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# Agent-Based Simulation of Rumor Propagation on Social Network Based on Active Immune Mechanism

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**Abstract** To simulate the rumor propagation process on online social network during emergency, a new rumor propagation model was built based on active immune mechanism. The rumor propagation mechanisms were analyzed and corresponding parameters were defined. BA scale free network and NW small world network that can be used for representing the online social network structure were constructed and their characteristics were compared. Agent-based simulations were conducted on both networks and results show that BA scale free network is more conductive to spreading rumors and it can facilitate the rumor refutation process at the same time. Rumors paid attention to by more people is likely to spread quicker and broader but for which the rumor refutation process will be more effective. The model provides a useful tool for understanding and predicting the rumor propagation process on online social network during emergency, providing useful instructions for rumor propagation intervention.

**Keywords** rumor; emergency; online social network; agent-based simulation; active immune

## 1 Introduction

Increasing population are occupying in frequently receiving and sharing information on online social network. However, in the times of information explosion, much false information appears on the internet, which is often the case during emergency. Public have strong information demands during emergency. When official information is absent, false information may arouse public's attention and be widely spread. People may be misled by the false information and even show unreasonable behaviors. For example, an earthquake happened on March, 11, 2011 in Japan, which led to Fukushima Nuclear Power Station explosion, and after that the

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rumor saying that iodized salt can provide radiation protection was widely spread and many people showed great passion for purchasing iodized salt, which badly disrupted the economic and social order. Thus, preventing rumor propagation during emergency management is a key issue.

Many researchers studied rumor propagation through mathematical modeling mainly from the perspectives of rumor spreading behaviors[1–8], countermeasures[9–14] and social network[15–20]. Some did research with agent-based modeling method[21, 22] or social survey method[23]. Agent-based modeling is an effective tool for exploring rumor spreading process on online social network in that it makes possible considering the heterogeneity of nodes and their interactions.

Wen, et al. compared two ways of intervening rumor propagation, namely providing rumor refutation information and immunizing nodes through information technological means, and pointed out that the former had more adaptability[24]. Generally, when a rumor is widely spread on the online social network during emergency, rumor refutation information is likely to be published by the official department after some time. Then, the rumor refutation information will be spread on the online social network to reply to the rumor. The official department can be seen as a special node followed by a certain number of common nodes. Here, common nodes are defined as individuals that can receive and spread information but can not generate rumor refutation information. Thus, the official department can receive rumor from the common nodes and the common nodes can receive rumor refutation information from the official department. From the perspective of rumor management during emergency, the special nodes are to represent agents that can generate rumor refutation information, such as experts or official departments. There may exist more than one special node on the online social network.

Mainly three immune mechanisms are considered by the related researchers. The first is forgetting immune mechanism, which refers to that an agent can stop spreading a rumor spontaneously without any contact because of forgetting or losing interest in spreading the rumor further. The second is contact immune mechanism, which means that an agent may stop spreading a rumor considering that it is outdated when contacting with another agent that has known about the rumor. The third is active immune mechanism, which represents that an agent may have the ability to identify a rumor and generate rumor refutation information. Actually, on online social network an individual usually gets information by browsing status updates of its friends and may forward some of the information, and the forwarded information can be saved forever. An individual can also create new information that will be browsed by its friends. Thus, contact immune mechanism does not conform to the real situation, and forgetting immune mechanism and active immune mechanism will be considered here.

Based on the above analyses, a new rumor propagation model more close to the situation of rumor propagation on online social network during emergency is built in this paper. Agent-based simulation method is used to analyze the influence of network characteristics and other related parameters on rumor propagation process.

## 2 Rumor Propagation System

### 2.1 Online Social Network

It has been verified that most social networks show either power-law degree distribution or exponential degree distribution. For the former, the nodes are evidently heterogeneous and most nodes have small degree and there exist a certain amount of nodes that have rather large degree and are called hub nodes. BA scale free network is often chosen as representation of the heterogeneous networks. For the latter, the nodes are approximately homogeneous and the number of nodes rapidly reduces when node degree increases or decreases from the average node degree and there exist no hub nodes. NW small world network is often chosen as representation of the homogeneous networks.

BA scale free network is constructed as the following steps:

1) Construct a full connected network that has $m_0$ nodes;

2) Add a new node to the existed network and connect the new node to $m_1$ existed nodes following the preference attachment principle according to Equation (1):

$$P(i) = \frac{k_i}{\sum_{j=1}^{M} k_j}, \tag{1}$$

where $M$ represents the existed network size, $k_i$ represents the node degree of $i$, $P(i)$ represents the possibility that the new node connects to $i$;

3) Repeat Step 2) until the network size meets the requirements.

