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MEDICINE DELIVERY STRATEGY OVER THE AIRLINES NETWORK AGAINST VIRUS SPREADING

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Abstract

This paper discusses the medicine delivery strategy over the US Airlines network to help eliminate virus spreading. The paper analyzes the characteristics of the general susceptible-infected-susceptible epidemics model and the targeted immunization strategy against virus spreading. The proposed strategy combines the characteristics of epidemics model and immunization strategy applied on US Airlines network. The fundamental analysis of US Airlines network is conducted, and the corresponding simulations of the proposed strategy demonstrate that the new strategy can effectively accomplish the medicine delivery over the airlines network within a short period.

Key words

airlines network; immunization strategy; epidemics; virus spreading; medicine delivery

1 Introduction

As the human civilization and the economy are developing, epidemics are always accompanied with these developments such as malaria, measles, SARS, avian flu, Ebola, etc. As the social network and communications all over the world is becoming bigger and stronger, the world becomes smaller. This enhances the wider spread of epidemics. However, human beings can also take advantages of the developed transportation networks to deliver medicines to the areas suffering from the epidemics in order to reduce the threats of diseases. The motivation of this paper is inspired by recent breakout of Ebola and SARS happened around a decade ago. A problem arises that how to design a strategy to deliver the medicine or vaccine. Studies of virus spreading have a long history and some mathematical models have been illustrated in References [Anderson and May, 1992; Diekmann and Heesterbeek, 2000] such as Susceptible-Infected (SI), Susceptible-Infected-Susceptible (SIS), Susceptible-Infected-Recovered (SIR) models, etc. The network-based epidemic threshold theorems for virus spreading and epidemics immunization strategies are studied and available in the literatures [Pastor-Satorras and Vespingnani, 2001; 2003; Yan, 2014]. Epidemic thresholds on heterogeneous networks was presented in [Pastor-Satorras and Vespingnani, 2001] where scale-free networks belong to. Further, analysis on Barabási Albert (BA) networks, a special example of the scale-free network, was reported in [Pastor-Satorras and Vespingnani, 2003]. [Pastor-Satorras and Vespingnani, 2001; 2004] reveals that the scale-free network can model a virus spreading well. The epidemic threshold analysis demonstrates that a little source of virus is probably break out over the entire huge network because of the epidemic threshold tending to zero. Correspondingly, some immunizations such as targeted, random, acquaintance immunizations are discussed in Literatures [Cohen, 2003; Madar, 2004] to overcome the fragility of the heterogeneous networks. Compared to the random immunization, the targeted immunization can sooner immunize virus over the scale-free network. This paper analyze the characteristics of the US Airlines network which belongs to the heterogeneous network. And the network-based virus spreading and the targeted immunization strategy are considered. Therefore, the paper develops a US Airlines network-based medicine delivery strategy in order to help eliminate the epidemics.

The paper is organized as follows. US Airlines network analysis such as nodes degrees and degree distribution are introduced in Section 2. The used virus spreading model SIS is presented in Section 3. The developed medicine delivery strategy working on the US Airlines network has been described and explained in Section 4 in detail. Finally, conclusions are drawn.

2 Airlines Network Characteristics Analysis

The US Airlines network data was downloaded from the website [http]. This network consists of 332 cities which are represented by nodes and 2461 edges referred to the connections among cities. Figure 1

