Beyond Contingency Analysis New Approaches to Cascading Failures Risk Analysis

Los Alamos Grid Science Conference
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Credits
Good ideas: P. Rezaei, M. Eppstein
Funding: Dept. of Energy, Nat. Science Foundation
Errors: Paul Hines

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Contingency analysis

- N-1 security has been the core power systems operating principle for >50 years
- While it has served us well, it also has limitations:
  - Not all contingencies are equally **likely**.
  - Not all limit **violations** are equally important—some produce blackouts, others don't.
  - Sometimes components fail in **sets** (e.g., storms) or in **unexpected** ways (Aug. 14 2003 blackout).
  - **Binary**: Imperfect data (e.g., from neighboring areas) can change the apparent state of system from insecure to secure. (2011 SW blackout)

Beyond contingency analysis

- Valuable insight comes from contingency analysis, so replacing it would be unwise.
- However, operators need additional indicators of risk.
- Lots of ongoing work:
  PMU angle difference analysis, statistical indicators (variance, autocorrelation), energy function/Lyaponav methods, …
- Focus: Given a state estimator or day-ahead planning model, quantify ***and explain*** the risk posed by ***all*** potential cascading blackouts.

Beyond contingency analysis

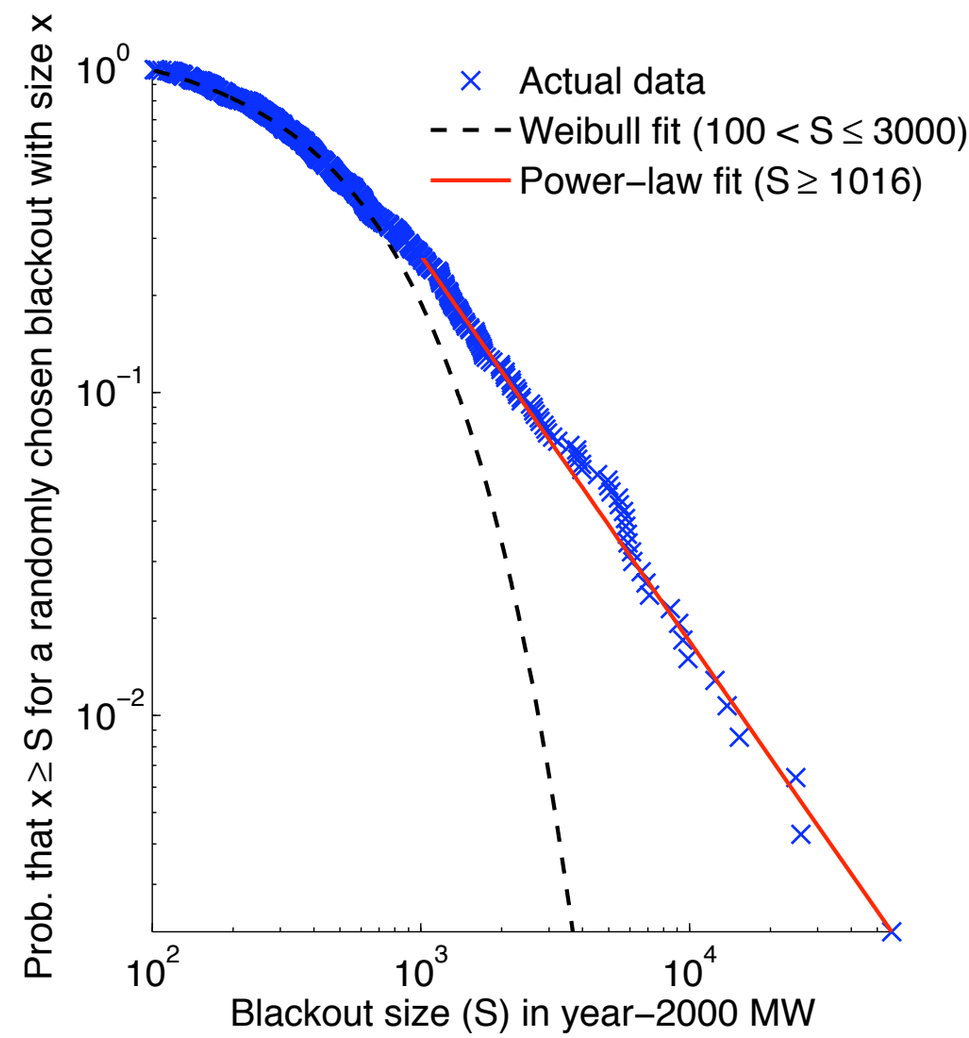
- Focus: Given a state estimator or day-ahead planning model, quantify ***and explain*** the risk posed by ***all*** potential cascading blackouts.

- Why this is hard:

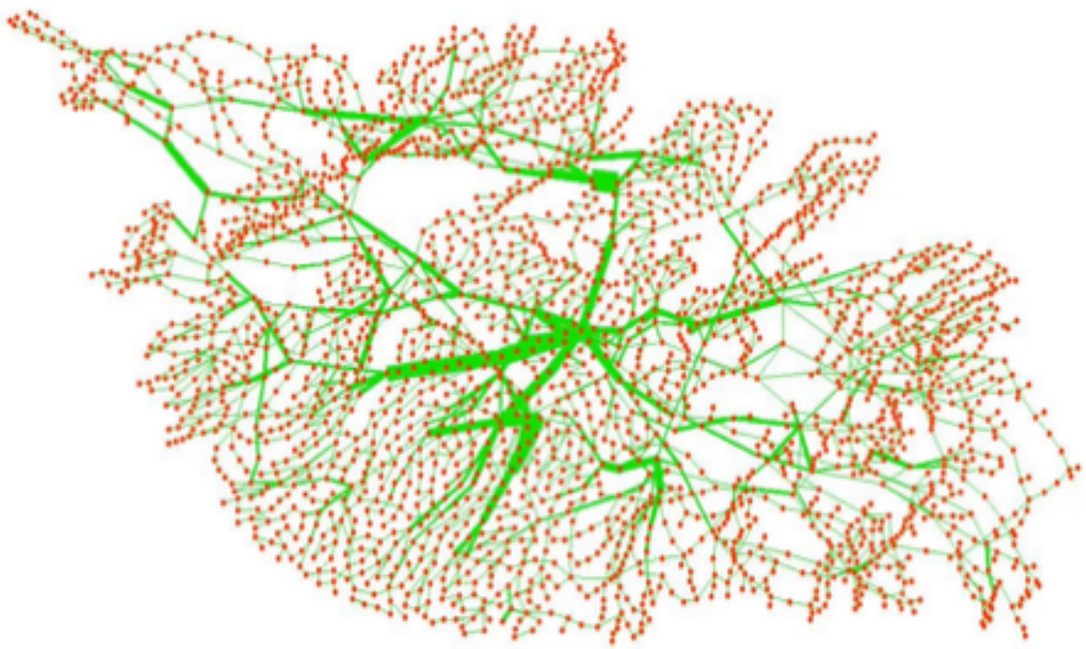
  - All n-1 contingencies and most n-{2,3,4}s do not cause blackouts. Many samples needed to find one blackout.

  - Power-law in blackout sizes means that we need many blackout simulations to describe the risk.

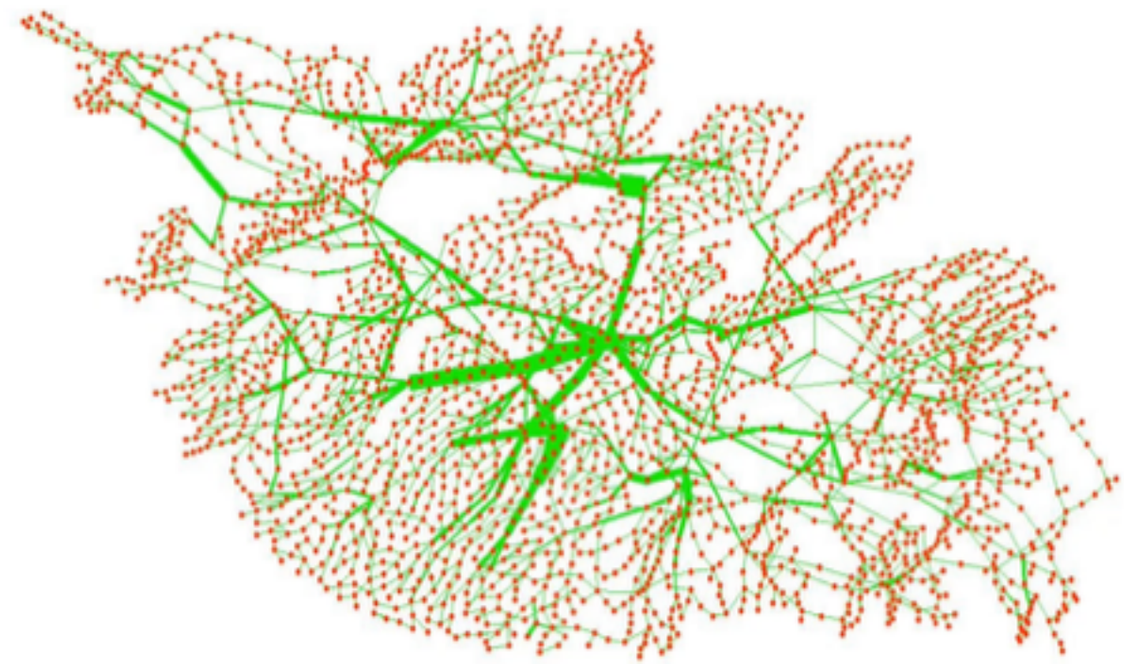
  - Explaining why is always difficult (but probably the most important thing we can do)



Illustration



Case 1 (noon tomorrow)
High blackout risk



Case 2 (2 pm tomorrow)
Low blackout risk

Both cases are secure.
What makes the two cases different?
How can we make Case 1 more like Case 2?