NW small world network is constructed as the following steps:

1) Construct a network that has $N$ nodes and arrange the nodes on a circle, connect each node to its nearest $m_2$ neighbor nodes on each side;

2) Choose one of the unconnected node pairs and connect the pair of nodes with probability $p$;

3) Repeat Step 2) until all the unconnected node pairs are connected once.

Network attributes mainly include maximum degree ($MaxD$), minimum degree ($MinD$), mean degree ($MeanD$), average path length ($APL$) and clustering coefficient ($CCo$). Parameter $m_0$ is set as 5 and $m_1$ is set as 5, and BA scale free networks with size $N = 500$, 1000, 2000, 3000 are constructed respectively. Attribute values of the networks are shown in Table 1 and degree distributions of the networks are shown in Figure 1. To compare network attribute values between NW small world network and BA scale free network, $p$ should be set a proper value so that in theory the two kinds of networks with the same size have the same $MeanD$. Equation (2) is used for determining $p$. Parameter $m_2$ is set as 1 and $p$ is 0.012, 0.006, 0.003, 0.002 respectively when $N$ is 500, 1000, 2000, 3000. NW small world networks with size $N = 500$, 1000, 2000, 3000 are constructed respectively. Corresponding network attribute values are shown in Table 2 and degree distributions are shown in Figure 2.

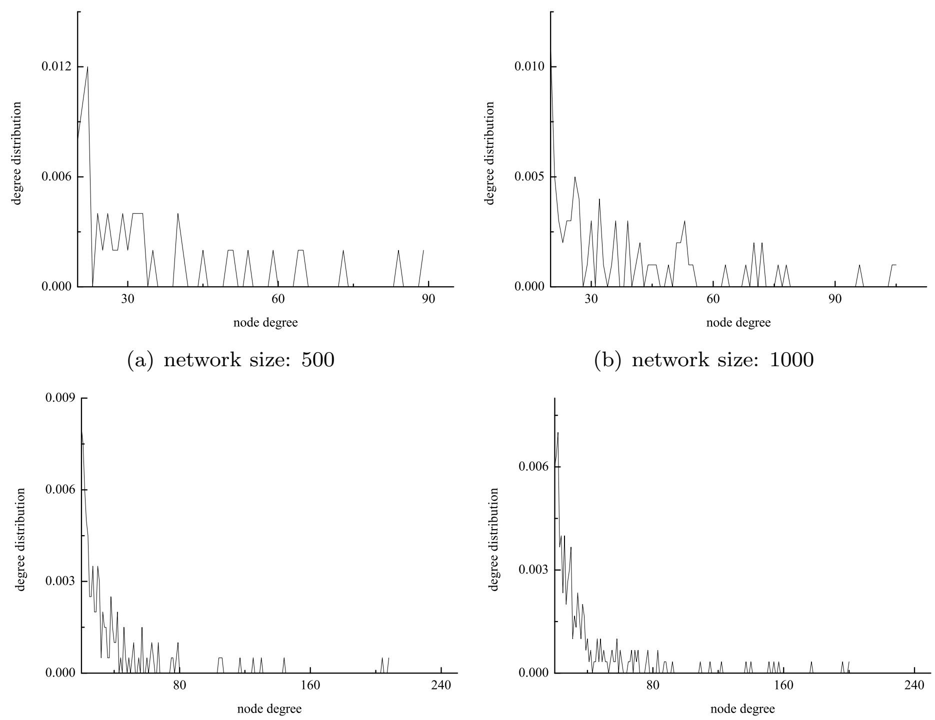
$$\frac{m_0 \times (m_0 - 1)}{2} + m_1 \times (N - m_0) = 2 \times m_2 \times N + p \times \left[\frac{N \times (N-1)}{2} - 2 \times m_2 \times N\right]. \tag{2}$$

**Table 1** Attribute values of BA scale free network with size $N = 500, 1000, 2000, 3000$

| $N$ | $MaxD$ | $MinD$ | $MeanD$ | $APL$ | $CCo$ |
|---|---|---|---|---|---|
| 500 | 88 | 5 | 9.9400 | 2.7562 | 0.0705 |
| 1000 | 104 | 5 | 9.9700 | 2.9707 | 0.0391 |
| 2000 | 207 | 5 | 9.9850 | 3.1595 | 0.0278 |
| 3000 | 199 | 5 | 9.9900 | 3.2986 | 0.0190 |

**Table 2** Attribute values of NW small world network with size $N = 500, 1000, 2000, 3000$

| $N$ | $MaxD$ | $MinD$ | $MeanD$ | $APL$ | $CCo$ |
|---|---|---|---|---|---|
| 500 | 17 | 3 | 8.2000 | 3.1883 | 0.0145 |
| 1000 | 16 | 2 | 7.7520 | 3.6121 | 0.0066 |
| 2000 | 17 | 2 | 7.9400 | 3.9135 | 0.0036 |
| 3000 | 17 | 2 | 7.9673 | 4.1070 | 0.0026 |



