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An immunization based on node activity

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ABSTRACT

In this paper, a standard susceptible-infected-recovered-susceptible (SIRS) epidemic model based on the dynamic network model is established. The dynamic network based on the Barabasi–Albert (BA) scale-free network model is constructed, keeping the same total number of edges, adding and deleting edges are operated according to the corresponding node activity level. These operations also can change the node activity. At the same time, a new immunization scheme - "immunization based on node activity" is proposed, in which the nodes with most active be immunized firstly. The propagation situations of random immunization, immunization based on node activity and high-risk immunization are investigated, the influence of some parameters on the density of infected individuals is also analyzed in detail. When the number of immunization nodes is the same, the results show that the effect of immunization based on node activity is the best. Therefore, immunization based on node activity is effective, and it is more feasible in dynamic network.

1. Introduction

With the development of society, various infectious diseases appear sequentially. There will almost be an infectious disease every few years. [1–3] Such as the Ebola virus in 1976 [4], the AIDS in 1981 [5], the SARS in 2003 [6], the H1N1 flu in 2005 [7], the H7N9 in 2013 [8], the MERS [9] and the Zika virus [10] in 2015, etc. Infectious diseases have become the most important public health problem in the world, which is a serious threat to the whole human beings [11].

Why infectious diseases emerge in an endless stream and spread widely? As far as China is concerned, since reforming and opening, China's economic power improved greatly, people's living standard improved markedly, overall national strength increased notably, international status grew significantly, science and technology advanced rapidly, etc. On the contrary, the surrounding natural environment and social environment have also been a huge change, which promotes outbreak of infectious diseases [12,13]. The reality makes us understand a truth: the fight against infectious diseases is not once and for all. Humanity is facing a serious threat to the new and old infectious diseases. Therefore, the research on the transmission mechanism and the immunization strategies of the infectious diseases is becoming more and more important, which has become a major problem to be solved urgently in the world [14–17]. In order to reduce and control the harm to human beings, studying the transmission mechanism of infectious diseases and exploring immune strategy has important practical significance [18–20].

Epidemic model is the bridge to study the problems of infectious diseases in real, establishing a suitable propagation model is the basis of the experimental simulation. Scholars have conducted a lot of research by the propagation law of infectious diseases, and the epidemic model is also in constant improvement. Classical propagation models: susceptible-infected (SI) [21], susceptible-infected-susceptible (SIS) [22,23], susceptible-infected-recovered(SIR) [24], susceptible-infected-recovered-susceptible(SIRS) [25]. According to the transmission mechanism of the infectious diseases, the spread of incurable virus, similarly to aids, is summarized as SI virus; the spread of multiple infected and curable but can't immune virus, similarly to flu virus, is summarized as SIS virus; acquiring immunity virus spread after vaccination, similarly to measles and chicken pox, is summarized as SIR virus; losing immunity virus spread, similarly to mumps, is summarized as SIRS virus; Recent years, with the emergence of various infectious diseases, new propagation models are also generated. Such as susceptible-exposed-infected (SEI) [26,27], susceptible-exposed-infected- susceptible (SEIS) [28–30], etc.

Many realistic systems can be described by networks. The epidemic system can be represented as a network where nodes standing for individuals, and edges standing for interactions between individuals. There are many cases in real network to meet the characteristics of the scale-free and small-world, but most

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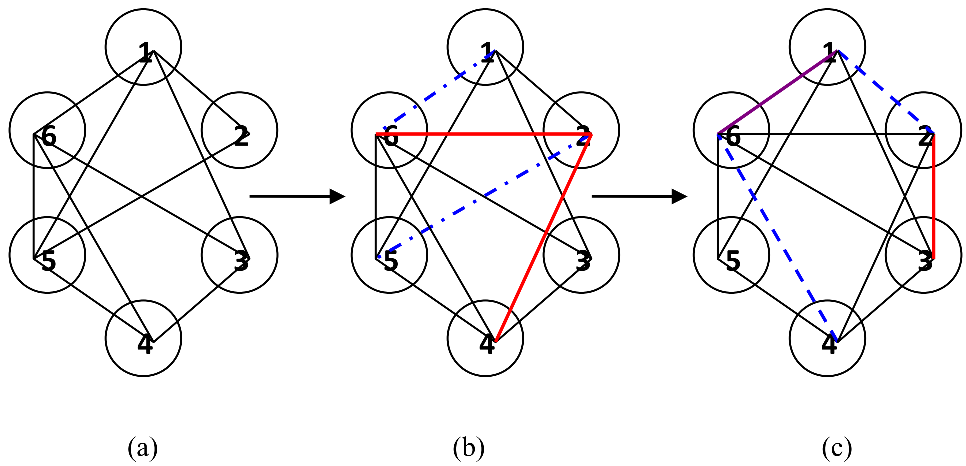

