RUMOR PROPAGATION CONTROLLING BASED ON FINDING IMPORTANT NODES IN COMPLEX NETWORK

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Abstract. The rumor propagation analysis and important nodes detection is a hot topic in complex network under crisis situation. The traditional propagation model does not consider enough states, so it cannot intact reflect the real world. In this paper, a new rumor propagation model which considers the Wiseman and the Truth Spreader is proposed based on the Graph Theory. Then, 3 new methods are proposed to find important nodes in the new model. These methods consider the differences between nodes to evaluate the importance of the nodes. Finally, 4 networks are demonstrated to show that the 3 proposed methods are useful to control rumor propagation.

1. Introduction. Complex network are widely used in the real world, like music field [11], urban transport field [12]. In recent years, a variety of online social networks grow rapidly, such as Facebook, weibo and WeChat [17]. Netizens have many ways to get news and speak for themselves, but network has become a double-edged sword [20]: On one hand, more netizens participate in public events [14]; However, on the other hand, network provides a fruitful way to create and propagate rumors, especially in crisis situation [7]. For example, when nuclear radiation occurred in Japan, lots of Chinese rushed to purchase salt because of the rumor which was propagated widely in network: Japanese nuclear radiation polluted the sea. As a result: Salt would not be edible. At that time, such phrases as King of salt and Salt becomes jade were the most popular catchword. With the rapidly development of the network [16]-[19], social rumor propagation in crisis situation caused enough attention for scholars. In order to reduce the harm to innocent people caused by

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Rumors and avoid public panic, how to control rumor propagation has become an important issue at present. The study of rumor propagation can be divided into the following two steps: Firstly, to improve the rumor propagation model, we should make sure that the establishment of the new model can be effectively applied to a variety of specific networks and problems. Then, we should find the important nodes, which means to find the key groups in the network. We figured that such people can control or even inhibit rumor propagation effectively.

Rumor propagation research began in the 1960s. Daley and Kendal [3] first studied the phenomenon of rumor propagation and put forward the corresponding mathematical model. Then, the scholars called it DK model named after Daley and Kendall. DK model proposed that the conversion between each status should be subject to certain mathematical probability distribution, and then they studied rumor propagation by the method of stochastic process. Zanette [18] first applied the complex networks theory to rumor propagation by using the mean-field theory to build a model in the small-world network. The research proved that there is no non-zero threshold in homogeneous network. Moreno Y [9] established a rumor propagation model in scale-free network. He pointed out that the ultimate number of immunes have a close relationship with infection probability, and it is irrelevant with the degree of the source. He did this by comparing the conclusions obtained from computer simulation and random analysis. Wang et al. [10] focused on the clustering coefficient of the network. They found that the rumor propagation can be inhibited effectively by increasing the network clustering coefficient.

In recent years, many indicators of node ordering in non-directional networks have been presented [15]-[2], including degree centrality, betweenness centrality, closeness centrality, PageRank, etc. The degree centrality measure is used to identify influential nodes in complex networks. It is a straightforward and efficient measure but it has failed to consider the global properties of the network. Closeness centrality was defined as the inverse sum of the shortest distance to all other nodes, but it failed to consider the neighborhood nodes. PageRank is a classical algorithm widely used for ranking different web pages in a search engine. If the PageRank value of a certain page is very high, it will be searched out earlier than others with relevant keywords. That is to say, PageRank value is an index that can represent the significance of web pages effectively. Google searching engine has already gained huge profits by using PageRank ranking frame. Thus, PageRank is suitable for solving the problem about calculating and evaluating node importance in some network fields. Influential spreaders have been identified in [1]-[8]. They either did not consider the position of the nodes or the rationality of the model. However, the two factors are the most important points for the research of the rumor propagation controlling. In this paper, we proposed a new rumor propagation model and 3 methods to find important nodes, in order to considering the control of rumor propagation comprehensively.

2. Constructing the rumor propagation model. The existing models of rumor propagation in online social networks are not reasonable enough. The states of the nodes in the network are few. The probability of propagation is given as a fixed value. These are quite different from the real rumor propagation network. Methods that assess the importance of nodes usually ignore global properties or the difference between the adjacent nodes. In order to control rumor propagation more effectively and reduce the harm of rumor, we compared former model and methods with ours,
and analyzed the advantages and disadvantages of each method. In this paper, we propose a new rumor propagation model, and 3 methods to assess the importance of nodes.

In the new rumor propagation model, nodes contain 8 states: (1) Spreader: people who propagate rumor. Initial Spreaders are rumor mongers, such as some paparazzi who publish false news; (2) Wiseman: people with authority, such as official accounts in weibo; (3) Active Wiseman: people who know the rumor is false and they spread only the truth; who evolved from Wiseman; (4) Silent Wiseman: People who spread neither rumor nor truth; (5) Gullible: People who easily have faith in others; (6) Silent Gullible: People who know the truth first, spread neither the rumor nor the truth; who evolved from Gullible; (7) Truth Spreader: People who know the truth and propagate it; who evolved from Spreader; (8) Face-saving Spreader: people who know the truth but doesn’t spread to anybody due to face; who evolved from Spreader.