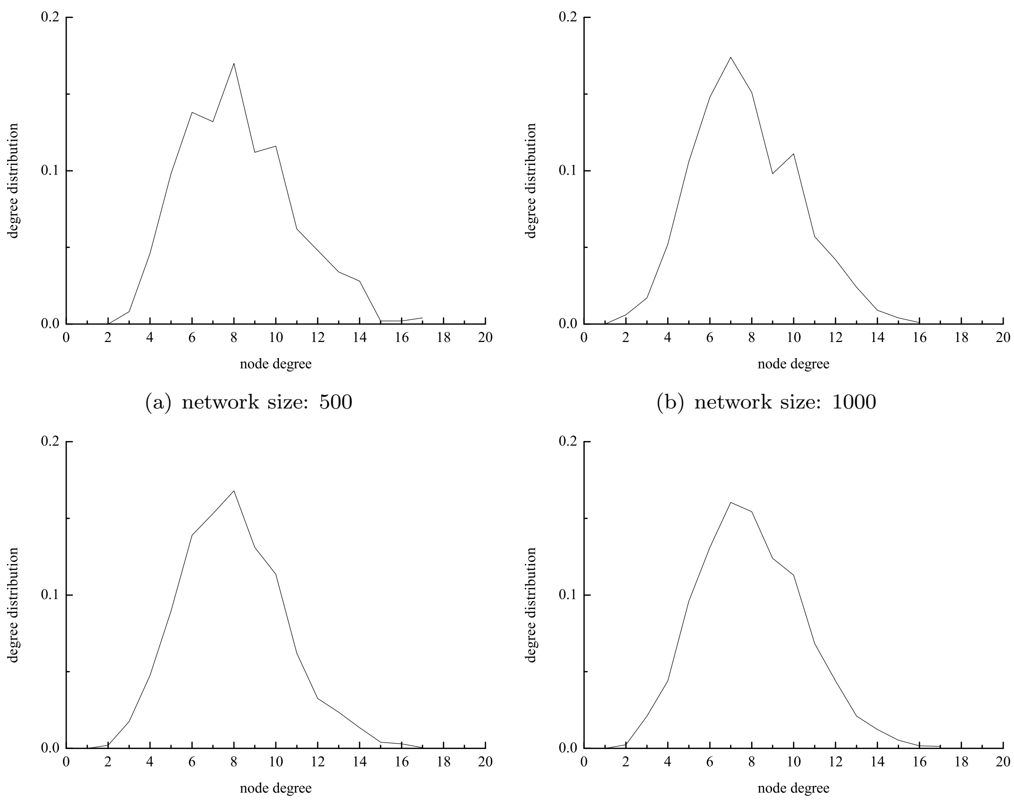

(a) network size: 500 (b) network size: 1000

(c) network size: 2000 (d) network size: 3000

**Figure 1** Degree distributions of BA scale free network with size $N = 500, 1000, 2000, 3000$

Table 1 and Table 2 show that $MeanD$ values of the constructed BA scale free networks are nearly 10 while those of the constructed NW small world networks are nearly 8, which has some difference from the theoretical results because of the randomness in generating network.

Still, characteristics of networks still can be analyzed. Values of *MaxD* and *MinD* in Table 1 show that with the increase of $N$, the nodes tend to be more heterogeneous. Values of *MaxD* and *MinD* in Table 2 show that with the increase of $N$, node degree is always distributed in a short interval and the nodes can be regarded as homogeneous. Values of $APL$ and $CCo$ show that though *MeanD* is a little increased with the increase of $N$, $APL$ becomes larger and $CCo$ becomes smaller for both BA scale free network and NW small world network, which suggests that information is easier to be spread across on a small scale network. $CCo$ in NW small world network is much smaller than that in BA scale free network. NW small world network with size $N = 1000$ is taken for example to compare attributes between the two kinds of network, $p$ is reset as 0.009 and $MeanD$ of the constructed network is 10.9680, which is larger than that in BA scale free network with $N = 1000$, and accordingly $APL$ is 3.1449 and $CCo$ is 0.0110. Comparing the values with that in Table 1, we can find that $APL$ in NW small world network is a little bigger than that in BA scale free network and $CCo$ in NW small world network is much smaller than that in BA scale free network, which suggests that BA scale free network is more conductive to spreading information.




(a) network size: 500 (b) network size: 1000

(c) network size: 2000 (d) network size: 3000

**Figure 2** Degree distributions of NW small world network with size $N = 500$, 1000, 2000, 3000

Figure 1 indicates that node degree of BA scale free network approximately confirms to power-law distribution and there exist certain amount of hub nodes. Figure 2 indicates that node degree of NW small world network approximately confirms to exponential distribution and there exist no hub nodes. BA scale free network and NW small world network with $N$ set as 1000 are chosen for simulations and the simulation results are averaged value of 100 simulations on the same network.

