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Rumor spreading in online social networks by considering the bipolar social reinforcement

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HIGHLIGHTS

- The bipolar social reinforcement that includes positive and negative effects is considered.
- By using generation function and cavity method, the rumor spreading threshold could be theoretically calculated.
- Some control strategies are presented to curb the rumor spreading.

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ABSTRACT

Considering the bipolar social reinforcement which includes positive and negative effects, in this paper we explore the rumor spreading dynamics in online social networks. By means of the generation function and cavity method developed from statistical physics of disordered system, the rumor spreading threshold can be theoretically drawn. Simulation results indicate that decreasing the positive reinforcement factor or increasing the negative reinforcement factor can suppress the rumor spreading effectively. By analyzing the topological properties of the real world social network, we find that the nodes with lower degree usually have smaller weight. However, the nodes with lower degree may have larger k-shell. In order to curb rumor spreading, some control strategies that are based on the nodes' degree, k-shell and weight are presented. By comparison, we show that controlling those nodes that have larger degree or weight are two effective strategies to prevent the rumor spreading.

1. Introduction

Nowadays, online social networks, such as Facebook, LiveJournal, Twitter, etc., are becoming more and more popular, which make it possible for people to acquire and spread rumor faster and wider than ever before [1,2]. However, the fictitious rumors can induce panic psychology or potential loss on the accompanying unexpected events [3–5]. Therefore, tackling the rumor spreading through a population or an Internet network has been considered a major topic in recent years [6–8].

Network science is widely researched in many fields [9–11]. The advent of the network science could provide the important set of computational and statistical physics tools for describing the problem of spreading [12–20]. Zhao et al. [21] studied a rumor spreading model in an online social blogging LiveJournal with consideration of forgetting mechanism. The results showed that there exists a threshold of the average degree of the LiveJournal and above which the influence of rumor reaches saturation. Han et al. [22] presented a novel model based on the heat energy theory to analyze the mechanisms of rumor propagation on large-scale social networks. Their results indicated rumor propagation is greatly influenced by a

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rumor's attraction, the initial rumormonger and the sending probability. Sathe [23] applied SIR model on the LiveJournal and studied the rumor spreading process. Their simulation results indicated that the behavior of the rumor spreading process is considerably different in social networks as compared to the one observed on synthetic random graphs. Zhou et al. [24] researched the influence of network structure on rumor propagation. They presented that the number of the total final infected nodes depends on the network topological structure and will decrease when the structure changes from random to scale-free network.

Social reinforcement plays a crucial role in the spreading of online behavior [25]. The so-called social reinforcement is defined as the situation in which an individual requires multiple prompts from neighbors before adopting an opinion or behavior [26]. That means individuals are more likely to accept and spread the rumor if they have received the rumor many times [27,28]. However, in the real world when people receive the same information more than one time, that may lead to the information redundancy. Meanwhile, because of the education or rational analysis, individuals would doubt the rumor if they received the same information again. That would significantly reduce the probability of spreading. The former social reinforcement is essentially positive and the latter is negative. Both social reinforcement effects have great influence on individuals' behaviors. Therefore, in this paper we take into account the bipolar social reinforcement that including positive and negative effects.

It is very important to study how to curb the rumor spreading in online social networks. In general, firstly we need to identify the influential spreaders in the network, and then limiting their activities [29]. Various measures are designed to find the influential spreaders in some certain networks [30–32]. Many previous investigations can be described as follows: one first ranks all nodes in the network with respect to some topological properties and then controlling some nodes by the certain sequence in order. Initially, some researchers argued hubs that maintain extremely large numbers of social relations are supposed to be the key spreaders [33–35]. The most common topologically-based methods are high degree (HD) and high betweenness centrality (HB) immunization. Further improvement has been implemented by recalculating the topological properties of the remaining network after each controlling step, leading to high degree adaptive (HDA) and high betweenness centrality adaptive (HBA) controlling. However, not all hubs are guaranteed to be influential spreaders. For instance, if a hub is located in the periphery of the network, its spreading ability would be limited [36]. Pei et al. [37] studied the topic that searching for superspreaders of information in real-world social media. The results indicated that the widely-used degree and PageRank fail in ranking users' influence. However, the best spreaders are consistently located in the k-core across dissimilar social platforms. Zeng et al. [38] proposed a mixed degree decomposition (MDD) to distinguish the node spreading influence within the node set with the same shell value. Their results indicated that the MDD method can outperform the k-shell and degree methods in ranking spreaders. Liu et al. [39] presented an improved method to evaluate the node spreading influence by taking into account the shortest distance between a target node and the node set with the highest shell value. The results shown the parameterless method could identify the node spreading influence more accurately.

Under the complexity of human mobility and interaction, individuals' actions and choices are affected by their surroundings at every moment. Indeed, human behavior is usually pretty complicated beyond our imagination. How to exactly describe the rumor process still is an open question. However, we may use some simple rules to depict the main features of real rumor process. Thus, in this paper, we investigate the effect of bipolar social reinforcement on the rumor spreading dynamics in the online social network. By means of the generation function and cavity method developed from statistical physics of disordered system, the threshold for rumor spreading could be theoretically drawn. Simulation results indicate that increasing the negative reinforcement factor or decreasing the positive factor can suppress the rumor spreading effectively. Moreover, in order to curb rumor spreading, some control methods that are based on the degree, k-shell and nodes' weight are presented. By comparison, we show that controlling those nodes that have larger degree or weight are two effective strategies to prevent the rumor spreading.

The rest of this paper is organized as follows: In Section 2, we analyze the rumor spreading dynamics and calculate the rumor spreading threshold. In Section 3, the control effects of various strategies are compared. Section 4 presents the conclusions.

2. Rumor spreading dynamics and threshold solution

We consider a population consisting of N individuals, and the whole population is divided into three groups: ignorants (I), spreaders (S) and stiflers (R). Ignorants are the people who never heard the rumor or heard the rumor but do not spread it temporarily. Spreaders are those who are spreading the rumor. Stiflers are those individuals who refuse to diffuse the rumor after they successfully diffuse the rumor. When an ignorant receives the rumor from a spreader, the ignorant becomes a spreader with the rate λ. A spreader becomes a stifler at a rate β because she or he learns that the rumor has become stale news. The rumor process can be characterized by the following two transition equations:

$$\begin{cases} S + I \xrightarrow{\lambda} 2S, \\ \quad\;\; S \xrightarrow{\beta} R. \end{cases} \tag{1}$$

Under the complexity of human mobility and interaction, individuals' actions and choices are affected by their surroundings at every moment. However, considering the two facts that: (1) It is possible for the individuals to believe