The Spread of Rumors and Positive Energy in Social Network

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Abstract

On the basis of prior studies, this paper modifies the parameters of the information propagation process under SIR model, and analyses the impact of various parameters of the information propagation process. Firstly, we add weight and threshold of nodes in the SIR model. Moreover, the weight (activity) of the whole network is added. Then, we analyzed the impact of the weight of nodes and the whole network based on the complex network model. Furthermore, we keep on studying the characteristics and propagation process of the information in the social network. At last, we classified the information into rumors, normal information and positive energy. According to the information category, we run simulation experiment to analyze the propagation results of different kinds of information. The simulation results indicate that the information propagation process can be controlled by changing the parameters and weights at an appropriate time. Finally, some suggestions and ideas are suggested.

Keywords: Complex network, Social network, Information propagation, Rumor, Positive energy

1 Introduction

On February 27, 2014, the central leading group on the network security and information was set up and held its first meeting in Beijing. It means that the state pays attention to the development of network security and informatization. So, the internet info deserves more attention.

In the study of complex networks, two seminal papers can be regarded as the symbol of the new era. Complex networks describe a wide range of systems in nature and society [1-4]. By studying on complex networks, the indistinct world can be quantified and forecasted. Therefore, study on complex networks, social networks and interpersonal interactions have obviously received a great deal of scholarly attention [5-6].

How do social individuals influence each other? And how do they exchange messages and ideas? According to methods and ideas of complex networks, the solutions are obtained [7]. With the information technology develops, new media such as We Chat, micro-blog and Internet are emerging. Information propagation is faster and wider than it has ever been. Information includes rumors, normal information and "positive energy" [8-12].

Normal social behavior is to make friends or exchange daily information. Rumors may cause serious social public opinion and affect social stability, while the "positive energy" may bring people hope and inspiration. Related algorithms of data mining can be used to analyze information.

In recent years, due to the impact of Internet, more and more scholars come to study rumors [13]. Most scholars study rumors through some significant crisis events, such as, the earthquake, SARS or Fukushima nuclear leak in Japan. Commonly, the study is based upon a fixed platform, for example QQ, We Chat, micro-blog [14-15]. But information is not always rumors, some is "positive energy". There are few articles relating to comprehensive study in rumors and positive energy. In this paper, the effects of "positive energy" and rumors are analyzed.

The rest of the paper is structured as follows. In Section 2, the network model is established and the basic concepts and characteristics of social network are introduced. In Section 3, we reveal and analyze the results of experiments. The weights (or activities) of the whole network are considered and the results are discussed in Section 4. Section 5 is the summary. Finally references and acknowledgments are presented.

2 Model of Social Network

The social network is composed of nodes and edges [16-18]. Nodes usually refer to individual or organization, and edges refer to the relationship between people.

As shown in Figure 1, social network model reflects the small-world and scale-free property of complex networks [19-20].

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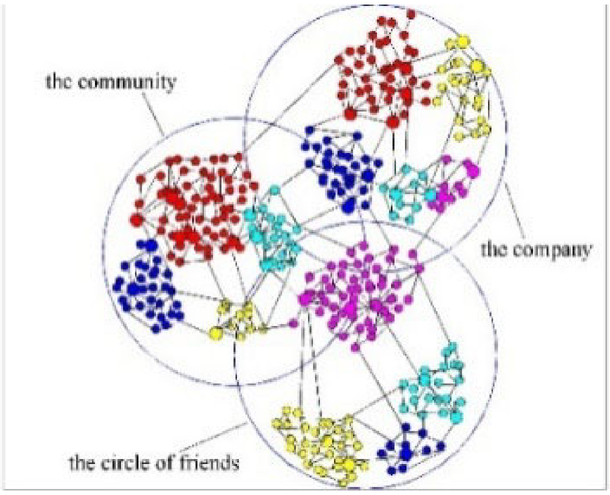


Figure 1. Social network model. The three circles represent community, company and circle of friends. The bigger the dot, the heavier the weight, which means the dot has greater authority

Now watching the information propagate in a circle. We do not consider the specific ways of information propagation in social networks.

Information propagation is similar to the transmission of infectious disease, but it has its specific characteristics [12]. The info spreads through social relations, which is called social contact propagation. At the beginning, the number of information disseminator is little, then increases rapidly. Next, a lot of people propagate the message but the growth rate slows down. Finally, the number of new communicators drop steadily and the propagation process slowly stops. The characteristic of this mode is a chain reaction, which could be depicted as the first infected one spreads some information to his contacts, and these contacts spread to the next one, thus gradually spreading [21-22].

The hypothesis of model: A social network consists of N individuals. Do not consider the situation of the second contact.

