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ORIGINAL ARTICLE

A game theory-based network rumor spreading model: based on game experiments

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Abstract
This paper considers the relation between a rumor maker and many disseminators as a game and sets up Explosion-Trust (ET) Game Model. This model regards rumor explosion degree and trust degree of source node as influential factors of rumor making and spreading. The purpose of on both sides of a game is to obtain a maximum benefit. Based on ET model, we make experiments imitating the mode of information dissemination in social networks. We find rumor makers don't make rumors with quite a high explosion degree because others will doubt the truth of such rumor bringing a low transmission rate. This paper finds an optimal value for rumor spreading by experiments and on what condition trust degree will have an important impact on rumor spreading. Based on experiment results, the authors sum up the universal characteristics of rumors spread widely. Conclusions will be used to detect rumors.

Keywords Game theory · Rumor · Network rumor · Rumor spreading

1 Introduction

There are rumors since ancient times. But as People use such mobile applications as WeChat, Microblog and QQ space, anytime and anywhere, the spreading and influence of rumors have reached an unprecedented height. According to Tencent 2015 third quarter financial statement, as of September 30, the number of active users reached 650 million. Sina Microblog 2015 third quarter financial statement shows that there are 10 million active users every day. Surfing the Internet (including surfing the Internet through mobile terminal and PC terminal) is the main information source of Internet users in China. The range and speed of network information transmission are far more than traditional media information's. The complicated and convenient network environment provides a great space for the formation and spreading of rumors. The network rumors' influence is very large, especially for important events. It is difficult to estimate rumors' negative impact to public opinions and its damage to social trust system. As a result, more and more scholars commit to research the formation, spreading and control of network rumors. They try to identify and block rumors at the beginning of its formation or spreading.

Rumor is a kind of hearsay or public opinion which is lack of conclusive evidence, unproven, or is hard to distinguish between true and false [1]. Shenghong Jiang claims network rumor is a novel special form of rumor, and it is from and spreading on network [2]. Most researches on network rumors reference the Infectious Diseases Spread Model. SIR (Susceptible-Infective-Removal) Model [3] considers Internet rumors as infectious diseases, and the people are divided into three classes. The first is the susceptible. These people are easy to be infected, i.e., they believe in rumors easily. When people believe in rumors, they become the second class. The second is the infective and they have been infected, i.e., they believe rumors and they are capable of spreading rumors. The third kind is the removal, who don't believe rumors after clarifying events. Susceptible-infective-susceptible (SIS) Model [3] considers that the infective don't acquire immunity by clarifying rumors, i.e., the infective become susceptible again after clarifying rumors. It's much closer to the real situation of rumor spreading: nodes that believed and spread a rumor will become susceptible for other rumors after clarifying the last one. Based on SIR and SIS models, SIRS (Susceptible-Infective-Removal-Susceptible) Model [4] considers the removals become susceptible after a period of time, i.e., infected nodes obtain immunity

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after clarifying rumors, but these nodes become susceptible to other rumors after a period of time.

The Infectious Diseases Spread Model just makes a simple classification to nodes, and finds the probability of mutual transformation among different types according to the relations between nodes. Different infectious diseases have different transmission ability and different people have different resistance to different infectious disease, i.e., the nature of the disease itself can affect the spreading of the disease. The connection between nodes will influence the rumor spreading, too. But the Infectious Diseases Spread Model of rumors doesn't take these two factors into consideration. The network rumor spreading model based on game theory in this paper takes the nature of rumors and the strength of relation between nodes into account, and the authors find the nature of rumors which can spread most widely. This paper also confirms the effect of relationship among nodes on rumor spreading. These are useful and helpful for the research of rumor detection and blocking.

2 Related work

At present, most researches on network rumor spreading are based on the SIR model or molecular dynamics model and they simulate the information spreading in weighted connected graph.

Huo et al. [5] investigate a molecular dynamics model of rumor spreading with incubation based on infection model. They use the geometric approach for ordinary differential equations and find that when the number of rumor infective individuals approaches to zero, rumors still exist in the network. They also validate the research results numerically. Moreno et al. [6] investigate the mean-field equations characterizing the dynamics of a rumor process on top of complex heterogeneous networks. These equations can be solved numerically using a stochastic approach. Their conclusions are helpful to database maintenance, peer-to-peer communication networks and social spreading phenomena.

Han et al. [7] propose a novel rumor spreading model based on physical theory. The model divides rumor spreading into three evolutionary stages. They investigate why some rumor resurgence after weakening using a heat energy calculation formula and Metropolis rule and they find different people have different effects on rumor spreading. They confirm the influence of rumor's attraction, the initial rumormonger and the sending probability on the dynamics of rumor spreading.