### 2.2 Rumor Propagation Mechanisms

Active immune mechanism is necessary for conquering rumor propagation during emergency and should be established and perfected. Cultivating agents that have the consciousness and ability of identifying rumors and generating rumor refutation information is one way of achieving active immune mechanism. These agents are called special nodes in this paper. As the special nodes tend to have bigger influence, they are represented by nodes with bigger degree. The special nodes are assumed to specially refuse rumors during emergency. The remaining nodes are common nodes and some of them have enough critical consciousness, doubt about reliability of rumor and do not immediately believe and post rumor. It is also assumed that rumor refutation information is superior to rumor for the former often has greater reliability and is more convincing. Thus, an agent will ignore rumor the moment it sees rumor refutation information.

The nodes of the social network are divided into six groups according to the rumor propagation process, namely ignorant ($I$), wise ($W$), spreader ($S$), unbeliever ($U$), indifference ($IN$), opponent ($O$) and reasonable immune ($RI$). Before a rumor appears on the social network, the nodes are either $I$ or $W$. $I$ refers to the common nodes that have certain critical consciousness but cannot identify the rumor. $W$ refers to the special nodes that have the ability of refuting the rumor. $IN$ refers to the common nodes that have no interest in the rumor. $S$ refers to the common nodes that have posted the rumor but have not posted the rumor refutation information. $U$ refers to the common nodes that have seen the rumor and doubt about the rumor and actively search for the rumor refutation information. $O$ refers to the common nodes that have posted the rumor refutation information. $RI$ refers to the special nodes that have posted the rumor refutation information.

The rumor propagation mechanisms are as follows and are shown in Figure 3.

1) Some nodes are set as $W$ and nodes with bigger degree have more chance to be chosen as $W$. It is assumed that $W$ can share the rumor and the rumor refutation information immediately with each other through special channels, such as joining in one group chat. The rest are common nodes and some of them are randomly chosen as $IN$.

2) The special nodes are always online and can know their friends' updates immediately. The common nodes browse their friends' updates at a certain frequency.

3) When one of the common nodes posts the rumor on the social network, the rumor propagation process begins.

4) When one of $W$ sees the rumor, it will inform the other $W$ about the rumor and the rumor refutation process begins. After a certain time, they finish the rumor refutation information and post the information on the social network. At the same time, $W$ transfers to $RI$. The rumor refutation information may also be published in the media.

5) When $I$ sees the rumor posted by $S$, if $I$ is lack of critical consciousness it is likely to immediately post the rumor, and if $I$ has enough critical consciousness it is likely to doubt

about the rumor and transfer to $U$ with the behavior of searching for the rumor refutation information from its friends or the media.

6) When $U$ gets the rumor refutation information within one time step, it transfers to $O$. Otherwise, it transfers to $S$.

7) When $I$ or $S$ see the rumor refutation information, they immediately post the information and transfer to $O$.

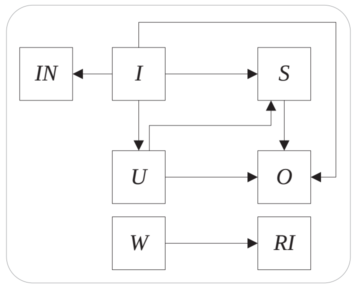



**Figure 3** Rumor propagation mechanisms

## 3 Parameters for Rumor Propagation

According to the rumor propagation mechanisms in Subsection 2.2, the rumor propagation process involves many parameters. The parameters are analyzed and defined as follows.

1) Possibility of the common nodes browsing updates at a certain time ($BP$)

The time a common node browses its friends' updates is random but every agent has a relatively stable time interval for updates browsing behaviour ($TI$). It is assumed that a common node browses its friends' updates at least one time in 24 hours and at most one time within one hour. The unit of time step is set as one hour. $TI$ of each agent is set as a random integer on the interval of $[1, 24]$. Let $TI_i$ represent $TI$ of agent $i$ and $BP_i$ represent the possibility of agent $i$ checking its friends' updates at a certain time, then $BP_i = 1/TI_i$.