Information transmission is a one-way communication model, as shown in Figure 2. Each node has a weight μ and threshold f. Weight μ represents the influence of a person, threshold f reflects the difficulty of being influenced by information. Because the ability of person to accept information is different, the threshold is also different. If $\mu_i > f_j$, then the node j will be affected by node i, and then it will influence the other nodes. If $\mu_i = f_j$, node j will also be affected by node i, but it might not affect other nodes. Otherwise, the node j will not be affected by node i, namely, it refuses information from node i. The threshold is not unchangeable. The person will become an infector, when he or she contacts with more people who was an infector. Hearing the information from different sources will convince a person to believe in it [22]. The propagation process as illustrated in Figure 3.

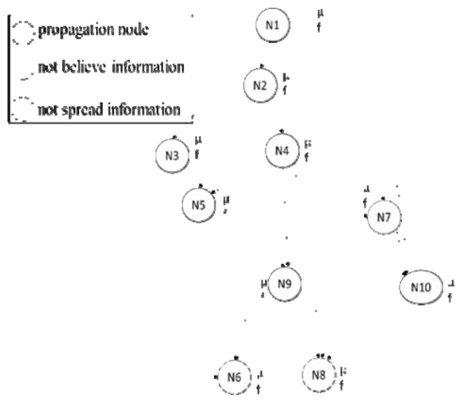


Figure 2. The model of information communication

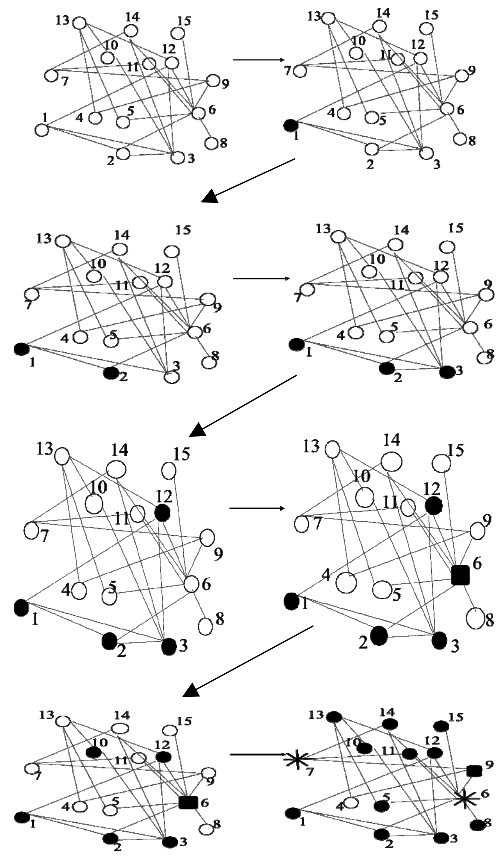


Figure 3. The propagation process

As shown in Figure 3, the circles are initial nodes. Black nodes are affected by information, the * nodes refuse to accept the message, and the square may accept or reject the news.

The meaning of each symbol: (1) There are N individuals in a social network, everyone has three types of possible states: an inactive node, a spreader and the people who has been affected but he or she no longer spreads the information, respectively I(t), S(t), R(t) [23]. This ratio is cumulative percentage. (2) λ represents the rate of increase in people who has been influenced by information per unit time. (3) The percentage of affected person becoming non-communicators is θ. (4) μ represents the weight of a node. The greater the weight, the more leverage and authority he has. But the authority would not increase infinitely along with the increase of weight. When the value increases to a certain extent, the authority no longer increases. In large-scale networks, high-degree nodes usually have greater authority [24- 26].

In actual social networks, some people may not to spread or accept messages, so the total amount of package (or information) is fixed. The model establishing process is as follows.

(1) Assuming node activity degree is *h*. Active nodes can affect the inactive node. If the node does not activate others, then its activity will be decreased (A timer can be set. If the node does not activate other nodes within the set time, then its activity will be decreased).

(2) In the process of information transmission each node has a random threshold *f*. If the weight is greater than threshold, the inactive state will convert into active state, the active degree will rise, and then active node will influence other nodes. If the weight is equal to threshold, the node will also become activity, and its active degree will rise, but the node might not to influence other nodes. Otherwise, the node does not accept the information, and its active degree stays the same.

(3) After a node becomes communicator, it is likely to influence the neighbor nodes around it. If the node does not affect other nodes within the set time, then the activity decreased. Repeat the steps above.

3 The Results and Analysis of Experiments

3.1 The Data and Method of the Experiment

Now, Internet has a lot of free resources about social network data sets, such as the snap program at Stanford University, the network data columns at University of Michigan, and the data-tang all provide free social network data sets [27]. So we can use these data to study social networks. The method used in this paper is mainly controlling variables method. This paper also uses the comparison method.