The Random Chemistry Method

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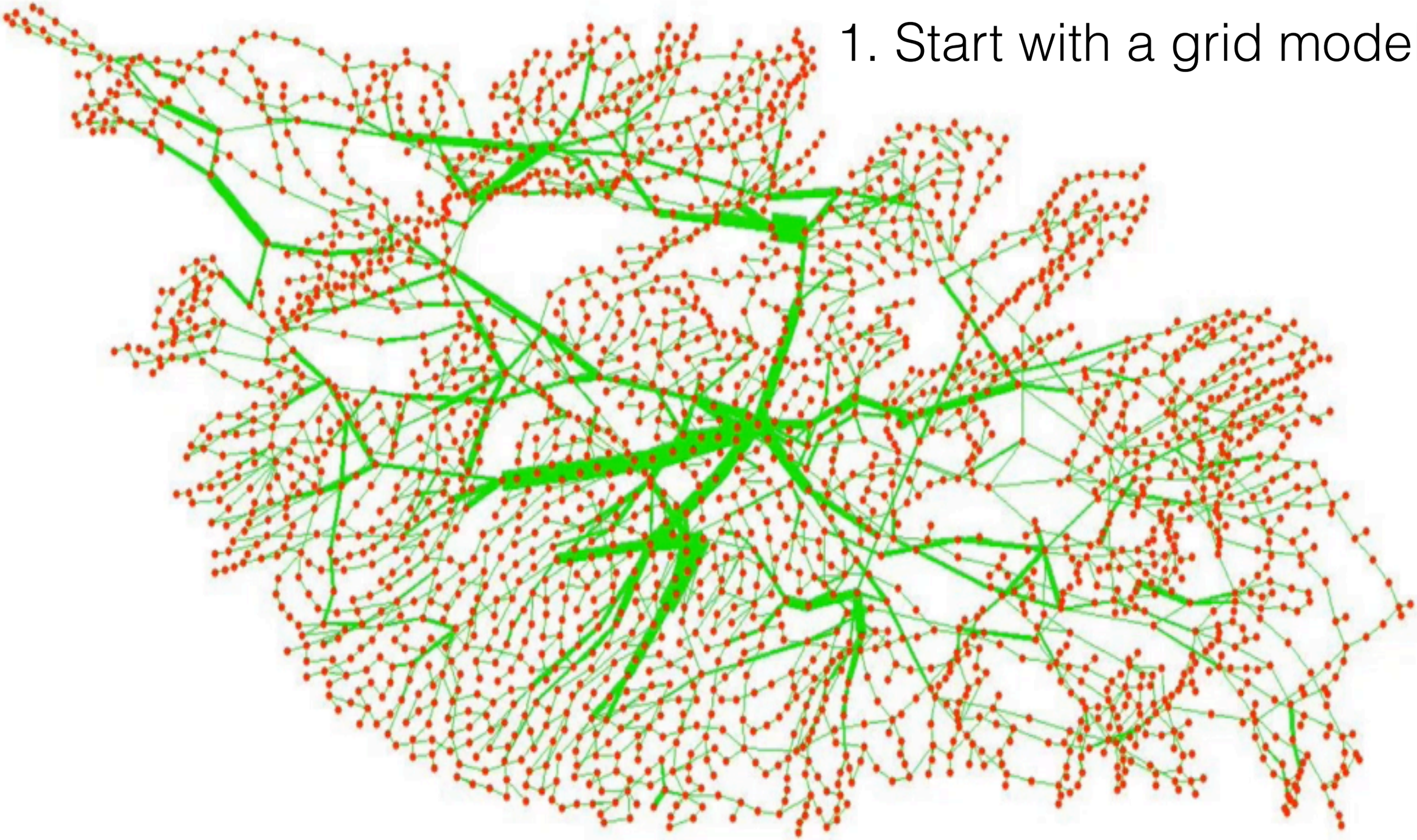
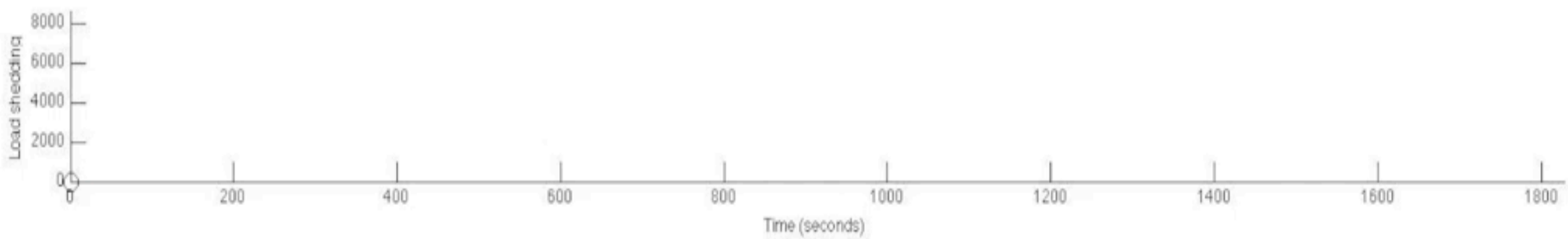
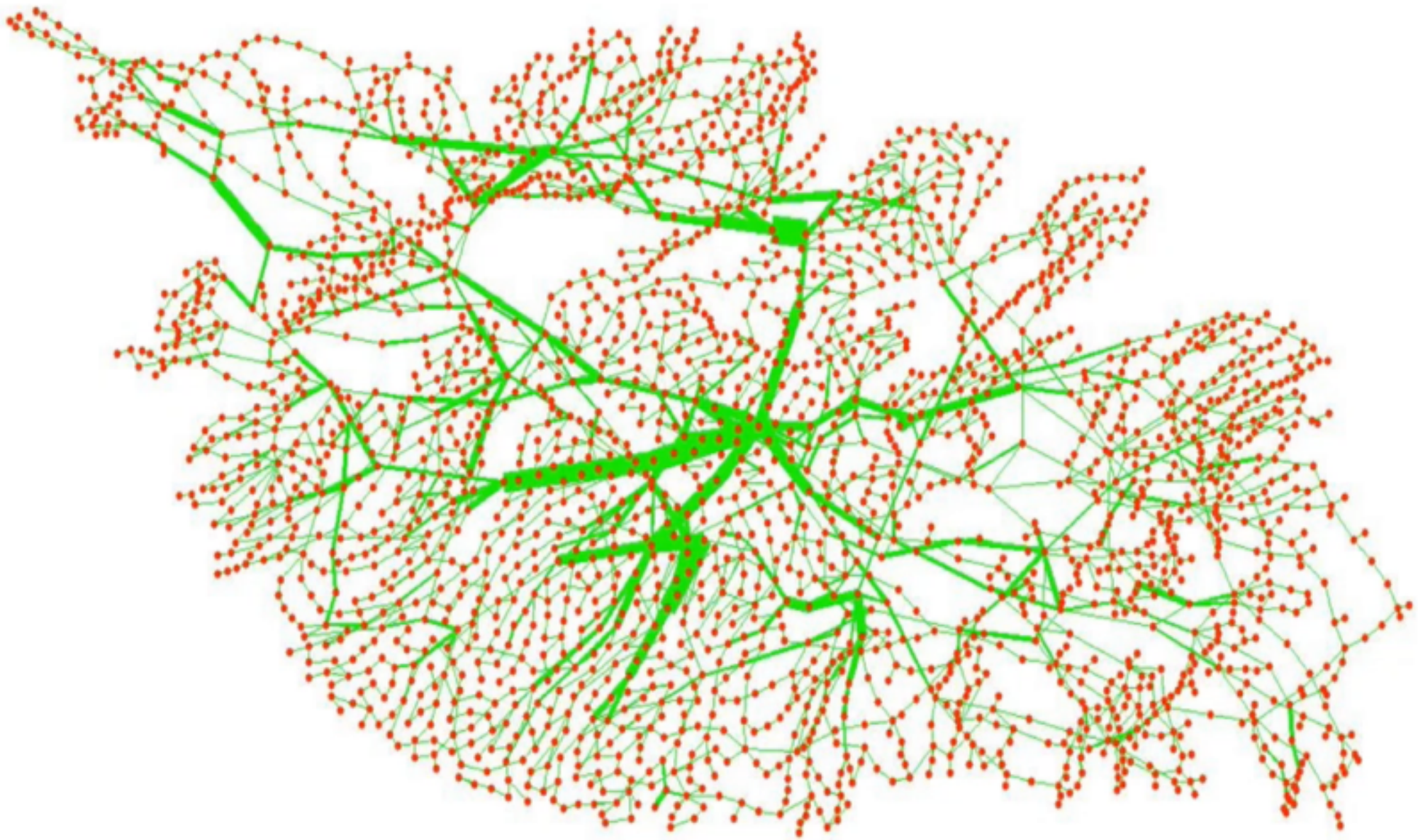
1. Start with a grid model.

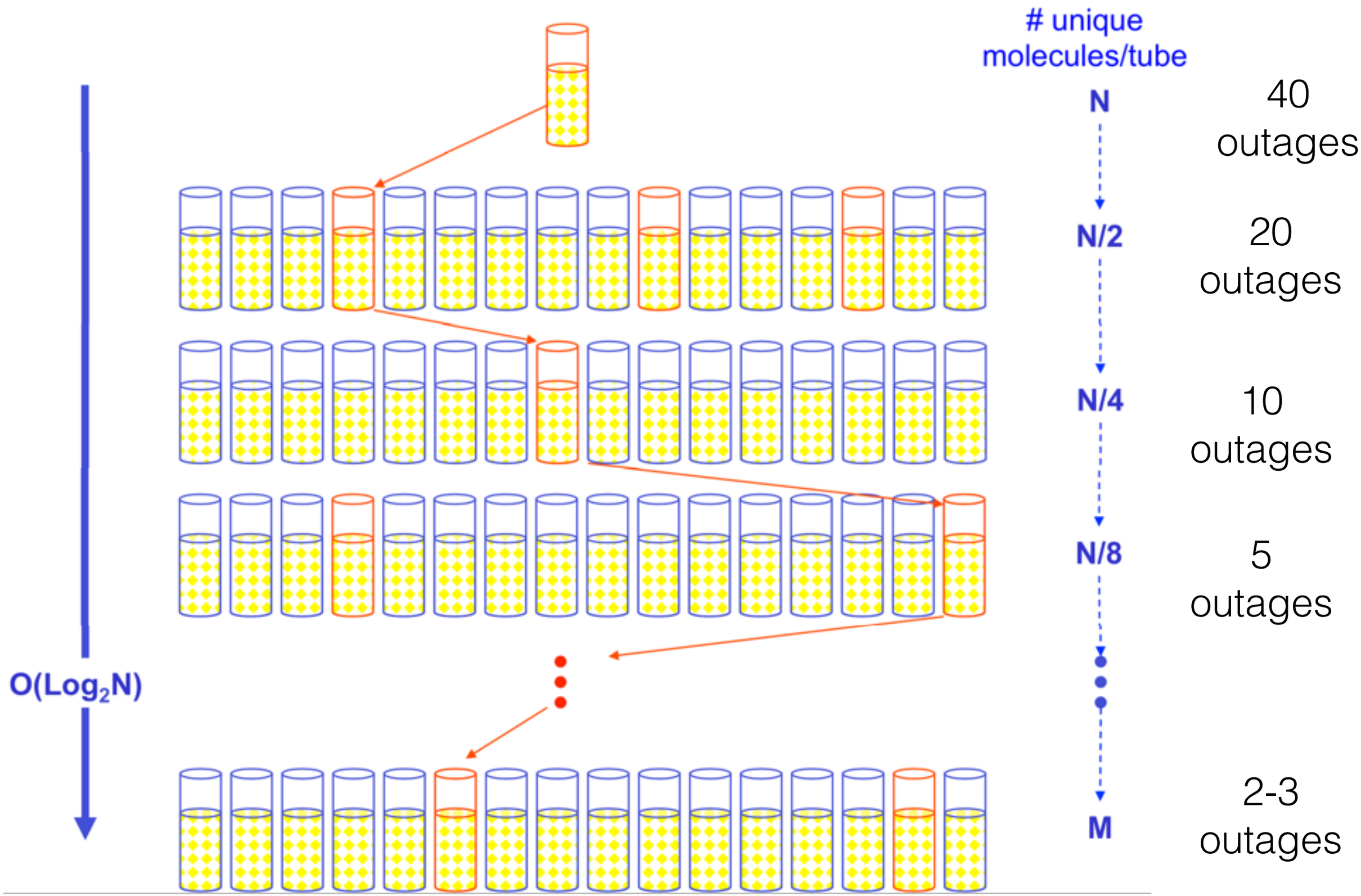




2. Now find many of the outage combinations that cause blackouts (the malignancies)



The Random Chemistry algorithm



3. Use the results to quantify blackout risk

The estimated number of malignancies of size k

Blackout sizes

$$\hat{R}_{RC}(x) = \sum_{k=2}^{k_{\max}} \frac{\hat{M}_k}{|\Omega_{RC,k}|} \sum_{m \in \Omega_{RC,k}} \Pr(m) S(m,x)$$

