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Rumor spreading model considering hesitating mechanism in complex social networks

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HIGHLIGHTS

- SEIR rumor spreading model considering hesitating mechanism is proposed.
- The attractiveness and fuzziness of rumor are introduced into the SEIR model.
- The dynamical equations of SEIR model by using the mean-field method are derived.
- There exists the spreading threshold in the SEIR model with hesitating mechanism.
- The spreading threshold and final rumor size are greatly impacted by the fuzziness.

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ABSTRACT

The study of rumor spreading has become an important issue on complex social networks. On the basis of prior studies, we propose a modified susceptible–exposed–infected–removed (SEIR) model with hesitating mechanism by considering the attractiveness and fuzziness of the content of rumors. We derive mean-field equations to characterize the dynamics of SEIR model on both homogeneous and heterogeneous networks. Then a steady-state analysis is conducted to investigate the spreading threshold and the final rumor size. Simulations on both artificial and real networks show that a decrease of fuzziness can effectively increase the spreading threshold of the SEIR model and reduce the maximum rumor influence. In addition, the spreading threshold is independent of the attractiveness of rumor. Simulation results also show that the speed of rumor spreading obeys the relation "BA network > WS network", whereas the final scale of spreading obeys the opposite relation.

1. Introduction

Rumor spreading is a fundamental problem and has been widely studied by scholars [1–8]. Rumor is often defined as the spreading of public interested things, events or unconfirmed interpretations of problems through various channels. As an important form of social communication, rumor also can be perceived as the contagion of thoughts whose authenticity cannot be judged, which has a great influence on people's life.

With the development of Web2.0 technology, Social Network Service (SNS) networks characterizing diversity and interactivity provide the public with more extensive, fast and real-time information access and exchange platform. More and more SNS networks, such as Facebook, Twitter, LinkedIn and so on, which are seemingly like cobwebs to connect people from different cultures, are emerging in our social life. On the social networks, SNS users are free to make friends, share

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information and deliver comments. On the positive side, netizens can spontaneously form many study groups to share resources and exchange opinions on social networking websites. However, each coin has two sides. With the fast increase of the number of SNS users, more and more hot topics on Twitter or Facebook can cause a heated discussion even a debate. If you login social network, you will be free to browse the information posted by your friends and publish opinions on public affairs. As a result, social networks will inevitably generate some malicious messages or rumors. For example, flight MH370 and MH17 incidents had aroused a lot of comments on social networks, some of which caused massive public panic. Social network has now become one of major platforms, where rumors always occur. Thus, the investigation of the problem of rumor spreading on the complex social networks has an important scientific significance for the authoritative organizations to make effective control strategies in case of emergency.

Considered as a typical application, the complex social networks have general characteristics of complex networks. Therefore, the rumor spreading issues based on the complex social networks can be looked as spreading dynamics on complex networks. In recent years, more and more researchers have started to study the problems of rumor spreading on complex networks. They derive corresponding mean-field equations describing the dynamics of the models to understand the characteristics of rumor propagation and analyze the critical threshold of rumor spreading on the complex networks. Daley and Kendal [1] pointed out the differences between the spreading of an infectious disease and the dissemination of a rumor, and they proposed the classic Daley–Kendal (DK) model of rumor spreading with detailed transition rules of state variables. Since then, most of the existing susceptible–infected–removed (SIR) models [2–7] of rumor spreading based on DK model have divided individuals into three categories: ignorants (S), spreaders (I), and stiflers (R). To overcome the weaknesses of DK model, researchers [2–8] took into account the topological characteristics of underlying networks. Moreno et al. [2] introduced a useful stochastic method based on the numerical solution of the mean-field rate equations describing the generic rumor model [1] to obtain meaningful time profiles for the quantities characterizing the propagation process. They found that there is no rumor threshold in homogeneous networks, which is different from the case of epidemic spreading. After that, Nekovee and Moreno et al. [3] introduced a general stochastic model and derived corresponding mean-field equations to further study the threshold behavior and the impact of degree correlations on the final size of rumors on general networks. They obtained a conclusion that scale-free social networks are prone to the spreading of rumors, just as the spreading of epidemics. In Ref. [4], the authors considered the influence of network topological structure and unequal footings between the father and the other neighboring nodes. They found that the degree distribution influences directly the final rumor size. Recently, scientists [5–9] started to take serious consideration about the role of human behaviors and different mechanisms in the spreading of rumors. The effects of forgetting mechanism on the dynamics of rumor spreading were analyzed [5,6], and the numerical solution results on LiveJournal showed that forgetting rate can affect rumor spreading. Wang et al. [7] proposed a novel SIR model by introducing the trust mechanism between the ignorant nodes and the spreader nodes. They got the conclusion that the introduction of trust mechanism not only greatly reduces the maximum rumor influence, but also postpones the rumor terminal time. In Ref. [8], the authors presented a variant rumor spreading model on the basis of online social networks considering negative or positive social reinforcements in the acceptant probability model. They analyzed how the social reinforcement affected the spreading rate. In Ref. [9], the impact of the population's education rate on the rumor dynamics was investigated, and numerical results showed that education significantly contributed to the rumor spreading cessation. In fact, the effects of individual behavior have already been investigated in a series of epidemiological models [10–15]. Rizzo and Frasca et al. [15] studied the effects of behavioral changes of individuals on epidemic spreading in activity-driven network, where the network topology and the state of each node evolved concurrently [16]. Their results confirmed that both self-protecting and quarantinelike behaviors were effective means for controlling the epidemic spreading. Borge-Holthoefer and Moreno [17] discussed the absence of influential spreaders in spreading dynamics of rumors, and showed that central nodes (they might be high k-shell nodes or hubs) were not as enhancers of the dissemination. However, they behave like firewalls that interrupt the propagation of information.

In general, most works above focused on the dynamics of rumor spreading on the basis of typical SIR model with three states. To reflect both forgetting and remembering mechanisms, Zhao et al. [18,19] began to further investigate the rumor spreading SIHR model with four states. Individuals can spontaneously cease spreading the rumor by forgetting, also can spontaneously or stimulated restart spreading the rumor by remembering. They added an additional group called Hibernators (H) coming from the spreaders due to forgetting mechanism and later becoming spreaders again due to remembering mechanism. Their model was based on the situation that when an ignorant contacts with a spreader, the ignorant may immediately become spreader or stifler at a certain probability. Thus, susceptible node would transform into infected state or removed state with a certain probability in the next step of spreading process. However, in the real social life, due to the characteristics, education background, legal consciousness of individuals and some other factors, some SNS users will not immediately spread the rumor after they know a rumor topic, and they will first become exposed state (hesitating state). People in the hesitating state are not sure of the authenticity of rumor, so they do not spread rumor. However for the literatures of the rumor spreading, many researchers ignored the hesitating mechanism, which can affect the people's attitudes and behaviors to rumors and further influence the rumor spreading of the whole network. Besides that, they only considered the impact of network structure or the characteristics of human social behavior on the rumor propagation, but ignored the characteristics (such as attractiveness and fuzziness) of the rumor itself that may affect the dynamics of rumor spreading. As Wang et al. [20] mentioned that the more important and fuzzy events were, the greater the effects of rumors will be. For example, the events of Malaysia Airlines MH370 and MH17 are very important and attract global attention, so various rumors about the flight incidents have spread on the social networks. People in the exposed (hesitating) state will read all friends' activities of "news