Naimi and Naim [8] research reliability and efficiency of generalized rumor spreading model on complicated social networks. They define two parameters $\alpha(1)$ and $\alpha(2)$ for SS and SR respectively and research the effect of these two parameters on the final density of stiflers. They come to a conclusion that while networks with homogeneous connectivity pattern reach a higher reliability, scale-free topologies need less time to reach a steady state with respect the rumor.

Many scholars consider the relation net between users as fully connected graphs and research rumor spreading based on that. Giakkoupis and Wowlfel [9] investigate the randomness requirements of rumor spreading problem on fully connected graphs. They consider general rumor spreading protocols and put forward a push-protocol. They also investigate the theoretical minimal randomness requirements of efficient rumor spreading. Berenbrink et al. [10] consider rumor spreading as a kind of information spreading that follows the quasirandom phone call model on random graphs. Their experiments show that the communication complexity of the quasirandom phone call model is significantly smaller than that of the standard phone call model.

Sauerwald and Stauffer [11] focus on researching the relation between the vertex expansion of a graph and the randomized rumor spreading. They prove it takes less time for the randomized rumor to spread on any regular n-vertex graph with vertex expansion α. They also propose that it takes more time for rumors to spread on regular graphs with constant vertex expansion than on any regular graph with constant conductance. Isham et al. [12] investigate the stochastic spreading of epidemics and rumors on finite random networks. They consider the structure of the underlying network at the level of the degree–degree correlation function on networks with different random structures. They also simulate the full stochastic model to explore the effects on the final size distribution of network size and structure.

Benjamin et al. [13] make experimental analysis for rumor spreading in social networks. They confirm that a small amount of memory can reduce the run-time of the protocol even for small network sizes.

Zhao et al. [14]. modified a flow chart of the rumor spreading process with SIR model. It makes the rumor spreading process more realistic and apparent. They also analyze the impact of different parameters on the rumor spreading process. On the basis of prior studies, Zhao et al. develop a rumor spreading model called SIRaRu Model [15] by supplementing some realistic conditions on previous rumor spreading models. This model uses mean-field equations to describe the dynamics of the SIRaRu rumor spreading in complex networks and indicates the immunization threshold and spreading threshold of node contact strength existing in both homogeneous networks and inhomogeneous networks. They show the network topology exerts significant influence on the rumor spreading by numerical simulations conducted in complex networks.

Gu et al. [16] introduce the forget-remember mechanism into the information spreading process. They consider people also switch their state between active (with message) and inactive (without message). The probability of state switch has relationship with linear or exponential forget-remember functions. By simulations they reveal that the forget-remember mechanism has significant effects on information spreading.

Zhao et al. [17]. develop a rumor spreading model with variable forgetting rate on the basis of Gu's research. This model researches how the change of forgetting rate influences rumor spreading in small-world. They conclude the forgetting rate has a significant impact on the final size of rumor spreading: the final size of the rumor spreading is smaller when the initial forgetting rate is larger or the forgetting speed is faster according to numerical solutions. This model also shows the final size of rumor spreading is much larger under a variable forgetting rate compared to that under a constant forgetting rate. Zhao et al. [18]. further investigate rumor spreading model considering forgetting and remembering mechanisms in inhomogeneous networks. They conclude that the rumor spreads faster and the final size of the rumor is smaller in BA scale-free network compared with the ER network by numerical simulations. In the same way, they examine the effects of the spreading rate and the stifling rate on the rumor by numerical simulations.

Zhang and Xu [19] proposed a rumor spreading model which examines how memory effects rate changes over time in artificial networks and real social networks. Their model emphasizes a special rumor spreading characteristic called "the cumulative effects of memory". The model establishes cumulative memory effects function. Model simulations show that all the parameters but the initial memory rate of memory effects function has a significant impact on rumor spreading. They conclude that the peak value and final size of the rumor spreading are much larger under a variable memory effects rate than under a constant rate.

Zhao et al. [20] develop dynamical behaviors model of rumor spreading with control measures. The dynamical system they established includes the following four classes: the susceptible individual, the spreader, the stifler, and the messages in media. The model considers the government behavior and the ability of cognizance of the public. According to the analysis of several parameters, they conclude the number of messages released by the authority have the greatest influence on rumor spreading. The effect of controlling rumors is obvious when the government punishes the minority of rumor makers and disseminators. Monitoring the Internet to prevent the discussion of rumors is more important than deleting messages in media that has appeared.