Probability of (multiple) contingency

The number of malignancies of size k found by RC

4. Estimating the number of blackout-causing contingencies by modeling the rate at which unique malignancies are found

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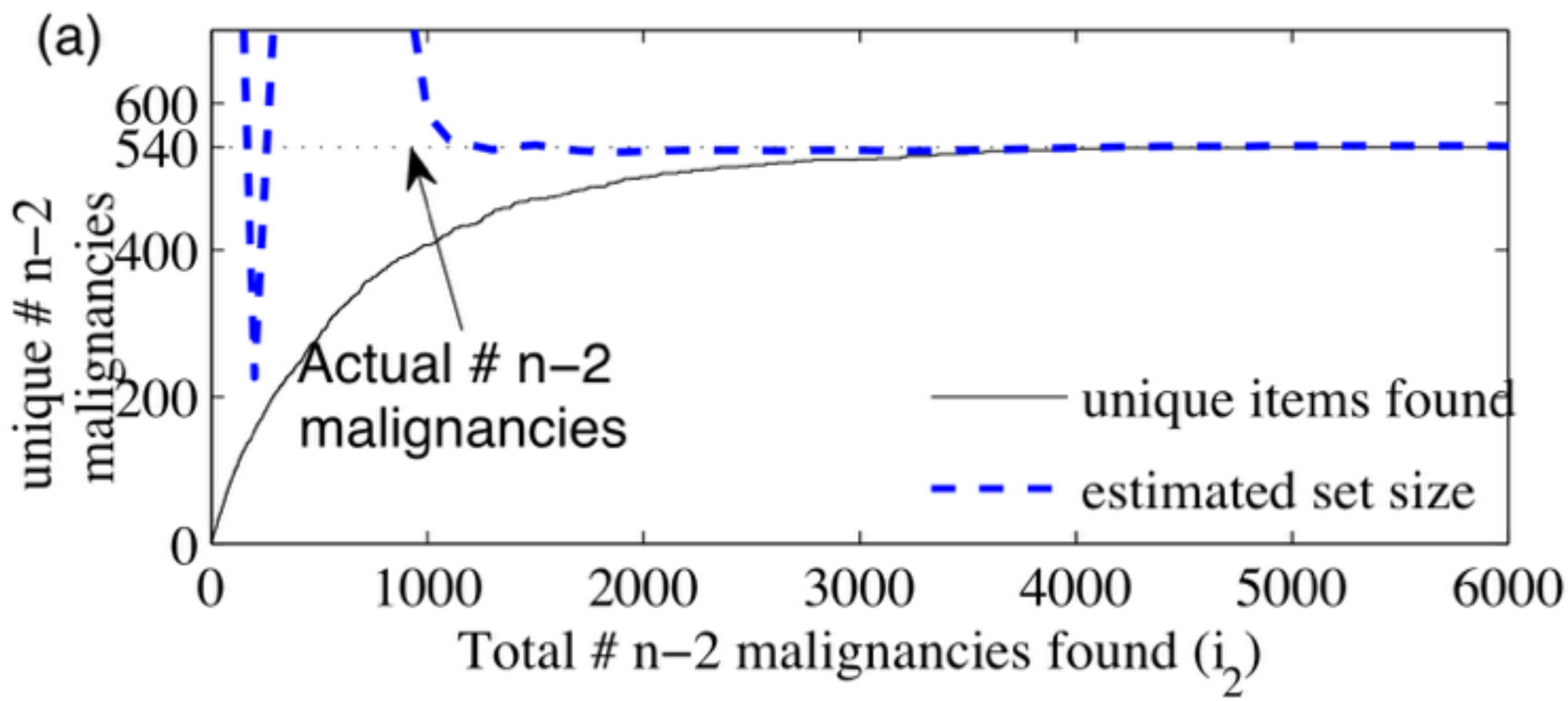
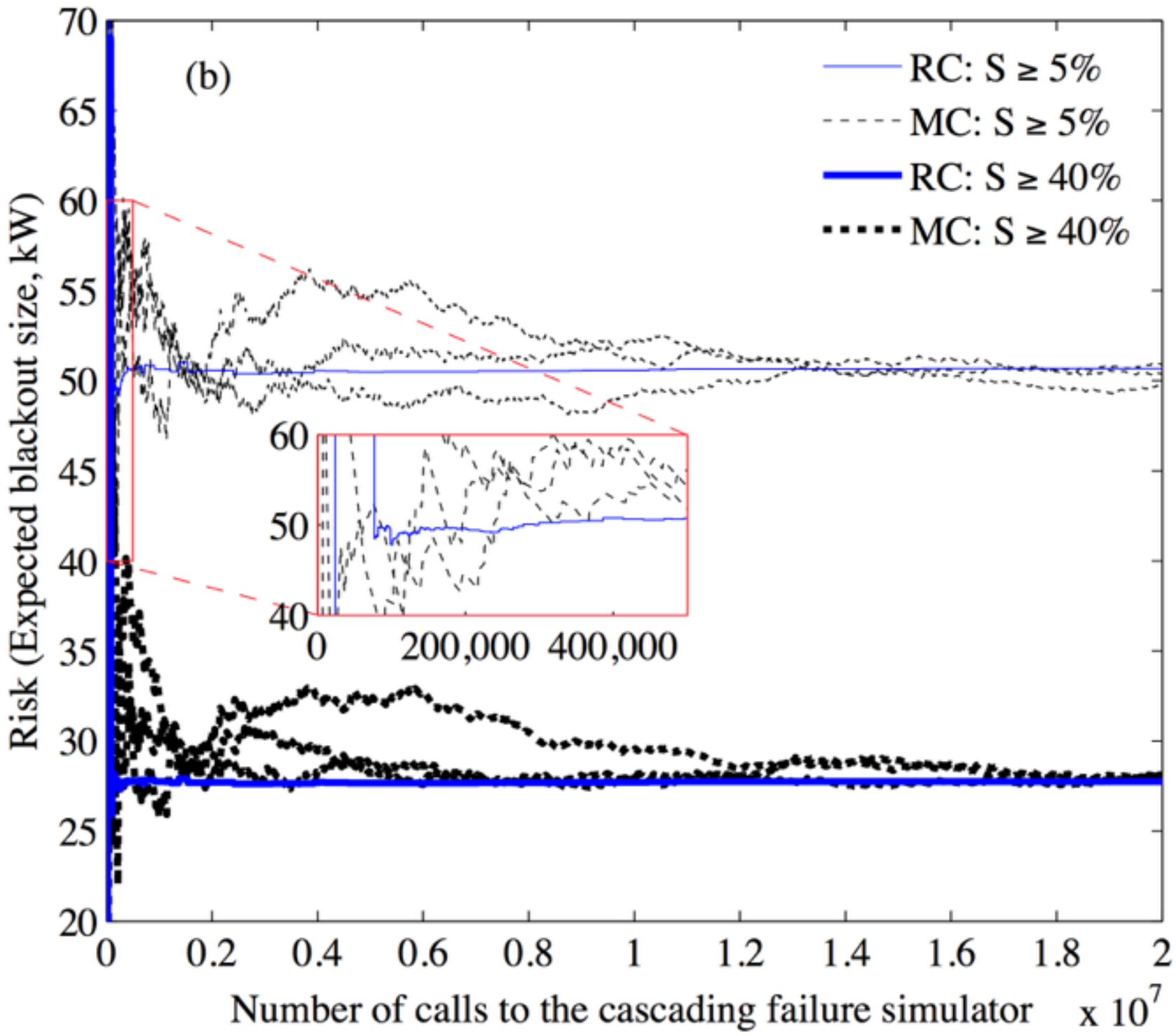
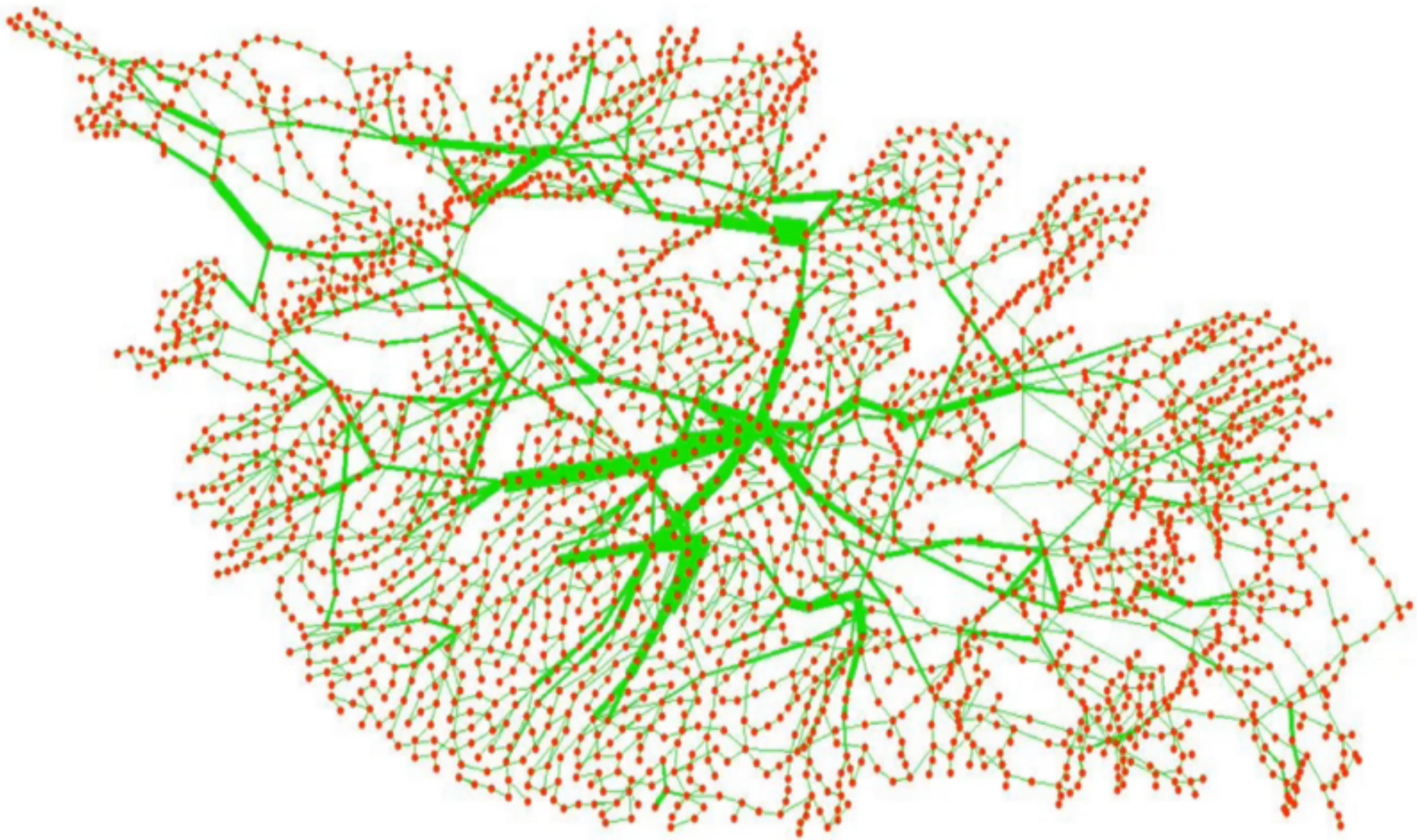