3.2 The Results of the Experiment

When we do not consider the composition of groups and immigration or emigration. "The increasing amount of influenced people = the number of people affected by information * the increase rate of people who has been influenced by information". Information propagation can be expressed as [25]

$$N\frac{dS}{dt} = N(\lambda S) \Rightarrow \frac{dS}{S} = \lambda dt. \quad \textbf{(1)}$$

When we do not consider the formation of groups. The people who have not accessed to information plus the one who are affected is the total number *N* which stays the same. Combined with the equation (1), we have [25]

$$N\frac{dS}{dt} = (NS)\lambda I\ . \quad \textbf{(2)}$$

Where *(N*S)* indicates the number of people affected by information, λ**I* indicates the rate of increase in people who has been influenced per unit time [25]. The equation (1) and equation (2) are identical in nature.

The proportion of people who do not contact information and the ratio of people who are affected is 1. So we have

$$S(t) + I(t) = 1\ . \quad \textbf{(3)}$$

According to equation (3) and equation (2), we can get

$$\frac{dS}{dt} - S\lambda = -S^2\lambda\ . \quad \textbf{(4)}$$

Equation (4) is the Bernoulli equation. From equation (4), we have

$$S^{-2}\frac{dS}{dt} - S^{-1}\lambda = -\lambda\ .$$

If we define $p = S^{-1}$, then $\frac{dp}{dt} = -S^{-2}\frac{dS}{dt}$, so

$$-\frac{dp}{dt} - \lambda p = -\lambda$$

$$\Rightarrow \frac{dp}{1-p} = \lambda dt$$

$$\Rightarrow \ln(1-p) = -\lambda t - c_1$$

$$\Rightarrow p = 1 - ce^{-\lambda t}$$

$$\Rightarrow S = \frac{1}{1-ce^{-\lambda t}}\ .$$

If we define $S(0)=S_0$, then $S(t) = \frac{1}{1+(\frac{1}{S_0}-1)e^{-\lambda t}}$.

According to the expression of *S(t)*, the diagram of the relationship between S and *t* can be drawn (Figure 4). As shown in Figure 4, over time, the percentage of people who has been effected becomes larger. At a certain moment, almost all members are affected by information, and the percentage of people who is affected approaches 100%. After that, the ratio remains the same.

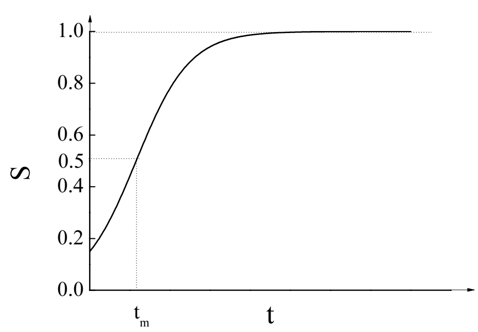


Figure 4. The diagram of *S(t)* changes over t

The diffusion curve in Figure 4 is a logistic S-shape, with which accord the characteristics of a chain reaction [21]. In Figure 4, the point (t_m, 1/2) is an inflection point [28]. It means that, at the moment t_m the image has a maximum slope and propagation speed.

The t_m can be obtained by equation (4). From equation (4), we could get

$$\frac{dS}{dt} = -\lambda(S - \frac{1}{2})^2 + \frac{1}{4}\lambda .$$

When S=1/2, dS/dt has a maximum value.

$$S(t) = \frac{1}{1 + (\frac{1}{S_0} - 1)e^{-\lambda t}} = \frac{1}{2}$$

$$\Rightarrow 1 + (\frac{1}{S_0} - 1)e^{-\lambda t} = 2$$

$$\Rightarrow e^{-\lambda t} = \frac{1}{\frac{1}{S_0} - 1}$$

$$\Rightarrow -\lambda t = \ln(\frac{1}{\frac{1}{S_0} - 1})$$

$$\Rightarrow t_m = \lambda^{-1}\ln(\frac{1}{S_0} - 1) .$$

According to equation (4), the diagram of relationship between dS/dt and S (Figure 5) can be drawn. It can be concluded from Figure 4 and Figure 5 that when S= 1/2, $t_m = \lambda^{-1}\ln(\frac{1}{S_0} - 1)$ dS/dt has the maximum value. It means that at the moment t_m the number of people affected by information increased dramatically, and then the information propagation speed began to slow down. Therefore, if you want to intervene information, the moment before t_m is the best time. The period before t_m can be used to control rumors or motivate “positive energy”.

