Physica A 390 (2011) 2619–2625

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Rumor spreading model with consideration of forgetting mechanism: A case of online blogging LiveJournal

Laijun Zhao, Qin Wang *, Jingjing Cheng, Yucheng Chen, Jiajia Wang, Wei Huang

Management School, Shanghai University, Shanghai 200444, PR China

ARTICLE INFO

Article history:
Received 12 October 2010
Received in revised form 18 January 2011
Available online 21 March 2011

Keywords:
SIR model
Rumor spreading
Forgetting mechanism
Runge–Kutta method

ABSTRACT

Rumor is an important form of social interaction, and its spreading has a significant impact on people's lives. In the age of Web, people are using electronic media more frequently than ever before, and blog has become one of the main online social interactions. Therefore, it is essential to learn the evolution mechanism of rumor spreading on homogeneous network in consideration of the forgetting mechanism of spreaders. Here we study a rumor spreading model on an online social blogging platform called LiveJournal. In comparison with the Susceptible–Infected–Removed (SIR) model, we provide a more detailed and realistic description of rumor spreading process with combination of forgetting mechanism and the SIR model of epidemics. A mathematical model has been presented and numerical solutions of the model were used to analyze the impact factors of rumor spreading, such as the average degree, forgetting rate and stifling rate. Our results show that there exist a threshold of the average degree of LiveJournal and above which the influence of rumor reaches saturation. Forgetting mechanism and stifling rate exert great influence on rumor spreading on online social network. The analysis results can guide people's behaviors in view of the theoretical and practical aspects.

1. Introduction

Rumor is usually defined as the unconfirmed elaboration or annotation of the public interesting things, events or issues that spread through various channels, in itself neither true nor false [1–4]. Over these years, online social networks, such as Facebook, LiveJournal, Orkut, Twitter, YouTube, Hi5, Flickr and other social networks are becoming more and more popular. Rumor spreading on such social networks often results in wide spread of information or misinformation through actions of individual agents. On the positive side, we can utilize the fast and efficient "epidemic" characteristic of rumor spreading to warn the public and let them take pertinent precaution measures [5–7]. Unfortunately most rumors induce panic psychology or economic loss in the accompanying unexpected events [8,9].

Rumor models can be used to elaborate many phenomena, including the dissemination of information, viral marketing, panics caused by epidemics or emergencies [1,2,7,10–13]. Daley and Kendall [14] first studied the phenomenon of rumor spreading and proposed the basic DK model of rumor spreading. Maki and Thomson [15], Murray [16] mainly focused on the analysis of the rumor spreading model based on mathematical theory. Newman, Ebel, Wang et al. and Csanyi et al., and Smith et al. believed that the DK and MK models contribute significantly to describing rumors spreading on small-scale social networks [17–21], but major shortcomings of these models were that they either neglected the topological characteristics of social networks or some of these models were not suitable for large-scale spreading process. Sudbury [22] studied dynamic mechanisms of information transmission on social networks and insisted that the dynamic behavior of

* Corresponding author. Tel.: +86 13816833416; fax: +86 021 66134284.
E-mail address: wangqin3700@163.com (Q. Wang).

0378-4371/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.physa.2011.03.010

rumor spreading matched SIR model. As for applications, Zanette [23,24] and Buzna et al. [25] established rumor spreading model on the small-world networks, and found the existence of rumor spreading critical value. Moreno [26] studied the stochastic MK model on scale-free networks and insisted that the uniformity of networks had a significant impact on the dynamic mechanism of rumor spreading. Isham [27] studied the final size distribution of rumors on general networks. Extensive studies [28–32] on rumor spreading had carried out on social networks or bulletin board systems. Sathe [33] applied SIR model on LiveJournal and studied the behavior of rumor spreading process. A flaw in Sathe's study was that the influence of forgetting mechanism upon rumor spreading was neglected. Gu and Cai [34] and Gu et al. [35] introduced the forget and remember functions with linear and exponential forms into a 2-state model called SI model to study the percentage of active individuals on BA scale-free network whose degree fits the power law distribution. They pointed out that the mechanism had significant impact on message spreading of social networks since rapid pace of life and scarce attention make netizens neglect rumors easily. Gu et al. [35] reached the following conclusions: (1) the forget–remember mechanism could result in a termination of dissemination; (2) the probability of state switch between active and inactive mainly depends on the competition between the forget and remember mechanism.