3 The proposed model

Based on current research, in the fabrication and spreading of network rumors, we consider there are two roles: rumors makers and disseminators. In order to achieve some certain purposes, makers make rumors and release them [21]. Rumors are usually related to current hot events, or are designed for certain people (such as college students, investors, etc.). This paper defines explosion degree as the explosive sensation level of information. The strength of the relationship between nodes determines the trust level basically and can be represented by trust degree. Based on graph theory, an Internet user is regarded as a node. We consider a neighboring node as a next node. The members of a social network form a well-connected network. There are different connectivity between nodes. Any node who can contact the maker or other disseminators is likely to become a new disseminator of rumors. These nodes will evaluate the explosion degree of the information and the trust degree of the information source node after reading the information that they don't know it's true or false. Then they decide whether to forward or comment. Rumor makers will fully consider minds of disseminators when they fabricate rumors. Therefore, lots of rumors are about hot events, and then rumor makers make a certain extent exaggeration and distortion about the event.

Fundamentally speaking, whether makers to fabricate rumors or disseminators to spread rumors, they want to obtain some benefits, such as psychological benefits, i.e., emotional benefits, and money income. For example, in 2010, Wuben Zhang put forward that green beans could cure any diseases in a TV program. He publicized you can recovery without doctors if you eat one pound of green beans every day when you are sick. The rumor green beans can cure any diseases spread explosively in life since then. Whether in network or in traditional media, its wide spreading and huge influence is very rare. In this rumor event, the rumor maker Wuben Zhang received unprecedented attention and reputation. His psychological benefit is the largest in the rumor spreading. Because of the increasing of reputation, he received a huge money income, too. Numerous rumors disseminators, especially the green beans sellers, gained large money income as the rising bean prices in the rumor spreading. General viewers, as buyer of green beans, their psychological benefits are the sense of accomplishment that they obtained important information preferentially and they succeed to rush to buy green beans. Before fabricating and spreading rumors, makers and disseminators will estimate their possible earnings. People are more possible to fabricate and spread rumors when it is more possible to get earnings. Therefore, this paper will consider various factors and quantify the earnings of rumor makers and disseminators. We not only give the revenue function of makers and disseminators, but also establish Network Rumors Spread Model Based on game theory.

For makers, their psychological benefits are mainly from the accomplishment sense of the discovery of hot events and making rumors and the benefits can be measured by social influence caused by rumors. Social influence can be measured by the amount of reading (r), forwarding (f) and comments (c). Money income (e) can be measured by direct economic income (μ) and indirect economic income (ξ), i.e.,

$$e = \mu + \xi \tag{1}$$

For disseminators, its psychological benefits are mainly from a sense of priority to discover and spread hotspot preferentially, and it is inversely proportional to time. Their psychological benefits are also from the amount of reading, forwarding and comments. Their money income can also be measured by direct economic income and indirect economic income. In the short term, we cannot confirm the truth of rumors, and so there are only benefits but not negative effects for makers and disseminators. In the long run, the credit of makers and disseminators will be affected after clarifications, which is a negative income for them. These negative returns are positively correlated with the amount of reading, forwarding and comments. We use -α and -β to represent negative returns in revenue functions.

Thus, authors define revenue functions of makers and disseminators as follows:

$$\pi_m = (1 - a)s,\ s = r + f + c + e\Box\Box \tag{2}$$

$$\pi_d = (1 - \beta)s,\ s = r + f + c + e\Box\Box \tag{3}$$

r, f, c are functions about trust and explosion degree. We claim the neighboring nodes of nodes which spread rumors will read the rumor. Comment rate (ε) is the ratio of the number of comments and the total number of nodes, and forwarding rate (γ) is the ratio of the number of forwarding and the total number of nodes. Comment rate and forwarding rate are called by a joint name: transmission rate (θ). Considering the influence of comment and forwarding on rumor spreading is different, we definite transmission rate $\theta = t \times \varepsilon + (1 - t) \times \gamma$.

This paper proposes it is easier to take a large-scale spreading of information and get more attention with a higher explosion degree. When nodes read information they are interested in, they will evaluate the explosion degree and consider it with other factors to decide whether to spread the information. This decision is related with the extent of exaggerating. So there is a game between the makers and disseminators. When makers fabricate a rumor, they don't exaggerate it unlimitedly. If information is too fake for the next nodes, they will judge it untrue directly and not spread it and makers will not have any income. At the same time, makers do not release real or familiar information, because next nodes do not consider the information is explosive and will not concern or spread it. Therefore, when makers fabricate a rumor, the explosion degree is within a certain range. There is a game balance which can bring the most widely rumor spreading and the maximum benefits of both sides.

In a social network, all nodes constitute a complicated relation network and nodes are inextricably linked. Nodes make credit assessment according to familiarity, understanding to a node and the authenticity of previous information. If the trust level of source node is 0, next nodes will not forward or make comment. The authors claim the probability of spreading rumors is higher when the trust degree of source nodes is higher, but there is not a strictly positive proportionality between the two factors. It is because the probability of spreading a rumor depends on its own explosion degree and the trust degree of source nodes. For example, when a piece of information is obviously false, i.e., the explosion degree is very high, other nodes will not spread it even though they trust the source node fairly.