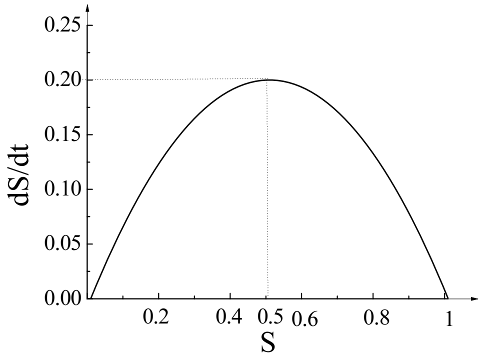


Figure 5. The diagram of dS/dt and S

If there are three possible states for each person, the inaction, spreaders, and the one who no longer spreads the information (represented by I(t), S(t), and R(t), respectively) [12, 29]. We have

$$I(t)+S(t)+R(t)=1. \quad \textbf{(5)}$$

“The increasing amount of people who do not spread information = the ratio of people who do not propagate info * the number of people who has been affected by information”. So we have [29]

$$N\frac{dR}{dt} = \theta\left(NS(t)\right). \quad \textbf{(6)}$$

The number of people who do not spread information is subtracted from equation (2), then we can get [25]

$$N\frac{dS}{dt} = \left(NS(t)\right)\left(\lambda I(t)\right) - \theta\left(NS(t)\right). \quad \textbf{(7)}$$

From equation (5), equation (6) and equation (7), we get [27]

$$\frac{dS}{dt} = \lambda IS - \theta S , \quad \textbf{(8)}$$

$$\frac{dI}{dt} = -\lambda IS . \quad \textbf{(9)}$$

They are non-linear differential equations [30], so the expression of S(t) and I(t) cannot be got. But the variation trend of S(t) and I(t) can be got using the nonlinear dynamics [31].

The tendency chart can be drawn by the method of nonlinear dynamics [31-32]. As is shown in Figure 6 and Figure 7. Figure 6 reflects the changes of various proportions with time *t.* The percentage of effected people is getting bigger and bigger as time goes by, however, the proportion of people who have not been affected is gradually reduced. Figure 7 is a graph about the relations between S and I. The arrows in Figure 7 represent the track direction of curve. The values of S(t) increase with time increasing and the values of I(t) reduce with time. But when S(t) increases to a certain extent, S(t) will reduce with time *t*.

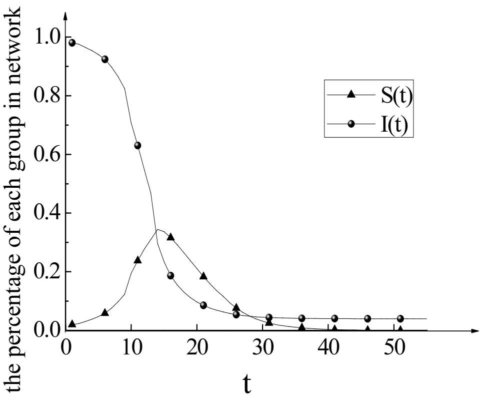


Figure 6. The diagram of S(t) and I(t) changes over t

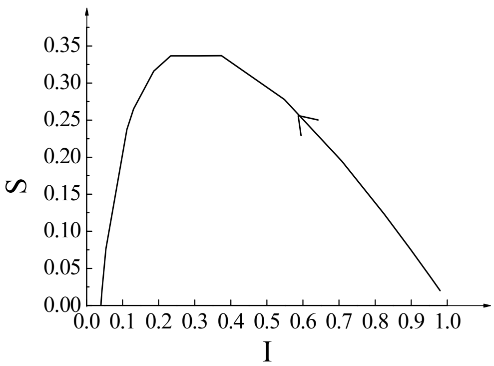


Figure 7. The relationship of S and I

If we only change the value of S_0 or λ in the formula $S(t)=\dfrac{1}{1+(\frac{1}{S_0}-1)e^{-\lambda t}}$, the diagram of S(t) and t can be got (Figure 8 and Figure 9). Due to the different values of S_0 or λ, the time required to reach 1 is different. With the increase of S_0 or λ, the time required for S(t) to approach 1 is reduced. According to the formula $\dfrac{dS}{dt}=-\lambda(S-\dfrac{1}{2})^2+\dfrac{1}{4}\lambda$ and $t_m=\lambda^{-1}\ln(\dfrac{1}{S_0}-1)$, it can be deduced that when S=1/2, dS/dt has the maximum value. But the time t_m which affected by λ and S_0 is different. In order to transfer "positive energy", the information should be discussed more at the initial time, then the information can be quickly spread through the whole network. As to rumor, effective measures should be taken to prevent it from spreading before t_m. For example, the government timely releases information to reduce λ or controls rumormongers contact with others. The normal information will slowly fade away.