2) Rumor spreading rate ($SR$)

During emergency, people tend to show panic to some extent after receiving the rumor. They may ease the panic emotion by posting the rumor hoping that they may get support or attention from their friends. Thus, people's panic emotion tends to promote rumor spreading. Generally speaking, people with high safety culture ($SC$) tend to show high rationality level which can relief people's panic emotion during emergency. What's more, if people believe in the official's emergency management ability ($EMA$), they may feel less panic during emergency. It is assumed that $SC$ of the common nodes conforms to uniform distribution on the interval of $[0, 1]$. Let $SC(i)$ represent $SC$ of agent $i$. $EMA$ is a constant on the interval of $[0, 1]$. It is assumed that $SC$ and $EMA$ have the equal weight. Generally, an individual's panic emotion level is negative to its critical consciousness. More panic emotion means less critical consciousness and more possibility of spreading rumors. Let $SR(i)$ represent $SR$ of agent $i$ and it is defined as $SR(i) = 1 - (SC(i) + EMA)/2$. When $SR(i) > 0.5$, $i$ transfers to $U$ when it sees the rumor. Else, $i$ transfers to $S$ when it sees the rumor.

3) Percentage of $IN$ ($INP$)

$IN$ doesn't participate in the rumor propagation process. $INP$ is a constant on the interval of

$[0,1]$. $INP$ is related to a rumor's attractiveness directly reflects the rumor's potential influence scope. The existence of $IN$ can inhibit both the rumor propagation process and the rumor refutation process.

4) Number of $W$ ($NW$)

$W$ is critical for the rumor refutation process during emergency. The bigger the value of $NW$ the better. However, cultivating $W$ requires a certain amount of cost. $NW$ should be set as a proper value so that the rumor propagation process can be effectively intervened without resources wasted. The proper value of $NW$ can be determined by analyzing the simulation results with $NW$ set as different values.

5) Time delay of generating rumor refutation information ($TD$)

Rumor refutation information should have high reliability so that it can persuade the common nodes to accept it and ignore the rumor. Generating rumor refutation information requires some time and the corresponding time span is represented by $TD$. Improving the efficiency of $W$ generating rumor refutation information can reduce $TD$. The efficiency can be defined as the timeliness of finishing the rumor refutation information ($FT$) within a limited time ($LT$). $FT$ is determined by $W$'s ability of generating the rumor refutation information ($RRA$). $RRA$ is a constant on the interval of $[0,1]$. $LT$ refers to the maximum allowed time for $W$ to generate rumor refutation information. It is assumed that when there are more than half of the common nodes having seen the rumor, the situation is uncontrolled and the rumor refutation work is failed. $LT$ can be determined by calculating the time span from the time when the rumor propagation process begins to the time when half of the common nodes have seen the rumor under ideal conditions. $LT$ is a constant and $TD$ is determined by the equation $TD = 1 + LT \times (1 - RRA)$. The equation guarantees that $TD$ is not less than one time step. $RRA$ is 0 when $TD = 1 + LT$, which means that the rumor refutation information is posted too late to control the negative influence brought by the widely spread rumor.

6) Possibility of the common nodes finding the rumor refutation information in media ($FP$)

When a common node doubts about a rumor, it is likely to search for the rumor refutation information. Generally, there are two ways of getting information for the common nodes. One is from its friends and the other is from the media. It is assumed for simplification that $FP$ is determined by media coverage ($MC$), thus $FP = MC$. $MC$ is a constant on the interval of $[0,1]$. According to the above rumor propagation model, only $U$ has the behavior of searching for the rumor refutation information in the media and $U$ exists only for one time step. Thus, the main function of publishing rumor refutation information in the media is to speed up the rumor refutation process and slow down the rumor propagation process under the condition that there exist $U$ in the system. Larger $MC$ means more cost. Media resources are usually limited during emergency and $MC$ should be set as a proper value according to the requirements for controlling rumor spreading during emergency.

