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An improved acquaintance immunization strategy for complex network

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HIGHLIGHTS

- We create a new strategy to suppress epidemic on complex network.
- Our strategy takes time-varying and structure information into consideration.
- Our strategy is an improvement to acquaintance immunization strategy.

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ABSTRACT

The acquaintance immunization strategy is a common strategy to suppress epidemic on complex network which achieves a seemingly perfect balance between cost and effectiveness compared with other canonical immunization strategies. However, the acquaintance immunization strategy fails to take the time-varying factor and local information of nodes into consideration, which limits its effectiveness in some specific network topology. Our improved immunization strategy is based on a new mathematical model Network Structure Index (NSI), which digs deep to measure the connection property and surrounding influence of a node's neighbor nodes to better determine the importance of nodes during immunization. Both mathematical derivation and the simulation program tested on various network topology support our idea that this improved acquaintance immunization strategy protects more nodes from infection and immunizes important nodes more efficiently than the original strategies. As to say, our strategy has more adaptability and achieves a more reasonable balanced point between cost and effectiveness.

1. Introduction

Epidemic is an important issue to our lives. Both worm virus on Internet and Ebola virus disease spreading rampantly in Africa have caused great threat and panic to the masses. The suppression of epidemic attracts much attention in recent decades. Generally, there are several classic immunization strategies to suppress the epidemics on networks such as the random immunization (Anderson and May, 1992), the target immunization (Dobrescu, 2007), and the acquaintance immunization (Cohen et al., 2003). All of these strategies are conditioned by the immunization cost and immunization effectiveness, which are influenced by network topology, information of the network we have, possibility of virus spreading, size of the network, etc. Following are the obvious limitations of these three classic strategies.

Random immunization strategy immunizes a node randomly. It requires high immunization threshold which means it need immunize a very large fraction of a network to be effective. Target immunization strategy immunizes a node with most neighbor nodes. It is of great accuracy and effectiveness, but it is based on global information about the network, which is not available for most occasions. Acquaintance immunization strategy avoids the disadvantages of the previous strategies. It randomly chooses a node and randomly immunizes one of its neighbor nodes. Little information about networks is required, but randomly immunizing neighbor node is of blindness and is not efficient enough to protect important nodes, especially to some particular network topology.

As all these existing canonical strategies have their obvious limitations, we badly need an improved strategy which is more adaptive to almost all network topology and achieve a better balance between cost and effectiveness.

In recent years, many research works have shown up to present new ideas of finding a more effective and practical immunization strategy. Many of these methods are based on the acquaintance

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immunization, focusing on finding common neighbors (Pan Liu, 2009), searching out highly connected nodes to build a threaded-tree (Chai et al., 2011), double- immunization strategy (Jing et al., 2012), etc. These methods are effective in certain situation, however, they cannot avoid the limitation of the acquaintance immunization effectively. Other researchers focus on the importance ranking of nodes, which is to determine the ranking with a time-varying perspective (Starnini et al., 2013; Hill and Braha, 2010) or local information (Xin et al., 2011; Hadjichrysanthou and Sharkey, 2015), but these methods fail to deploy the benefits of acquaintance immunization strategy.

The immunization strategy based on acquaintance immunization provides a strong adaptability of various network structure using little information about the whole network; determining the importance of nodes with local and time-varying information ensures the accuracy during the immunization. So we propose a strategy combining these two benefits may be an innovative approach towards an effective and practical immunization strategy which can also achieve the balance between the amount of information we need and the result we can achieve.

In this paper, we start from a specific topology and propose the idea that the connection property and surrounding influence of nodes should not be neglected during immunization, which also reveals the limitation of the acquaintance immunization strategy. Based on that, we create a new index, Network Structure Index (NSI) to comprehensively assess the value, especially the potential value of nodes. With NSI which considers local and time-varying factor of a node, we improved the acquaintance immunization strategy by immunizing the neighbor node with highest NSI value. After that, mathematic derivation and computer simulation are used to support the advantage of our strategy.

