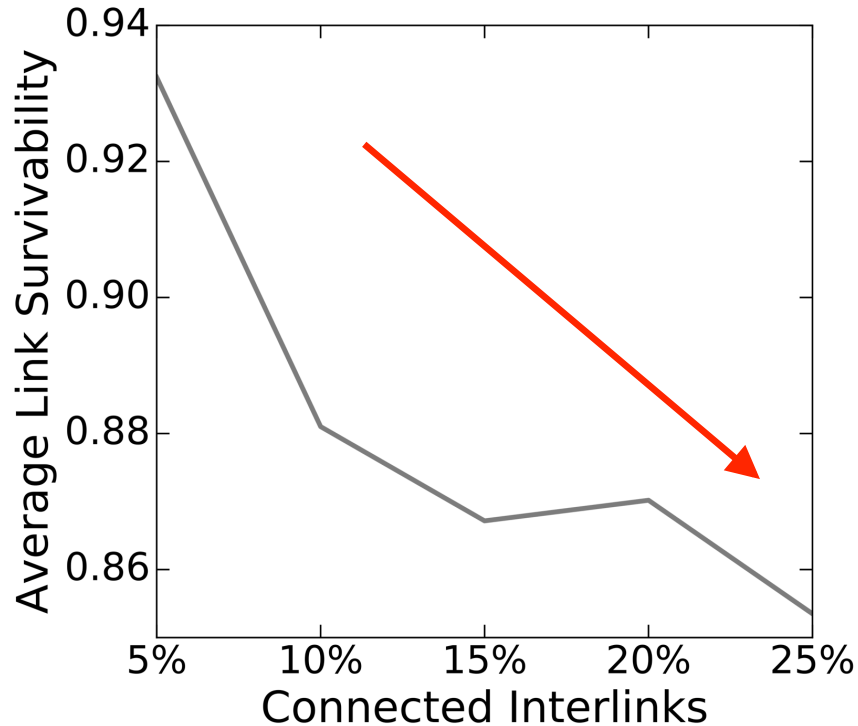case-30 <> case 39   case-39 <> case 30   case-57 <> case 2383

Number of Interlinks

case-30 <> case 39

Trade-off: *links survivability* vs. *served load*

Conclusion & Future Work

SFINA Artifact: Multi-domain modeling & simulation of flow networks **made feasible**!

Solid basis for community building: *Open source code, domain backends, application examples, GUI, documentation*

Proof-of-concept: Self-healing synergies against cascading failures
Simple applicability of general-purpose computational intelligence in a domain problem traditionally addressed by power engineers

Experimental findings
1. Significant reduction of damage level
2. Trade-offs of interdependencies*: links survivability vs. served load*

Future work: Interdependent networks of different domains
Power-communication, power-transport, power-water-gas networks

Questions?

ETH Zurich

Evangelos Pournaras

epournaras@ethz.ch

www.sfina-net.org
http://sfina-net.org/shared/SFINA.zip

[1] Evangelos Pournaras, Jose Espejo-Uribe*, Self-repairable Smart Grids via Online Coordination of Smart Transformers*, IEEE Transactions on Industrial Informatics, Vol. 13, Nr. 4, pp. 1783-1793, 2017

[2] Evangelos Pournaras, Ben-Elias Brandt, Manish Thapa, Dinesh Acharya, Jose Espejo-Uribe, Mark Ballandies, Dirk Helbing, *SFINA-Simulation Framework for Intelligent Network Adaptations*, Simulation Modelling Practice and Theory, Vol. 72, pp. 34-50, 2017

[3] Manish Thapa, Jose Espejo-Uribe and Evangelos Pournaras, *Measuring Network Reliability and Repairability against Cascading Failures*, Journal of Intelligent Information Systems, 2017

Time Management