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Networks: structure, function and optimisation

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Abstract

Recent studies have shown that the structure and connectivity properties of networks have important consequences for their function and efficiency. It is therefore useful to ask whether these properties can be exploited to enhance the performance and efficiency of networks. We examine this question in two specific contexts, the load-bearing properties of a branching hierarchical network, and jamming and congestion in a two-dimensional communication network. We show that the capacity and performance of these networks can be enormously enhanced by judicious manipulation of connectivity properties. We discuss the relevance of these results to the general context of information spread processes on networks.

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Keywords: Networks; Performance; Efficiency; Connectivity

1. Introduction

The study of networks has been a topic of vigorous recent interest. A network consists of nodes plus links between nodes. Each node may be capable of some function and may have some capacity. Power grids, the internet, traffic networks, and telephone networks constitute examples of engineered networks, whereas

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metabolic networks and neural networks are examples of natural networks. The structure and connectivity properties of networks, as well as the capacities of their nodes have important consequences for their performance and efficiency. In practice, it is relatively easy to change the connectivity properties of the network structure. In the World Wide Web, pages and links are created and destroyed every second, and neural synaptic connections are created and destroyed due to learning and aging processes. It is therefore interesting to ask whether the connectivity properties of networks can be exploited to enhance their capacities and thereby their performance and efficiency. We examine this question in the context of two networks, a branching hierarchical network and a two-dimensional network, and discuss common lessons drawn from the performance enhancement of the two cases.

2. A hierarchical weight-bearing network

The network is a 2-d triangular lattice. Each site can be connected to one, both or none of its neighbours in the layer above, and to exactly one of its neighbours in the layer below. The weight bearing capacity of each site is the sum of the capacities of the sites it is connected to in the layer above plus one. Sites in the top layer each have capacity one. Such models have been used for river networks and for granular media. The network consists of clusters, viz. a set of sites connected with each other. The largest such collection of sites is the maximal cluster. See Fig. 1 for an illustration of this network [1].

The weight transmission in the network takes place along the connections between sites which serve as paths. When a site in the first layer of the network receives a weight $\tilde{W}$, it retains an amount equal to its capacity W and transmits the rest, i.e. $\tilde{W} - W$, to the site it is connected to, in the layer below. This site continues the downward transmission by accommodating the weight equal to its capacity and transmitting the rest. The process of downward transmission is defined as an avalanche. In a M layer lattice, if there is still excess weight left at the Mth layer, it is then transmitted to the corresponding site in the first layer and the second cycle of

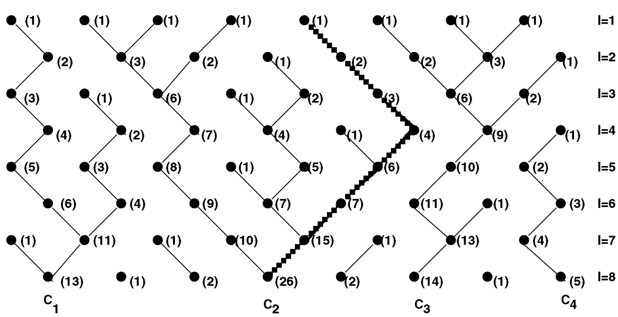

Fig. 1. A network of $M = 8$ layers with 8 sites per layer. C_2 is the maximal cluster. The beaded line is trunk of the maximal cluster. The weight-bearing capacity of the trunk is $W_T = 64$.