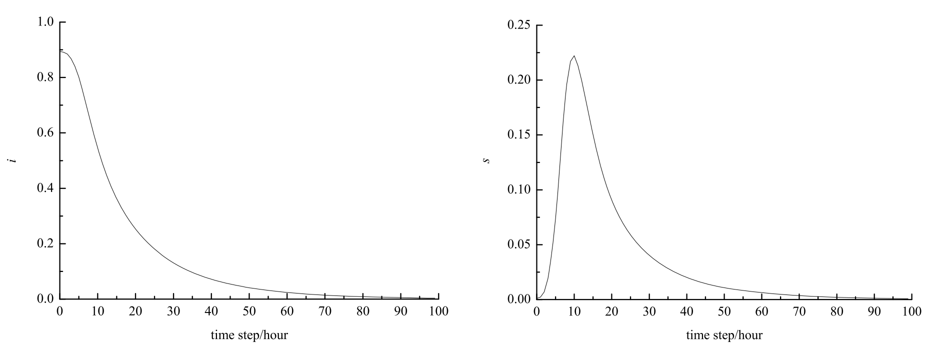
## 4 Simulations and Results

### 4.1 Determination of *LT*

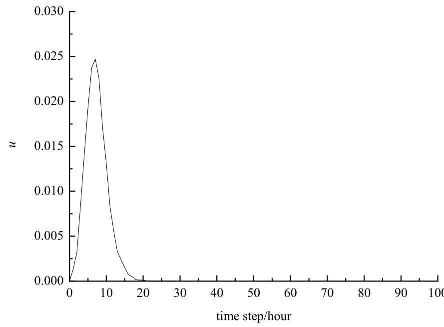
The ideal condition for rumor propagation is set as follows: $EMA = 0$, $INP = 0$, $NW = 0$, $RRA = 0$, $MC = 0$. For BA scale free network, the averaged value of $LT$ is 7.28 and $LT$ is set as 7. For NW small world network, the averaged value of $LT$ is 19.93 and $LT$ is set as 19. Thus, according to the definition of $LT$, special nodes have almost three times the time for generating rumor refutation information in NW small world network than that in BA scale free network. $TD$ is larger in NW small world network than that in BA scale free network when $RRA$ is the same while $RRA$ is less than 1. Rumor propagation intervention requires less of $RRA$ on NW small world network than that on BA scale free network. Generally, there exist hub nodes on social network that cannot be ignored and the network is BA scale free network where $RRA$ should be strengthened. The above results are caused by the fact that rumors spread quicker on BA scale network than on NW small world network as has been indicated in Subsection 2.1.

### 4.2 General Rumor Propagation Process on Different Networks

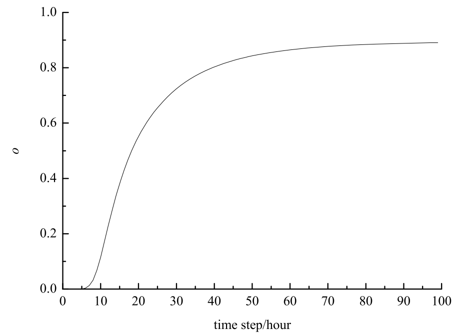
Let $i$, $s$, $u$, $o$, $w$ and $ri$ represent group density of $I$, $S$, $U$, $O$, $W$ and $RI$. The changing curves of $i$, $s$, $u$, $o$, $w$ and $ri$ against time can reflect the rumor propagation process. To analyze the general rumor propagation process, the general situation is considered where the parameters are set as follows: $EMA = 0.5$, $INP = 0.1$, $NW = 5$, $RRA = 0.5$, $MC = 0.5$. The results are shown in Figure 4 and Figure 5. The rumor propagation process is similar on the two kinds of network both including the rumor propagation process and the rumor refutation information spreading process. Curves of $s$ show that the rumor spreads quicker on BA scale free network than on NW small world network at the initial stage, which is consistent to the theoretical results analyzed in Subsection 2.1. The rumor spreads out and $s$ is accumulated before the rumor refutation information is posted. After the rumor refutation information is posted, $s$ can be reduced and $o$ is accumulated. $w$ and $ri$ are vertical lines for one simulation according to our assumptions and here are sloping curves because of the randomness of each simulation. The time of posting the rumor refutation information is not only related to $LT$ and $RRA$ but also influenced by the time when $W$ sees the rumor. Curves of $w$ and $ri$ show that the time when $W$ sees the rumor is most likely earlier on BA scale free network than that on NW small world network, which can be interpreted by the fact that $W$ is most likely hub node in BA scale free network and has more chance to see the rumor earlier.



