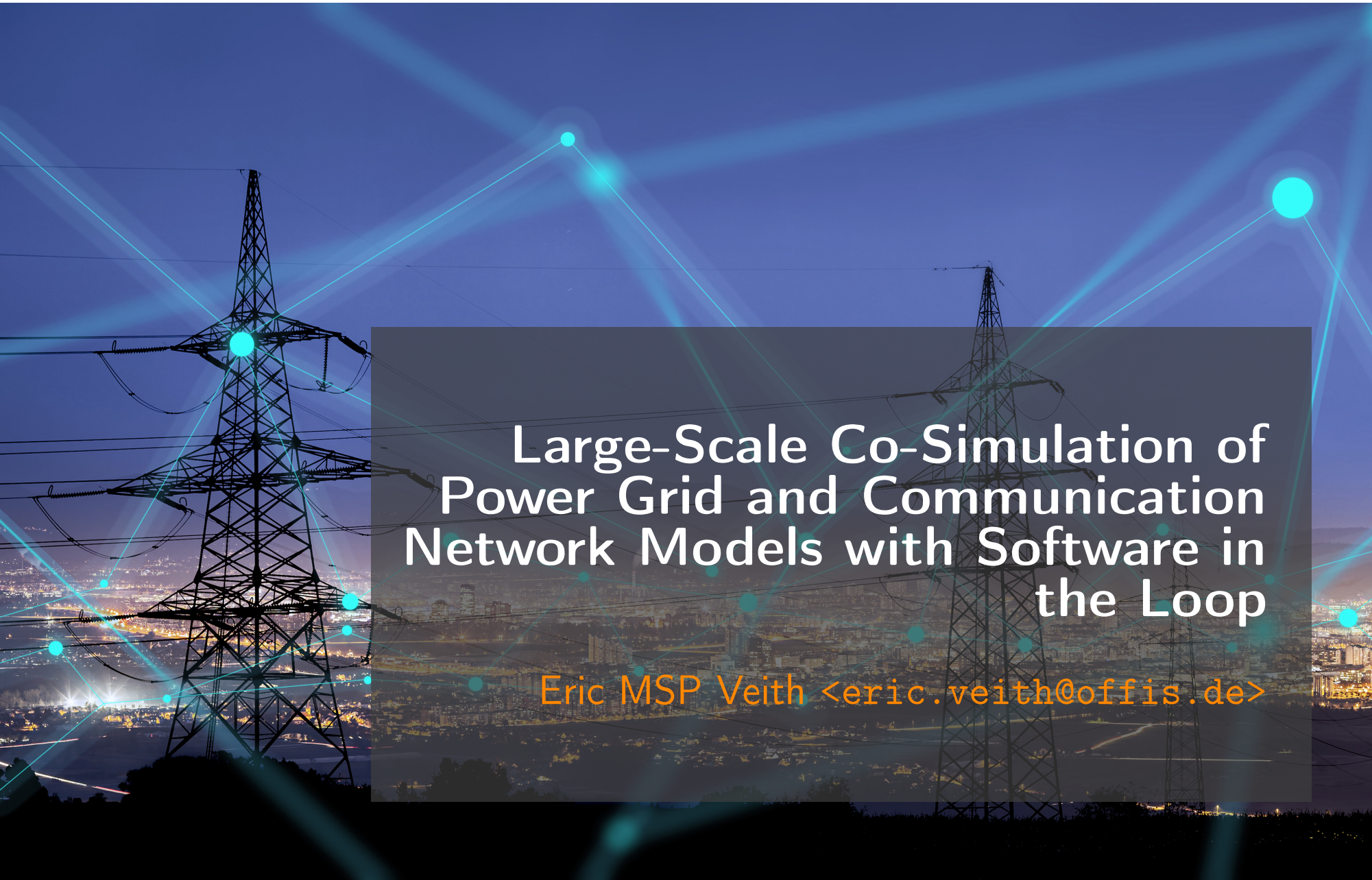


Large-Scale Co-Simulation of Power Grid and Communication Network Models with Software in the Loop

Eric MSP Veith <eric.veith@offis.de>

About the Authors

Eric MSP Veith Manager of the research group *Power Systems Intelligence* at *OFFIS*, Oldenburg, Germany. Likes to have Deep Reinforcement Learning agents compete for control of the power grid; researches AI-based modelling, analysis, and resilient operation of CPS.

Jawad Kazmi Researcher at AIT, Vienna, Austria. Researches flexible, yet complex test beds with HIL and SIL for real-time and steady-state analysis of the power grid.

Stephan Balduin Researcher in the *Power Systems Intelligence* group at *OFFIS*. Researches efficient sampling of complex CPS in order to create surrogate models for fast simulation.