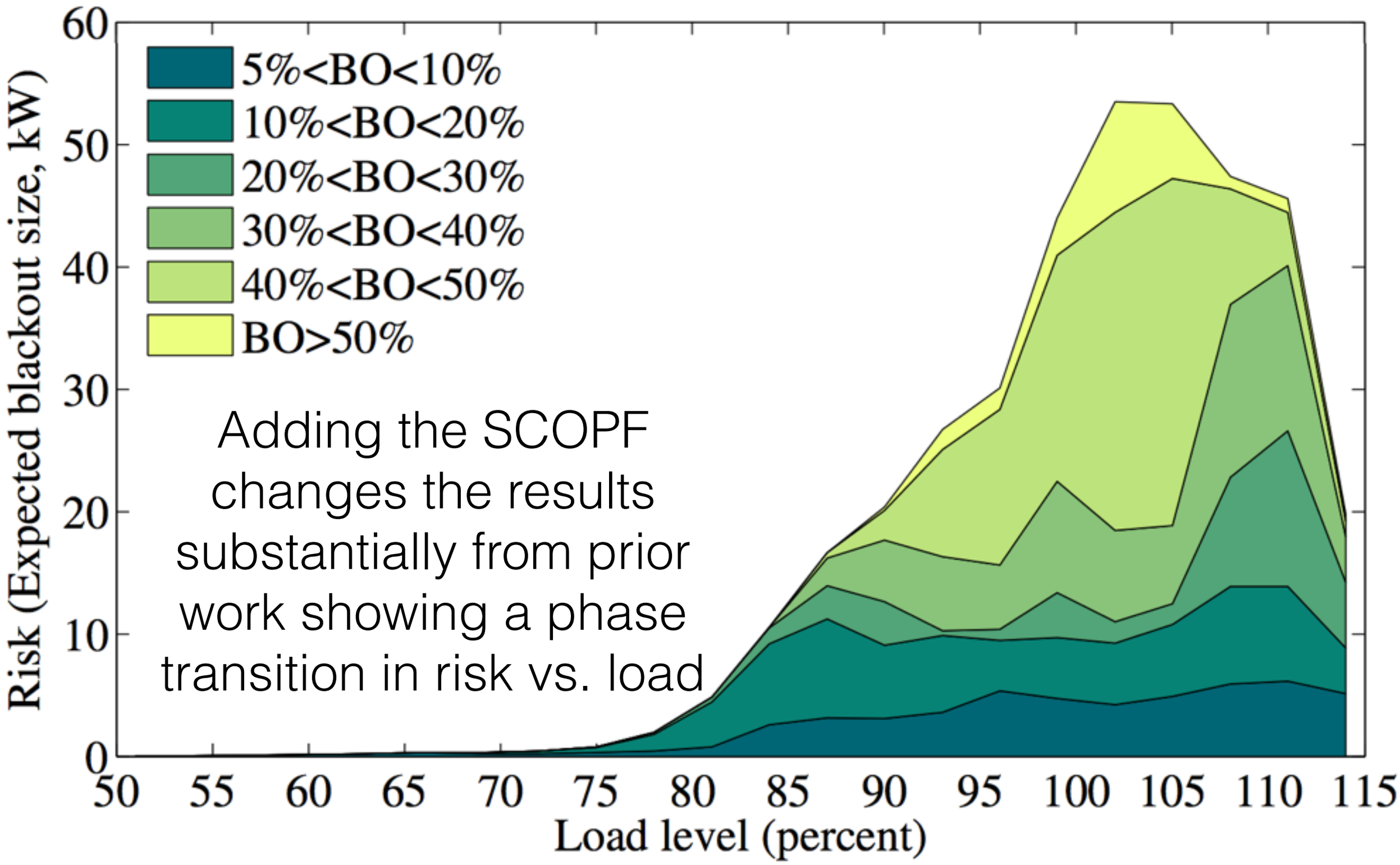
Comparing RC to Monte Carlo



Now that we can estimate blackout risk, what insight can we gain?



Risk vs. load, given SCOPF



Adding the SCOPF changes the results substantially from prior work showing a phase transition in risk vs. load

Why?

- At high load levels SCOPF leaves larger margins on long inter-area tie lines (to allow for potential contingencies)

Total absolute flow on lines with large (>200MW) base case flow

Load level	95%	100%	105%	110%	115%
MW flow	16,312	17,032	17,102	16,869	15,916

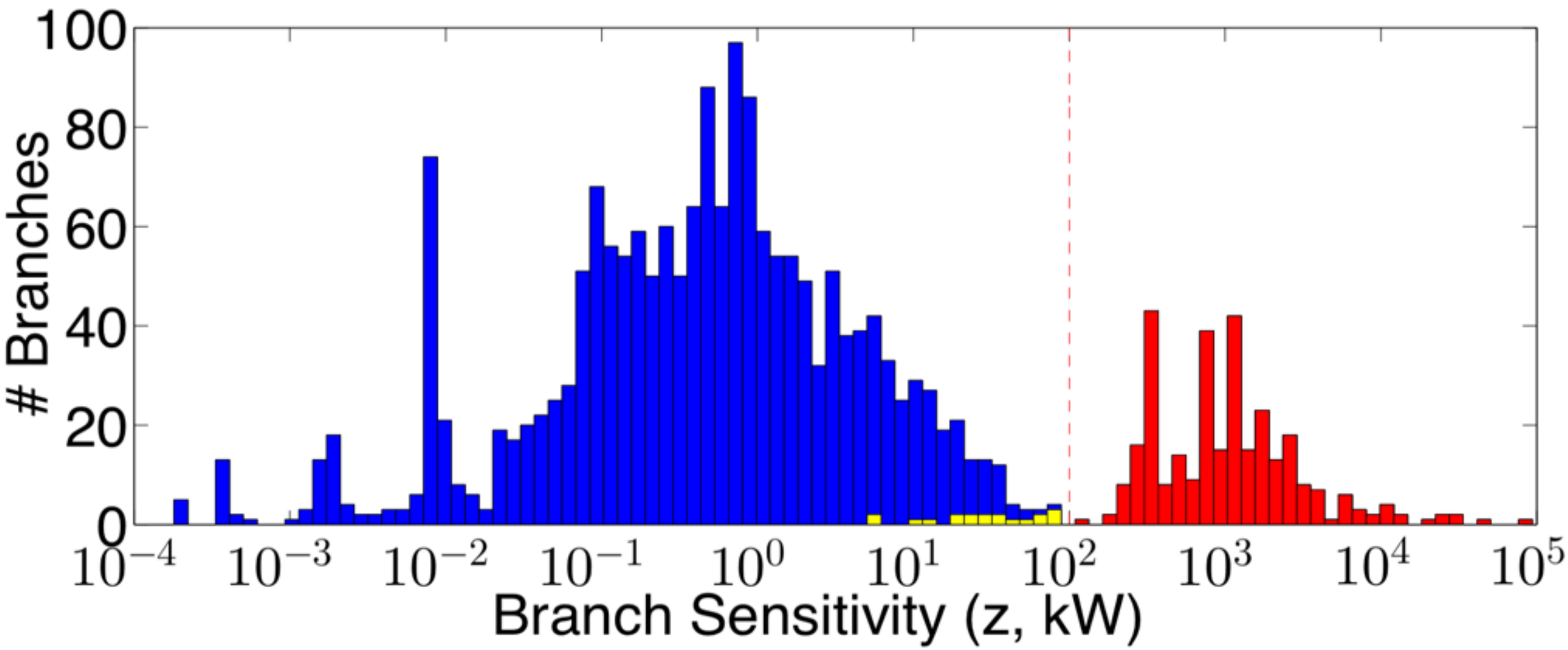
Finding the contribution of elements to risk

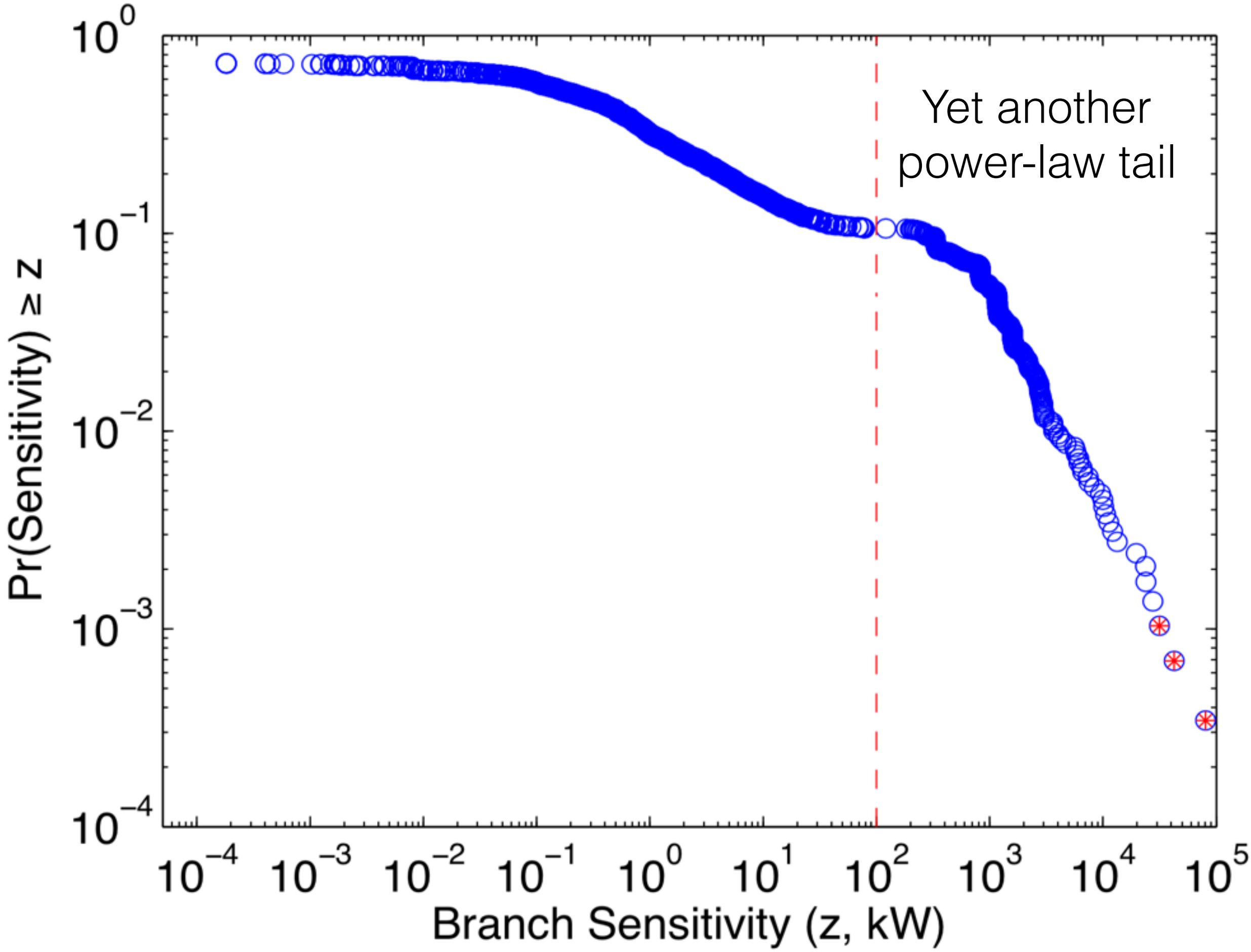
Differentiate the risk equation with respect to element outage probabilities

$$\hat{R}_{RC}(x) = \sum_{k=2}^{k_{\max}} \frac{\hat{M}_k}{|\Omega_{RC,k}|} \sum_{m \in \Omega_{RC,k}} \Pr(m) S(m,x)$$

$$\frac{\partial \hat{R}_{RC,k}}{\partial p_i} = \frac{\hat{M}_k}{|\Omega_{RC,k}|} \sum_{m \in \Omega_{RC,k}} S(m,x) \frac{\partial}{\partial p_i} \Pr(m)$$

Distribution of "risk sensitivity"