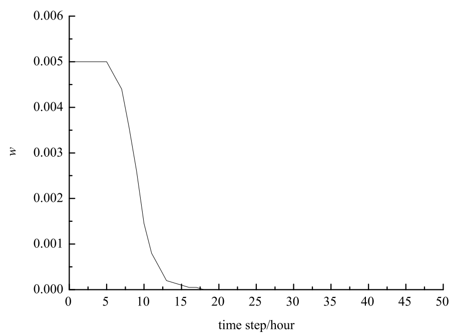

(a) $i$ (b) $s$



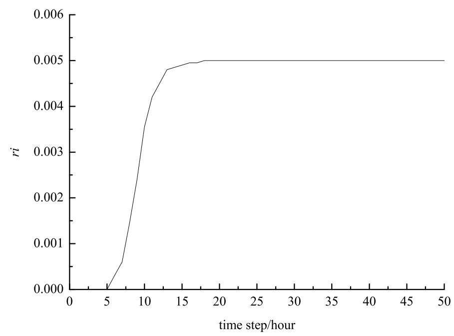

(c) $u$




(d) $o$

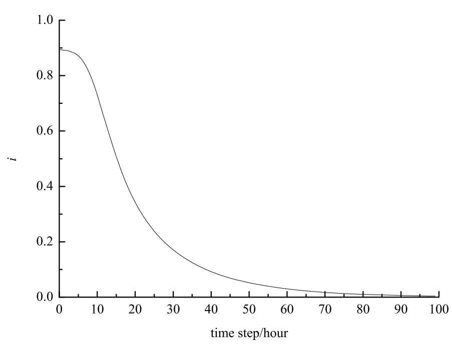



(e) $w$

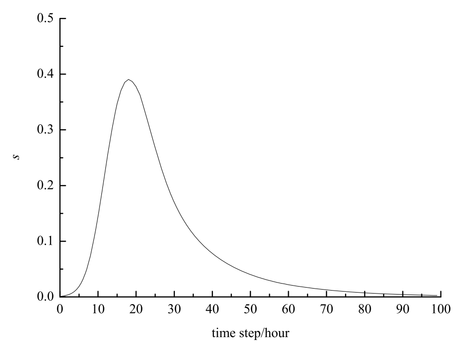



(f) $ri$

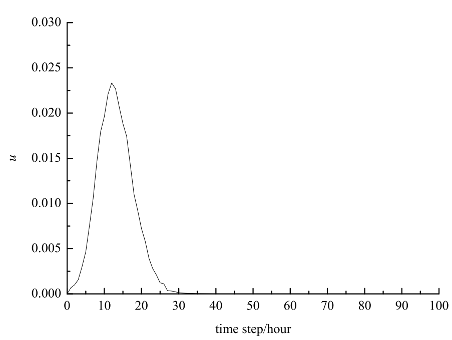
**Figure 4** General rumor propagation process on BA scale free network



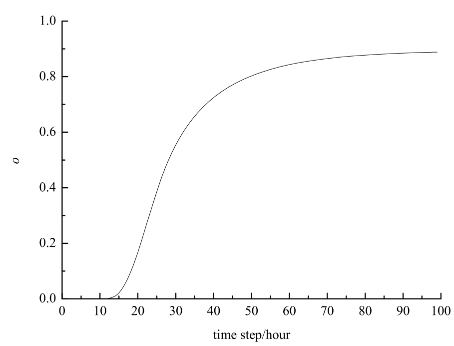

(a) $i$



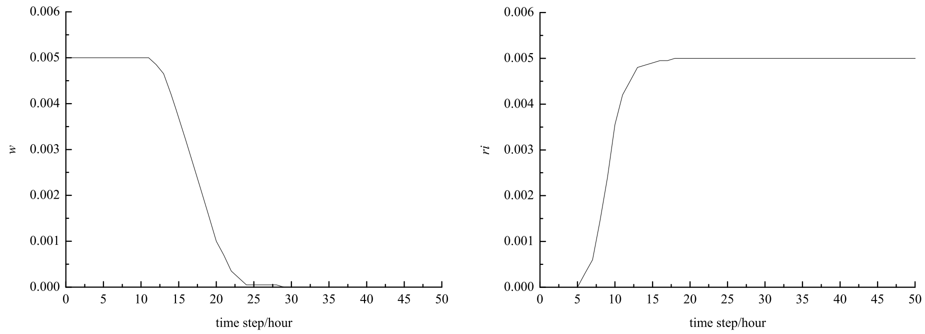

(b) $s$




(c) $u$




(d) $o$




(e) $w$ (f) $ri$

**Figure 5** General rumor propagation process on NW small world network

### 4.3 Influence of *INP*

*INP* is set as 0, 0.2, 0.6, 0.8 respectively and the other parameters are set as values in Subsection 4.2. The changing curves of $s$ are shown in Figure 6. The curves show that with the increase of *INP*, rumor spreading speed is reduced, rumor refutation information spreading speed is also reduced, and the time when $W$ sees the rumor tends to be later. Thus, the existence of *IN* can inhibit the diffusion process of both rumor and rumor refutation information. For rumors that can gain more widespread attention, which is always the case during emergency, active immune mechanism can be more effective in timeliness. Active immune mechanism is necessary and workable for conquering rumor propagation on online social network during emergency.