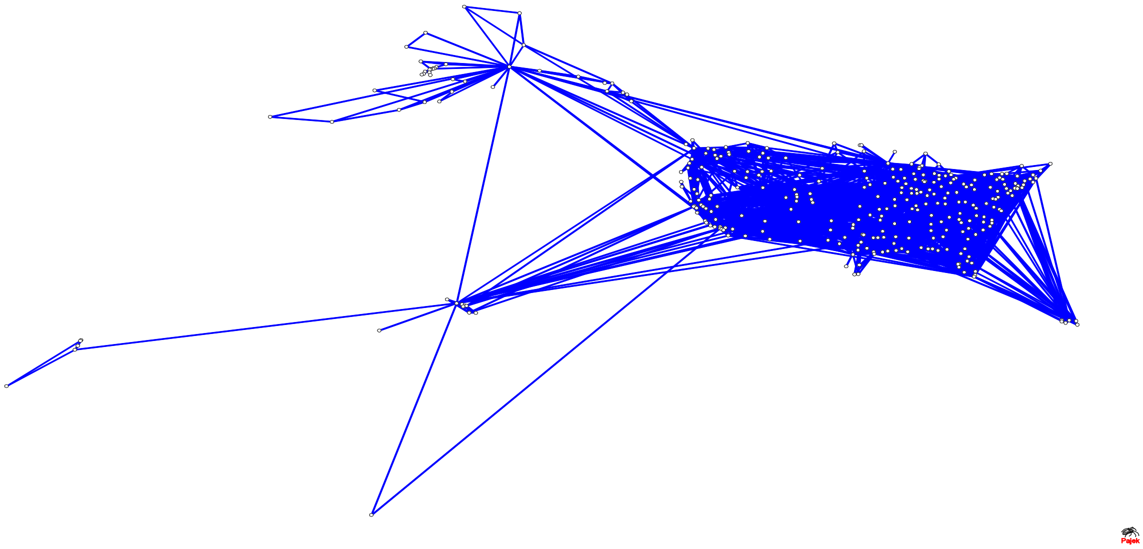


Figure1: The US Airlines network topology

shows the US Airlines network topology which graphs the cities with dots and connections with lines.

Table I: List of a part of cities and connections over the US Airlines network

City nodes (332 in total)			
1	2	3	4
Wiley Post-Will Rogers Mem	Deadhorse	Ralph Wien Memorial	Fairbanks Intl
5	118	119	332
…	Chicago O'hare Intl	…	West Tinian
City connections (2461 in total)			
118	182	261	128
118	152	…	…
…	…	261	255
118	301	311	94
255	313	…	…

Table II: List of the cities with the top 10 highest degrees

Rank	City Number	Degree	Rank	City Number	Degree
1	118	139	6	230	87
2	261	118	7	166	85
3	255	101	8	67	78
4	182	94	9	112	70
5	152	94	10	201	68

The partial information about the network topology is shown in Table I including city names and connections among them. Complex Network Analysis Software Pajek is used to analyze the characteristics of US Airlines network. The software can calculate the degree of each node (city) and the average degree value. Chicago O'hare Intl airport owns the biggest degree, 139, and the average degree of the network is around 12.8. The top 10 highest degree rank is shown in Table II. The relevant degree data analysis is conducted and explained in [Xu, 2010]. This literature demonstrates that the degree distribution of the US Airlines network follows the power-law node degree distribution with

$$P(k) \sim k^{-r}, \quad r=1.8.$$

Therefore, this network is a scale-free network. As References [Pastor-Satorras and Vespingnani, 2001; 2004] revealed, the scale-free network can well model the virus spreading. That the epidemic threshold tends to zero implies that a tiny source of virus is already sufficient to spread over the entire network. This paper is motivated by these characteristics. The aim of the immunization strategies is to eliminate the virus spreading, somehow, it is equivalent to the goal of the medicine delivery strategy. The paper, thereby, develops the medicine delivery strategy over the scale-free network by applying the targeted immunization illustrated in the following sections.

3 Virus Spreading Model

Initially, virus infected cities are supposed to be susceptible or infected. After medicines are delivered to the infected cities, these cities gradually get rid of infections. However, because of the population mobility among cities, recovered cities are probably to be infected again. Susceptible-Infected-Susceptible Model (SIS), therefore, is used to describe the virus spreading among cities. In general, immunization strategy is always used to avoid the virus further spreading. This paper uses the targeted immunization strategy to deliver medicine over the airlines network in order to help eliminate virus. Therefore, the paper finally proposes the airlines network-based medicine deliver system analysis combining with immunization strategy based on the SIS virus spreading model.

Let γ_S be the probability of an 'infected' node being cured and becomes "susceptible" and 0< γ_S<1, β be the probability of a node become 'infected' from 'susceptible' and 0<β<1. Then the SIS model is shown below [Chen, 2015],

$$\begin{cases} \dfrac{ds}{dt} = \gamma_S - \beta si \\ \dfrac{di}{dt} = \beta si - \gamma_S i \end{cases}$$

The epidemic threshold (virus effective spreading rate threshold), λ_c, on heterogeneous network is derived from [Pastor-Satorras and Vespingnani, 2002] and is shown below.

$$\lambda_c = \frac{\langle k \rangle}{\langle k^2 \rangle},$$

where $<k>$ is the average degree of the node, and $<k^2>$ is the average degree of the second moment, that is,

$$\langle k^2 \rangle = \frac{1}{N} \sum_{i=1}^{N} k_i^m .$$

As the size of the network grows, $<k^2>\rightarrow\infty$ then $\lambda_c \rightarrow 0$. It is also known that the scale-free network is a typical example of heterogeneous networks. This implies that virus can easily propagate throughout the scale-free network. This characteristics also shows the fragile weakness of scale-free network for the virus spreading. In reality, the size of the airlines network is relatively stable. However, this paper assumes that the whole medicine delivery network including other transportation methods can grow and belong to the scale-free network. Furthermore, in some emergency situations such as the virus breaking out in a short time, then the airlines network can temporarily increase and change for the emergency issue. Therefore, the so called weakness can be employed in medicine delivery system because if the main cities are received the necessary medicine services, the whole network can be immunized easily. This characteristic can help human beings delivery medicine or goods soon and smoothly in order to inhibit virus spreading.