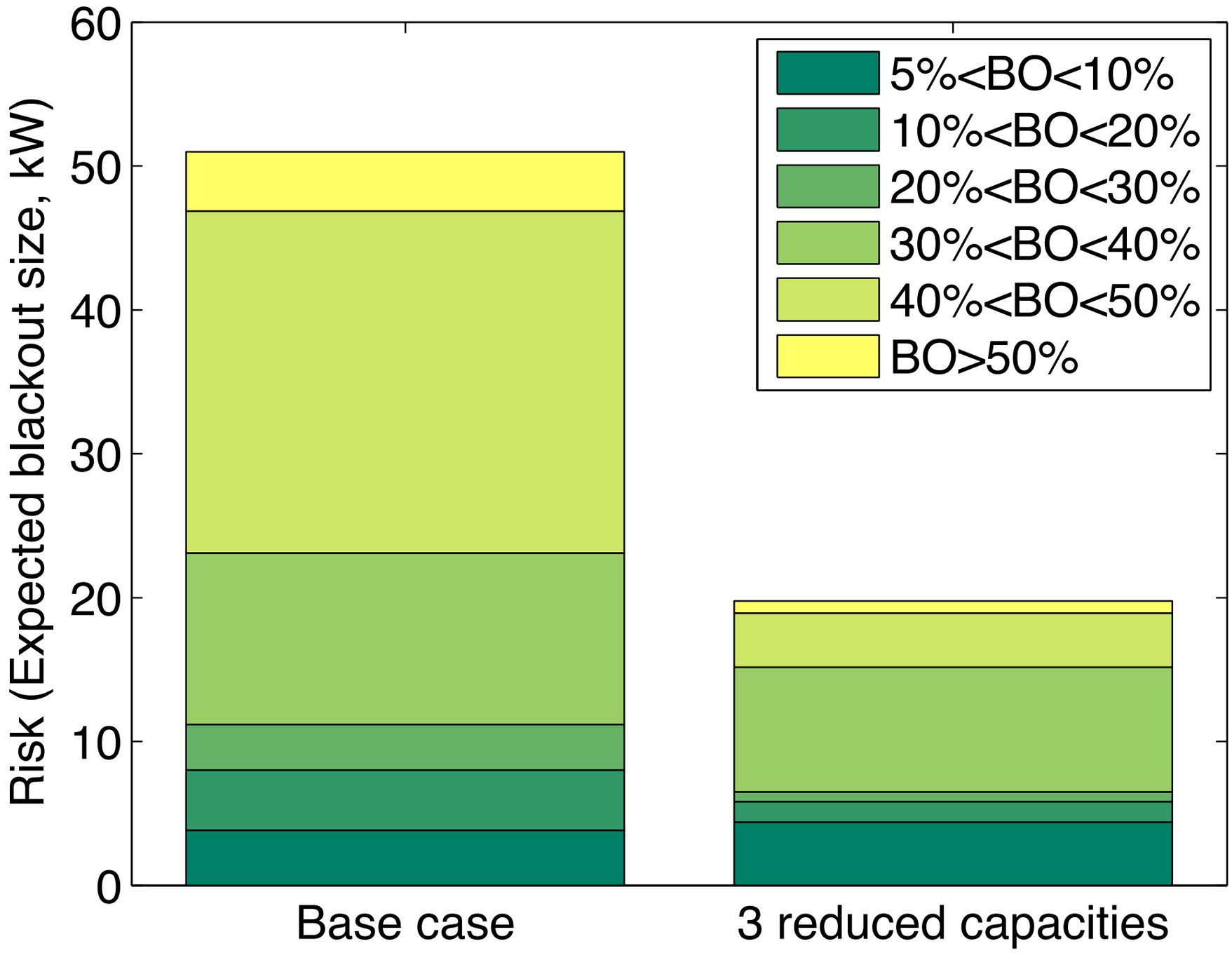



Yet another
power-law tail
Pr(Sensitivity) ≥ z
Branch Sensitivity (z, kW)
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5}

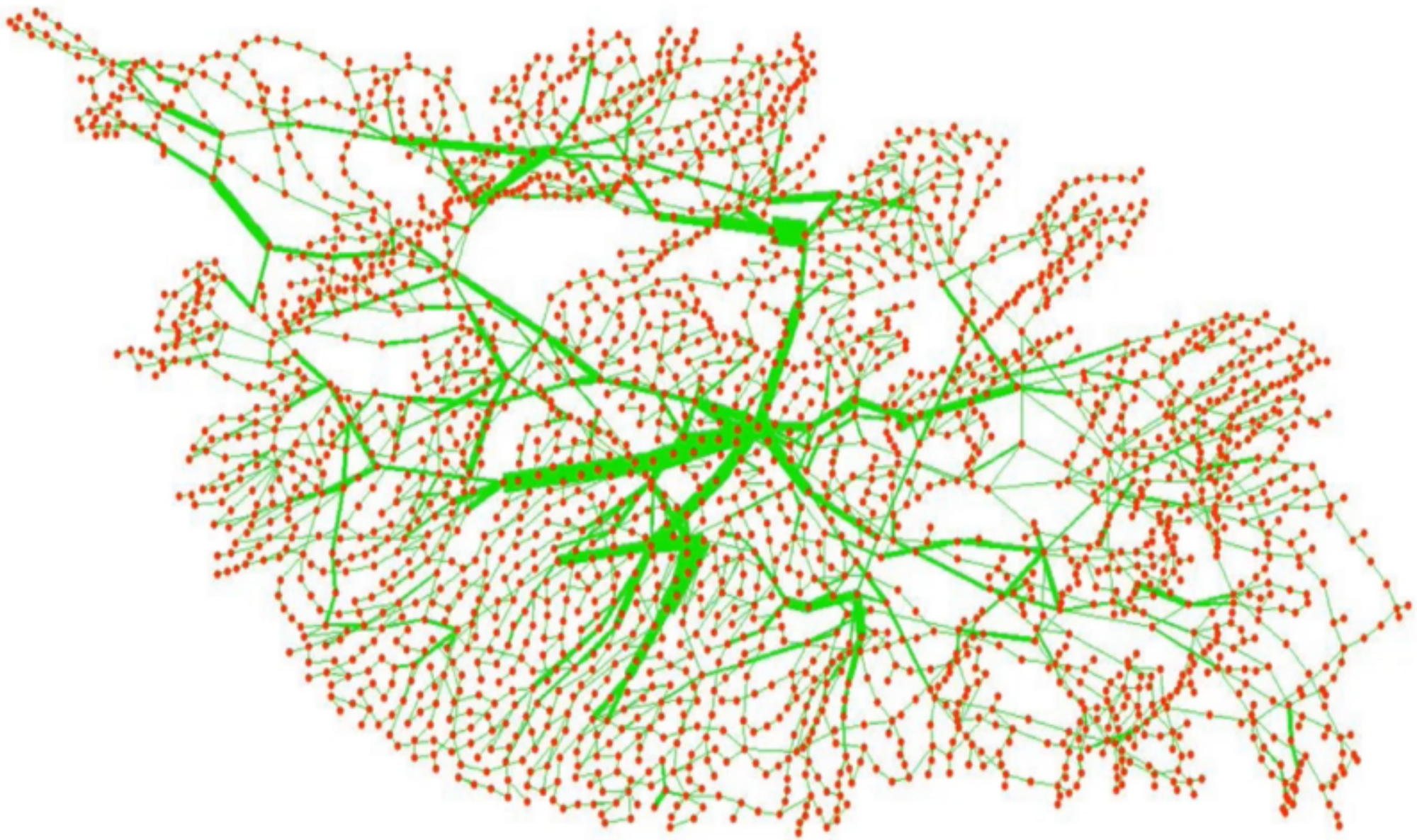
Can we use this insight to reduce risk?

- Take the 3 lines that contribute most to blackout risk
- Re-dispatch generators to leave more margin between the flow on these lines and the limit (cut the limit in half)
- Fuel costs increase by 1.6%
- Large (S>5%) blackout risk decreases by 61%
- Very large (S>40%) blackout risk decreases by 83%
- Perhaps we would be better off without these lines?

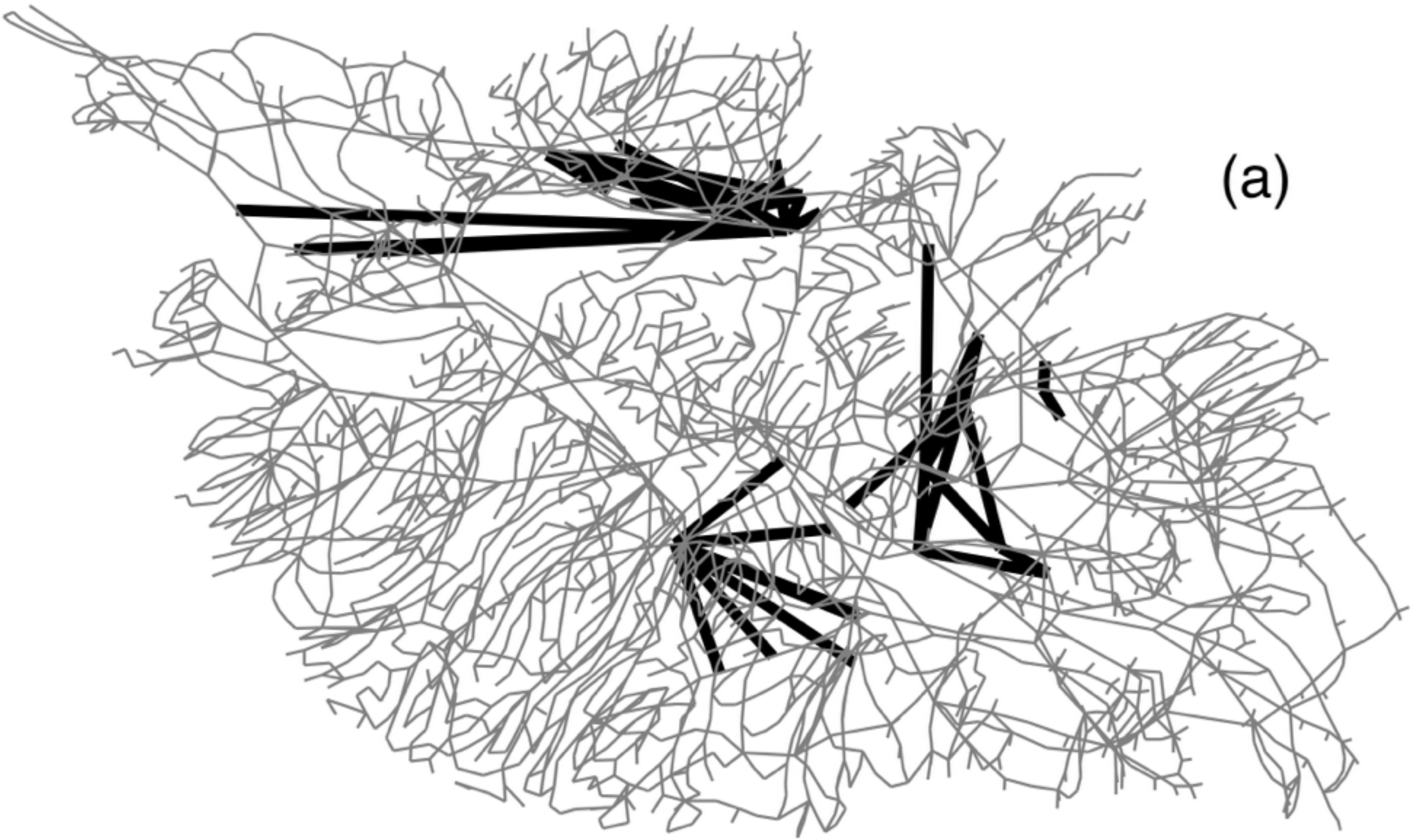
Before and after



Do the blackout-causing n-2 contingencies change at different load levels?