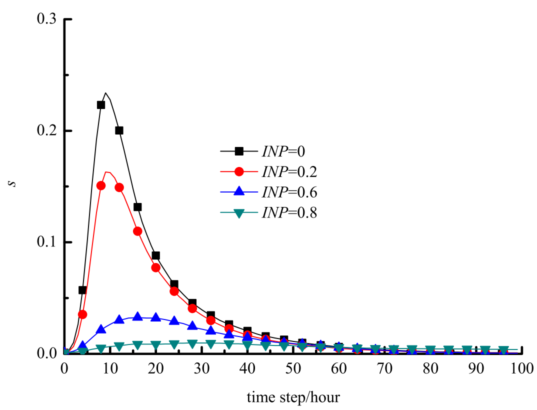



**Figure 6** Changing curves of $s$ with *INP* set as 0, 0.2, 0.6, 0.8

### 4.4 Effectiveness Analysis of Rumor Propagation Countermeasures

Rumor propagation countermeasures aim to reduce the peak value of $s$ that can represent the potential negative influence scope brought by rumor propagation. According to our rumor propagation model there are some possible ways to attain that goal. Firstly, improving the whole population's *SC*. Secondly, improving the official's *EMA*. Thirdly, increasing *MC*. Fourthly, increasing *SNN*. And lastly, improving $W$'s *RRA*. Improving $W$'s *RRA* is a critical measure for controlling rumor propagation. The first two measures are possibly effective in that they make an individual less panic when they see a rumor during emergency and the individual is less likely to spread the rumor immediately when it sees the rumor but will actively search for the rumor refutation information from its friends or the media. Increasing $MC$ can improve the possibility of an individual finding the rumor refutation information. The previous three measures can work only when there exists rumor refutation information. Increasing $NW$ can promote the rumor refutation process for $W$ is more likely to detect a rumor earlier. The effectiveness of the last two measures are tested here.

To test the effectiveness of the fourth measure, $SNN$ is set as 1, 2, 5, 10 and the other parameters are set as values in Subsection 4.2. The results are shown in Figure 7. To test the effectiveness of the fifth measure, $RRA$ is set as 0.1, 0.2, 0.5, 1 and the other parameters are set as values in Subsection 4.2. The results are shown in Figure 8. Both Figure 7 and Figure 8 show that by taking the measures the rumor refutation information is more likely to be posted earlier and the peak value of $s$ on the whole shows a decreasing trend. Generally, the countermeasures aim to make sure that the peak value of $s$ is kept under a safety point. Thus, $SNN$ can be set a proper value according to the simulation results to avoid wasting of resources. For example, when the safety point is set as 0.2, $SNN$ should be set as a value slightly larger than 5 according to Figure 7.

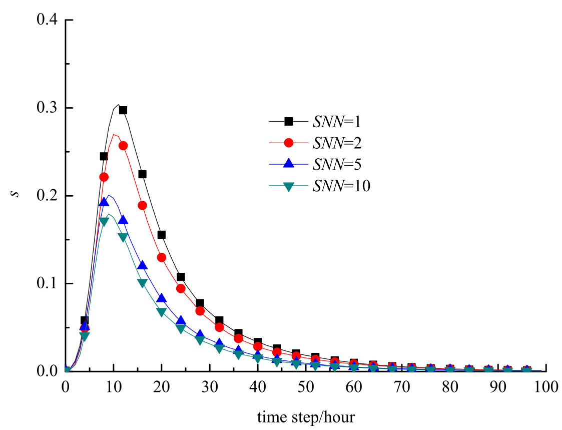



**Figure 7** Changing curves of $s$ with $SNN$ set as 1, 2, 5, 10

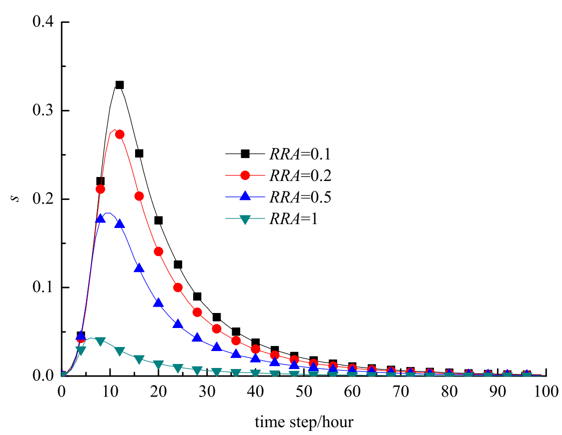



**Figure 8** Changing curves of $s$ with $RRA$ set as 0.1, 0.2, 0.5, 1

## 5 Conclusions

The established rumor propagation model in this paper is more in accordance with the actual situation of rumor propagation on social network during emergency and is more applicable to rumor management during emergency in that it incorporates the main influencing factors in rumor propagation and the possible countermeasures.

Agent-based simulation method provides convenience for considering the characteristics difference among individuals, many attributes of an individual and other factors. The simulation results suggest that network characteristics can influence the rumor propagation process and BA scale free network is more conductive to spreading rumors and also to spreading of rumor refutation information. Social network which mostly likely is BA scale free network should be made good use of in that it brings both challenges and chances. With more people paying attention to a rumor, the rumor tend to diffuse quicker and to more people and at the same time promote the rumor refutation process. To effectively conquer rumor propagation during emergency, active immune mechanism should be established. There are many effective rumor propagation countermeasures and the measures should be combined and optimized to achieve the best performance and avoid resources waste. This paper provides a useful tool for studying the rumor propagation laws and evaluating the official's rumor management ability.

The model is just a basic model and to perfect the simulation results much more work should be done mainly from the aspects of online social network structure and further analysis of the characteristics of rumor propagation parameters.

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