In this paper we present a mathematical model and its applications of rumor spreading on LiveJournal. We consider a constant forgetting rate into a 3-state model called SIR model to study the impact of the forgetting rate, spreading rate, stifling rate and average degree on rumor spreading. The rest of this paper is organized as follows. In Section 2, we describe the rumor spreading model with forgetting mechanism. In Section 3, we present analytical results followed by a discussion of how model results applied to the details of rumor spreading on LiveJoural. Finally, conclusions are drawn in Section 4.

2. A model with forgetting mechanism

Nekovee [27] has considered that forgetfulness is an indispensable ingredient to the existence of a finite threshold. Rumor spreading is significantly different from epidemic spreading as spreaders may forget or disincline to spread the rumor. Obviously, when a spreader contacts another spreader or a stifler, forgetting and stifling mechanism mutually result in the cessation of rumor spreading. The tendency of individuals to accept a rumor with a certain probability depends on the importance and credibility of the rumor; on the other hand, individuals no longer spread a rumor when they know that the rumor is dated or wrong. However, when a rumor starts to propagate on networks, stifling is not the only way to stop it, thus we should consider the factor of forgetting mechanism, especially when the forgetting rate δ is large enough. We include this mechanism in SIR model by assuming that spreaders may stop spreading a rumor spontaneously at a rate δ. The spreading process starts with one individual becoming informed of a rumor and terminates when no spreaders are left in the population.

As rumor spreading shows great resemblance to that of epidemics, we borrow epidemic model to study rumor spreading on social networks. We consider a closed and homogeneously mixed population consisting of N individuals, who meet one another with homogeneous mixing. In the model, the population is subdivided into three groups: ignorants, spreaders and stiflers. Ignorants are those individuals who have not heard the rumor and hence they are susceptible to believe the rumor (i.e. become a spreader) with a certain probability. Spreaders comprise individuals that spreading the rumor actively. Finally, stiflers are those individuals who refuse to spread the rumor because they are immune to rumor spreading and perceive that the rumor is already well known by most people on the network. Even if people contact with them, the rumor will not spread on networks. When a spreader contacts with another spreader, only the initiating spreader becomes a stifler.

Similar to the characteristics of epidemic spreading, rumor spreading progress can be simply summarized as follows: only a small number of spreaders at the initial stage, the others are ignorants, and the number of stiflers are zero. As spreaders began to propagate a rumor, the number of ignorants is quickly reduced, and there is a sharp increase in the number of spreaders. With further spreading of rumor, the number of stiflers begins to increase, while the number of spreaders reaches a peak and thereafter declines. Finally, the number of spreaders is zero and this leads to a termination of rumor spreading, and the network has only stiflers and a small number of ignorants left in the end.

The contacts between spreaders and the rest fractions are governed by the following series of rules: whenever a spreader contacts an ignorant, the ignorant becomes a spreader at a rate λ. When a spreader contacts another spreader or a stifler, the initiating spreader becomes a stifler at a rate α. Considering different types of personality, cognitive style, knowledge background and experience of the spreaders, we take forgetting mechanism into account by assuming that spreaders may also cease spreading a rumor spontaneously at a rate δ. Therefore, there is $1-\alpha-\delta$ possibility that the initiating spreader remains to be a spreader after one round of contact. This kind of rumor spreading process is shown in Fig. 1.

