Available online at www.sciencedirect.com
ScienceDirect

ELSEVIER

The Journal of China Universities of Posts and Telecommunications

October 2016, 23(5): 82–87
www.sciencedirect.com/science/journal/10058885

http://jcupt.bupt.edu.cn

Modeling and analysis of epidemic spreading on community network with node's birth and death

Li Chanchan[1], Jiang Guoping[2] (✉)

1. School of Computer, Nanjing University of Posts and Telecommunications, Nanjing 210003, China
2. School of Automation, Nanjing University of Posts and Telecommunications, Nanjing 210003, China

Abstract

In this paper, a modified susceptible infected susceptible (SIS) epidemic model is proposed on community structure networks considering birth and death of node. For the existence of node's death would change the topology of global network, the characteristic of network with death rate is discussed. Then we study the epidemiology behavior based on the mean-field theory and derive the relationships between epidemic threshold and other parameters, such as modularity coefficient, birth rate and death rates (caused by disease or other reasons). In addition, the stability of endemic equilibrium is analyzed. Theoretical analysis and simulations show that the epidemic threshold increases with the increase of two kinds of death rates, while it decreases with the increase of the modularity coefficient and network size.

Keywords community structure, epidemic dynamics, complex networks, mean-field theory

1 Introduction

With the development of complex network theory, many social, biological and technological systems, such as the transportation networks, Internet and social network, can be properly analyzed from the perspective of complex network. And many common characteristics of most real-life networks have been found out, e.g., small-world effect and scale-free property. For some kind of networks, the degree distributions have small fluctuations, and they are called as homogeneous networks [1], e.g., random networks, small world networks and regular networks. In contrary to the homogeneous networks, heterogeneous networks [2] show power law distribution.

Based on the mean-field theory, many epidemic models, such as susceptible-infected (SI), SIS and susceptible-infected-recovered/ removed (SIR), have been proposed to describe the epidemic spreading process and investigate the epidemiology. It has been demonstrated that a threshold value exists in the homogeneous networks, while it is absent in the heterogeneous networks with sufficiently large size [3]. Compared to the lifetime of individuals, the infectious period of the majority of infectious diseases is short. Therefore, in most of the epidemic models, researchers generally choose to ignore the impact of individuals' birth and death on epidemic spreading. However, in real life, some infectious diseases have high death rate and may result in people's death in just a few days or even a few hours, such as severe acute respiratory syndrome (SARS), Hemagglutinin 7 Neuraminidase 9 (H7N9) and the recent Ebola. And some infectious diseases may have longer spreading time, like HBV, Tuberculosis. Besides, on the Internet, nodes' adding and removing every time can also be treated as nodes' birth and death. In Ref. [4], Liu et al. analyzed the spread of diseases with individuals' birth and death on regular and scale-free networks. They find that on a regular network the epidemic threshold increases with the increase of the treatment rate and death rate, while for a power law degree distribution network the epidemic threshold is absent in the thermodynamic limit. Sanz et al. have investigated a Tuberculosis-like infection epidemiological model with

Received date: 01-02-2016
Corresponding author: Jiang Guoping, E-mail: jianggp@njupt.edu.cn
DOI: 10.1016/S1005-8885(16)60061-4

constant birth and death rates [5]. It is found that the constant change of the network topology which caused by the individuals' birth and death enhances the epidemic incidence and reduces the epidemic threshold. Zhang et al. considered the epidemic thresholds for a staged progression model with birth and death on homogeneous and heterogeneous networks respectively [6]. In Ref. [7], an SIS model with nonlinear infection rate, as well as birth and death of nodes, is investigated on heterogeneous networks. In Ref. [8], Zhu et al. proposed a modified SIS model with a birth-death process and nonlinear infection rate on an adaptive and weighted contact network. It is indicated that the fixed weights setting can raise the disease risk, and that the variation of the weight cannot change the epidemic threshold but it can affect the epidemic size.

Recently, it has been revealed that many real networks have the so-called community structure [9], such as social networks, Internet and citation networks. A lot of researchers focus on the study of epidemic spreading on community structure networks. Liu et al. investigated the epidemic propagation in the SIS model on homogeneous network with community structure. They found that community structure suppress the global spread but increase the threshold [10]. Many researchers studied the epidemic spreading in scale-free networks with community structure based on different epidemic model, such as SI model [11], SIS model [12], SIR model [13–14] and susceptible exposed asymptomatically infected recovered (SEAIR) model [15]. Chu et al. investigated the epidemic spreading in weighted scale-free networks with community structure [16]. In Ref. [17], Shao et al. proposed an traffic-driven SIS epidemic model in which the epidemic pathway is decided by the traffic of nodes in community structure networks. It is found that the community structure can accelerate the epidemic propagation in the traffic-driven model, which is different from the traditional model.

The social network has the property of community structure and some infectious diseases have high mortality rates or long infection period, while the previous studies only consider the impact of one of the aforementioned factors. So in this paper, we study the epidemic spreading in a modified SIS epidemic model with birth and death of individuals on a community structure network. The rest of this paper is organized as follows. In Sect. 2, we introduce in detail the network model and epidemic spreading process, and discuss the network characteristics either. In Sect. 3, mean-field theory is utilized to analyze the spreading properties of the modified SIS epidemic model. Sect. 4 gives some numerical and simulations which support the theoretical analysis. At last, Sect. 5 concludes the paper.

2 The community structure network model

As there exists the phenomena of the individual's birth and death in real networks, the topology of the network changes over time. We consider undirected and un-weighted graphs in this paper. The generating algorithm of the network with community structure can be summarized as follows:

1) There are m different communities with n_i (i=1, 2,…, m) sites, the network size $N=\sum_i n_i$. We assume that each site of this network is empty or occupied by only one individual.

2) The probability to have a link between the individuals (non-empty sites) in the same community is p_{i}.

3) We create a link between two nodes (non-empty sites) belonging to different communities with probability p_{e}.

4) Every site has its own state and may change with the evolution of epidemic. In each time step, susceptible individuals and infected individuals may respectively die with probability α and β, meanwhile, the corresponding site becomes empty, and the links of these sites are broken.

5) For each empty site, a susceptible individual may be born with probability b, and then it create links with other individuals with probability p_{i} in the same community or p_{e} belonging to different communities.

Suppose the initial number of edges is K, then we have:

$$K=\sum_{i=1}^{m}\frac{n_i\left(n_i-1\right)p_{\mathrm{i}}}{2}+\sum_{i<j}^{m}n_in_jp_{\mathrm{e}} \tag{1}$$

The state transition rules of the transmission process are schematically shown in Fig. 1. All the sites of the network are described as parameters: E, S or I, which respectively represent the empty states, susceptible individual occupations and infected individual occupations. The specific process are as follows: an empty site can give birth to a healthy individual at rate b; a healthy individual can be infected by contacting with infected neighbors at rate λ or die at rate α (due to other reasons); an infected individual can be cured at rate γ or die at rate β (on account of the disease). When an individual dies, this site becomes