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A new perspective of epidemic controlling: immunization therapy strategy in weighted complex network

Yu-Ying Huang[1], Yu-Xin Ma[2],Yi-Xian Chen[2],Lin-Zi Zhang[2] and Han-Li[3]
1 2 3 School of Management Science and Engineering, Central University of Finance and Economics
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Abstract. The immunization strategy towards the epidemic spreading problem has attracted widespread attention of scientists from many different fields. However, the traditional immune behavior is achieved by deleting the edges in the network, which can lead to variations in the network structure and furthermore, seriously damage the efficiency of the network. In this paper, we studied a new type of immune strategy applied to weighted networks–immunization therapy strategy, which is to maintain the necessary network efficiency by lowering the weight of edges to suppress the spread of epidemic. It is similar to the inflammation around the infected parts of our body, which can either prevent epidemic from further spreading or do no harm to the function of the body. Thus, we name this novel strategy as "immunization therapy strategy". We first let the rate of transmission be proportional to the edge weight according to the $S-I$ epidemic spreading model. In addition, we give specific dynamic evolution for infected nodes that boosts efficient epidemic control. Theoretical analysis and simulation outputs indicate that the immunization therapy strategy can efficaciously prevent the spread of the epidemic, while maintaining the high efficiency of the network.

Keywords: complex network; $S-I$ model; epidemic controlling; immunization therapy.

1. Introduction

As the theories of complex networks developed [1], researchers have been paying more and more attention to epidemic spreading in complex networks. In the real world, usually there are only a few infection sources at the very beginning. However, without effective control and management, the epidemic spread will boom in a large-scale society. The immunization strategies in previous studies concentrated on selecting nodes according to their statues among the whole network, for instance, in terms of their nodes degrees. There are mainly 3 immunization that have been studied most up to now: random immunization[2]-[3],target immunization[4] and the distance-based local immunization[5].

Random immunization means the nodes are randomly chosen during the implement period. Without considering whether the node degrees are heavy or tiny, we choose all the nodes with the same probability. Target immunization takes the heterogeneity characteristic of the network into consideration and pick out nodes with larger degree for immunization. All of the edges connected to certain nodes will be eliminated from the network if these nodes are immunized. Eliminating such edges will change the structure of the whole network, which means some spreading paths of the epidemic will disappear. However, it is necessary to acquire the global information of the network in implementation of target immunization. To put things into a further step, the local immunization does not require us to get the global information. It just makes use of the nearby local information of infected nodes while controlling epidemic spread. Local immunization achieves the goal of controlling epidemic spreading in large-scale society by isolating infected nodes as well as nodes within a certain distance d of them.

The main idea of traditional immunization is eliminating the interconnections of some chosen nodes and the rest parts of the network. All the connections that link a node to others will be cut off immediately as long as it is immunized. Thought the epidemic spreading can be controlled by this way, the problem is the network is always destructed [6]- [7]. When the proportion of immunized nodes heat a certain point, the whole network will become invalid. As a result, the traditional immunization methods are not proper for comprehensive implement.

Actually, the epidemic spreading chances can be reduced by receiving prophylactic vaccination in the real stage. In weighted networks, the weight of each edge is defined as the tightness among nodes, and different degrees of tightness have different influence on epidemic spreading rate. Thus, we can control epidemic outbreak not by absolutely eliminating some edges but by just reducing the weights (degrees of tightness) of some edges, just like what we do in the real world. This method can either provide us with the same epidemic-control effect as tradition immunizations do or maintain the connectivity and the desirable efficiency of the whole network.

Having recognized the drawbacks of traditional immunizations [8]-[9], in this essay, we propose a concise immunization strategy with high efficiency on the perspective of weighted network – immunization therapy strategy. We achieve it by decreasing the weights of certain edges, i.e. reducing the weights of those edges that are connected with specific nodes. We derive the term "therapy" from a kind of physiological phenomenon: In order to prevent epidemic from spreading, whenever certain tissues are infected, there will be self-repair and inflammatory activities nearby these tissues. In such condition, self-repair therapy takes effect without absolutely destroy body functions. In the respect of epidemic-controlling efficiency and maintaining of the efficiency of the whole network, we make some contrasts between our new immunization therapy strategy and traditional immunization strategies. Both simulation and theoretical analysis tell us that immunization therapy strategy can either effectively control epidemic diffusion or keep the network efficiency high. What is more, we introduce mechanism of self-repair therapy into the target immunization, i.e. decrease weights of the edges connected to nodes with high degrees. In this paper, an accurate mathematical model is constructed and some applicable knowledge is deduced. The immunization, whose usefulness has been proved by experiments, is significant in guiding immune behaviors in the real stage.

2. Methods

2.1. Our definition of immunization therapy

In complex networks, the common immunization [10]-[11] way cuts the spreading path of epidemic by deleting nodes, such as deleting the edges around given nodes. The result is identical to the errors and attacks rules in the reality. Concretely, only less than half of the efficiency of the original network will be achieved while 15% of the maximum nodes are attacked. Moreover, when this proportion comes to 30%, the overall network will be collapsed and may finally be desperate to turn out to be unconnected pieces. As a result, in the real world, the conventional immunization methods are not possible to be carried out. Thus, we attempt to lower the edges weight associated with the immunized nodes, but we do not lower the weight down to 0 to prevent from damaging the entire network. This implementation will assure the appropriate immune effects while maintaining the essential information transmission, and meanwhile, the overall network can preserve the normal operation in a certain range.

To make things more simple, we make an assumption when we apply the immunization method in complex network: The edges connected to immunized nodes will be reduced by q times, where q>1. If q tends toward infinity, our immunization therapy strategy equals to traditional strategies. If q equals to 1, the immunize effect will become extremely weak, which means we let the epidemic spread without any immunize intervene. We consider the weights of classical binary BA network [12]-[13] as the tightness between nodes and add weighted mechanism to it, in which various degrees of tightness have different impacts on epidemic spreading efficiency. Especially, we use $w_{kk'} = w_0(kk')^{\beta}$ to describe the proportional relation between epidemic spreading speed and edge weights, where $w_{kk'}$ is weight of the edge connecting a node with degree k and another node with degree k'. w_0 is invariant and different types of network have different β. Then, the strength of k degree node can be calculated according to the edge weight:

$$N_k = k\Sigma_{k'} Pro(k'/k)w_{kk'} \tag{1}$$

Here, we only take non-associative network whose degree correlation probability can be described as $Pro(k'/k) = k' Pro(k')/\langle k\rangle$ into consideration. From what has been analyzed above, we can draw a function:

$$N_k = w_0\langle k^{1+\beta}\rangle k^{1+\beta}/\langle k\rangle \tag{2}$$

2.2. Our epidemic spreading model

We implement the well-known Susceptible-Infected ($S - I$) model to conduct our research about the dynamic spreading behavior of epidemic in the weighted networks. In this model, the node has two statuses only: susceptible state (S) and infected state (I), where infected nodes cannot be recovered. During the be-