Physica A 438 (2015) 169–177

Contents lists available at ScienceDirect

Physica A

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

Can rewiring strategy control the epidemic spreading?

Chao Dong, Qiuju Yin, Wenyang Liu, Zhijun Yan *, Tianyu Shi

School of Management & Economics, Beijing Institute of Technology, Beijing 100081, China

HIGHLIGHTS

- A novel epidemic spreading model in weighted adaptive network is proposed.
- The relation intimacy among individuals is considered in rewiring strategy.
- The effect of the modified rewiring strategy is evaluated.
- As well as strong links, weak links play an important role in the epidemic spreading.

ARTICLE INFO

Article history:
Received 9 February 2015
Received in revised form 19 May 2015
Available online 9 July 2015

Keywords:
Relation
Rewiring strategy
Adaptive network
Epidemic spreading

ABSTRACT

Relation existed in the social contact network can affect individuals' behaviors greatly. Considering the diversity of relation intimacy among network nodes, an epidemic propagation model is proposed by incorporating the link-breaking threshold, which is normally neglected in the rewiring strategy. The impact of rewiring strategy on the epidemic spreading in the weighted adaptive network is explored. The results show that the rewiring strategy cannot always control the epidemic prevalence, especially when the link-breaking threshold is low. Meanwhile, as well as strong links, weak links also play a significant role on epidemic spreading.

1. Introduction

Recent global infectious diseases, including H1N1 (Swine Influenza), SARS (Severe Acute Respiratory Syndrome), H7N9 (Avian Influenza) and Ebola (Ebola virus disease), have caused major public health threats due to the potential high mortalities and substantial economic impacts. To analyze the spreading process of infectious diseases and make better decisions on the controlling strategy, epidemic spreading process is usually modeled based on complex networks, with nodes representing individuals and links denoting their interactions [1–3].

Meanwhile, facing the epidemic threat, individuals may take some self-protective actions such as reducing outside activities, wearing face masks, washing hands frequently, taking the vaccination and so on [4–7]. Such self-protective actions will influence the network topology and may significantly change the predicted course of epidemic dynamic [8,9]. Based on the Susceptible–Infected–Susceptible (SIS) model, Gross et al. proposed the adaptive network to depict the impact of the dynamic change of network structure on epidemic spreading [10]. In their model, the network structure changed all the time according to the states of neighboring nodes and this in turn affected epidemic dynamics. Specifically, the susceptible individuals might protect themselves by rewiring their links. The susceptible node would break the link (SI link) with the infected node based on a fixed probability and form a new link with another randomly selected susceptible node. Following this, there are many literatures studying the epidemic propagation on an adaptive network. Shaw et al. analyzed the epidemic spreading process in adaptive networks based on Susceptible–Infected–Recovered–Susceptible (SIRS)

* Corresponding author. Tel.: +86 10 68912845.
E-mail address: yanzhijun@bit.edu.cn (Z. Yan).

http://dx.doi.org/10.1016/j.physa.2015.06.037

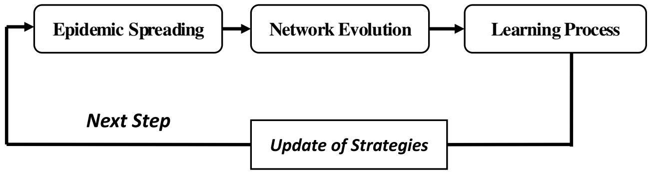

Fig. 1. Schematic of the proposed model.

model [11]. Lagorio et al. studied the critical effect of quarantine on the epidemic propagation on an adaptive social contact network [12]. Guo et al. proposed a continuous-time Adaptive Susceptible–Infected–Susceptible (ASIS) model to study the interplay between epidemic dynamics and the dynamics of network structure [13]. Song et al. introduced a new preferentially reconnecting edge strategy of adaptive networks depending on spatial distance. For this rewiring strategy, when an SI link was broken, the S node would reconnect to a random node with probability p and a neighboring node with probability 1-p. They found that a smaller value of probability p led to a slower epidemic spreading [14].

However, prior works have several main limitations. First, rewiring strategy in adaptive network has been accepted as an effective strategy to suppress the epidemic spreading [15,16]. Many factors that influence the rewiring strategy were explored [14,17]. However, interpersonal relations, generally present in the social network, are seldom considered. Though relation has attracted more and more attention in the static network research [18,19], it is still unclear how the relation affects the epidemic propagation in adaptive networks. Second, the rewiring mechanism of adaptive network models [20] includes two processes, that is, link-breaking and link-creating, which are explored by most studies. But these studies only considered the influencing factors of link-creating process (such as spatial space [14,17]), and the influencing factors related with link-breaking process were ignored. In this study, we incorporated interpersonal relation as the influencing factor of link-breaking process. Thus the link would not be broken randomly but according to the relation intimacy between two nodes that lie in two sides of a link. Third, vaccination is an important fundamental method to block transmission of diseases for the fixed network topology [21–25]. Although some previous literatures studied the selection method of vaccinated nodes and explored the effect of vaccination strategy in adaptive networks [26], the interplay between rewiring strategy and vaccination is less investigated.

Incorporating the interpersonal relations and vaccination strategy, this paper develops a novel epidemic spreading model in weighted adaptive network. We divide our model into three processes, including epidemic spreading process, network evolution process and learning process. Then we study the epidemic spreading in adaptive network based on relation intimacy. Our results demonstrate that the rewiring strategy has a close relationship with the epidemic spreading, and this strategy cannot always suppress the disease, which is different from some previous studies [15,27]. When breaking some weak links, the epidemic size is still very large. However, as strong links gradually being cut, the epidemic can be controlled effectively. Meanwhile, the results also show that weak links play an important role on the epidemic spreading as well as strong links.

This study contributes to the literature in three important aspects. First, this study proposes a new model to examine the influencing factors of epidemic spreading in adaptive networks. The new model consists of three main processes, which describe the epidemic spreading, network structure adjustment and individuals' strategy learning respectively. Second, interpersonal relation has significant influence on individuals' behavior. The proposed model takes the interpersonal relation into consideration and analyzes the impact of interpersonal relation on epidemic spreading. Third, this study also investigates the interplay between rewiring strategy and vaccination strategy. The result shows that, without vaccination, the disease cannot be suppressed very well only through rewiring strategy.

The rest of this paper is organized as follows. In Section 2, we describe the proposed model in detail, including epidemic spreading process, network evolution process and learning process. The relationship between rewiring strategy and epidemic spreading is investigated in Section 3. Finally, we conclude this study and discuss future work in Section 4.

2. Model

Many infectious diseases, such as influenza, are hard to be eradicated and may spread for many seasons. Inspired by prior studies [28,29], in this paper, each step is divided into three processes, namely, epidemic spreading process, network evolution process and learning process. Schematic of the proposed model is given in Fig. 1.

At the beginning of a season, each susceptible individual can choose vaccination or not. Normally only a small part of population ρ'_V takes vaccination. In this study, we assume that the vaccine is not fully effective and the successful rate of the vaccination is e.

A vaccinated individual (V) will pay a cost υ that accounts for not only the monetary cost of the vaccine, but also the side effect. If an individual gets infected during the epidemic season, he/she has to pay a cost r. Obviously, $r > \upsilon > 0$. Without loss of generality, we take the cost of being infected as $r = 1$. Because of the imperfect vaccine, the population will have the following four types of individuals:

(1) Vaccinated individuals that remain healthy (V_e) during the epidemic season have payoff $\pi = -\upsilon$.
(2) Vaccinated individuals that were infected (V_i) during the epidemic season have payoff $\pi = -\upsilon - r$.