4 Targeted Immunization Strategy Applications in Delivery Systems over the US Airlines network

Immunization strategy is intuitive to be applied on inhibiting virus spreading. Medicine delivery system, in fact, can employ the immunization strategy to arrange medicine delivery over the airlines network with the virus spreading method. The primary motivation to apply targeted immunization strategy on medicine delivery system considers the fundamental principle of targeted immunization such as selecting the important nodes to be immunized in order to avoid the further virus spreading. Correspondingly, this paper utilizes this principle on the medicine delivery system. Several reasons are addressed below. First, when medicines are delivered to the selected important nodes, it can effectively cure the persons in these areas and further suppress the contagion. Second, under the government regulation control, medicines should be guaranteed to be dispatched to other necessary locations over the airlines network or other transportation networks in order to eliminate the epidemic. However, virus itself can automatically spread over the huge network. Typically, biological virus epidemics spread among the exposed population group automatically. It is because of this phenomenon that immunization strategies can effectively avoid virus spreading. Compared to biological virus immunization, medical delivery will not automatically dispatch. Therefore, it is necessary to address an assumption in this paper that some regulations are drawn up in order to guarantee that medicines are expanded to every necessary locations over the airlines network or other transportation methods. An algorithm for medicine delivery system strategy is addresses below.

Algorithm 1:

Step 1: Initial network status: city nodes are located in the airline network. They are in states, susceptible, infected respectively;

Step 2: Select the important nodes depending on Hyperlink-Induced Topic Search (**HITS)** algorithm [Kleinberg, 1999; Ren, 2014];

Step 3: Deliver medicines to the selected city nodes with the targeted immunization probability γ_S and change their states to the normal;

Step 4: Some new city nodes over the airline network might be infected with the infection probability β because of the population mobility;

Step 5: Exclude nodes which have received medicines;

Step 6: Turn to ***Step 3***; else, exit.

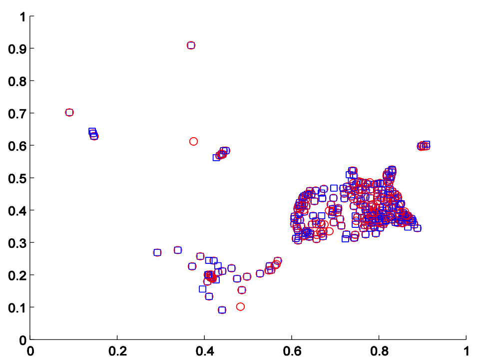
When considering the important nodes selection in ***Algorithm 1***, nodes with biggest degrees are intuitively selected as the important nodes. Even though the degree of a node is an important source of information. However, it could not provide complete information on the role of the node in the network. HITS algorithm gives the nodes two values, authorities and hubs. Hubs values reflect the capability of nodes in broadcast. Authority can evaluate the originality of nodes information [Laureti, 2006; Jiang, 2010]. Therefore, this paper considers these two factors to determine the important nodes by HITS algorithm. Further, each factor is assume to account for 50% respectively when determining important nodes by using HITS algorithm in this paper. Table III shows the first 10 selected city nodes where medicines will deliver over the US Airlines network by HITS algorithm.

Table III: The first selected city nodes by HITS algorithm

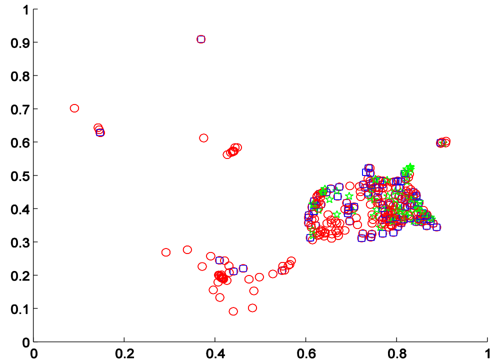
(Two factors account for 50% respectively.) (Order is from left to right.) (10/332)			
118	182	255	261
Chicago O'hare Intl	Lambert-St Louis Intl	The William B Hartsfield Atlan	Dallas/Fort Worth Intl
152	230	176	166
Pittsburgh Intll	Charlotte/ Douglas Intl	Cincinnati /Northern Kentucky I	Stapleton Intl
162	147	…	…
Philadelphia Intl	Newark Intl	…	…

