1. Introduction

We study the effectiveness of recovery strategies for a dynamic model of failure spreading in networks. These strategies control the distribution of resources based on information about the current network state and network topology. In order to assess their success, we have performed a series of simulation experiments. The considered parameters of these experiments are the network topology, the response time delay, and the overall disposition of resources. Our investigations are focused on the comparison of strategies for different scenarios and the determination of the most appropriate strategy. The investigation of causal networks provides a methodology which allows one to assess the dependencies and potential cascading effects.

2. Modeling the dynamics of disaster spreading

A. Node dynamics:

\[ \frac{dx_i}{dt} = -\gamma_i + \sum_{j \neq i} M_{ij} \left( 1 - f_{ij} \right) \theta_j + \zeta(t) \]

- state of the node
- usual situation
- node is destroyed
- node threshold
- time delay
- link strength
- internal noise
- fit parameters

B. Mobilization of resources:

\[ r(t) = a_1 t^b \exp(-c t) \]

- healing rate
- node out-degree
- fit parameters

C. Activation of resources:

Assumptions:
- Resources have only a positive influence on the state of the node
- Initial recovery rate is positive (internal resources) 1/\( \gamma_i = 1/\tau_{init} > 0 \)
- The speed of recovery process is limited i.e. for \( R_i = 0 \) we get 1/\( \gamma_i = 1/\beta_2 > 0 \)

\[ R_i(t) = \frac{1}{\tau_{init} + \gamma_i \exp(-c \tau_{init})} \]

- cumulative resources
- initial healing rate
- fit parameters

D. Disaster management and disaster recovery strategies:

- Network topology
- Level of damage
- Uniform dissemination
- out – degree based dissemination
- Uniform reinforcement of challenged nodes
- Simple targeted reinforcement of destroyed nodes
- Simple targeted reinforcement of highly connected nodes
- out – degree based targeted reinforcement of destroyed nodes

3. Worst case scenario

We determined the minimum required resources \( R_{\text{min}} \) as a function of the response strategy and the network topology, and we study how \( R_{\text{min}} \) changes when the response time delay increases. \( R_{\text{min}} \) is the minimum quantity of resources that guarantees the complete recovery of the network for each particular scenario. We estimate this quantity by performing a huge number of numerical calculations separately for each studied network. In each simulation run, the location of the initial disturbance and the time delays \( t_{ij} \) are randomly varied.

4. Average impact of the different strategies

A. Relative difference in damage between strategies \( S_6 \) and \( S_1 \)

\[ D_{6,1} = 80 \% \]

B. Most efficient strategies

- There is no unique optimal response strategy:
  1. Strategies based on the network structure has been proved as the most suitable for scale-free structures.
  2. Strategies based on the damage information are more appropriate for regular networks.
  3. The situation in random and small-world networks depends on the time delay:
     - (short time delay => damage based strategies)
     - (large time delay => network structure based strategies).