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# Cascading failures of $k$ uniform hyper-network based on the hyper adjacent matrix[☆]

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## HIGHLIGHTS

- A new model to describe cascading failures in hyper-network is proposed.
- Scale-free hyper-networks are both robust and vulnerable.
- Hyper-networks are more robust than general complex networks.
- An approximate solution to the disturbance threshold of hyper-network is obtained.

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## ABSTRACT

Cascading failures are widely found in hyper-networks. In this paper, a new cascading failure model based on couple map lattice is proposed in terms of the hyper-adjacent matrix and joint degree. The cascading failure model is rather universal describing the cascading failure behavior of $k$ uniform hyper-network and many typical complex networks. Simulation results show that 3 uniform scale-free hyper-network is robust against random attacks but is vulnerable to deliberate attacks. In addition, a scale-free hyper-network is more robust than a general complex network against the same attack. Finally, an approximate solution to the disturbance threshold of $k$ uniform scale-free hyper-network is obtained.

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## 1. Introduction

With the advancement of research on complex networks, it has been found that the complex network theory based on simple graphs is useful for modeling many real complex systems. However, the complex network theory based on simple graphs cannot provide a complete description for some real systems [1–6]. For instance, in an authors' collaboration complex network [1,2], researchers can be regarded as nodes and their joint articles as edges. This authors' collaboration complex network based on a simple graph can only show the cooperative relationships among the authors, but cannot know the number of articles produced from their cooperation. A similar issue occurs in a logistic network [4] represented by a simple graph. In the logistic network, nodes denote different couriers and edges denote the relationships between different couriers. One only knows whether two couriers have cooperation, but does not know how many couriers provide logistic services for

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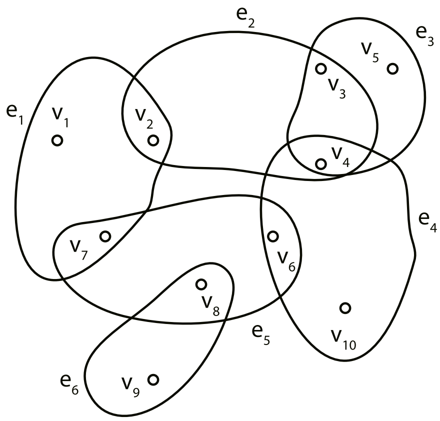


**Fig. 1.** A hyper-graph with 10 nodes and 6 hyper-edges. The set of nodes is $V = \{v_1, v_2, v_3, v_4, v_5, v_6, v_7, v_8, v_9, v_{10}\}$ and the set of hyper-edges is $E = \{e_1, e_2, e_3, e_4, e_5, e_6\}$, where $e_1 = \{v_1, v_2, v_7\}$, $e_2 = \{v_2, v_3, v_4\}$, $e_3 = \{v_3, v_4, v_5\}$, $e_4 = \{v_4, v_6, v_{10}\}$, $e_5 = \{v_6, v_7, v_8\}$, $e_6 = \{v_8, v_9\}$. The hyper-degrees of nodes $v_1$ to $v_{10}$ are 1, 2, 2, 3, 1, 2, 2, 2, 1, 1, respectively. The hyper-edge degrees of hyper-edges $e_1$ to $e_6$ are 2, 3, 2, 3, 3, 1, respectively.

the same online retailer. Therefore, it is an important and interesting topic to find a network topology that can describe these phenomena.

In a complex network based on the simply graph theory, two nodes are connected by an edge. However in a hyper-network based on the hyper-graph theory, an edge is called a hyper-edge, which may contain more than two nodes. Thus, the hyper-network based on the hyper-graph theory is more suitable to represent the collaboration network or the logistic network, among others. In the collaboration hyper-network [1,2], nodes denote the authors and hyper-edges denote the articles that are completed in cooperation by a group of authors. In the logistic hyper-network [4], nodes represent the couriers and hyper-edges denote the online retailers: if several couriers provide logistic services for the same online retailer then these couriers are contained in the same hyper-edge.

Recently, more and more researcher are focusing on the hyper-networks [1–5,7–21]. In particular, the dynamical behaviors of hyper-networks had attracted lots of attention [4,10,12,18–20,22–25]. Researchers obtain some results about synchronization [19,22] and knowledge diffusion [18,20] on hyper-networks. In real systems, cascading failures widely existing in different complex networks [26–28] and independent network [23,24] can also found in hyper-networks [4]. For example, in the logistic hyper-network, the logistic system of a courier may fail because of shipment overload. In this case, online retailer will put the goods to other couriers in the same hyper-edge. Consequently, the shipments of these couriers will increase. Once the shipment go beyond the transportation capability of the couriers, it can lead the logistics system to fail. And, the failure of this logistic system will continue to spread over the entire logistic hyper-network.

Although there are very few results about cascading failures of hyper-networks based on the hyper-graph theory. Ma et al. [4] studied the cascading failures of a hyper-network, proposing two methods to study the cascading failures of hyper-networks, which are 2-*section* graph analytical method and line-graph analytical method. They described the characteristics of the cascading failures occurred in the 3 uniform scale-free hyper-network. In their study, they use the couple map lattice (CML) cascading failure model to study the cascading failures of hyper-networks. However, their analytical method requires the nodes in a hyper-edge be completely connected. So, their analytical method had some limitations. Therefore, one needs to find a more powerful cascading failure model for analyzing the cascading failures of the general hyper-networks.

In this paper, we propose a new cascading failure model based on the CML which is good for describing the cascading failure behavior in $k$ uniform hyper-network based on the hyper-adjacent matrix and joint degree. We simulate the cascading process of 3 uniform scale-free hyper-network and analyze their robustness and influencing factors. Moreover, we provide an approximate solution to the disturbance threshold.

## 2. Theory and calculation

### 2.1. Hyper-graph and hyper-network

A hyper-graph $H$ is denoted by $H = (V, E)$, where $V$ is a finite node set and $E$ is a hyper-edge set [29]. Two nodes in a hyper-graph are adjacent if there is a hyper-edge which contains them. Two hyper-edges in a hyper-graph are adjacent if their intersection is not empty. The hyper-degree of node $i$ is denoted by $d_H(v)$ is defined as the number of hyper-edges containing node $v$. Fig. 1 is a hyper-graph containing 10 nodes and 6 hyper-edges. The network based on the hyper-graph be called a hyper-network.

If each hyper-edge contains $k$ nodes in a hyper-network, then the hyper-network be called $k$ uniform hyper-network.

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