Motivation

Interaction of Power Grid and ICT

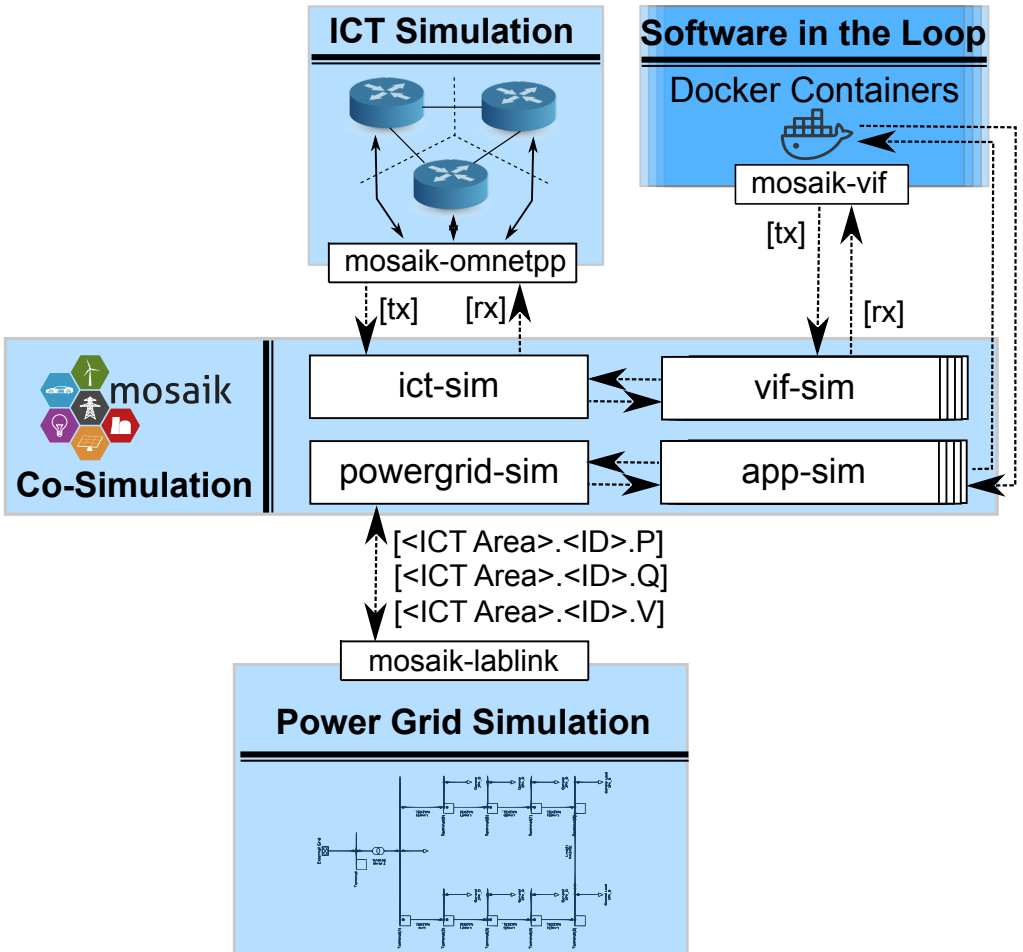
- Nodes in a power grid become a software plattforms
  - Obviously Smart Metering
  - Direct-marketing of PV, Wind
  - Virtual Power Plants (through, e.g., MAS)
  - even Transformers
- Software needs to be updated and deployed
- Software updates interact with the power grid
  - Wrong configurations, bugs in the software
  - Attacks on nodes or updates
  - Power fluctuations cause updates to fail
- **Simulation of power grid, ICT, and software required**: Witness interactions in all domains
- Requires SIL

Co-Simulation Schema

Nodes exist Threefold

Each node exists thrice:

- Power grid representation (simulate power, voltages, etc.)
- ICT representation (route packets, observe losses)
- Real software (actual update)



The ICT Environment

Three Areas of Interest

Network	10.64.0.0/10
Network Range	10.64.0.1 – 10.127.255.255
Dedicated Network	10.64.0.0/12
Shared Links Network	10.80.0.0/12
High-Impairment Network	10.96.0.0/12
Misc./Unallocated	10.112.0.0/12

- Power grid as MV ring with LV branches
- Each part can be placed in one of the three zones
- Zones modelled through delay primarily

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Dedicated Links Area 1 Gbit/s dedicated links

$$d \sim 10 + 50 \cdot f_\lambda(x, 1) \text{ [ms]} . \tag{1}$$

$f_\lambda(x, 1)$: Exponential distribution

Shared Links Area VPN over public infrastructure

$$d \sim \mathcal{N}(250; 20) \text{ [ms]} . \tag{2}$$

$\mathcal{N}(250; 20)$: Normal distribution

High-Impairment Area Mostly wireless/mobile, spotty connections

$$d \sim \mathcal{U}[100; \infty] \text{ [ms]} , \tag{3}$$

$\mathcal{U}[100; \infty]$: Uniform distribution

ICT Simulation

Interface between *mosaik* and *OMNeT++*

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```
someapp_vif_entity = \
    someapp_vif_simulator.vif()
someapp_ict_entity = next(
    x for x in ict_model.children
    if x.eid == \
        'SimulatedNetwork/SomeApp/app-0')

world.connect(someapp_vif_entity,
              someapp_ict_entity,
              ('tx', 'rx'))
world.connect(someapp_ict_entity,
              someapp_vif_entity,
              ('tx', 'rx'),
              time_shifted=True,
              initial_data={'tx': None})
```

Design Considerations

SIL is tricky

- Each docker container has a `tun` adapter — Setup routes carefully!
- Efficient interaction between co-simulator and docker container: Boost ASIO (*vif*)
- Multiplexer for co-simulation (*vif-sim*)
- Communication between *vif* and *vif-sim* via UDP (TCP Meltdown)

Test Results

RTT and Throughput