In the new model, the propagation function is redefined. Compared with the former propagation model: Information is propagated on a fixed probability. The new model defines the propagation function based on the property of the node and the current state of the network. Rumor propagation function is defined as: \( R(n) = \frac{x}{y} \cdot z \), and truth propagation function is defined as: \( Z(n) = \frac{t}{y} \). Where \( x \) is the total number of Spreaders in the neighbor node of node \( n \), \( t \) is the total number of Truth Spreaders in the neighbor node of node \( n \), \( y \) is the total number of neighbor nodes of node \( n \), and \( z \) is the proportion of the Spreaders in the whole network.

Specifically, our model is closer to a real propagation process. Figure 1 shows the rumor propagation process:

![Figure 1. The proposed rumor propagation model](image)

In Figure 1, the dotted line represents the propagation process of the information, and the solid line represents the change of the node’s state. For example, when the rumor begin to spread, in process 1, Spreaders spread rumors to Wiseman, and the Wiseman changes into Active Wiseman with the probability of \( p_1 = 0.7 \) and into Silent Wiseman with the probability of \( p_2 = 0.3 \). In Process 3, \( p_3 = R(n) \). In Process 5, \( p_4 = Z(n) \). In Process 6, \( p_5 = 0.8 \times Z(n) \), \( p_6 = 0.2 \times Z(n) \). In
Process (7), \( p_7 = 0.8, p_8 = 0.2 \). For all the other processes which are not specified above, their probability is 1. Compared with the former propagation model: On the one hand, nodes in the new propagation model will be divided into eight states which is more in line with the situation of the real network. On the other hand, the new propagation model defines the propagation function, and the conversion probability between different nodes states are different, so it enhances the rationality.

In order to show the rumor propagation process, simulation experiment was performed in a BA scale-free network, which has 500 nodes and the average degree is 8. 1% nodes were randomly selected as the Wiseman and 1% as the initial Spreaders. The experimental results shown in Figure 2, shows the changes about the number of Gullible, Spreaders and Truth Spreaders in the network. As shown in

![Figure 2. The number of Gullible, Spreaders and Truth Spreaders in BA network](image)

Figure 2, the number of Gullible decreases with time, the number of Truth Spreader increases with time, and the number of Spreader rises sharply at \( t = 200 \), indicating that rumor outbreaks at that moment. The peak of Spreader’s number can reflect the severity of the rumor propagation.

3. **Finding important nodes.** In order to decrease the effect of rumor, delay the time of rumor outbreak. The important nodes are selected in the network as Wiseman to control the number of Spreader. Compared with other methods, 3 methods are presented to find important nodes in this paper:

3.1. **Method 1: Based on reducing propagation probability (BRPP).** Based on the propagation probability function defined in this paper, the bigger the degree of neighbor node \( m \), the weaker the effect of central node \( i \) on it. Therefore, the importance of the central node \( i \) is defined as \( I_i = \sum \frac{1}{k_m} \), where \( M \) is a set neighbors of node \( i \).

As shown in Figure 3, node A has five neighbors, the importance of A is \( 1/2 + 1/2 + 1/2 + 1/2 + 1/1 = 3 \), and node B has five neighbors, its importance is \( 1/3 + 1/3 + 1/3 + 1/3 + 1/3 = 5/3 \). Compared with node B, if node A becomes a Spreader, it has a greater impact on its neighbors. In order to control such nodes, defining them as Wiseman will effectively suppress the propagation.
3.2. **Method 2: Improved PageRank algorithm (IPA).** PageRank is a commonly used method of selecting important nodes. The defects of the traditional PageRank algorithm are as follows: Firstly, the PR value is evenly distributed to the nodes which the central node points to, ignoring the difference between nodes. Secondly, traditional PageRank algorithm only applies to the directed network. In order to fully consider the difference of importance between nodes, we apply PageRank algorithm to rumor propagation network. So undirected network is used as bidirectional network to distribute PR value in this paper. And the distribution rule of the PR value is redefined: Distribute the PR value of the centre node according to the proportion of neighbor nodes’ degree. Take an example in Figure 4 as a brief description: The initial PR value of each node is 1.

\[
\begin{align*}
T_1: & A = 1, B = 1, C = 1, D = 1, E = 1 \\
T_2: & A = 3/5 + 1 + 3/5, B = 2/5 + 1/2, C = 1/5, D = 2/5 + 1/2, E = 2/5 + 2/5 \\
T_3: & A = 9/10 * 3/5 + 1/5 + 9/10 * 3/5, B = 11/5 * 2/5 + 4/5 * 1/2, C = 11/5 * 1/5, \\
     & D = 11/5 * 2/5 + 4/5 * 1/2, E = 9/10 * 2/5 + 9/10 * 2/5 \\
& \vdots
\end{align*}
\]

Repeat the process until the network reaches a balanced state.

