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Robustness of Interdependent Cyber-Physical Networks

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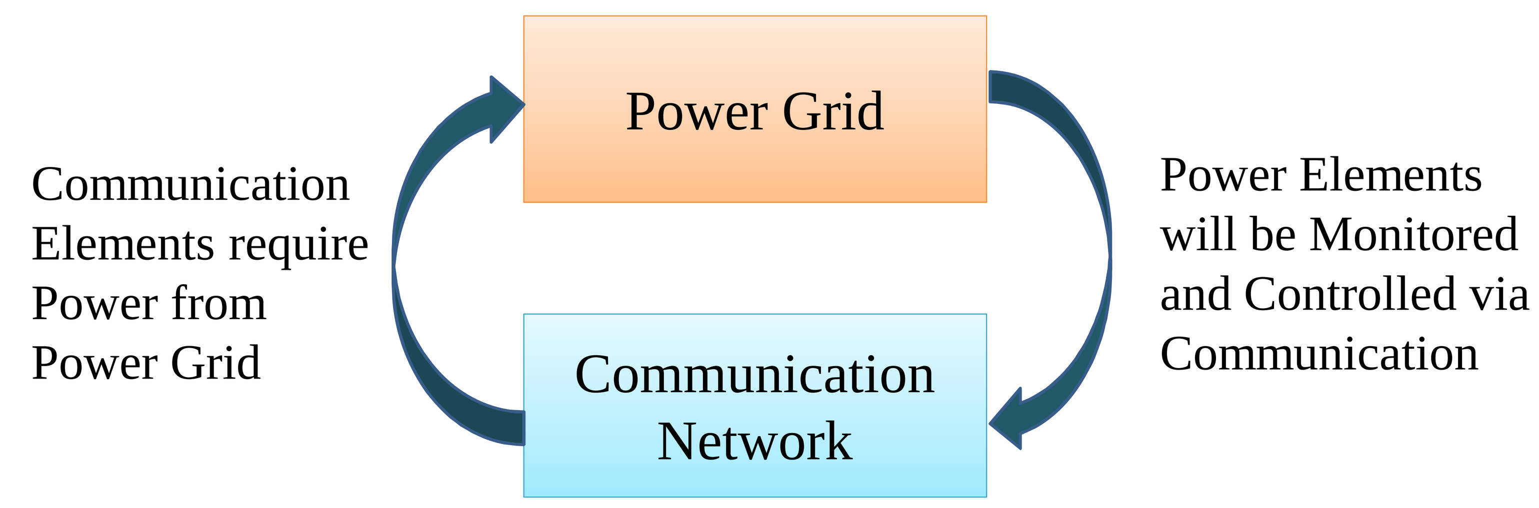
LIDS

Motivation

Concerns in Current and Future Power Grid:
1- Non-decreasing Trend of Large Blackouts and their Impacts;
2- Extra Fluctuations due to Integrating Renewable Energy and Electric Vehicles.

Necessity for a Wide Area Monitoring and Control System → **Requires a Communication Network**