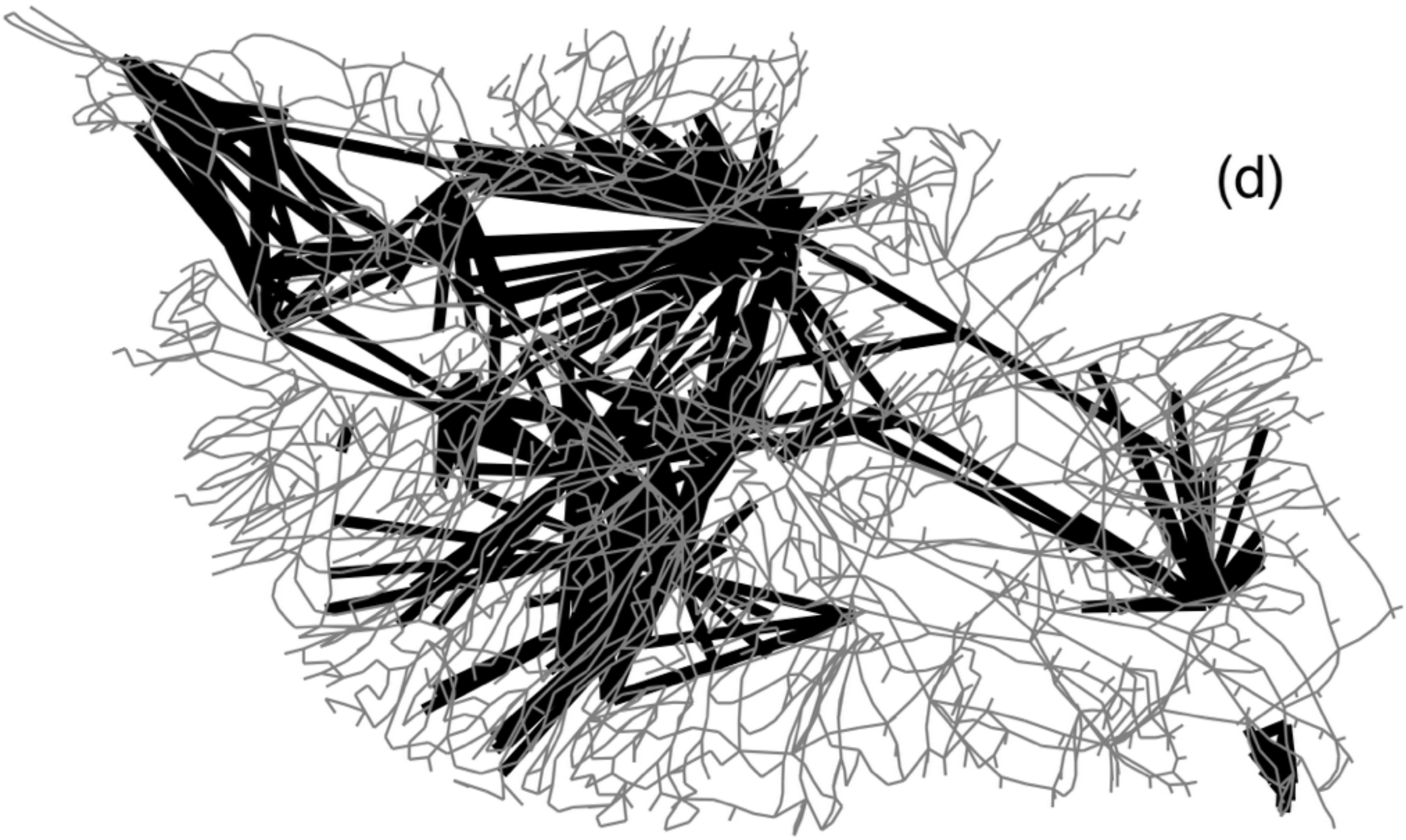


39 n-2 malignancies at 75% load

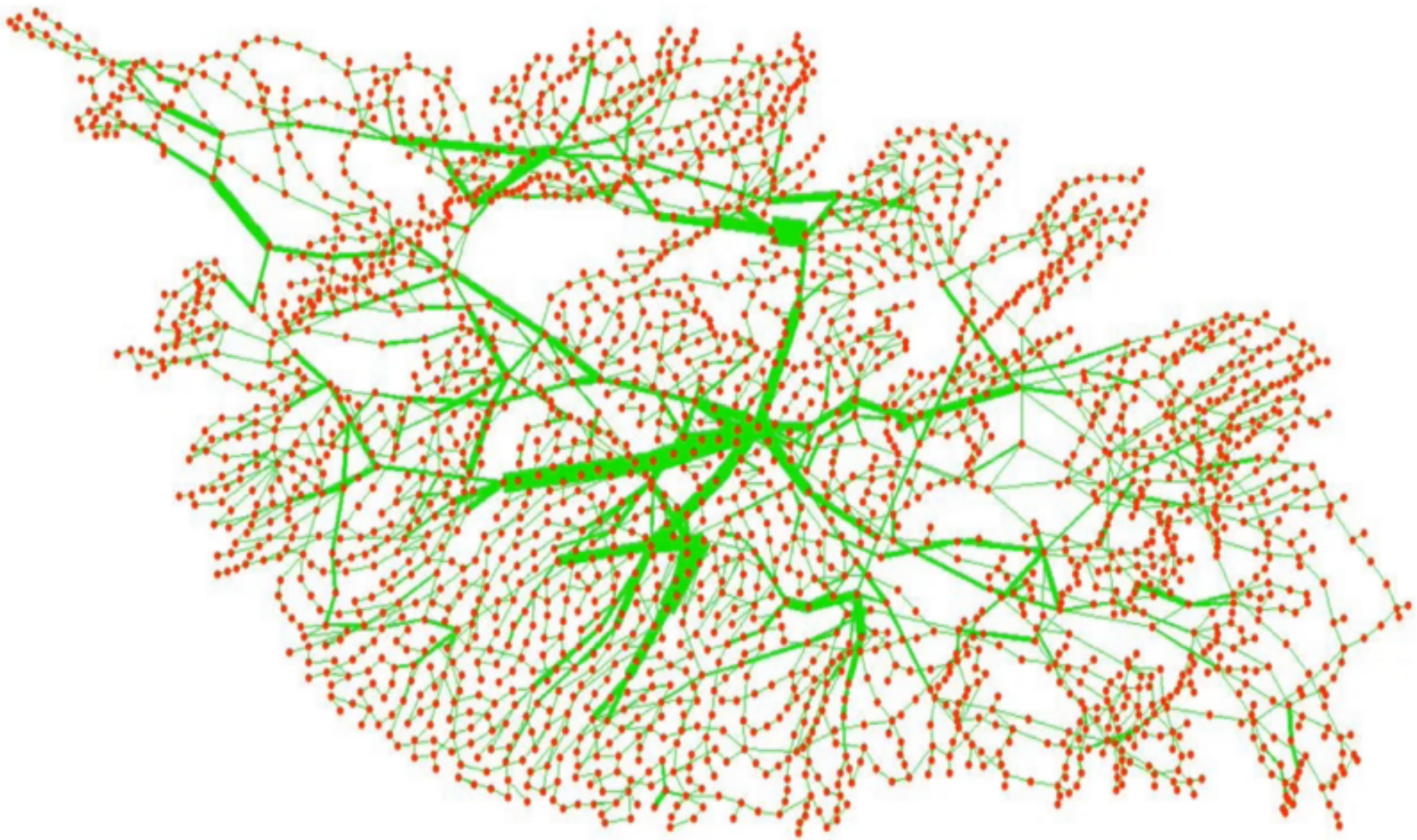


540 n-2 malignancies at 100%

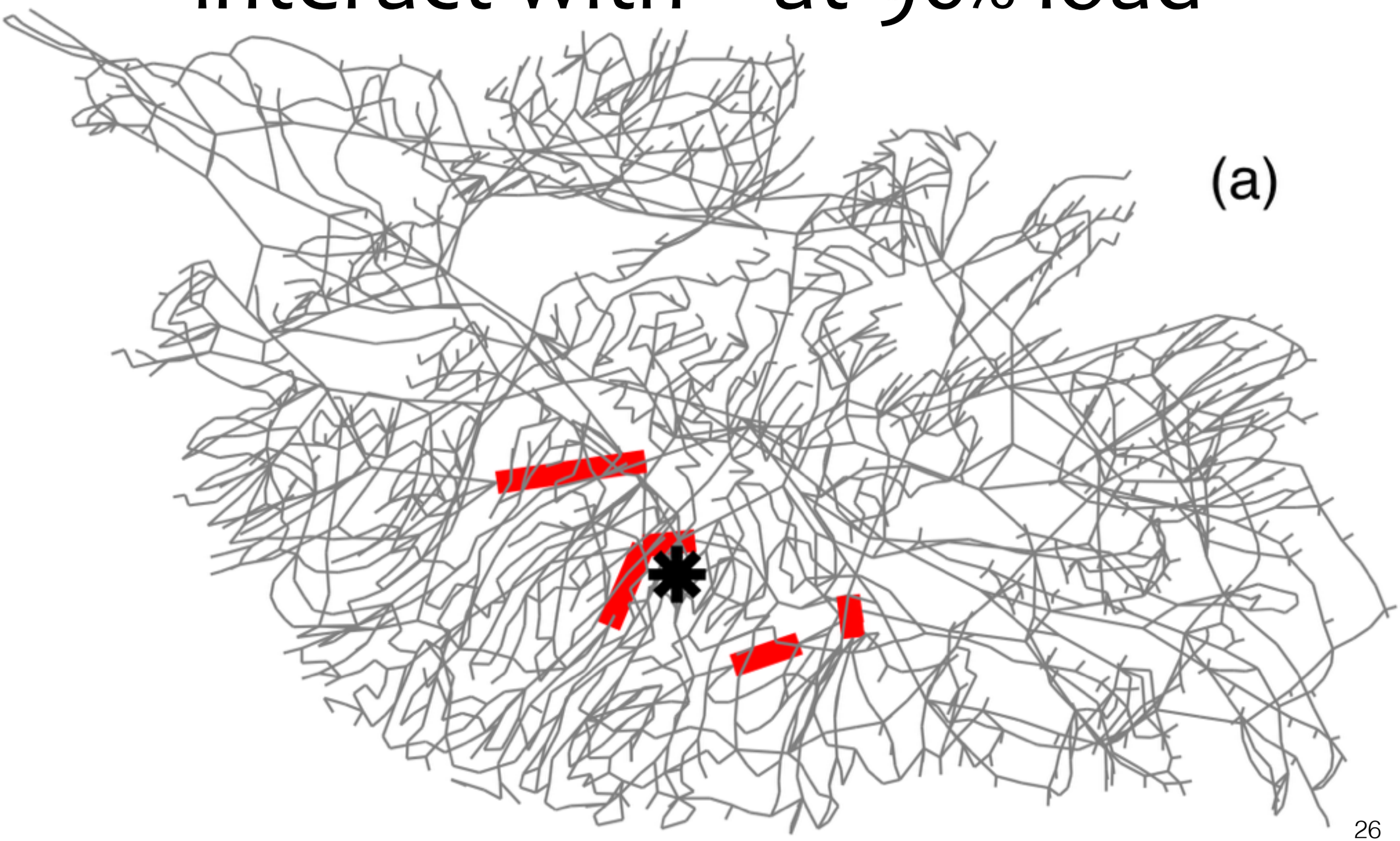
378 n-2 malignancies at 115%



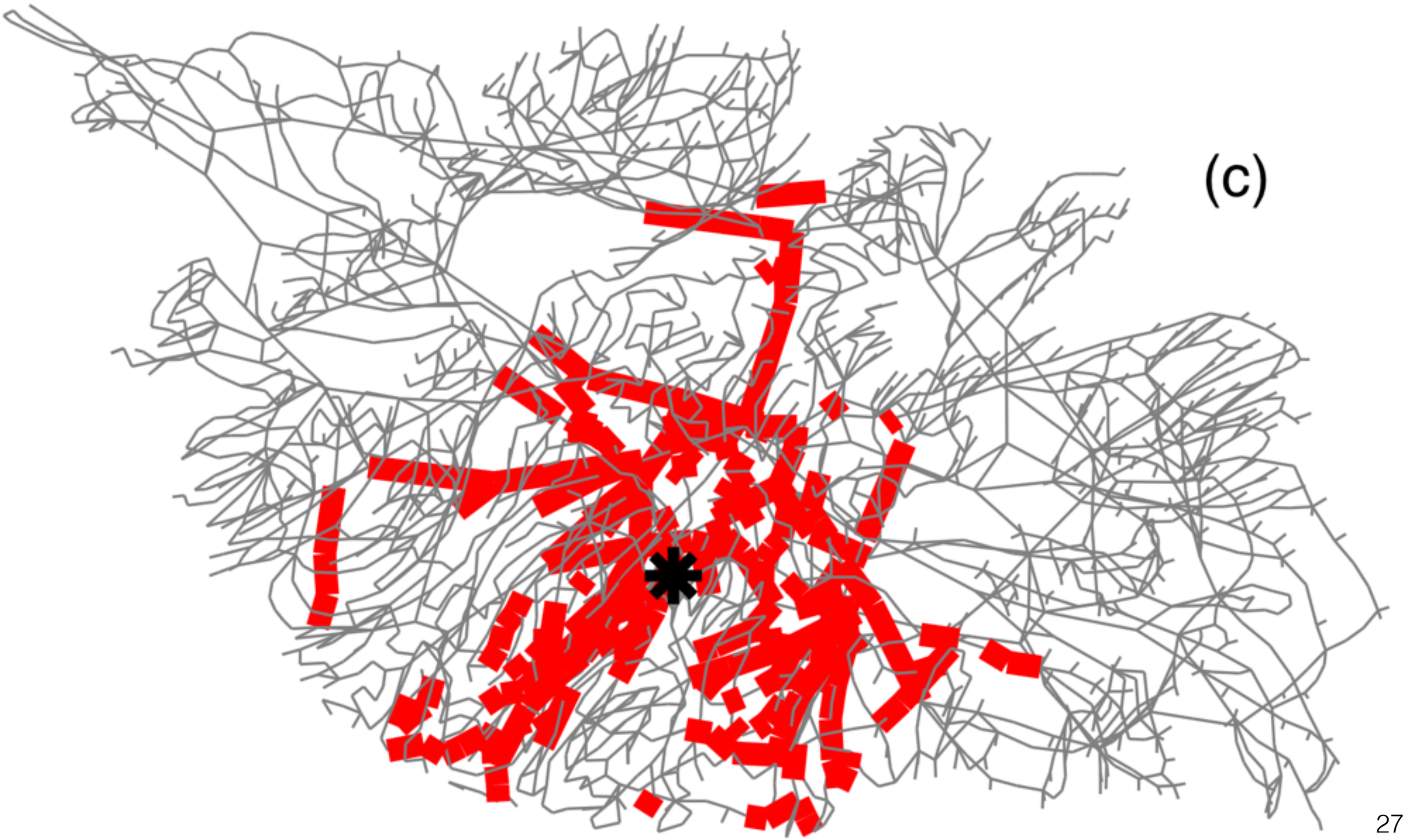
Which components negatively interact with a given component at different load levels?



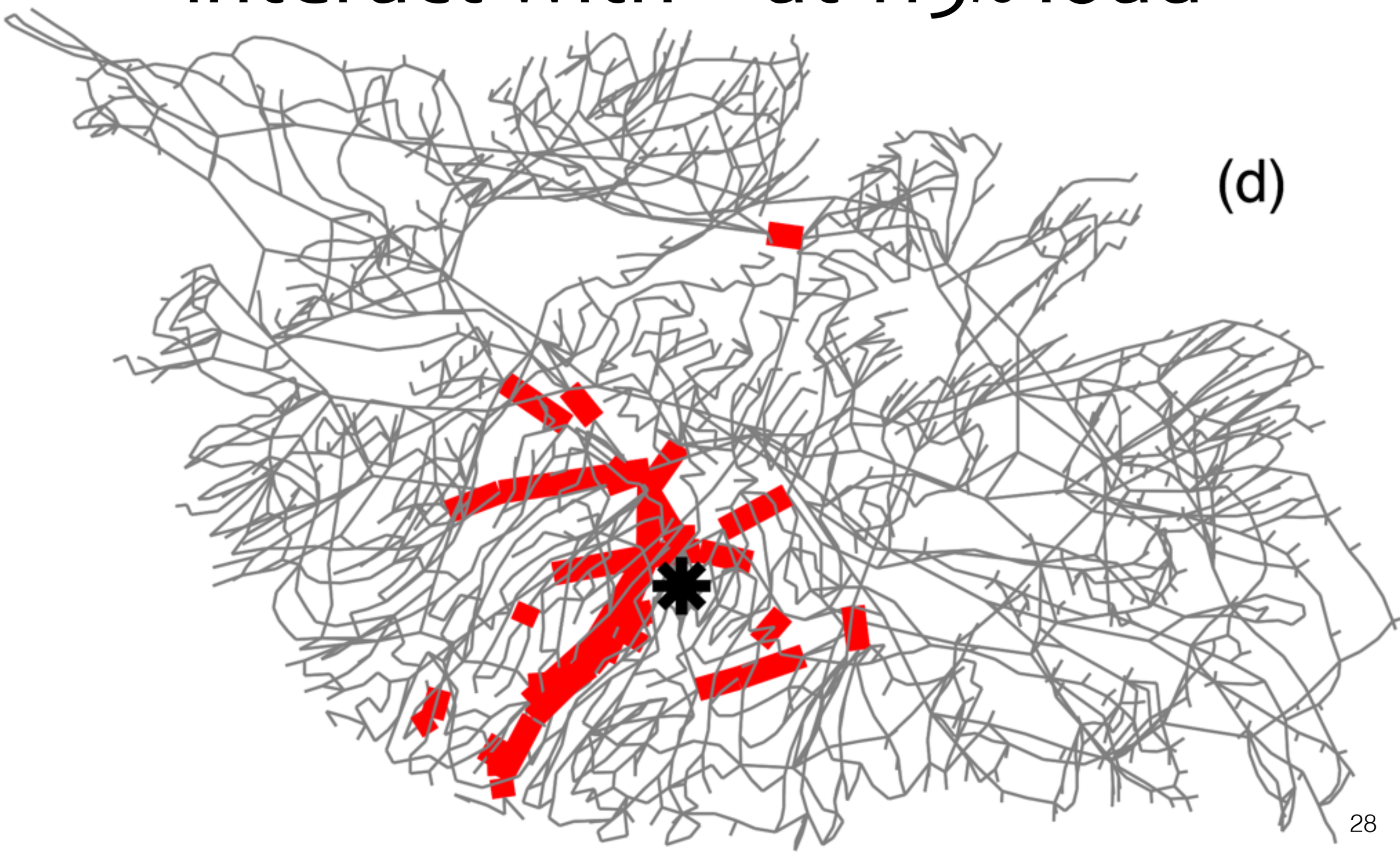
Branches that negatively interact with * at 90% load