2. Model

2.1. Possible improvements on acquaintance immunization

In many situations, it is so hard for us to acquire the global information about the network. Comparatively we can easily get the information of a selected node from the local network, especially some information of its nearby neighbors. In that case, target immunization is still not applicable, but acquaintance immunization can be greatly improved via changing the process of immunization with the help of its neighbor information and immunizing a most valuable neighbor instead of a random one.

Network is made up of many nodes and connections. We can easily notice that the importance of each node is diverse. Before we take actions to suppress the epidemics on networks, we need to find an objective value to give us reference about which node is worth protecting

The degree of node is a possible reference. The degree is the number of its links connected to other nodes. One solution is to immunize the neighbor node with highest degree. But the solution is not ideal in some occasions such as the case shown in Fig. 1.

Node 1 marked in red is the randomly selected node which is able to immunize a neighbor node. Its neighbor node 2 has a degree of four, while neighbor node 3 has a degree of two, but clearly we should immunize node 3 instead of node 2 because it has much more child nodes than node 2.

Another possible solution is to immunize the neighbor node with highest betweenness centrality. Betweenness centrality is equal to the number of shortest paths from all vertices to all others that pass through that node. It is an obvious and useful measure of both the load and importance of a node, but the calculation needs the knowledge of a large part of network topology, which is not easy to realize. As to say, if we have known the whole network topology, we would choose the target immunization instead.

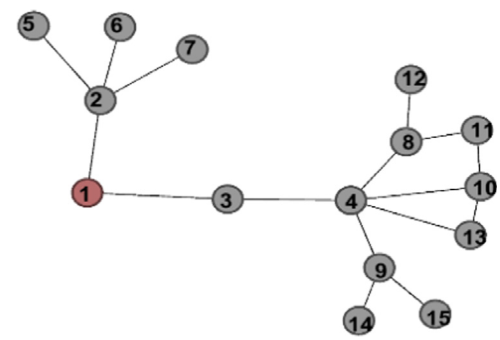

Fig. 1. One occasion when immunizing top degree neighbor node is not ideal.

So creating a new and low cost index to assess the value of each node is of top priority. The index should not only consider its degree, but also reflects its connection property and surrounding influence in its nearby sub-network as well.

We create such index called Network Structure Index (NSI).

2.2. Network Structure Index (NSI)

Suppose there is a network with m nodes. We can use an m$*$m matrix to describe the connectivity of the network. We know that the connection properties and defense systems of each connection are not the same, so the possibility a node to be infected is not the same to each other. To have a clear view of that possibility, we define the p_{ij} which means node i has a percentage of p_{ij} spreading virus to node j. $p_{ij}=0$ means that node i and node j are not connected.

$$\text{The connectivity matrix } P=\begin{bmatrix} p_{11}, p_{12}, \ldots\ldots, p_{1M} \\ p_{21}, p_{22}, \ldots\ldots, p_{2M} \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ p_{M1}, p_{M2}, \ldots\ldots, p_{MM} \end{bmatrix}$$

Each node has different values. For example, computers used in banks are much more important than computers used for entertainment at home, we define the value of node i as v_i to mark their difference. To be normalized, $v_i=1$ represents the nodes with highest importance $(0<i<M)$.

So when the node i is infected and starts spreading virus, the potential damage to node j is $d_{ij}=p_{ij}*v_j$. If node i and node j is connected directly, d_{ij} is a positive number, otherwise it is zero.

Before we look into the influence of a node in its nearby sub-network, we must have a clear view of nodes surrounding it and classify them into groups according to their importance. A node has neighbors which are the nodes connected directly with the node, it also has level 2 neighbors which are the neighbors of its neighbors, and so on. We can mark them as level 1–level T with the following steps. T is the number of top level we choose to stop the marking process.

Firstly, mark the node we choose to analyze (node 1 in Fig. 2) as level 1 (painted blue in Fig. 2).

Secondly, mark the nodes which have direct connection with level 1(node 2, 3, 4, 5) as level 2 (painted green in Fig. 2).

Thirdly, from each node of level 2, mark nodes which have direct connection with it (nodes 6, 7, 8, 9, 10 in Fig. 2) as level 3 (painted gray in Fig. 2). If the node has already been marked, ignore them (node 5 in Fig. 2).

Fourthly, mark higher level numbers from previous level nodes until the level T.