3.3. **Method 3: Based on half radius (BHR).** Previous researches on important nodes selection mainly focus on using some parameters such as degree, betweenness and eigenvector which chooses small number of nodes as the important nodes. These methods may cause uneven distribution of important nodes which may likely result in less controlling of the rumor propagation. In order to achieve the desired effect, The selected important nodes should have two properties: high
importance and distribution evenly.

Method steps:

**Step 1:** Calculate the diameter of the network.
Suppose \( N \) is the set of nodes in the network, according to the formula \( D_G = \max \{ d(u, v) \mid u, v \in N \} \), calculating the diameter of the network, where \( d(u, v) \) is the shortest path length from \( u \) to \( v \).

**Step 2:** Find the center node.
For a diameter, there must be at least one node \( g \) in the path from \( u \) to \( v \) that has \( F(g) = \max \{ d(u, g) \cdot d(g, v) \} \), the node \( g \) is the center node of the network.

**Step 3:** Look for two nodes \( g_1 \) and \( g_2 \) on the diameter with the distance of \( 1/4D_G \) from node \( g \).

**Step 4:** Make a traversal at the nodes which is \( 1/4D_G \) far from node \( g \), sorting these nodes according to the betweenness \( BC_i = \sum_{s \neq i \neq t} \frac{n_{st}}{D_{st}} \).

**Step 5:** Select nodes \( g, g_1, g_2 \), and the top \( x \) nodes in step 4 as important nodes.

4. **Simulation analysis.** In order to illustrate the validity of the methods proposed in this paper, the 3 methods are compared with the random selection method, the degree ranking method and the PageRank method. In the ER network, BA scale-free network, the real network in Facebook network and E-mail communication network, 1% of nodes are randomly selected as the initial Spreaders respectively. Using 5 methods to select 1% of the nodes as Wiseman, the simulation experiment is as follows:

4.1. **BA scale-free network.** BA scale-free network: Size is 500, the average degree is 8. Simulation result is shown in Figure 5.

As shown in Figure 5, IPA has a great effect in controlling the time of rumor outbreak. BHR has a great effect in controlling the number of Spreaders. Using BRPP, IPA, PageRank and Degree Ranking method to select important nodes, although the time of rumor outbreak is delayed, after the rumor outbreak, the number of Spreaders never fall again. Because the Silent Gullible blocked the network, so the Spreaders will never know the truth. To sum up, although BHR could not delay the rumor outbreak, the number of Spreaders decreases in a short time and even approaches zero, so BHR is the best method in BA scale-free network.

![Figure 5. The number of spreaders in BA scale-free network](image-url)
4.2. **ER network.** ER network: Size is 500, the average degree is 8. Simulation result is shown in Figure 6. Figure 6 shows that 3 methods proposed in this paper all have some effect in the rumor propagation controlling. BRPP has a great effect on controlling the time of rumor outbreak. BHR has a great effect on controlling the number of Spreaders. Selecting important nodes by Degree Ranking caused the truth to be isolated.

4.3. **Facebook network.** Facebook network: Size is 4039, edges are 88234. Simulation result is shown in Figure 7. Figure 7 shows that considering both the time of rumor outbreak and the number of Spreaders, BRPP is the best. It can not only control the Spreaders at about 800, but also reduces the number of Spreaders to 0 in a short time.

4.4. **E-mail communication network.** E-mail communication network: Size is 1133, edges are 5451. Simulation results are shown in Figure 8. Figure 8 BHR has a great effect both on controlling the time of rumor outbreak and the number of Spreaders. BRPP and IPA also do well in controlling the rumor propagation.
5. **Conclusions.** Rumor propagation problems are prevalent in the real network, so it has great practical significance to research the impact of important nodes on the rumor propagation. We proposed a new rumor propagation model and 3 methods to find important nodes, the purpose is to control the rumor propagation more efficiently. They are more reasonable and comprehensive than existing models and methods. The conclusion shows that: in the real networks, BRPP, IPA and BHR all have a good effect on controlling the time of rumor outbreak and the number of Spreaders. And in each simulation experiment, IPA works well than the PageRank method. This proves that it makes sense for us to improve the PageRank method. Degree Ranking can also control the time of the rumor outbreak, but it is easy to cause the truth to be isolated. Degree is an important attribute, but it does not take the global property of the network into account. The final conclusion shows that the higher the status of the important nodes and the more evenly distributed they are, the better the effect of rumor controlling. Both the new model and the methods are useful for controlling rumor propagation.

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