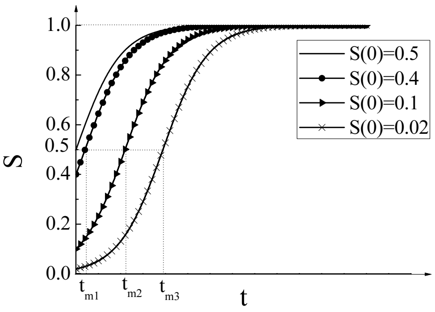


Figure 8. The diagram of S(t) and t

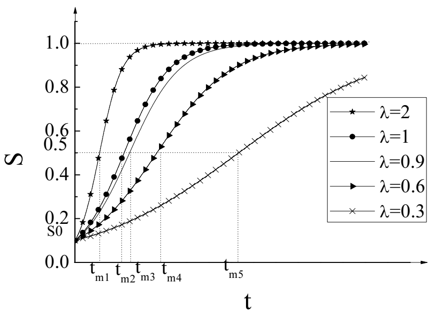
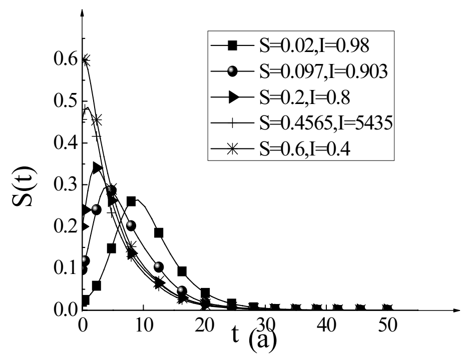
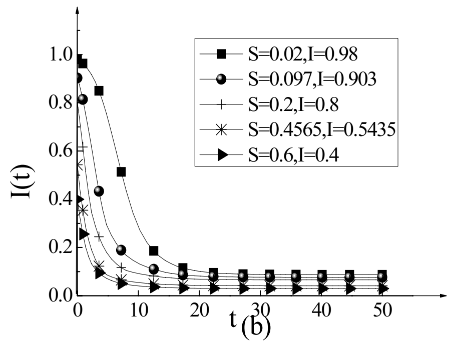


Figure 9. The diagram of S(t) and t

If we only change the value of S and I in formula (8) and formula (9), Figure 10 and Figure 11 can be obtained. In Figure 10, sub graph (a) is a relationship diagram between S(t) and t, when the original value is not the same; with the different original value, the relationship between I(t) and t is shown in sub graph (b). As can be seen from Figure 10, each curve of S(t) has rising and falling process, while I(t) is a directly decline curve. This is consistent with the actual situation. In the process of information propagation, more and more people are affected by information, at the same time, the number people who have not been affected is gradually decreasing. The information propagation can be divided into transmission stage and weaken stage. In transmission stage S(t) increases rapidly. While in decay stage S(t) gradually reduces. If the initial value increases, then the number of infector is likely go on rising at the beginning, and the time required for S(t) and I(t) to reach a relatively stable state is shorter. Information need to be intervened in dissemination phase, in order to control information dissemination. Rumors propagation can be throttled or "positive energy" be encouraged by controlling the number of infector at the beginning. As we all know S(t)≥0; I(t)≥0. According to formula (5) we can get $I(t)+S(t)\le 1$. The relation graph of S and I in region D can be drawn, as shown in Figure 11 [27] (D={ $(S,I)\,|\,S(t)\ge 0, I(t)\ge 0, I(t)+S(t)\le 1$ }). As can be seen from Figure 11, no matter how changes the initial values, curves will intersect with X axis. Whether rumors, normal information or "positive energy", they will disappear.



(a) The diagram of S(t) changes with t on the different initial value S_0, I_0.



(b) The diagram of I(t) changes with t on the different initial value S_0, I_0

Figure 10.

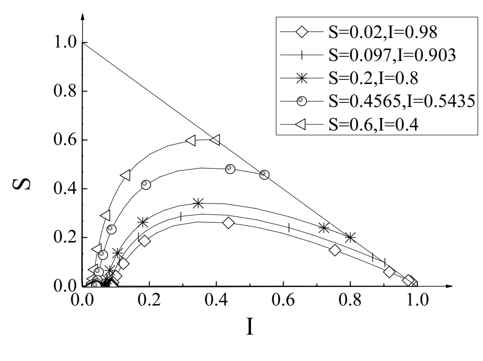


Figure 11. The diagram of S and I

If we only change λ in formula (8) and formula (9), Figure 12 and Figure 13 can be obtained. The I(t) variation with time t is shown in Figure 12. Figure 13 is a relationship between S(t) and t. Seen from Figure 12, Figure 13, I(t) has different final values and S(t) has different peaks. It means that the information has high transmission rate and wide impact scope, when the value of λ is bigger. So there is a larger S(t) in the stage of transmission, that is to say the proportion of infector is larger. With the relatively large λ, the propagation speed becomes lager, and the number of people who is not affected will reduce. The number of infector can be throttled by controlling the value of λ.