3.1 The basic model

Based on the current social network environment and user habits, we make two hypotheses:

1. All nodes associated with disseminators will read the rumor;
2. Nodes spread rumors by comment and forwarding and they will not reprocess the information before releasing it.

We regarded rumor spreading as multiple games on the Internet, i.e., there is a game between rumor makers and any node who read the information. Information receiving nodes decide whether to spread rumors which determines the benefits for both sides. The beginning of a game is to make rumors. When makers set up a rumor explosion degree, the set value basically determines whether the rumor will be spread widely by other nodes who can read the information. Firstly, we research the games in a short term. We do not consider the negative earnings to neither participants of the game after a rumor clarified.

Definition definite quintuple $<N,S,U,P,E>$ as mixed strategy game model of network rumor spreading.

1. $N = \{Agent_1, Agent_2\}$ is the participant set. There are two participants, $Agent_1$ is rumor maker, $Agent_2$ is information receiving node. $Agent_1$ sets up explosion degree and fabricates a rumor; $Agent_2$ receives information and decide whether to spread information.
2. $S = \{S_1, S_2\}$, S_i is policy space of $Agent_i$, $i = 1, 2$. We suppose that any agent has two alternative strategies, i.e., $S_1 = \{S_{11}, S_{12}\}$, represents low explosion degree and high explosion degree respectively; $S_2 = \{S_{21}, S_{22}\}$, represents to spread and not to spread rumors respectively.
3. $U = \{U_1, U_2\}$, U_1 is the revenue function of $Agent_1$, and U_2 is the revenue function of $Agent_2$. Table 1 is the revenue function list of $Agent_i$.

Table 1 The revenue function of $Agent_i$ ($b>a>0, d>c>0$)

$Agent_1$	$Agent_2$
$U_1(s_{11}, s_{21})=a$	$U_2(s_{11}, s_{21})=c$
$U_1(s_{11}, s_{22})=0$	$U_2(s_{11}, s_{22})=0$
$U_1(s_{12}, s_{21})=b$	$U_2(s_{12}, s_{21})=d$
$U_1(s_{12}, s_{22})=0$	$U_2(s_{11}, s_{22})=0$

Table 2 Revenue Statistics of $Agent_i$

Agent2	Agent1	
	s_{11}	s_{12}
s_{21}	$(aq, d+p\,(c-d))$	$(bq, d+p\,(c-d))$
s_{22}	$(aq, 0)$	$(bq, 0)$

4. $P=\{P_1, P_2\}$, $P_1=\{p, 1-p\}$ is the mixed strategy probability set of $Agent_1$; p represents the probability of releasing low explosion degree rumors and 1-p represents the probability of releasing high explosion degree rumors. $P_2=\{q, 1-q\}$ is the mixed strategy probability set of $Agent_2$; q represents the probability of spreading rumors and 1-q represents the probability of not spreading rumors (Tables 2, 3, 4, 5, 6).
5. $E=\{E_1, E_2\}$, E_i is the expected revenue function of $Agent_i$, wherein:

$$E_1(s_{11}) = q \cdot U_1(s_{11}, s_{21}) + (1-q) \cdot U_1(s_{11}, s_{22}) = aq. \square\square \tag{4}$$

$$E_1(s_{12}) = q \cdot U_1(s_{12}, s_{21}) + (1-q) \cdot U_1(s_{12}, s_{22}) = bq \square\square\square\square \tag{5}$$

Table 3 Average value of set-value and estimate of explosion degree, comment and forwarding rate

Rumor no.	1	2	3	4	5	6	7	8	9	10
m	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
n	0.08	0.16	0.24	0.36	0.42	0.52	0.60	0.73	0.86	0.92
ε	0.03	0.06	0.10	0.12	0.27	0.46	0.66	0.72	0.63	0.50
γ	0.02	0.02	0.09	0.10	0.30	0.47	0.60	0.68	0.56	0.51

Table 4 Variance of estimate of explosion degree, comment and forwarding rate

Rumor no.	1	2	3	4	5	6	7	8	9	10
m	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
$n(10^{-4})$	9.9	21.2	45.6	62.1	60.3	73.4	61.7	74.6	90.5	113.5
$\varepsilon\ (10^{-5})$	0.3	2.9	4.8	17.3	31.2	34.7	36.2	33.3	30.5	36.4
$\gamma\ (10^{-5})$	1.2	0.8	4.7	12.3	21.9	37.0	30.4	35.1	36.3	30.7