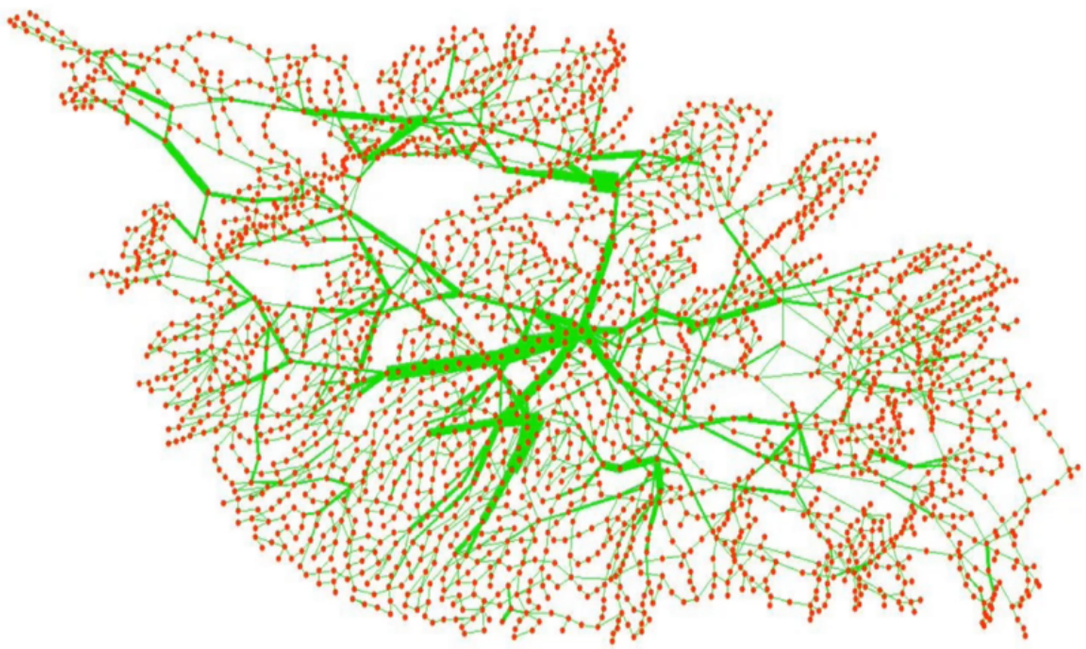
Branches that negatively interact with * at 100% load



Branches that negatively interact with * at 115% load



Returning to the Illustration



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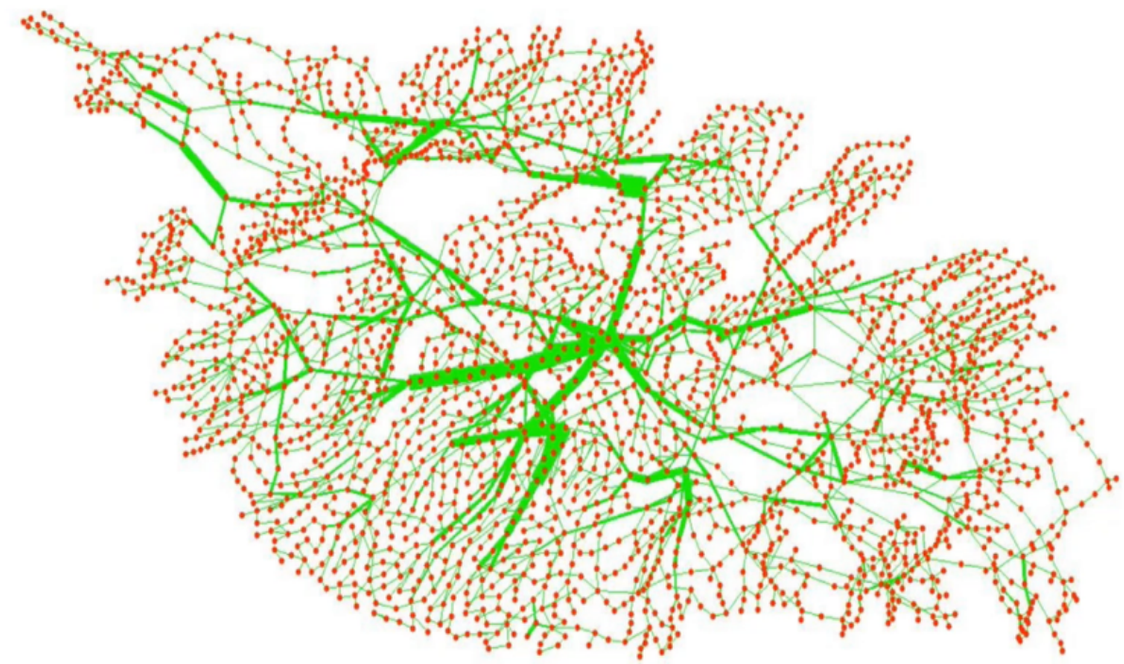
High blackout risk



Case 2 (2 pm tomorrow)
Low blackout risk

We now have a way to describe the differences in risk between these two cases and explain why the two cases are different.