As ***Algorithm 1*** illustrated, the process is described below. First, the initial status, susceptible (blue squares shown in Figure 2) or infected (red dots shown in Figure 2), of the cities over the network mean that no medicines are delivered initially. Some important cities are selected where medicines are delivered, then, these areas will become normal (green stars shown in Figure 2). As ***Algorithm 1*** iterations work on the airlines network, medicines are delivered to more and more cities. At the end, all the cities throughout the network have received the necessary medicines. In reality, virus might not only spread throughout the airlines network, therefore, the spreading is not limited to the cities over the airlines network. However, airlines network is the crucial transportation system. Therefore, this paper assumes that medicines are delivered mainly through the cities over the network, and other methods can be guaranteed that these medicines can be further delivered to other areas.

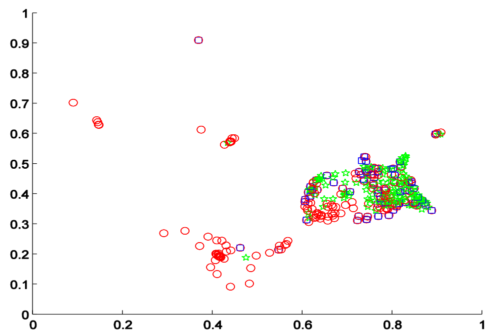
Figure 2 (a)-(f) demonstrate that the process of medicine delivery over the airlines network by using ***Algorithm 1***. It is clear that medicines can be delivered through the networks after six ***Algorithm 1*** iterations. This as well demonstrates that medicine can be efficiently delivered to the cities over the airlines network. Nodes illustrated in Figure 2 are located in the relatively geographic position. Scales of the axis are normalized.



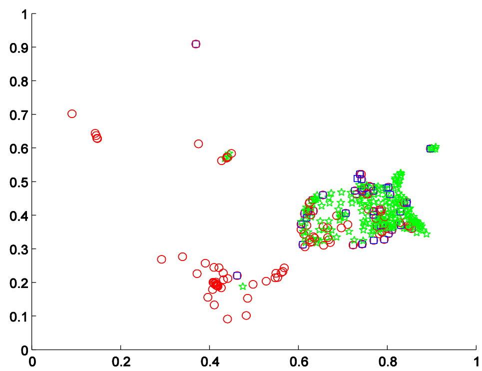
(*a*) Initial status



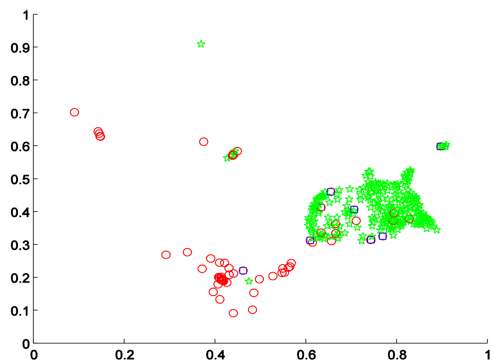
(*b*) The second iteration



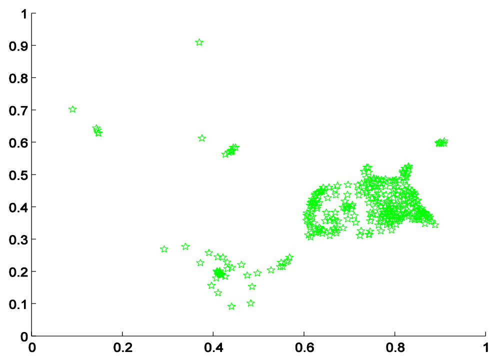
(*c*) The third iteration



(*d*) The fourth iteration



(*e*) The fifth iteration



(*f*) The sixth iteration

Figure 2: Iteration processes for the delivery system by using ***Algorithm 1*** when γ_S=0.2, β=0.8 (the infected-red dots; the susceptible-blue square; the normal-green star)

5 Conclusion

The paper described the network-based SIS epidemic model and targeted immunization strategy. US Airlines network analysis were conducted as well including city-node degrees and the degree distribution. The focus of this paper is to develop a strategy for medicine delivery system which applies the targeted immunization on SIS epidemic model over US Airlines network. This strategy is based on some assumptions, and the simulations demonstrate this strategy can efficiently deliver medicines to the cities throughout the airlines network.

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