Simulation Modelling Practice and Theory 75 (2017) 67–76

Contents lists available at ScienceDirect

Simulation Modelling Practice and Theory

journal homepage: www.elsevier.com/locate/simpat

Modelling heterogeneous information spreading abilities of social network ties

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ARTICLE INFO

Article history:
Received 7 August 2016
Revised 7 February 2017
Accepted 17 March 2017

Keywords:
Information spreading
Small world network
Random network
User attention modelling

ABSTRACT

Information spreading is often analyzed comparatively on small-world and random networks. Topological differences between small-world networks and random networks are believed to be main reasons that lead to various different spreading behaviours on these two types of networks. Besides those differences, the heterogeneity of spreading abilities of network ties is often overlooked. In this study, we analyze the impacts of the heterogeneity on information spreading over small-world networks and random networks. Through simulations on both artificial and realistic networks, we find that the strong heterogeneity leads to lower efficiency of spreading over small-world networks. The heterogeneity not only slows down the spreading pace, but also lengthens the life span of the information spread over small-world networks. Under such strong heterogeneity, random networks, which are affected little, are better for information spreading. However, as the heterogeneity decreases, small-world networks finally exceed random networks when regarding information spreading. We also conduct experiments to review the weak ties assumption in small-world networks. We find that the heterogeneity forces information to bypass weak ties and travels along strongly connected nodes.

1. Introduction

Understanding the dynamics of information spreading in social networks is an interesting and challenging problem that has been studied by researchers from different fields for many years. At the early stage, researchers employed mathematical models, such as, the Susceptible-Infected (SI) model, the Susceptible-Infected-Susceptible (SIS) model [1], and the Susceptible-Infected-Recovered (SIR) model [2], to characterize information spreading in social networks. Recently, with the emergence of online social networks, physicists and computer scientists became interested in adopting various types of social network data, such as, phone communication log files [3], friend relationships of Facebook [4], and retweets of Twitters [5], to analyze how the dynamics of information spreading is affected by network topology and intended to identify essential factors in the mechanism of information spreading.

In the real world, lots of networks (e.g., online social networks and telecommunication networks) have been identified as small-world networks [3,4]. Therefore, to understand how epidemics, advertising slogans and computer viruses spread on this kind of networks is of much significance. Random networks, unlike small-world networks whose average shortest path is short, has long pathes between nodes and are also observed in the real world, such as, P2P networks [6]. Because

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http://dx.doi.org/10.1016/j.simpat.2017.03.007
1569-190X/

of above mentioned similarities and differences in topologies, these two types of networks are usually evaluated and even compared when studying information spreading.

Centola conducted an online experiment to verify whether small-world networks or random networks more favor information spreading, where volunteers were randomly chosen as a node in a small-world network or in a random network as created by the author [7]. These volunteers were recommended to adopt a healthy behaviour once their neighbours had done so. Results turned out that users received multiple recommendations adopt the healthy behaviour with a higher probability than those who received fewer recommendations. Lots of redundant ties within a local community in small-world networks provided an ideal topology for multiple recommendations. Consequently, the adoption behaviour spreads faster and further within small-world networks. Similarly, a more mathematical model was proposed in [8], where the authors analyzed the impact of social reinforcement on information spreading [9]. The above studies conclude that small-world networks are more suitable for information spreading than random networks.

However, some other studies on small-world networks find that information is often trapped by local communities in small-world networks and it thus spreads slower than what is expected [10–14]. To explain this phenomenon, Karsai et al. adopted the SI model and null models to probe into possible factors [10]. They found that two factors leading to the inefficiency of information spreading in small-world networks. The first is that the community structures and their correlation with the weights of network ties, while the second is the inhomogeneous and bursty activity patterns on the ties. Local information is also analyzed on social simulations in small-world networks [15]. It finds that local information, like weak individuals can have significant impacts on the spreading of epidemics or ideas. All of these studies reveal that local structures may have an important impact on information spreading, which is overlooked in [7,8].

Motivated by the above two opposite observations on information spreading, we analyze and identify the key differences between these studies [7,8,14]. We find that the roles of network ties are treated differently. In [7,8], ties are equal, that is, the neighbours of a node are of the same importance to it, while in [14] network ties are supposed to have different weights according to the relationships of two connected nodes. Therefore, in this paper, we propose an information spreading model that takes into consideration the different spreading abilities of network ties in order to see whether small-world or random networks more favor information spreading. In the proposed model, the spreading abilities of network ties, which are also called weights or strengths in other studies [14], are referred as the probabilities of information spreading from one node to another. Therefore, the proposed model focuses on the heterogeneity of spreading abilities of ties and analyzes how such heterogeneity affects information spreading.

In general, the novelty and main contributions of this study can be summarized as follows:

- We propose a new information spreading model, in which the heterogeneity of spreading abilities of network ties is carefully characterized for the first time;
- Through simulating the proposed model on both artificial and realistic social networks, we find that whether small-world or random networks are better for information spreading largely depends on the heterogeneity of spreading abilities of network ties. Specifically, if the heterogeneity is negligible, small-world networks are the best ones for information spreading. On the contrary, if the heterogeneity is not negligible, information spreading over small-world networks is largely inhibited, while that over random networks is only slightly affected by the heterogeneity. In other words, the aforementioned opposite observations on information spreading over small-world networks are unified into one model.
- We also observe that the effect of such heterogeneity on small-world networks is twofold: While it certainly slows down the spreading process of information, it also unexpectedly lengthens its life span.
- Finally, weak tie assumptions are reviewed under the proposed model. We find that information is forced to bypass the weak ties and travel along those strong ties by the strong heterogeneity, thus travelling along a long way to spread out.

The remainder of this paper is organized as follows. In Section 2, we propose a mathematical model that characterizes the heterogeneity of spreading abilities of network ties, in which we are able to control it by tuning a parameter β. In Section 3, we briefly describe the design of our experiments for validating the proposed model. Section 4 presents the results and findings of our experiments conducted on both realistic and computer-generated social networks. This paper is concluded in Section 5.

2. The proposed model

In this section, we formally describe the proposed model in detail.

As analyzed in the previous section, network ties should not be treated equally when considering the spreading of messages along them. Local topological information of the social network must be taken into account. Therefore, the fundamental principle of the proposed model, which differs it from the state-of-the-art models (e.g., [7,8,14]), lies in that different network ties are supposed to have different abilities in spreading messages. In other words, the spreading abilities of network ties are heterogeneous. Therefore, the key of the proposed model focuses on modelling such heterogeneity in terms of local topological information of the social network. In addition, each message exposed to a user may cause his/her attention, and a message may be exposed to the same user for more than one time, as he/she may have multiple neighbours in the network who adopts the message. In this way, the attention of the user caused by the message may be gradually accumulated, which in turn prompts he/she to adopt and further spread it. Therefore, in the proposed model the attention of users