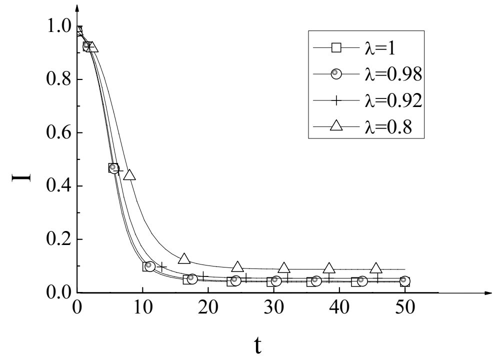


Figure 12. The diagram of I and t

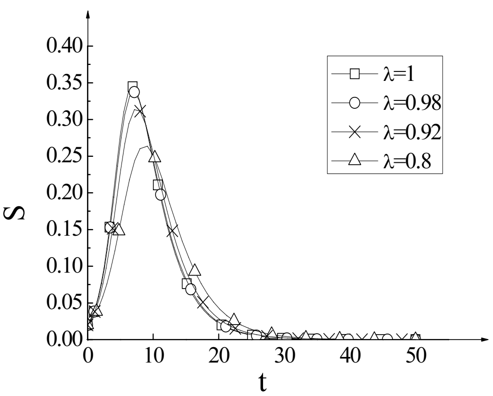


Figure 13. The diagram of S and t

If we only change the value of θ in formula (8) and formula (9), Figure 14 and Figure 15 can be drawn. The I(t) variation with time t is shown in Figure 14. Figure 15 is a relationship between S(t) and t. As shown in Figure 14, when the value of θ is different, I(t) reaches a stable state at different time and has a different final value. As the θ value increases, the time required for I(t) to reach a steady state is longer. In Figure 15, when the value of θ is different, the peak of S(t) is different too. With the increase of θ, the peak of S(t) is gradually reduced. Rumors can be eliminated or "positive energy" be encouraged by such means as government intervention or educational propaganda.

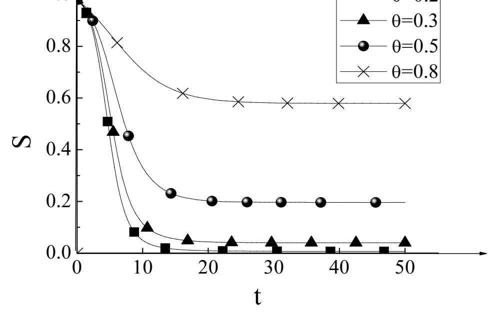


Figure 14. The diagram of I and t

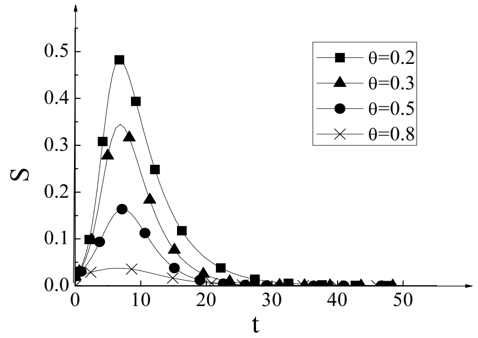


Figure 15. The diagram of S and t

The effects of a single parameter are not significant in the above graphs. What are the impacts of changing the multiple parameters? If we define $\sigma = \theta / \lambda$, then σ is called relative transfer rate [31]. From equation (8) and equation (9), we can get

$$\frac{dS}{dI} = \frac{\sigma}{I} - 1 . \qquad \textbf{(10)}$$

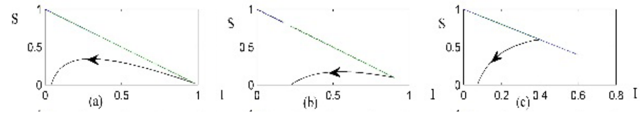
If we define

$$I = I_0 . \qquad \textbf{(11)}$$

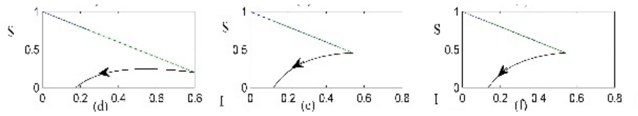
Then from equation (10) and equation (11), we have