Table 5 Variance of transmission rate with different explosion and trust degree

$\theta\ (\times 10^{-5})$	n									
k	0.08	0.16	0.24	0.35	0.43	0.52	0.61	0.76	0.87	0.93
0.4	0.3	0.3	0.45	2.6	10.7	17.7	15.6	10.4	6.4	3.2
0.5	0.3	0.4	1.3	4.7	4.8	15.1	26.9	18.4	10.2	8.7
0.6	0.3	0.3	0.9	2.6	9.9	20.4	30.8	19.6	9.2	10.6
0.7	0.2	0.3	3.4	9.5	19.3	35.6	40.2	22.3	24.8	21.2
0.8	0.3	0.5	2.9	6.5	18.0	26.4	17.9	9.0	13.7	24.6
0.9	0.2	0.3	1.7	6.3	12.6	18.6	12.3	4.9	8.7	19.7

Table 6 Transmission rate with different explosion and trust degree

θ	n									
k	0.08	0.16	0.24	0.35	0.43	0.52	0.61	0.76	0.87	0.93
0.4	0.01	0.01	0.04	0.08	0.20	0.36	0.36	0.42	0.18	0.13
0.5	0.01	0.02	0.06	0.08	0.24	0.35	0.40	0.50	0.20	0.15
0.6	0.02	0.04	0.06	0.11	0.26	0.40	0.42	0.57	0.32	0.25
0.7	0.02	0.04	0.09	0.14	0.25	0.42	0.46	0.64	0.44	0.42
0.8	0.03	0.03	0.09	0.14	0.26	0.46	0.53	0.69	0.65	0.62
0.9	0.02	0.03	0.11	0.16	0.25	0.46	0.61	0.74	0.75	0.72

$$E_2(s_{21}) = p \cdot U_2(s_{11}, s_{21}) + (1-p) \cdot U_2(s_{12}, s_{21}) = d + p(c-d) \tag{6}$$

$$E_2(s_{22}) = p \cdot U_2(s_{11}, s_{22}) + (1-p) \cdot U_2(s_{12}, s_{22}) = 0 \tag{7}$$

3.2 Model analysis

The expected revenue of participants is related to the probability of mixed strategy that another participant takes. The expected revenue of $Agent_1$ depends on the strategic choice of $Agent_2$ ($Agent_2$ trusts $Agent_1$ and spreads information with probability q. He does not trusts $Agent_1$ and not spreads information with probability 1-q). The expected revenue of the disseminator $Agent_2$ depends on the strategic choice of $Agent_1$ ($Agent_1$ releases low explosive information with probability p and releases high explosive information with probability 1-p).

For $Agent_1$, his income of releasing high explosive information is more than his income of releasing low explosive information, i.e., $E_1(s_{11}) > E_1(s_{12})$. For $Agent_2$, his income of spreading information is more than not spreading it, i.e., $E_2(s_{21}) > E_2(s_{22})$. Therefore, The Nash equilibrium of this game between agents is $Agent_1$ releases high explosive information and $Agent_2$ spreads it.

In the model, we make a hypothesis that there are high and low levels for the information explosion simply and come to a conclusion that when rumor makers set a high explosion degree, it's easier to spread a rumor and get higher earnings. But, as what we have already analyzed before, a higher explosion is not better for spreading of rumors. In a lower range, the increasing of explosion will bring a wider spreading, but when the explosion is too high, it will lead to nodes doubt the authenticity of the rumor. Therefore, we believe that there is an optimal value of explosion degree for rumor spreading.

In a social network, there are many other contacts in addition to releasing and reading information among nodes, because there are complex relationships between each node in real life or in the network. The level of trust between nodes will influence rumor spreading. A node will make a judgment for the authenticity of the source node in order to judge the truth of the information especially when rumor explosion is very high. We find the threshold by designing experiments here, i.e., what explosion degree is, the trust level will become a key factor in rumor spreading.

4 Experimental design

In order to get the threshold and the optimal value of explosion degree and trust degree in rumor spreading, the authors carried out the following experiments.