Conclusions

- It is possible to estimate cascading failure risk with a reasonable amount of computation (e.g., overnight given tomorrow's peak-load model).
  Random Chemistry approach is >100x faster than MC
  Does this hold up for correlated event probabilities?

- Doing so gives insight that can result in real risk reductions:
  More load is not always worse (8/14/2003, 9/8/2011)
  Adjusting the flow limits on critical lines
  Perhaps switching them out entirely?

- Providing visual feedback to operators may produce new isight and ideas for risk reduction

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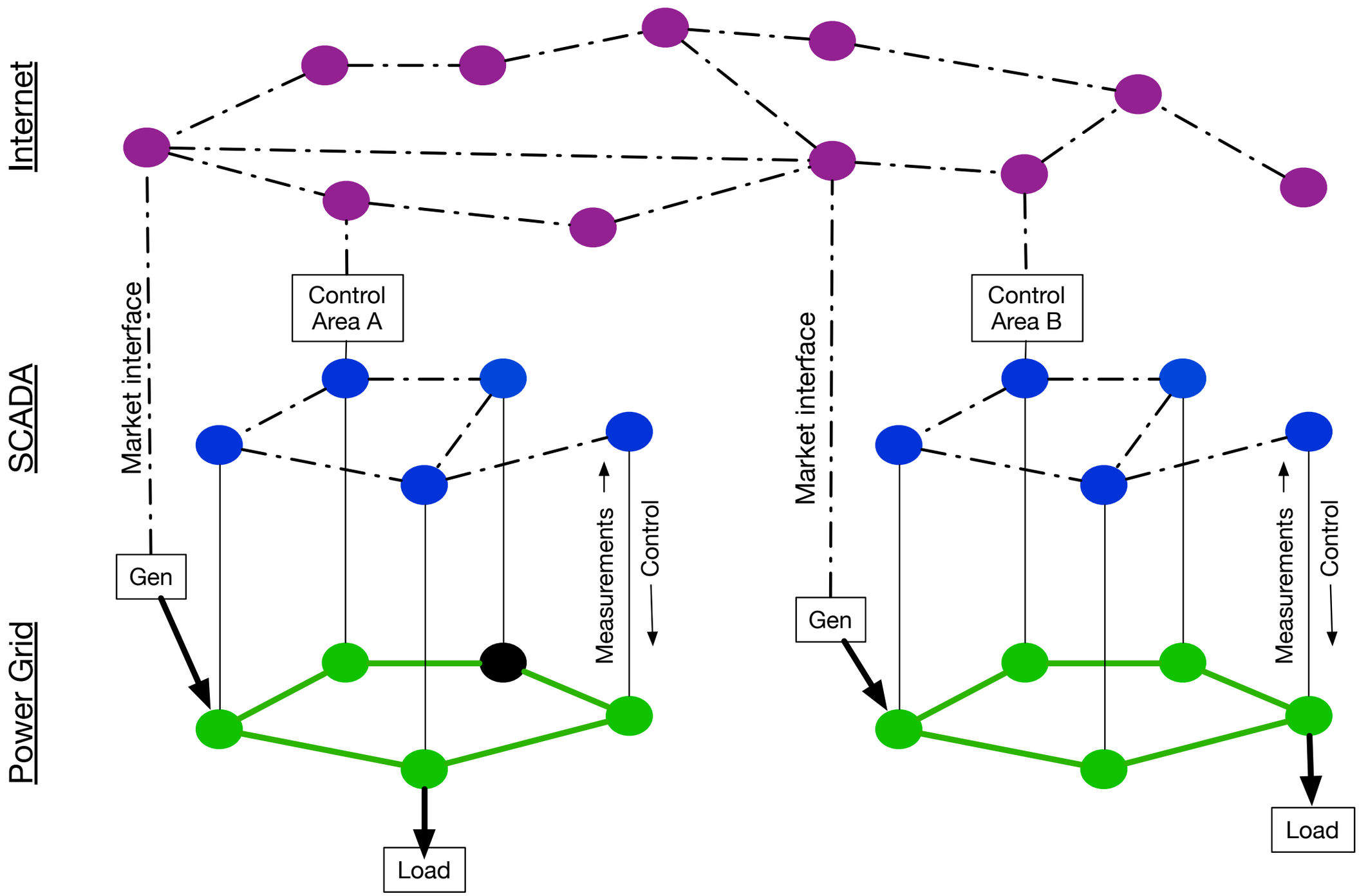
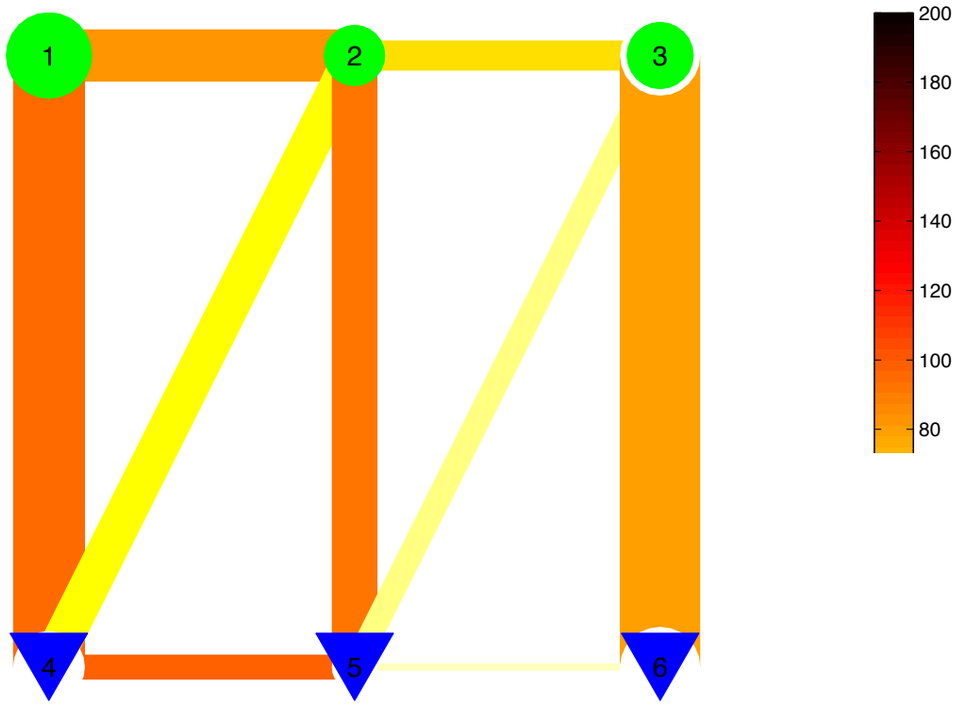
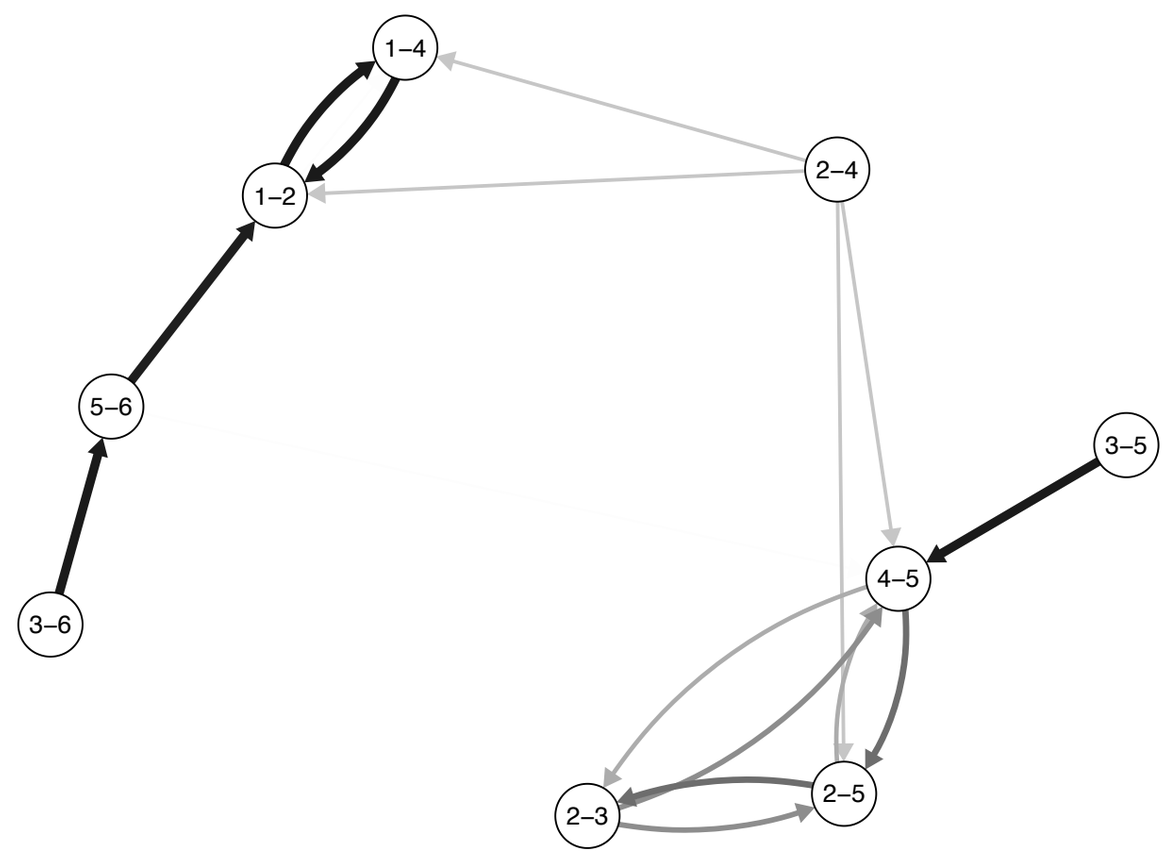
Importantly, this method is completely model-agnostic. Describing risk in interdependent systems

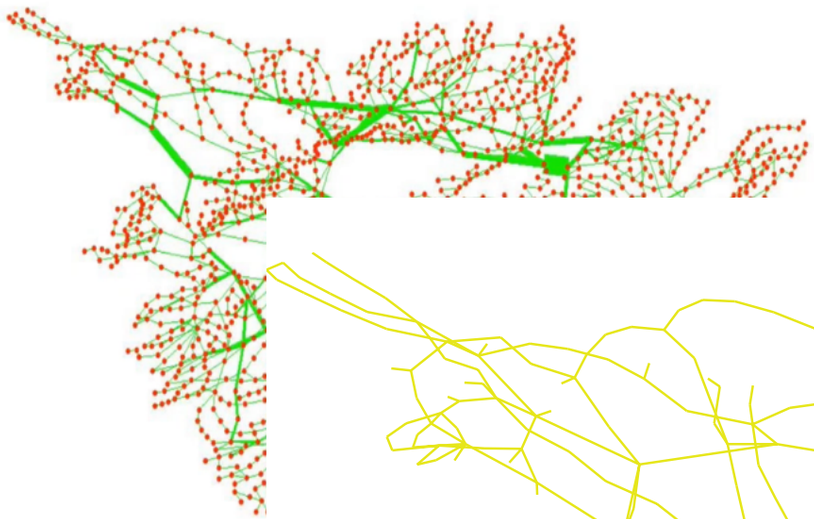


Work in Progress: Influence Graphs





A larger influence graph



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For more information: Pooya Rezaei, Paul Hines and Margaret Eppstein, “Estimating Cascading Failure Risk with Random Chemistry,” *IEEE Transactions on Power Systems* (in press)
http://arxiv.org/abs/1405.4213

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