$$S = (S_0 + I_0) - I + \sigma \ln \frac{I}{I_0} .$$

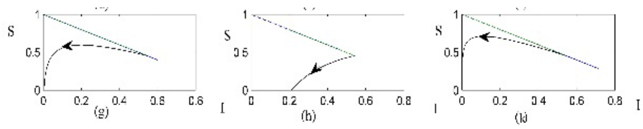
With different σ, the diagram about S and I in region D ($D = \{(S, I) \mid S(t) \geq 0, I(t) \geq 0, S(t) + I(t) \leq 1\}$) is shown in Figure 16. The arrow in Figure 16 represents the direction of motion. As shown in Figure 16, when $\sigma > I_0$, S(t) is a decreasing function and finally tends to 0, such as sub graph (c), sub graph (f) and sub graph (h). When $\sigma < I_0$, S(t) increases to the maximum and then gradually reduces to 0, such as sub graph (a), sub graph (b), sub graph (d), sub graph (g) and sub graph (k). However in the sub graph (e) $\sigma = I_0$, S(t) is a decreasing function. So the information propagation is not unconditional and it closely relates to every parameter. In order to control rumors, the government should publish information to explain or verify rumors [32]. Because of government involvement, more and more people no longer believe in or spread the rumor. The rumors could be controlled by increasing the value of θ or reducing the value of S(t). In order to motivate "positive energy", the government should publish information to expand the scope of information dissemination. The value of θ will decrease, and the curve of S(t) will rise. In this way, the scope of information transmission will be expanded. For normal information, it does not need too much intervention. But no matter how changes the parameters, S(t) will intersect with the X axis, and the information will disappear too. The difference is just time. Optimization algorithms can be used to find a moment which has the maximum velocity of propagation, such as particle swarm optimization algorithm (PSO) and ant colony algorithm (ACS). We could utilize this moment to control information propagation.



(a) S= 0.02, I = 0.98, θ = 0.3, λ = 1, σ = 0.3 (b) S=0.097, I=0.903, θ=0.5, λ=0.9, σ=0.5434 (c) S=0.6, I = 0.4, θ = 0.5, λ = 0.92, σ = 0.5434



(d) S = 0.2, I = 0.8, θ = 0.5, λ = 0.92, σ = 0.5434 (e) S = 0.4566, I = 0.5434 = 0.5, λ = 0.92, σ = 0.5434 (f) S = 0.4565, I = 0.5435, θ = 0.5, λ = 0.8, σ = 0.625



(g) S = 0.4565, I = 0.5435, θ = 0.2, λ = 0.99, σ = 0.202 (h) S = 0.4565, I = 0.5435, θ = 0.5, λ = 0.6, σ = 0.83 (k) S = 0.4565, I = 0.5435, θ = 0.1, λ = 0.9, σ = 0.11

Figure 16. The diagram of S and I

4 The Weight of the Whole Network

The weight of whole network will be considered in this section. A smaller weight represents an inactive network, in which the members have less connection. Adding a weight parameter, the previous equations can be expressed as the following form.

Adding a weight parameter in the equation (2), we can get

$$N \frac{dS}{dt} = (NS)\lambda\mu_1 I \qquad \textbf{(12)}$$

$$\Rightarrow \frac{dS}{dt} = S\lambda\mu_1 I .$$

Plugging equation (3) into the equation (12), we get

$$\frac{dS}{dt} = S\lambda\mu_1(1 - S), \qquad \textbf{(13)}$$

$$\frac{dS}{dt} - S\lambda\mu_1 = -\lambda\mu_1 S^2 .$$

Equation (13) is a Bernoulli equation, it is the same as equation (4). Based on equation (13), we can get

$$S^{-2}\frac{dS}{dt}-\lambda\mu_1 S^{-1}=-\lambda\mu_1$$

$$\Rightarrow S=\frac{1}{1-ce^{-\lambda\mu_1 t}}.$$

If we define S(0) =S_0, then S(t) can be expressed as $S(t)=\frac{1}{1+(\frac{1}{S_0}-1)e^{-\lambda\mu_1 t}}$. According to the expression of S(t), the relationship diagram about S and time t can be drawn (Figure 17).