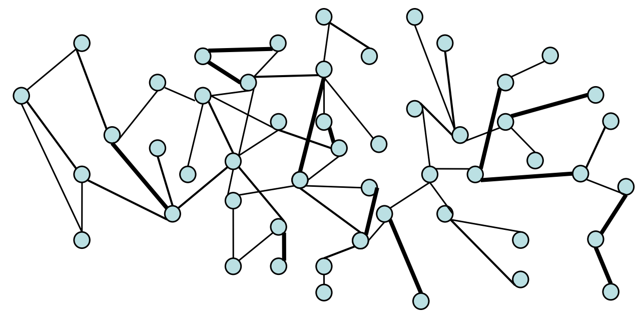

Fig. 1 Partial Nodes Network Diagram

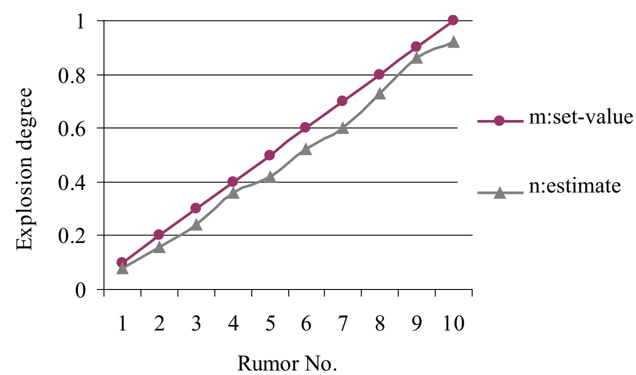

Fig. 2 Average Statistics of Set-value and Estimate of Explosion Degree

There are 272 participants in experiments. In order to simulate a social network environment, we selected 20 persons from 5 universities including teachers and students and invited them to participate the experiment. Then they were asked to invite their friends, neighbors, colleagues and families to participate our experiments. The invited persons can further invite others, and so on. Finally, in total 272 participants build up our experimental social network. They connect to each other by such relations as being classmates, colleagues, friends, forming of families etc.. There is no isolated node. Such interpersonal network environment and social network environment have a lot in common.

There are partial nodes of our experiments in Figs. 1, 2. Every node is a member of experimental social network. Edges between nodes represent the relation between nodes. There are 3 kinds of edges which represent different relation between nodes respectively. A thicker edge represents a stronger closer relation. Every node links to several other nodes, i.e., they can receive information from different node.

The authors write a simple social application resembling Sina Microblog. Each participant registered an account, and they are regarded as a node in the network. Then nodes establish friendship with others as the relations in Sina Microblog. Thus, everyone has direct or indirect contact with others. 272 individuals constitute a complicated topology with no isolated nodes. These nodes can release information like using any other social application, and the information will be seen by the next nodes, and the next nodes can comment or forward to spread information.

To study the impact of the makers' explosion set degree and the trust degree to source nodes on network rumor spreading, the authors conducted the following experiments. Authors pre-selected 20 hot topics as sources of rumor fabrication. Participants are only been told to operate on the messages they can see in the social network as we asked: first, evaluate the information explosion degree $n\in[0, 1]$ and the trust degree $k\in[0, 1]$ of sources nodes. Then, nodes decide whether to forward or comment according to comprehensive evaluations and fill the results in the specified table. To avoid the participants consider there must be some rumors in their social network and affect their normal judgment, they do not know it's an experiment about rumor spreading research.

In each experiment, the system selects a participant as rumor maker randomly, and the participant is asked to select one as the basis of writing a rumor in 20 hot topics. Given 10 rumor explosive degree: $m=0.1, 0.2, \ldots, 1$(explosion set value), the participant selects an explosion degree which has not been selected before to write a rumor, and releases the rumor to experimental platform. Meanwhile, other participants do not know that someone is selected as a rumor maker to release rumors, and also do not know which information is released in the experiment among a number of information they can see on the experiment platform. So participants need to evaluate all information they can see in a short time and fill in the forms.

Experimental procedures are as follows:

1. The system selects one of participants as a rumor maker randomly.
2. The rumor maker selects a hot topic and an explosion degree, and then fabricates a rumor according to these.
3. Rumor maker releases a rumor.
4. Next nodes observe the information and evaluate the explosion degree of it and the trust degree of source node. Then they fill the results in tables.
5. Nodes decide whether to forward or comment according to these two evaluations and fill in the specified table.

To get universal results, the authors carried out five sets of such experiments i.e., there are five experiments on each explosion degree. According to the above steps, each round follows the experiment principles.

At the end of experiments, participants were required to complete a post experiment questionnaire for rumor makers and disseminators respectively. Questions were designed to verify their understanding of the experiment and to obtain insights about their decisions.

5 Results

For each rumor, we have got all assessments from nodes who contact the rumor, including explosion degree of the information and trust degree of source nodes. The authors also get final results: whether to spread rumor. We take the average of every assessment of each rumor and results are as follows:

Through the analysis of Fig. 2, we find that explosion degree that nodes contacted the rumor evaluated is generally lower than explosion degree set by rumor makers. It reflects that makers fabricate rumors in a certain degree of conservatism. We find evidence for this argument in the participants' responses to the post experiment questionnaire. Majority of participants agree that they write rumors carefully after choosing an explosion degree because they know other nodes will decide whether to spread the information based on explosion degree. Therefore they will be cautious relatively when fabricating rumors after setting rumor explosion degree.