As can be seen from Fig. 1, the spreaders remain to be spreaders at rate $1-\alpha-\delta$, thus $1-\alpha-\delta \geq 0$, that is

$$\alpha + \delta \leq 1. \tag{1}$$

Previous studies in the field of rumor spreading neglect this constraint. The constraint makes the model of rumor spreading more fitting to the actual situation. In the following numerical analysis, we consider this inequality as an important constraint for parameters.

On LiveJournal, the density of ignorants, spreaders and stiflers can be described in terms of $I(t)$, $S(t)$ and $R(t)$ respectively, as a function of time. Besides, we have the normalization condition

$$I(t) + S(t) + R(t) = 1. \tag{2}$$

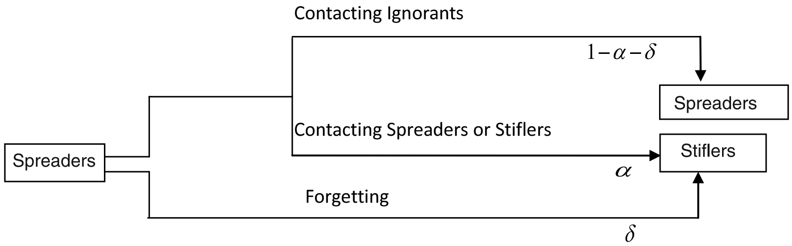


Fig. 1. Structure of rumor spreading process.

Further studies reveal that the degree of nodes on LiveJournal fits a Poisson distribution. In this case, we assume that the population on LiveJournal was mixed homogeneously. In the process of rumor spreading, we know that the population satisfies two inequalities of $I(t) > 0$ and $R(t) < 1$, meaning that there are some people never heard of the rumor and some people ever heard of the rumor but refused to spread it. Under the condition of $\Delta t \to 0$, Nekovee has studied the complex networks of rumor spreading and established a mean-field equation [10]. Guided by the theory of Nekovee and the existing achievements of Sathe [33], we use rumor spreading model with forgetting mechanism to investigate the properties of rumor spreading on LiveJournal. The model can be described as follows:

$$\frac{\mathrm{d}I(t)}{\mathrm{d}t} = -\lambda\bar{k}I(t)S(t) \tag{3}$$

$$\frac{\mathrm{d}S(t)}{\mathrm{d}t} = \lambda\bar{k}I(t)S(t) - \alpha\bar{k}S(t)(S(t)+R(t)) - \delta S(t) \tag{4}$$

$$\frac{\mathrm{d}R(t)}{\mathrm{d}t} = \alpha\bar{k}S(t)(S(t)+R(t)) + \delta S(t). \tag{5}$$

The initial condition for rumor spreading is given as follows:

$$I(0) = \frac{N-1}{N}, \qquad S(0) = \frac{1}{N}, \qquad R(0) = 0.$$

Here $\bar{k}$ denotes the average degree of LiveJournal social network. These equations mean that the number of ignorants changing into spreaders from the previous time $(t-1)$ to time (t) is $\lambda\bar{k}$ and the fraction of spreaders changing into stiflers is $\alpha\bar{k}$.

3. Applications of rumor spreading model with forgetting mechanism on online blogging LiveJournal

We currently study the characteristics of LiveJournal. It is a comprehensive SNS friend-making website, having the function of forums, blog and others, and was built on April 15, 1999 by Brad Fitzpatrick, who intended to keep in touch with his classmates. Nowadays, LiveJournal has been developed into an online community and its daily visitors are up to 5288,000 or more. Users can share life with each other through diary and blog. The members registered in LiveJournal can be viewed as vertices, and direct relationships between friends can be viewed as graph edges. We assume that the rumor propagates through direct contact between spreaders and the others in the population. However, these contacts can only take place along the links of an undirected social interaction network $G = (V, E)$, where V and E denote the vertices and the edges of the homogeneous network, respectively. The degree of nodes on homogeneous networks has a Poisson distribution, that is to say, most nodes have the same degree, whose value is equal to the average degree of the network. Mislove et al. [36] provided important statistic data of LiveJournal such as $\bar{k} = 29.2944$, $|V| = 5284{,}457$, $|E| = 77{,}402{,}652$.

