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Identifying node importance in complex networks

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HIGHLIGHTS

- We propose a novel node importance evaluation method, which considers multi-layer and uneven node importance contributions.
- Experiments demonstrate the feasibility and validity of our method.
- The cascading failures cause the worse network invulnerability under our method.

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ABSTRACT

In this paper, we propose a novel node importance evaluation method from the perspective of the existence of mutual dependence among nodes. The node importance comprises its initial importance and the importance contributions from both the adjacent and non-adjacent nodes according to the dependence strength between them. From the simulation analyses on an example network and the ARPA network, we observe that our method can well identify the node importance. Then, the cascading failures on the Netscience and E-mail networks demonstrate that the networks are more vulnerable when continuously removing the important nodes identified by our method, which further proves the accuracy of our method.

1. Introduction

The invulnerability investigation in complex networks has, up to now, been an exciting subject and acquired a great achievement [1–7]. Research exhibits that different networks present different invulnerability under different failure modes. For example, compared with random networks, scale-free networks show higher robustness under random failures, but seem to be extraordinarily fragile under intentional attacks, especially when a handful of important nodes suffer attacks, which may even lead to the collapse of the whole system [8–12]. Generally, the important nodes play a key role in the network function and have an important effect on network dynamic processes [13], such as network synchronization, disease propagation, traffic navigation and cascading failures. Therefore, identifying important nodes and then taking protective strategies before attacks can improve the reliability and stability of networks, which have much practical significance. For instance, finding important nodes and then paying special attention to these nodes on the urban transport network are not only good for the prevention of massive traffic paralysis under intentional attacks, but for the assistance of traffic controllers to do dynamic traffic assignment, traffic guidance or rapid human evacuation.

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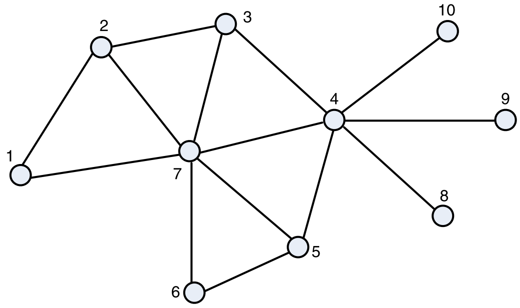

Fig. 1. A simple network.

Centrality measures reflect the position importance of a node in networks, and are often used to identify node importance. Some of the commonly used centrality measures include degree centrality [14], betweenness centrality [15–17], residual closeness centrality [18], semi-local centrality [19], second order centrality [20]. Since centrality measures are proposed to reflect different features of specific issues, they have different emphasis on node importance evaluation. In order to reduce the evaluation disparities, Ref. [21] proposed a multi-attribute decision making method based on the technique for order preference by similarity to an ideal solution (TOPSIS) to evaluate the node importance in complex networks. Although multiple indices can overcome the one-sidedness of the single index in the accuracy of node importance evaluation, neither multiple indices nor the single index cited above takes into account the importance dependence relationship among nodes, which has been mentioned but only between adjacent nodes [22,23]. Ref. [22] proposed a node importance contribution matrix (NICM) method, in which a node contributed its initial importance, characterized by betweenness, to its adjacent nodes evenly with the base of degree. So for node i, the node importance could be described as $C_i = B_i + \sum_j \frac{B_j}{D_j}$, where C_i and B_i indicate the importance and betweenness of node i respectively, j ran for all neighbors of node i. D_j and B_j denote the degree and betweenness of node j. However, it seems improper that the importance contributions of a node are inversely proportional to the degree. Ref. [23] developed a node importance evaluation matrix (NIEM) method, in which the importance of node i is determined by $C_i = I_i \times \sum_j \frac{D_j I_j}{\langle k \rangle^2}$, where I_i and I_j serve as the efficiency of node i and j respectively, and $\langle k \rangle$ is the average degree of the network. For node i, the efficiency $I_i = \frac{1}{n} \sum_{p=1,p\neq i}^{n} \frac{1}{d_{ip}}$, where n is the order of the network, and d_{ip} is the shortest path length from node i to node p. The introduction above shows that the NICM and NIEM methods consider the mutual dependence between adjacent nodes in terms of the importance contributions. Nevertheless, a common issue in both the methods is that the importance is contributed to only the adjacent nodes evenly. Therefore, we propose a novel node importance evaluation method called the node importance contribution correlation matrix (NICCM) method, in which a node contributes the importance to both the adjacent and the non-adjacent nodes unevenly. First, through analyzing the network performance changes on an example network and the Netscience network respectively, we indicate the necessity of the node importance evaluation under uneven importance contributions from nodes of adjacent and non-adjacent nodes. Then, the numerical calculations on an example and the Advanced Research Project Agency (ARPA) networks are made to evaluate the feasibility and validity of our method. Next, in order to further verify the accuracy of our method, we simulate cascading failures by continuously removing some important nodes on the Netscience and E-mail networks to analyze the network invulnerability.

The outline of this paper is as follows. In Section 2, we present our problem which is explained by an example network and the Netscience network and then introduce our novel method in Section 3. In Section 4, we make simulation analyses on the example network and the ARPA network to demonstrate the feasibility and validity of our method. The cascading failures are simulated on the Netscience and E-mail networks to further verify the accuracy of our method by analyzing the invulnerability in Section 5. Finally, a summary and some conclusions are stated in Section 6.

2. Problem presentation

There is intricate importance dependence relationship among nodes, and the dependence strength varies with node positions. For node i, we regard its adjacent nodes as the first layer nodes, its next adjacent nodes as the second layer nodes, and so on. Hence the importance contributions of node i to nodes in the same layers are different. Besides, the dependence relationship exists not only between the adjacent nodes but between the non-adjacent nodes.

Now we take Fig. 1 for example to explain the two aspects above. On the first issue, As shown in Fig. 1, node 7 is directly connected to nodes 1–6, which are in different positions but the same layer. We initialize the node importance as the efficiency [23], and show the efficiency differences of nodes 1–6 before and after removing node 7 in Table 1. Clearly, these difference values are dissimilar to each other, which suggests that the importance dependence strength of nodes 1–6 on node 7 is different from one another. So a node should contribute its importance to another node on the basis of the