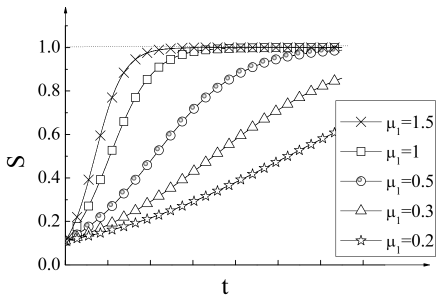


Figure 17. The relationship between S(t) and t

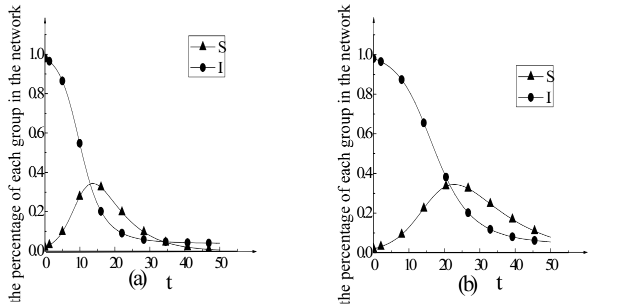
As shown in Figure 17, when the value of μ_1 increases, the time required for curve to reach the maximum will reduce. That is to say, the more active the whole network, the faster information spread. Rumors could be controlled by reducing the weight of whole network, for example forbidding speech or limiting the network speed. "Positive energy" could be motivated by increasing the weight of whole network. For example encourage people to discuss the "positive energy" or rolling broadcast this "positive energy" in various social networks.

Adding a weight parameter in equation (8) and equation (9), we can get

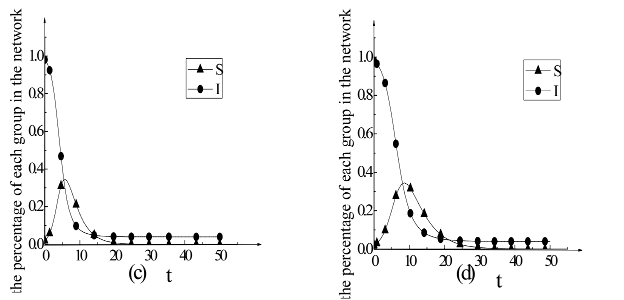
$$\frac{dS}{dt}=\lambda\mu_1 IS-\theta\mu_1 S\,, \tag{14}$$

$$\frac{dI}{dt}=-\lambda\mu_1 IS\,. \tag{15}$$

The equation (14) and equation (15) are non-linear differential equations. When the μ_1 is different, Figure 18 can be got. Figure 18 reflects the relationship about the various proportion and time. As shown in Figure 18, when the value of μ_1 increases, the time required for I(t) to reach a steady state will reduce, the time required for S(t) to appear a peak is earlier. As to rumor, we can reduce the weight of the whole network to delay peak time. In order to control rumor, government should take measures before the peak arrival. Such as limiting network speed, or preventing infector from contacting with others [33]. As to "positive energy", we can increase the weight of the whole network to let the peak earlier arrival. For example encouraging more people to discuss this "positive energy".



(a) $S_0 = 0.02$, $I_0 = 0.98$, $\lambda = 1$, $\theta = 0.3$, $\mu_1 = 0.5$ (b) $S_0 = 0.02$, $I_0 = 0.98$, $\lambda = 1$, $\theta = 0.3$, $\mu_1 = 0.3$



(c) $S_0 = 0.02$, $I_0 = 0.98$, $\lambda = 1$, $\theta = 0.3$, $\mu_1 = 1.2$ (d) $S_0 = 0.02$, $I_0 = 0.98$, $\lambda = 1$, $\theta = 0.3$, $\mu_1 = 0.8$

Figure 18. When the weight of network μ_1 is different, the relations about various proportion and t

5 Conclusions and Discussions

Good news never goes beyond the gate, while bad news spread far and wide. The rumor has a lot of harms, such as effecting a person's reputation, making a company bankruptcy, and even endangering state security. So effective measures should be taken to control rumors. While the "positive energy" could make a person more confident and optimistic. Therefore, we should establish a long-term control system that could decrease the negative influences and allow the positive functions of online rumors. In order to build a more harmonious society, the "positive energy" should be spread widely.

The propagation of rumors and positive energy is studied in this paper. Detailed information can be concluded as following. First, the model of information propagation which include rumor, normal information and "positive energy" is studied. Second, the effects of each parameter on model are analyzed. Third, the impact on weight of the whole network is studied. The experimental results show that the information propagation is not unconditional and it is closely related to many factors. According to different situations, the government or related departments should take appropriate measures to handle information propagation. Rumors can be controlled and "positive energy" be encouraged by changing the weight (activity) of whole network.

The research of information propagation is beneficial to social network studying, and it is necessary to do more research in information communication. For instance, what will happen when the scale of network changed? And how to propagate information when the structure of network changed? These problems will be further studied in the future.

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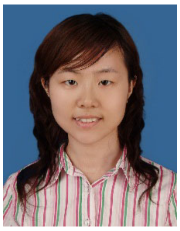

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