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The rumor diffusion process with emerging independent spreaders in complex networks

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HIGHLIGHTS

- The model considers rumor diffusion process with participation of independent spreaders.
- We use a new stochastic method to obtain an analytical result of the model on homogeneous networks.
- Simulation results on homogeneous and heterogeneous networks are presented.
- We discuss the influence of the independent spreaders and network topology on the results.

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ABSTRACT

Rumor diffusion on complex networks has been widely investigated assuming that an individual learns the rumor merely from its neighbors, which, however, is not always the case. Recent studies of layered models have shown that individuals belonging to many different networks can affect the spreading process on one network. In this paper, we take this phenomenon into consideration and discuss its influence on rumor diffusion in complex networks by introducing independent spreaders. Independent spreaders are nodes that know the rumor from other channels rather than their neighbors. A new stochastic technique is used to obtain the dynamics of rumor diffusion. Results reveal that independent spreaders boost the process by bringing the rumor to regions remote from current spreaders. In order to accelerate diffusion, we find that improving the network connectivity is more efficient than adding more independent spreaders.

1. Introduction

The rumor diffusion dynamics in complex networks has been widely investigated in recent years, with attention paid to various spreading mechanics in one network [1–4]. An extensively studied case is that of social networks, where users publish quotes or blogs on their sites that can be seen and republished by their friends. The rumor diffusion mechanism is also valid for marketing, where companies exploit social networks to promote their products. Thus the research of rumor diffusion has realistic significance.

The social rumor diffusion process is often analyzed in epidemiological models. In spreading models such as the SI, SIS, and SIR models (S for susceptible, I for infectious, and R for recovered), social network users are regarded as nodes and friendship ties as links [5–8]. In these models as well as various inherited models, a rumor is carried by a given number

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of nodes at the beginning of the diffusion. As the case in the SI epidemic model, at each time step a spreader passes the rumor to its neighbors with a certain probability, and different approaches are implemented to accelerate or retard the process [9]. Besides local reachability of the disease or rumor, global reachability is also discussed [1]. Researchers have also released empirical studies of gossip spreading using social network data, revealing factors that can be influential on gossip propagation [10,11]. However, in reality, thanks to the development of the Internet and increasing popularity of online social networks, participators of one network can have easy access to all kinds of information sources. They can obtain information from TV, various social networks including Facebook, Twitter, and LiveJournal, and newspapers alike from time to time. Among these people, some can receive the rumor from other channels and publish it there, without necessarily getting the rumor from neighbors in the original network. In this way, they become independent spreaders.

Recent studies on coupled networks including the layered model [12] suggest similar concerns. It is likely that participants in one network are also members of other networks. A network that can spread information may be involved and may make an impact on the rumor diffusion process in other networks. Many recent research studies have focused on this inter-network effect and have gained insightful results on its structural and dynamical mechanism [13,14]. Apart from that, the idea of mobile agents is also discussed by researchers to propose a model of mobile agents to construct social networks [15]. But as far as the topic is concerned, little attention has been paid to this phenomenon in the rumor diffusion process in complex networks.

To tackle this problem, we propose a new model in which independent spreaders, i.e., spreaders who publish the rumor in the network but do not learn the rumor from their neighbors in the network, emerge in the process. We assume in our model that the system is in a field that can turn nodes randomly into independent spreaders. We obtain analytic expressions for the number of spreaders as a function of time in the case of Erdös–Rényi (ER) networks [16], and also present simulation results for ER, Barabasi–Albert (BA) and scale-free (SF) networks. Though these network topologies and social network topologies are not identical [17], we hope to obtain some basic understanding of the model on these networks. And the numerical results reveal that independent spreaders are important in rumor diffusion because they can bring the rumor to regions far away from current spreaders. But increasing the number of independent spreaders cannot significantly speed up the rumor delivering process. Network connectivity is the most important factor in rumor diffusion, and a network with good connectivity can greatly enhance the spreading efficiency.

The paper is organized as follows. In Section 2, we first give a basic description of the model and present some related definitions. Next, in Section 3, results on homogeneous networks are presented. We further discuss the model on heterogeneous networks in Section 4, and show the simulation results. Our final conclusions are developed in Section 5.

2. The model and definitions

We consider a connected, undirected, and finite network with N nodes. The system consists of two types of node: ignorant and spreader. When a node gets a rumor, it becomes a spreader and will later at each time step deliver the rumor to everyone of its neighbors with probability λ, which we call the epidemic rate [9]. At time 0, all nodes are ignorant. After that, we turn σ nodes into independent spreaders at each time step. If a node that is supposed to become an independent spreader has already been infected, it will be regarded as an ordinary spreader. The mean degree of the network is $\langle k\rangle$, and we denote $p = N\langle k\rangle/2\binom{N}{2} = \frac{\langle k\rangle}{N-1}$, which is the probability that any two nodes within the network are connected by a link. An illustration of the model can be seen in Fig. 1

For a set of nodes M, if a link attaches two nodes with one belonging to M and the other not, we call the link an "out-link" of M. On condition that only one independent spreader exists at time 1 and no more other independent spreaders will appear later, at time t we let S_t denote the number of spreaders in the network and K_t denote the total degree of spreaders. Otherwise, if the independent spreaders emerge in the way described in the model above, which means that σ independent spreaders are to appear at each time step, we let V_t denote the number of all spreaders in the network at time t. In other words, we define S_t to represent the number of spreaders that get the rumor from one original independent spreader, while we denote V_t to represent the number of all spreaders in the system.

In order to calculate V_t, we define an "extended volume",

$$V_{t,\mathrm{ex}} = \sum_{\tau=0}^{t-1} \sigma S_{t-\tau}. \tag{1}$$

With $S_{t-\tau}$ denoting the number of spreaders that are directly or indirectly infected by the independent spreader that appears at time τ, $V_{t,\mathrm{ex}}$ sums the number of spreaders allowing repeated counting. Given the expression of S_t and the relation of V_t and $V_{t,\mathrm{ex}}$, we can predict the number of spreaders at any time step. We analyze the model in homogeneous and heterogeneous networks in the following sections, and present the numerical results to prove the validity of our analysis.

3. Results for homogeneous networks

For simplicity, we adopt an *Erdös–Rényi* (ER) random network as our network topology. Although this structure lacks many features of online social networks, it helps to draw a basic understanding of the model due to its homogeneity. At time