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A study on the interaction between two rumors in homogeneous complex networks under symmetric conditions

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HIGHLIGHTS

- Two rumors may have positive or negative impact on each other's spreading.
- A nine-state rumor interaction model in homogeneous complex network is proposed.
- Spreading properties are obtained by numerical solution of mean-field equations.
- Interactions between two rumors lead to the variation of spreading properties.

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ABSTRACT

The propagating dynamics of more than one rumor has received a substantial amount of attention in recent years. To investigate the effects of interactions between two rumors under symmetric conditions, we built a model based on an ordinary differential equation system while assuming that each individual's spreading rate after receiving one rumor depends on whether he/she knows the other rumor. In certain cases, two rumors accelerate the spread of each other, while in a portion of the other cases they impede or decelerate the spread of each other. We discuss these effects by dividing the total population into nine groups that correspond to nine states, and we subsequently build the mean-field equations for the two-rumor interaction based on the SIR model in a homogeneous complex network, and we find their numerical solution with varying interaction factors for the rates of spreading and becoming disinterested. The results show that when we change these interaction factors, the density curves of the nine states and their maximum values will change accordingly by a series of rules, which demonstrates the corresponding effects when there is a positive or negative interaction between the two rumors. Our work could establish a foundation for further study of this issue.

1. Introduction

A rumor has been defined as a type of social phenomenon in which a similar remark or saying spreads on a large scale in a relatively short time through chains of communication [1]. A rumor can cause damage to personal reputations, affect the

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financial market or cause social panic and instability. With the development of information technology in recent decades, the influence of rumors has become much larger than before. Conducting research on rumor propagation will give us a thorough understanding of this issue and allow us to predict and reduce the harm that could be caused by rumor propagation.

Previous studies have provided us with a large number of important properties of the single-rumor propagation process in social networks. In the 1960s, Daley and Kendall built the fundamental framework and proposed a model (DK-model) in which the total population is divided into three groups and their interaction follows the mass action law [2]. A variant model (MK model) proposed by Maki and Thomson in 1973 assumed that a rumor was spread by directed contact between spreaders and others [3]. Zenette performed a series of simulations on both static and dynamic small-world networks, showing that the MK model has a critical transition when the network randomness varies [4]. Moreno et al. studied rumor spreading dynamics on scale-free networks by performing Monte Carlo simulations and made numerical solutions of mean-field equations [5]. Nekovee et al. extended the former dynamic model to scale-free networks with assortative degree–degree correlations and derived the corresponding mean-field equations [6]. Gu et al. analyzed the forgetting and remembering mechanism of rumor propagation in 2007 [7], while Zhao et al. derived the mean-field equations with consideration of these two effects in homogeneous and inhomogeneous networks and performed some empirical work to make a comparison [8,9]. Zhao et al. [10] modified a classical SIR rumor spreading model in the new media age and introduced an extra condition by noticing that ignorants will inevitably change their status once they are made aware of a rumor. Other spreading models considered different types of individuals and an interaction mechanism based on the SIR model and mean-field method, including the SIHR model [11], SIRaRu model [12], SICR model [13] and 8-state-ICSAR model [14]. Recently, Qian et al. established an independent spreaders-involved SIR model and showed that the diffusion process and its steady state is greatly influenced by such spreaders [15].

In many cases, a rumor that concerns one event does not spread alone because there is always different information in an attempt to explain the event, and more than one rumor can break out simultaneously. Former research on two-rumor propagating models has mainly focused on the case in which one rumor expels the other. For example, in the work of Trpevski et al. [16], they proposed a two-rumor model based on the epidemic SIS model in which one of the rumors is always preferred by people. Numerical simulations on synthetic networks give the result that the preferred rumor is dominant when the degree of the nodes is high or a large clustered group of nodes is contained in the network, while it is possible for the less preferred rumor to occupy a nonzero fraction as well in some cases. Based on Trpevski's work and former studies on epidemic propagation with more than one disease, Wang et al. built a 2SI2R model that assumes that an individual can be a spreader or a stifler to each rumor [17]; then, they discussed two-rumor interaction dynamics in homogeneous networks by deriving and solving the corresponding mean-field equations.

However, when we address rumor spreading dynamics in social networks, especially on the internet, a fact that cannot be neglected is that when a rumor is propagating, it can be affected by the spread of another rumor, even though they might not have the relationship of rumor vs. anti-rumor information or expel each other. For example, during the Fukushima nuclear leak in 2011, a rumor claimed that radiation leakage would reach the Chinese mainland; this rumor triggered the breakout of another rumor claiming that salt can protect people from radiation, which in turn led to panic buying of salt in China. In this case, the first rumor had a positive impact on the spread of the second. Another case is that when the air crash of MH370 occurred in 2014, many rumors broke out, including a rumor that MH370 had sunk in the South India Ocean, while another rumor was that some of the remainder of the plane was found in that field. If an individual accepts one of these rumors, then there will be a larger possibility for him/her to accept the other, and thus, a positive interaction between the two rumors exists. Yet another rumor that MH370 was shot down by the air force of a certain country could bring about a negative effect on the former two rumors because the South India Ocean is far away from the route of MH370. Therefore, rumors can have a large influence on the propagation of other rumors, and this effect is worthwhile to study if we are attempting to predict or control the spreading process.

Indeed, interaction effects have been widely introduced in related fields such as epidemic models and other types of propagation processes. For example, Jolles et al. conducted a study on the interaction between macroparasites and microparasites, in which co-infection could favor transmission and progress of disease [18]. Lipsitch et al. also pointed out that multiple strains are maintained within host populations in most pathogens, and they built a quantitative model to study the mechanisms that underlie strain coexistence [19]. Roche et al. proposed an interaction model that considered the coexistence pattern of avian influenza viruses [20]. Another study concerned the virus interaction by Beutel et al. and modeled the effect that two viruses that were present at one host could simultaneously have one virus modify the susceptibility toward the other [21]. From a general perspective, Stanoev et al. proposed a stochastic model for the concurrent spread of an arbitrary number of contagions in complex networks [22], which can be adapted to the rumor interaction's case. In fact, a statistical model developed by S. Myers and J. Leskovec has shown that information interaction has a very strong effect and causes a relatively large change in the spreading probability of contagion [23], which also supports the existence of rumor interactions. Moreover, another approach to information propagation where there is interaction between different pieces of information is also proposed, which can be used to infer hidden or unobserved networks [24]. However, even though it widely exists and has a large influence on social behavior, the rumor interaction mechanism still does not receive a large amount of attention, and there is limited research in this area.

In our study, we proposed a two-rumor interaction model in which each individual has two states, which correspond to the attitudes toward each of the two rumors. When considering the correlation effect between two rumors, our model assumes that one rumor does not necessarily expel the other, which means that a person can be the spreader of both or be