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Model of epidemic control based on quarantine and message delivery

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HIGHLIGHTS

- Propose two parameters, denoting different isolating rates on latent period and invasion period respectively.
- Propose the method of delivering specific messages.
- Experiments on different complex networks show that the method has great performance.
- A location-based social network is used in the experiments, which is justified to have 30% similarity with the real world.

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ABSTRACT

The model provides two novel strategies for the preventive control of epidemic diseases. One approach is related to the different isolating rates in latent period and invasion period. Experiments show that the increasing of isolating rates in invasion period, as long as over 0.5, contributes little to the preventing of epidemic; the improvement of isolation rate in latent period is key to control the disease spreading. Another is a specific mechanism of message delivering and forwarding. Information quality and information accumulating process are also considered there. Macroscopically, diseases are easy to control as long as the immune messages reach a certain quality. Individually, the accumulating messages bring people with certain immunity to the disease. Also, the model is performed on the classic complex networks like scale-free network and small-world network, and location-based social networks. Results show that the proposed measures demonstrate superior performance and significantly reduce the negative impact of epidemic disease.

1. Introduction

Though the medical conditions are improved significantly, epidemics have never been away from human world, especially in developing countries. Of growing concerns are adverse synergistic interactions between the emerging diseases and other infectious. Poor sanitation and lack of medical knowledge lead to the wide spreading of disease in developing countries, such as Ebola and MERS (Middle East Respiratory Syndrome Coronavirus). Besides, some of traditional contagions are resistant to drug treatments now, such as malaria, tuberculosis, and bacterial pneumonia. These kinds of diseases are defined as new emerging infectious disease (EID), which have increased in the past 20 years and will keep growing in the near future [1]. There are several remarkable characteristics in the EID: unpredictable, not preventable, irremediable, high mortality, rapid transmission and wide scope of influence. The expansion of disease spreading can lead to social panic at some level. It is hence imperative to study effective control strategies to prevent the disease diffusion.

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Table 1
Latent period of several common infectious diseases.

Disease	Between	And	Period
Cholera	0.5	4.5	Days [16]
Malaria	9	14	Days [17]
Ebola	1	21 (95%), 42 (98%)	Days [18]
Marburg	5	10	Days [19]
Measles	9	12	Days [20]
SARS	1	10	Days [21]
Smallpox	7	17	Days [22]
MERS	2	14	Days [23]
Average-day	4.3125	13.6503	Days

Many of researchers have tried to explore the prevention measures of EID. As a practical method, the information diffusion on epidemic dynamic has attracted much attention in recent years. A path-breaking work in this field was taken by Funk et al., who proposed an epidemiological model that considers the spread of awareness about the disease [2,3]. Lima et al. proposed that the propagation of disease can be reduced by the spreading of immune information, which make individuals resistant to disease and then work against the epidemic propagating [4]. A model of competing epidemic spreading over completely overlapping networks was proposed by Karrer and Newman, revealing a coexistence regime in which both types of spreading can infect a substantial fraction of the network [5]. Wang and Tang distinguish two types of disease spreading and proposed the dynamic model of asymmetrically interacting and disease spreading. Their research focuses on three problems: the different network structures and information spreading dynamics; the asymmetric effects of one type of spreading dynamics on another; the timing of the two types of spreading [6]. Moreover, several researches are also meaningful to us [7–12]. Trpevski et al. explored the rumors propagation in multiple networks [7]. Zhang et al. proposed a model considering time delay and stochastic fluctuations [8]. Ababou et al. investigated the spreading of periodic diseases and synchronization phenomena on exponential networks [9]. Rakowski et al. put forward an individual based model to study the effects of influenza epidemic in Poland. A simple transportation rule is established to mimic individuals' travels in dynamic route-changing schemes, allowing for the infection spread during a journey [10]. All the above efforts are worth approving but the specific ways of message spreading are ignored. This paper enriches the research in this area, and the proposed methods are shown to have a significant effect in epidemic prevention.

The paper proceeds as follows. In Section 2, we first describe the characteristics of epidemic, then the SIQM models are developed, which contain the disease prevention measures based on quarantine and message delivery. Section 3 gives the sensitivity analysis of the model on classical complex networks. In Section 4, the common regularity of human mobility and experiment results on location-based social network are given. The paper is concluded in Section 5.

2. Epidemic dynamic model

2.1. Characteristics of epidemic

Normally, the process of infectious disease can be divided into three stages: susceptible period, infection period, recovery period [13]. The infection period is further divided into latent period and invasion period. The former is characterized by the tiny indisposition; the latter is featured by onset of clinical signs and symptoms. Moreover, according to the research of Lessler et al., the latent period is essential to the investigation and control of infectious disease [14]. In this period, the infectious individuals have obtained the ability to spread diseases, yet without obvious symptom to arise attention, e.g., the latent period of influenza remains only one to three days, yet the epidemic can sweep through a city in less than six weeks. Furthermore, according to the health experts Sartwell's research, the period of latent period varies between individuals in the same regular fashion as do other biological characteristics [15]. The distribution of days seems to follow the "normal" curve. Based on their theory, we investigate several common infectious diseases and collect their incubation period in Table 1 and then get the average length of latent period which approximates to 7 days.

To sum up, two assumptions are proposed here as the basic precondition of model: (1) the infection period of epidemic is divided into latent stage and invasion stage in epidemiology. Because the disease in former stage is hard to observe and diagnose, we preset a relative low value to its isolating rate which ranges from 0.01 to 0.5. The rate in invasion period ranges from 0.5 to 1. (2) To simplify the model, the average length of latent period is uniformly set to 7 days, which is important to the experiments in Section 4. The value is deduced by results shown in Table 1.

2.2. Definition of the model

Individual status in the model is divided into four types: susceptible, infected, in quarantine and in messaging. The susceptible means the people who are vulnerable to the disease. The infected denotes people who have already been infected consciously or unconsciously. When in quarantine, it means the infected ones have been isolated and will not spread disease anymore. When in "messaging" status, the specific persons, denoting the ones who have just been isolated or their directly