Resilience of networks as a function of node behaviour

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Cascading failures can be catastrophic to the function of many complex networks, including those that have become central to modern life, such as power grids, communication and transportation networks. Understanding how to build resilience into these networks is a crucial subject in complex systems science, with researchers focusing on the role of network topology on cascade dynamics, in order to optimise the topology for resilience [1,2]. In this work we instead focus on the role of the node behaviour, to ascertain how, for a network of fixed topology, the behaviour of its nodes can be controlled to promote resilience. This is motivated by smart power grids, whose nodes can variably be generators, consumers and batteries, the behaviour of which can be influenced by a central controller. We use ensembles of networks whose nodes may be either sources, sinks or passive conduits of flow, where the flow is given by a linearised steady state approximation. We then determine the severity of cascades, as a function of edge capacity. At a critical value of the edge capacity, the system undergoes a phase transition, beyond which most of the network survives a cascade. Using the location of this transition as a measure of resilience, we track how it varies as the configuration of nodes is changed, by projecting it into the node configuration space, as shown in Fig. 1. We uncover that for a broad class of realistic network topologies, the highest resilience is found when the proportions of source and sink nodes are approximately equal. Networks containing just one large source with many small sinks are found to be the most fragile. We also show that, counterintuitively, in some random networks, the reverse is true; having highly distributed small source and sink nodes can cause a drop in resilience.

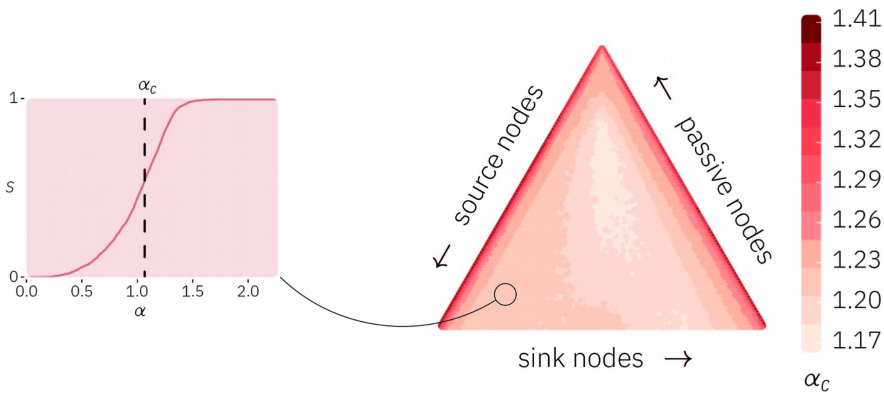

Figure 1: The percentage of surviving edges *S* as a function of edge capacity for a given configuration of source and sink nodes undergoes a transition towards resilience. The location of this transition is used as a measure of resilience and tracked in the node configuration space, shown in the triangular simplex. This reveals regimes of increased resilience in networks with highly distributed source nodes.

[1] Yang, Y., Nishikawa, T., & Motter, A.E. (2017). Small vulnerable sets determine large cascades in power grids. *Science, 358.*

[2] Witthaut, D., Timme, M. (2015). Nonlocal effects and countermeasures in cascading failures. *Phys. Rev. E,* 92