The forgetting rate δ and stifling rate α mutually affect the final proportion of a rumor and the impact of the rumor. In this section, we will investigate how the average degree of LiveJournal impacts the final fraction of a rumor, discuss how the forgetting rate δ and stifling rate α mutually impact the final fraction of a rumor. Afterward we describe how the density of spreaders and stiflers change over time steps. Finally, how the forgetting rate affects rumor dissemination is discussed.

At the end of rumor spreading process, the number of spreaders reduces to zero, and there are only ignorants and stiflers left in LiveJournal. We mainly analyze the final size of stiflers R, which can be used to measure the influence of the rumor. Take $R = 0.70$ as an example, it means that 30% of individuals have never heard of the rumor. As we know R is shown as a function of the average degree $\bar{k}$, spreading rate λ, stifling rate α and forgetting rate δ,

$$R = \mathrm{final}\{R(t)\} = \lim_{t\to\infty} R(t) = 1 - \mathrm{e}^{-\varepsilon R} \tag{6}$$

where

$$\varepsilon = \frac{(\alpha+\lambda)\bar{k}}{\delta + \alpha\bar{k}}. \tag{7}$$

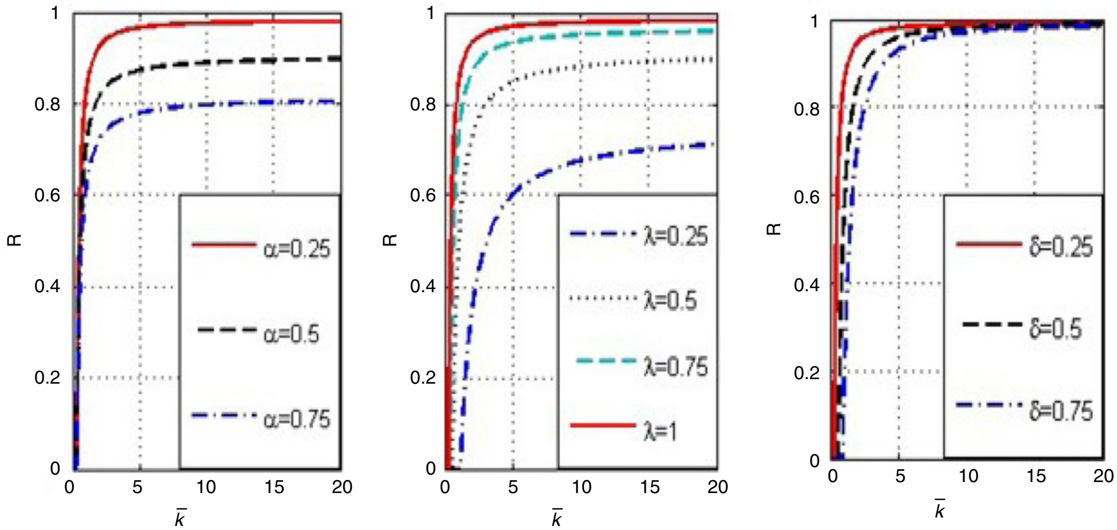


Fig. 2. Rumor influence R versus the average degree of LiveJournal. (a) α is fixed for each curve and takes 0.25, 0.5 and 0.75 for different curves from top to bottom where $\lambda = 0.8$, $\delta = 0.3$. (b) λ is fixed for each curve and takes 0.25, 0.5, 0.75 and 1 for different curves from top to bottom where $\alpha = 0.3$, $\delta = 0.3$. (c) δ is fixed for each curve and takes 0.25, 0.5 and 0.75 for different curves from top to bottom where $\lambda = 0.8$, $\alpha = 0.2$.