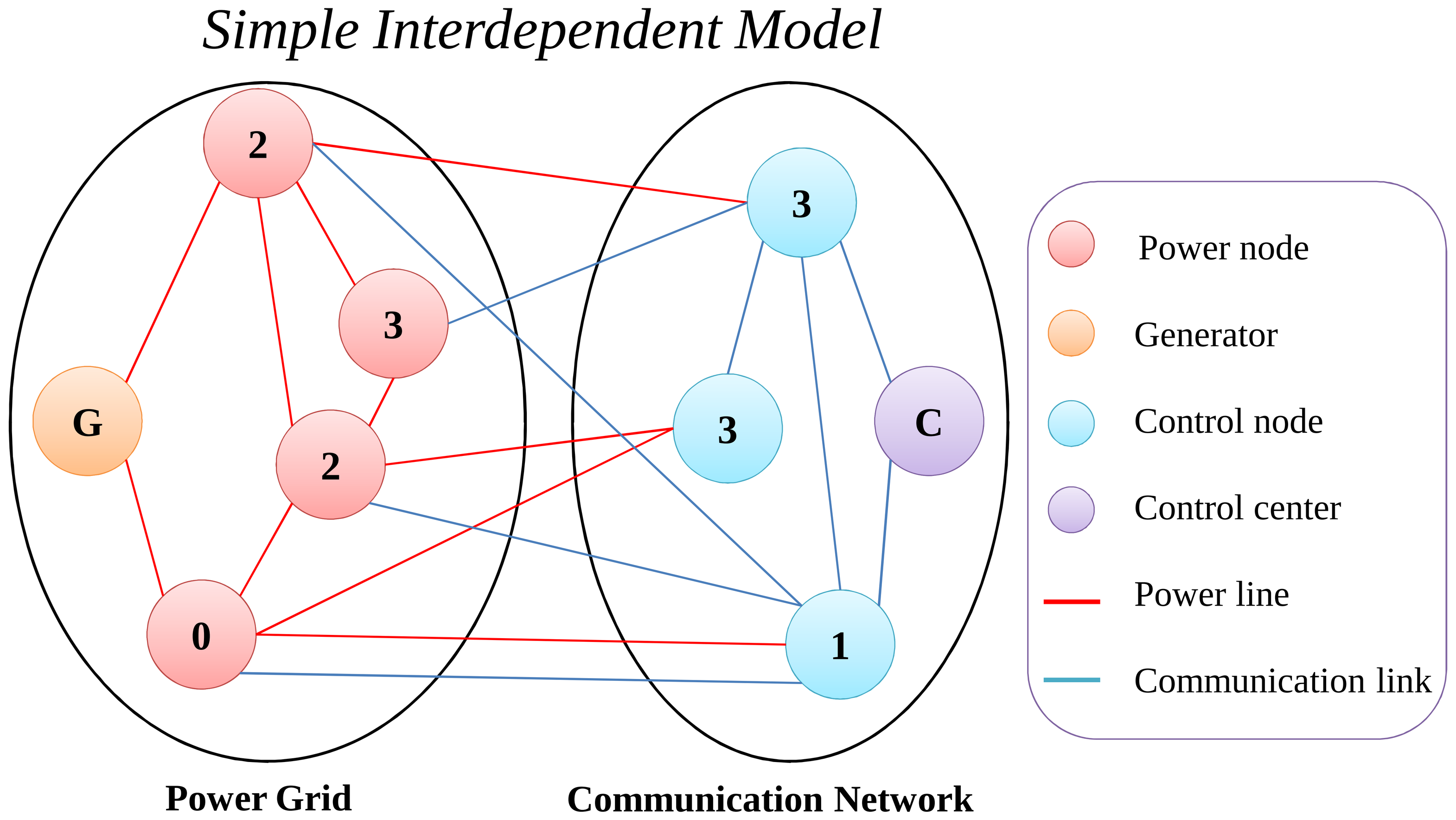
Cyber-Physical Interdependency



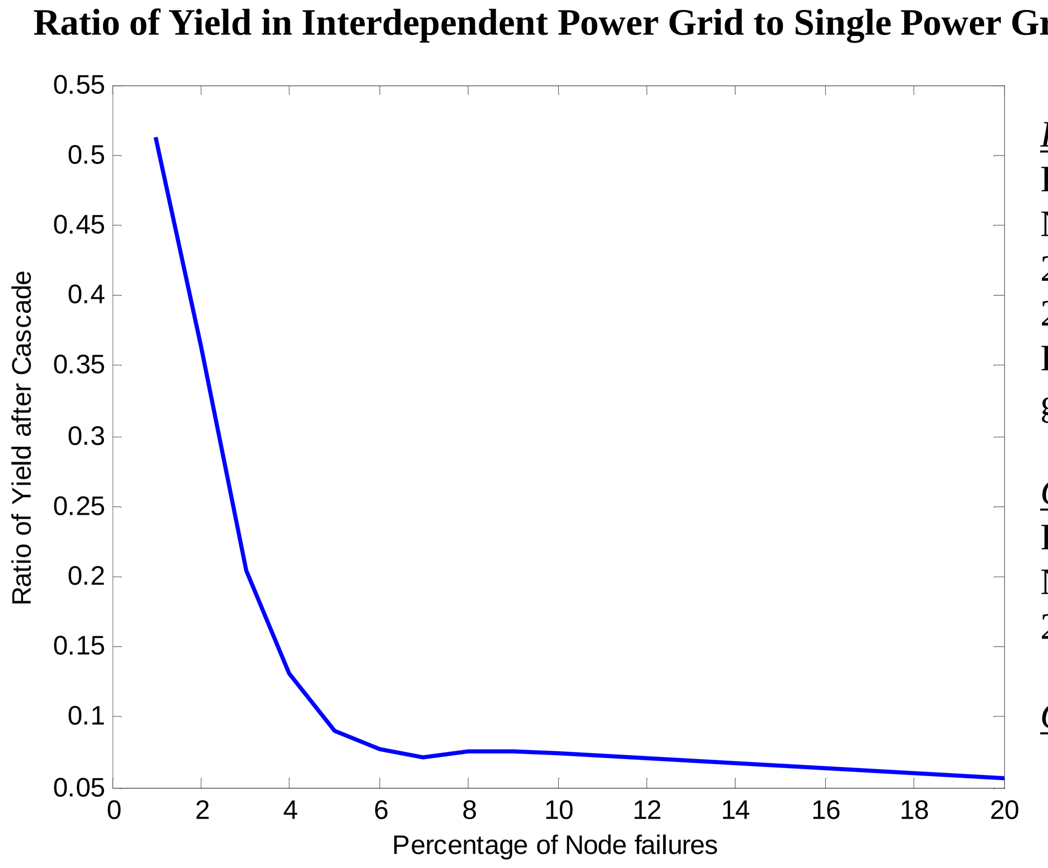
Failures in Power Grid ⇄ **Failures in Communication Network**