When $0.4<m<0.8$, i.e., the falsehood of a rumor i.e., explosion degree is within a relatively moderate range and others tend to believe in this information, rumor makers consider it is easier to spread rumors, so they fabricate rumors more carefully to let more people believe it, which makes there is a relatively large gap between m and n.

Through the analysis of Figs. 3, 4, we find that comment and forwarding rates are not always positively related to the explosion degree. In experiments, the peak transmission rates appears when $n=0.76$. The mean value of optimal explosion degree that the rumor makers given in post experiment questionnaire is 0.73, which is consistent with the experimental results. The range of estimates of explosion in experiments is [0.70, 0.79]. Thus, we conclude that the optimal value of n for rumor spreading is $0.745\pm0.5(0.745=(0.76+0.73)/2)$.

The conclusion is consistent with the *ET* Game Model, i.e., when explosion degree is low, the transmission rate is

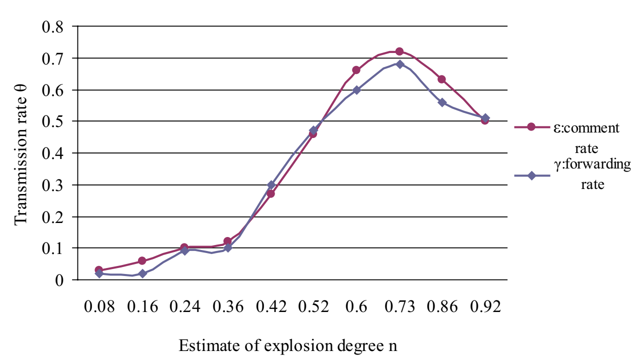

Fig. 3 Average value of comment and forwarding rate

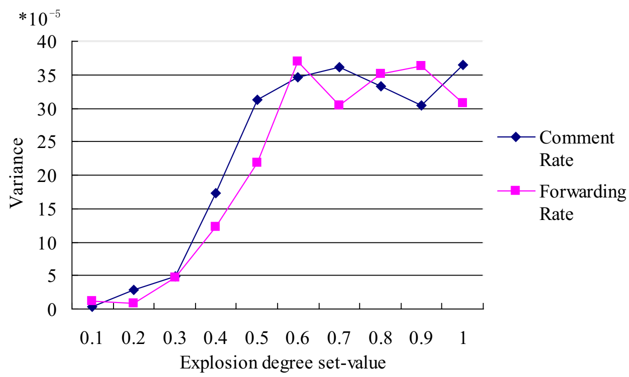

Fig. 4 Variance of comment and forwarding rates

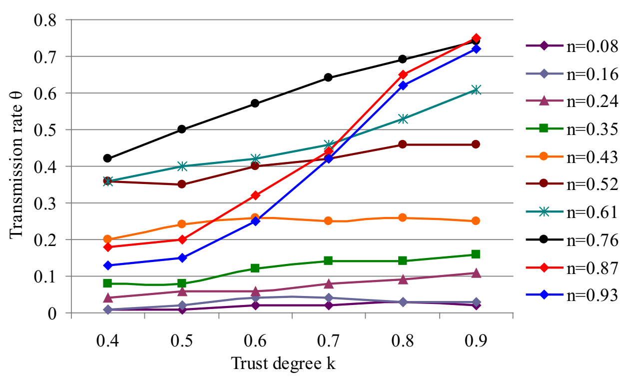

Fig. 5 The statistics of transmission rate under different explosion and trust degree

low too, thus, the income of $Agent_1$ is low. When explosion degree is high, transmission rate is higher, which makes the income of both sides higher. This is the Nash equilibrium of the game.

We found that the variance values of comment and forwarding rates increase with the increasing of explosion. Comment and forwarding rates of different rumors with the same explosion degree become more and more unstable. We calculate confidence limits using the variances, and confidence limits of $n = 0.745 \pm 0.5$ is 0.85.

Through the analysis of Fig. 5 we find that when $n < 0.7$, transmission rate is proportional to the trust degree basically. But when explosion degree is high($n > 0.7$), rumor makers can get a high transmission rate relatively at a high trust degree($k > 0.7$). When n is high, θ is still proportional to n with a high trust degree.

When explosion degree is high($n >= 0.7$), nodes with close relationship become key nodes for rumor spreading. Thus, these nodes are key to block rumor spreading.

6 Conclusion

The *ET* model accurately describes the relationship between rumor makers and disseminators: game relationship. This model considers explosion of rumors as strategic choice of $Agent_1$, and his strategic space is a continuous variable. We get a clear conclusion through analysis and experiments based on *ET* model: rumor spreading, i.e., forwarding and comment rates are functions related rumor explosion degree. There is an optimal value of explosion for rumor spreading. When explosion is high, the impact of trust degree on rumor spreading is bigger. In the actual rumor spreading, the assessed value of rumor explosion from disseminators is usually lower than the set value from makers. The optimal value is 0.745 ± 0.5 for rumor spreading and the confidence limits is 0.85.