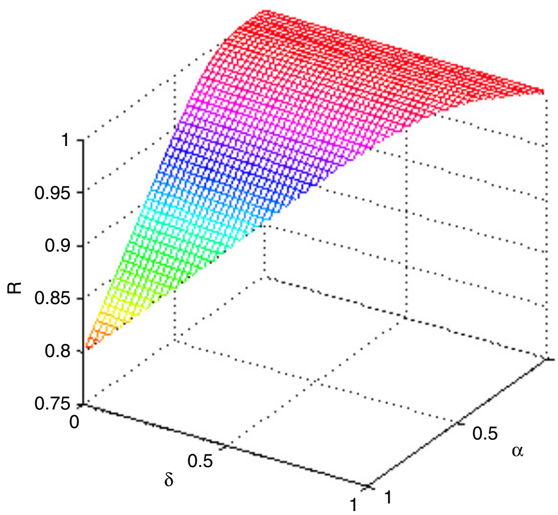


Fig. 3. The final size of the rumor R is shown as a function of the stifling rate α and the forgetting rate δ.

Fig. 2 displays the variation of rumor influence R versus average degree of LiveJournal with stifling rate α, spreading rate λ and forgetting rate δ respectively. From a macroscopic perspective, we find that as the average degree $\bar{k}$ increases, the number of final stiflers first increases steeply then stabilizes, and there exists a threshold of the average degree above which the influence of rumor achieves a steady state. The observations are as follows: (1) Fig. 2(a) reveals that stifling probability has a significant influence on rumor spreading. The greater the stifling probability α, the less the final size of a rumor R and the bigger the threshold on the network. (2) Fig. 2(b) shows that the larger the probability λ, the greater the impact of rumor and the smaller the threshold on LiveJournal. (3) Fig. 2(c) reveals that forgetting rate exerts great influence on rumor spreading on the network with small average degree, the greater the forgetting rate δ, the weaker the influence of a rumor and the greater the threshold for achieving a steady state.

The rules of rumor influence R changing with the stifling rate α and forgetting rate δ in LiveJournal under the constraint $\alpha + \delta \leq 1$ could be described by Fig. 3 and Table 1. The average degree of LiveJournal $\bar{k} = 29.2944$ comes from the statistical results of Mislove et al. [36]. As can be seen from Fig. 3 and Table 1, rumor impact reduces with the increase of the forgetting rate and the stifling rate. When the forgetting rate δ and the stifling rate α mutually converge to zero, the rumor impact reaches the highest point 1, meaning nearly 100% of the individuals on the network have heard of the rumor and become stiflers. When the forgetting rate decreases to 0 and stifling rate increases to 1, the rumor impact decreases to the lowest point, close to 0.8, meaning about 20% individuals on the network have never heard of the rumor when the rumor has ceased.

Table 1
R changing with the stifling rate α and forgetting rate δ under the constraint $\alpha + \delta \leq 1$.