Effect of Interdependency on the Cascade of Failures

Simple Interdependent Model



Ratio of Yield in Interdependent Power Grid to Single Power Grid



Power Grid:
Random Erdos-Renyi Graph
Node Num=200, Node Degree=4
20% of nodes are generators
20% of nodes are loads
Power values are randomly generated in the range [1000,2000]

Communication Network:
Random Erdos-Renyi Graph
Node Num=200, Node Degree=4
20% of nodes are control centers

One-to-One Interdependency

Challenge 1
Modeling Interdependency and Cascading Failures

Dependency of Communication on Power Grid

- Modeling the Impact of Loss of Power
  1) Deterministic Failure: All communication nodes receive power from power grid
  2) Probabilistic Failure: Some communication nodes have backup generator
  3) Time Dependent Failure Model: Some communication nodes have backup battery
- Modeling the Impact of Loss of Communication Nodes: Either Disconnection or Congestion

Dependency of Power Grid on Communication

- Modeling the Impact of Loss of Monitoring/Control
  1) Deterministic Failure: As a local control decision
  2) Probabilistic Failure:
     a) Loss of Control on Generators – Frequency Collapse
     b) Loss of Control on Loads – Voltage Collapse
- Modeling the Impact of Delay on Monitoring/Control

Challenge 2
Developing Optimal Control Policies

Centralized Control

- Impact of Loss or Delay in Communication on Control
- Types of Control:
  1) General Load Shedding: Mitigating cascade of failures both inside and between networks
  2) Frequency Control: e.g. AGC
  3) New Technologies: e.g. FACTS

Distributed Control

- Operators in Different Regions Do Not Share Data

  1) Regional Control Policy with Limited Information
  2) Minimum Requirement for Information Sharing
  3) Regulation Policies to Increase Incentives of Operators for Data Sharing

Challenge 3
Analysis and Design

Analysis

Impact of Interdependency and Control

- Defining Metrics:
  1) Percentage of Unserved Load
  2) Percentage of Failed Elements
  3) Connectivity
- Finding the Most Vulnerable and Robust Areas
- Statistical Analysis of Vulnerable and Robust Areas

Design

- Power Grid Improvement:
  1) Adding New Transmission Lines
  2) Increasing the Capacity of Current Transmission Lines
- Interdependency Design: Decrease Dependency
  1) Increasing Redundancy
  2) Increasing Backup Batteries/Generators
- Communication Design:
  Increasing Redundancy to Guarantee Connectivity and Decrease Congestion

References:
1- M. Parandehgheibi and E. Modiano, “Optimal Control Policy for Mitigating Failures in Interdependent Power grids and communication networks”, To be submitted.
2- M. Parandehgheibi and E. Modiano, “Robustness of Interdependent Networks: The case of communication networks and the power grid”, Global Communications Conference (GLOBECOM), IEEE, December 2013, Atlanta, GA.
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