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Information spreading on dynamic social networks

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ABSTRACT

Nowadays, information spreading on social networks has triggered an explosive attention in various disciplines. Most of previous works in this area mainly focus on discussing the effects of spreading probability or immunization strategy on static networks. However, in real systems, the peer-to-peer network structure changes constantly according to frequently social activities of users. In order to capture this dynamical property and study its impact on information spreading, in this paper, a link rewiring strategy based on the Fermi function is introduced. In the present model, the informed individuals tend to break old links and reconnect to their second-order friends with more uninformed neighbors. Simulation results on the susceptible-infected-recovered (*SIR*) model with fixed recovery time $T = 1$ indicate that the information would spread more faster and broader with the proposed rewiring strategy. Extensive analyses of the information cascade size distribution show that the spreading process of the initial steps plays a very important role, that is to say, the information will spread out if it is still survival at the beginning time. The proposed model may shed some light on the in-depth understanding of information spreading on dynamical social networks.

1. Introduction

The epidemic spreading based on complex networks, where nodes represent individuals or organizations and links denote their interactions, has attracted an increasing attention in recent years [1–3]. Epidemic spreading is a dynamic process in which an item is transmitted from an infected individual to a susceptible individual through the link between them. Therefore, the network structure is a particularly important factor for the efficiency of epidemic spreading. Recently, many pioneering works about susceptible-infected-susceptible (*SIS*) and susceptible-infected-recovered (*SIR*) models indicate that a highly heterogeneous structure will lead to the absence of any outbreak threshold [4] while the epidemic spreading on small-world network exhibits critical behavior [5]. The voluntary vaccination strategy under game theory framework shows that the epidemic spreading on scale-free networks can be favorably and easily controlled [6,7]. However, all those interesting results are obtained based on the research of the static network, where interactions are always fixed. By contrast, in real online systems, people communicate with various individuals and might make new friends everyday. That is to say, the social communication network, also referred to as the peer-to-peer network, would change its topology dynamically. Consequently, it would be very suitable to study such dynamic networks with the *rewiring strategy* [8], where the network structure changes by breaking old links and forming new ones.

In the past few years, many researches have focused on the epidemic spreading problem in such dynamically contacting networks based on the link rewiring strategy [9–15]. The most important and widely used one is the *adaptive model* [10,11], in which the susceptible individuals try to avoid contacting the infected individuals [10,12,13]. Simulation results of *SIS*

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[10,13] and susceptible-infected-recovery-susceptible (*SIRS*) models [12] on adaptive networks show that the epidemic outbreak threshold would be larger than that on static networks. It indicates that the rewiring process typically tends to suppress epidemic spreading via isolating infected individuals. Recently, Yoo et al. [14] proposed a *fitness-adaptive rewiring* model where each individual's degree is preserved in the adaptive model [15]. They found that the speed of approaching the epidemic threshold is delayed and the prevalence is reduced comparing with adaptive models. Above all, those epidemic spreading researches on dynamic networks based on the adaptive model indicate that segregating infected individuals (or susceptible individuals) is an efficient strategy of reducing the fraction of susceptible-infected interactions, as well as preventing the outbreak of the whole spreading process.

However, information spreading is quite different from disease infections due to its specific features, such as time decaying effect [16], tie strength [17], information contents [18], memory effects [19], social reinforcement [20,21], non-redundancy of contacts [22], etc. In this paper, we propose a new rewiring model to study information spreading on dynamic networks where individuals will select the neighbors with larger payoff [23] following the Fermi function [24–26]. In conventional statistical physics, Fermi function is used to describe the probability of occupancy for an electron energy state at certain energy level by an electron. In the present model, we consider such energy level as payoff of rewiring strategy. That is to say, a given node will change its connection by comparing the alternatives' payoff. There is already a vast class of researches trying to apply Fermi function in modeling social dynamics. Fu et al. [26] used the Fermi function to evaluate the expected costs and benefits of vaccination via exploring the roles of individual imitation behaviour and population structure. Zhang et al. [27] considered that individual would adopt rewiring or migration reaction to adverse neighborhoods following the Fermi function and the mixture of different reactions led to much more favorable for the evolution of cooperation. Pacheco et al. [28] adopted the pair-wise comparison strategy for seeking new interactions of rational individuals based on Fermi function. Analogously, Santos et al. [29] proposed a computational model to allow individuals to be able to self-organize their social ties, based exclusively on their self-interest, in order to solve the evolutionary cooperative-competitive dilemma. Van Segbroeck et al. [30] alternatively introduced a model using the payoff-dependent Fermi function. They demonstrated that defectors were more rapid to break adverse links in order to achieve maximum fitness state, which finally led to a more heterogeneous network structure and improved cooperators' survivability.

Different from adaptive models, in this model, the informed individual will break the susceptible-infected link if the susceptible individual's payoff (the number of susceptible neighbors of the considering individual) is less than one randomly selected among its second-order neighbors, and rewire the link to the selected susceptible individual (see Fig. 1). Simulation results on various networks show that the spreading on dynamic networks is more efficient than that on static networks. Especially for the scale-free network, the information spreading prevalence forms two regimes, indicating that the information diffusion either dies out quickly or spreads into a finite fraction of the total population.

2. Model

In this paper, we use the SIR model with fixed recovery time $T = 1$ to illustrate the proposed information spreading process. All individuals in the system must be one of the three discrete states: the uninformed individuals (defined as *S*-state), the active informed individuals (defined as *I*-state) which would transmit information to their *S* neighbors and the inactive informed individuals (defined as *R*-state) which know the information but would not transmit it any more. Initially, a node is randomly selected as the *I*-state, which is considered as the *seed* for the information spreading, and all other individuals are set as the *S*-state. At each time step, the *I* individuals transmit the information to the *S* nodes through $S - I$ links with the spreading rate λ. In social network, the individuals usually won't transfer an information item more than once to the same neighbor, namely the non-redundancy property [22]. Therefore, each *S*-*I* link can just be used once in our model, no matter the transmission through this link is successful or not. That is to say, when one *I* individual transmits the information to all its *S* neighbors at one time step, the *I* individual will change to *R*-state and would not be able to transmit information any more. The information spreading process stops until there is no *I*-state individual in the system.

Generally, information decays very fast [16], that is to say, some information would lose attraction within a very short period. Hence, how to spread the information quickly is a critically important problem in the social system [31]. The link

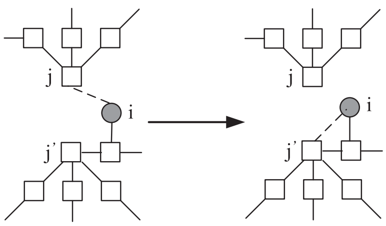

Fig. 1. Illustration of the one-step rewiring process for a given node *i*. The left panel is the original network, and the gray circle *i* represents the informed individual (*I*-state), while squares represent the uninformed individuals (*S*-state). In the original network, individual *j* is *i*'s neighbor and *j*′ is *i*'s second-order neighbor. The payoffs of *j* and *j*′ are $\pi_j = 3$ and $\pi_{j'} = 4$ respectively. Node *i* will break the link to *j* (left panel) and reconnect to *j*′ (right panel) with probability $p_f = \frac{1}{1+e^{-\beta(\pi_{j'}-\pi_j)}}$.