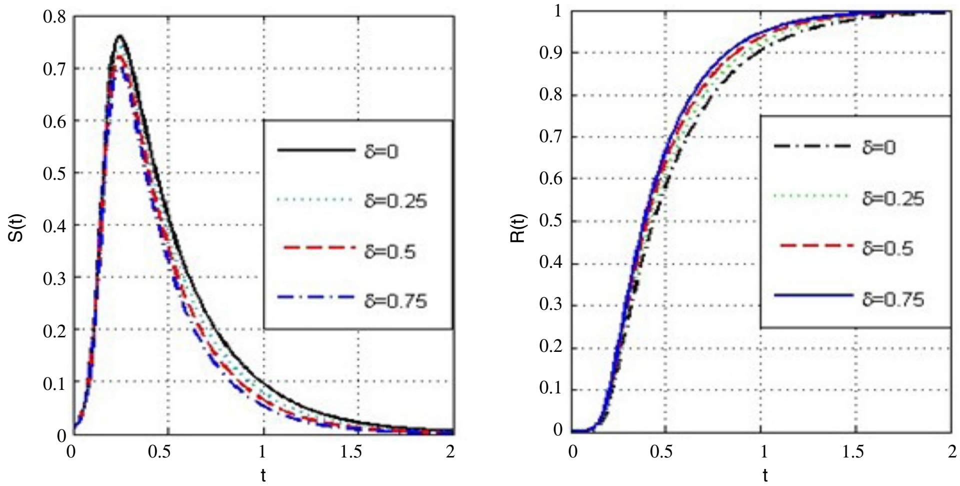
R		α										
		0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
	0	1	1	0.9975	0.9861	0.966	0.9405	0.9122	0.8828	0.8534	0.8246	0.7968
	0.1	1	1	0.9972	0.9953	0.9649	0.9391	0.9106	0.8811	0.8516	0.8228	
	0.2	1	1	0.9969	0.9846	0.9637	0.9377	0.909	0.8794	0.8498	–	–
	0.3	1	1	0.9966	0.9838	0.9626	0.9362	0.9074	0.8776	–	–	–
	0.4	1	0.9999	0.9963	0.983	0.9614	0.9348	0.9057	–	–	–	–
δ	0.5	1	0.9999	0.9959	0.9822	0.9602	0.9333	–	–	–	–	–
	0.6	1	0.9999	0.9956	0.9813	0.9589	–	–	–	–	–	–
	0.7	1	0.9999	0.9952	0.9805	–	–	–	–	–	–	–
	0.8	1	0.9998	0.9948	–	–	–	–	–	–	–	–
	0.9	1	0.9998	–	–	–	–	–	–	–	–	–
	1.0	1	–	–	–	–	–	–	–	–	–	–

As can be seen from Table 1, the forgetting rate has great influence on LiveJournal especially when forgetting rate is large enough.

We can use the fourth-order Runge–Kutta method to solve the coupled differential equations (3)–(5). The concrete steps of the algorithm are given as follows.

$$
\begin{aligned}
I_{i+1}(t) &= I_i(t) + \frac{h}{6}(K_1 + 2K_2 + 2K_3 + K_4),\\
S_{i+1}(t) &= S_i(t) + \frac{h}{6}(L_1 + 2L_2 + 2L_3 + L_4),\\
R_{i+1}(t) &= R_i(t) + \frac{h}{6}(M_1 + 2M_2 + 2M_3 + M_4),\\
K_1 &= -\lambda\bar{k}I_i(t)S_i(t),\\
L_1 &= \lambda\bar{k}I_i(t)S_i(t) - \alpha\bar{k}S_i(t)(S_i(t) + R_i(t)) - \delta S_i(t),\\
M_1 &= \alpha\bar{k}S_i(t)(S_i(t) + R_i(t)) + \delta S_i(t),\\
K_2 &= -\lambda\bar{k}\left(I_i(t) + \frac{h}{2}K_1\right)\left(S_i(t) + \frac{h}{2}L_1\right),\\
L_2 &= \lambda\bar{k}\left(I_i(t) + \frac{h}{2}K_1\right)\left(S_i(t) + \frac{h}{2}L_1\right) - \alpha\bar{k}\left(S_i(t) + \frac{h}{2}L_1\right)\\
&\quad \times\left(\left(S_i(t) + \frac{h}{2}L_1\right) + \left(R_i(t) + \frac{h}{2}M_1\right)\right) - \delta\left(S_i(t) + \frac{h}{2}L_1\right),\\
M_2 &= \alpha\bar{k}\left(S_i(t) + \frac{h}{2}L_1\right)\left(\left(S_i(t) + \frac{h}{2}L_1\right) + \left(R_i(t) + \frac{h}{2}M_1\right)\right) + \delta\left(S_i(t) + \frac{h}{2}L_1\right),\\
K_3 &= -\lambda\bar{k}\left(I_i(t) + \frac{h}{2}K_2\right)\left(S_i(t) + \frac{h}{2}L_2\right),\\
L_3 &= \lambda\bar{k}\left(I_i(t) + \frac{h}{2}K_2\right)\left(S_i(t) + \frac{h}{2}L_2\right) - \alpha\bar{k}\left(S_i(t) + \frac{h}{2}L_2\right)\\
&\quad \times\left(\left(S_i(t) + \frac{h}{2}L_2\right) + \left(R_i(t) + \frac{h}{2}M_2\right)\right) - \delta\left(S_i(t) + \frac{h}{2}L_2\right),\\
M_3 &= \alpha\bar{k}\left(S_i(t) + \frac{h}{2}L_2\right)\left(\left(S_i(t) + \frac{h}{2}L_2\right) + \left(R_i(t) + \frac{h}{2}M_2\right)\right) + \delta\left(S_i(t) + \frac{h}{2}L_2\right),\\
K_4 &= -\lambda\bar{k}(I_i(t) + hK_3)(S_i(t) + hL_3),\\
L_4 &= \lambda\bar{k}(I_i(t) + hK_3)(S_i(t) + hL_3) - \alpha\bar{k}(S_i(t) + hL_3)((S_i(t) + hL_3) + (R_i(t) + hM_3)) - \delta(S_i(t) + hL_3),\\
M_4 &= \alpha\bar{k}(S_i(t) + hL_3)((S_i(t) + hL_3) + (R_i(t) + hM_3)) + \delta(S_i(t) + hL_3), \quad i = 0, 1, 2, \ldots, \; h = 0.01.
\end{aligned}
$$