Conclusion through experiments and analysis in this paper is very similar to rumor spreading in a social network. In actual network rumor spreading, games between rumor makers and disseminators also follow the above rules. We can identify whether information is a rumor by assessing its explosion degree for widespread information because most network rumors' explosion degree is 0.745 ± 0.5. When explosion is high, trust degree is a main factor that influence rumor spreading. In this case, a node will spread piece of information from a node he trusts very much. Thus, we can infer information propagation path according to explosion degree and relation strength between nodes, thereby, we are able to block rumors after identifying rumors timely.

There are still some shortcomings in our research. The number of experimental participates and samples are relatively small. We intend to do larger scale experiments to obtain more accurate results. We will collect rumors, evaluate their explosion degree and design an appropriate method to measure trust degree between nodes to verify the experimental results. We will try to estimate the soundness of the proposed model. We are going to do research on rumor detection and consider results in this paper as a basis.

References

1. Peterson WA, Gist NP (1951) Rumor and public opinion. Am J Sociol 57(2):160–163
2. Jiang S (2012) Formation, transmission and public opinion guiding mechanism of network rumors. Chongqing Soc Sci 6:19–20
3. Fengming Liu L, Wang H, Johnson H, Zhao (2015) Analysis of network trust dynamics based on evolutionary game, Scientia Iranica. Trans E. Indus Eng 22(6):2548–2557
4. Huo L (2012) False information spreading research after emergencies. Shanghai Jiaotong University, Shanghai
5. Huo L, Huang P, Guo CX (2012) Analyzing the dynamics of a rumor transmission model with incubation. Discr Dyn Nat Soc 2012:21 (**Article ID 328151**)

6. Moreno Y, Nekovee M, Pacheco AF (2004) Dynamics of rumor spreading in complex networks. Phys Rev E 69(6):066130
7. Han S, Zhuang FZ, He Q, Shi Z, Ao X (2014) Energy model for rumor propagation on social networks. Physica A Stat Mech Appl 394(2):99–109
8. Naimi Y, Naimi M (2013) Reliability and efficiency of generalized rumor spreading model on complex social networks. Commun Theor Phys 07:139–144
9. Giakkoupis G, Wowlfel P (2011) On the randomness requirements of rumor spreading. Proceedings of the 22nd annual ACM-SIAM symposium on discrete algorithms. Society for Industrial and Applied Mathematics, Philadelphia, pp 449–461
10. Berenbrink P, Elsässer R, Sauerwald T (2010) Communication complexity of quasirandom rumor spreading. Algorithms—ESA 2010, Berlin, Germany, pp 134–145
11. Sauerwald T, Stauery A et al (2011) Rumor spreading and vertex expansion on regular graphs. Proceedings of the 22nd ACM-SIAM Symposium. Francisco, Calif, USA, pp 462–475
12. Isham V, Harden S, Nekovee M (2010) Stochastic epidemics and rumors on finite random networks. Phys A 389(3):561–576
13. Benjamin D, Mahmoud F, Tobias F (2012) Experimental analysis of rumor spreading in social networks. Design and analysis of algorithms, vol 7659 of Lecture Notes in Computer Science, Berlin, Germsny, pp 159–173
14. Zhao LJ, Cui HX, Qiu XY, Wang X, Wang J (2013) SIR rumor spreading model in the new media age. Phys A 392(4):995–1003
15. Zhao L, Wang J, Huang R (2014) SIRaRu rumor spreading model in complex networks. Phys A 398:43–55
16. Gu J, Li W, Cai X (2008) The effect of the forget-remember mechanism on spreading. Eur Phys J B 62(2):247–255
17. Zhao L, Xie W, Oliver Gao H, Qiu X, Wang X, Zhang S (2013) A rumor spreading model with variable forgetting rate. Physica A: Stat Mech Appl 392:6146–6154
18. Zhao LJ, Qiu XY, Wang XL, Wang J (2013) Rumor spreading model considering forgetting and remembering mechanisms in inhomogeneous networks. Phys A 392(4):987–994
19. Zhang Y, Xu J, Vecchio A (2015). A rumor spreading model considering the cumulative effects of memory. Discr Dyn Nat Soc 2015:11
20. Zhao XX, Wang JZ, Yuan S (2014) Dynamical behaviors of rumor spreading model with control measure. Abstr Appl Anal 2014:11
21. Zhu X, Liu F (2017) Research on behavior model of rumor maker based on system dynamics. Complexity 2017:9. https://doi.org/10.1155/2017/5094218 (**Article ID 5094218**)