Fig. 1. Sketch of the dynamic network evolution.

of the phenomena are complicated and changeable, real-time dynamic [31]. Hence, the dynamic networks can fit the real network more accurately, such as friendship networks. As far as personal behavior is concerned, people contact with strangers inevitably and make new friends, and some old friends may also lose contact. Therefore, the choice behavior of person's friends (individual dynamic behavior) has an important influence on the whole friendship networks (the topological structure). A large number of research results show that the dynamic network model can be more truly to reflect the real world.

The research of immunization strategy is the focus of attention in recent years. The main purpose is to prevent and control the prevalence of infectious diseases, and ultimately to reduce the risk of infectious diseases. For example, Ref. [32] proposed random immunization, which completely randomly selects a part of nodes over the whole network, and carries out immunization. Ref. [33] proposed targeted immunization, which chooses a small number of key nodes to immune first. Ref. [34] proposed acquaintance immunization, which vaccinates random acquaintances of random nodes. Ref. [35] proposed high-risk immunization, which treats direct susceptible neighbors with infected nodes as high-risk groups, and controls infectious diseases by immunizing high-risk groups. Ref. [36] proposed the two-step high-risk immunization, which immunes not only partial high-risk nodes, but also partial indirect neighbors of infected nodes. The latest literature proposed the most common friend first immunization, which immune partial direct neighbors and its partial neighbors with the most common friends. Ref. [30–32] based on the static network study the influence of various immunization strategies, but the paper study transmission of infectious disease on dynamic network, and put forward the corresponding immunization strategy—immunization based on node activity, which immune a certain proportion of nodes with maximum active degree. The so-called node activity, which has positive contribution factors to network connectivity.

The organization of this paper is as follows. In Section 2, dynamic network model is constructed. In Section 3, an immunization based on node activity on dynamic network is introduced. In Section 4, the results and discussion of computer simulation on dynamic network are given. Some corresponding conclusions are given in the last section.

2. Dynamic network model

The degree distributions of many networks obey power-law distribution, which includes the internet, WWW, and metabolic networks, etc. Because this network has not the particular scale characteristic, it is called scale-free networks. In 1999, Barabasi and Albert proposed scale-free network model on the basis of analyzing a large amount of network data. Compared with the previous network model, there are two important characteristics of the scale-free network model: One is the growth characteristics: the network scale is constantly expanding. For example, there are a lot of research articles to publish each month, and there are a lot of films to release each month. Two is the preferential attachment characteristics: new nodes tend to be connected with more nodes. For instance, the newly published scientific articles are more inclined to cite a number of widely cited references, the new movies tend to quote classic plot of some famous movies.

In everyday life, our friends are not static, but our social circle change slowly with time. For example, on university campuses, we often are surrounded with college classmates, alienate or even disconnect with the high school classmates gradually; in society, we're basically with our colleagues every day, also alienate or even disconnect with college classmates gradually. Therefore, static network model (small-world network model and scale-free network model) can't fit this phenomenon in real. Real networks are dynamic and real-time changeable. The dynamicity not only shows the change of the nodes' number, but also the real-time variation of the connections between nodes. Sketch of the dynamic network evolution is described in Fig. 1.

In Fig. 1, the state of each line is described as follows: the black solid line represents a connection between nodes; the red solid line represents the first connection; the blue dotted line represents the disconnection; the purple solid line represents the reestablished connection.

Fig. 1(a) represents the initial network topology. Fig. 1(b) and (c) represent the evolution process of dynamic network. From Fig. 1(b), the nodes 1 and 6, 2 and 5 are disconnected, and the nodes 2 and 4, 2 and 6 are the first connection at the next time period. From Fig. 1(c), the nodes 2 and 4, 2 and 6 continue to maintain connections, the nodes 2 and 3 establish a connection for the first time, and the nodes 1 and 6 reestablish the connection.

It can be seen from the sketch of the dynamic network evolution, the total number of edges remains unchanged, adding and deleting same edges are dynamically operated. In this paper, the dynamic network is on the basis of BA scale-free network. The dynamic network model is constructed as following steps:

(1) To start from the BA scale-free network: suppose that the network size is N, the number of adding or deleting edges is U every time. The initial active degree (q_i is the active degree of the node i) is equal to the original degree (q_0).