Calculated by the Runge–Kutta method, Fig. 4 vividly shows how the density of spreaders and stiflers change over time steps on homogeneous network before and after the forgetting mechanism is considered. The peak value of spreader density $\max\{s(t)\}$ denotes the biggest fraction of spreaders in the process of rumor spreading, which can be used to measure the maximum rumor influence. Fig. 4(a) clearly shows that over time steps spreader density first increases sharply, and then reaches a peak value, approximately 0.7, meaning that the maximum fraction of individuals spreading the rumor is about 70%. Finally, the spreader density decreases to a stable state value 0, meaning a termination of the rumor spreading. Another rule that should be mentioned is that with the presence of forgetting mechanism, rumor impact is weakened. For the same



(a) Density of spreaders. (b) Density of stiflers.

Fig. 4. Density of spreaders and stiflers over time is plotted with $\alpha = 0.1$.

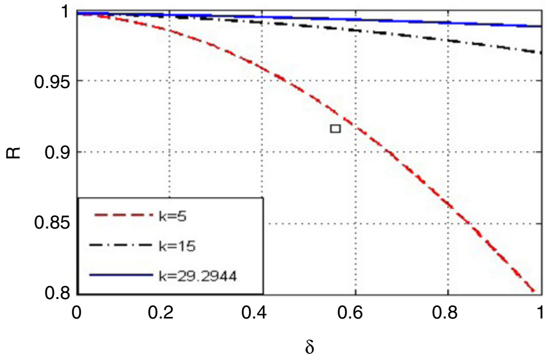


Fig. 5. R is plotted as a function of δ with $\lambda = 0.5$, $\alpha = 0.1$.

stifling rate, the bigger the forgetting rate δ, the smaller the maximum of rumor influence. But the experimental results indicate that forgetting rate δ has less influence on the saturation of spreader density. Fig. 4(b) clearly shows that the stifler density first increases steeply over time steps and at last reaches a peak value, approximately 1. Talking about the forgetting mechanism, we find that its presence results in the increase of the stifler density. The bigger the forgetting rate, the bigger the stifler density on LiveJournal. But as the time step goes on, the influence of the forgetting mechanism on the stifler density becomes remarkably weakened, the stifler density reaches the same level in the end with different values of forgetting rate δ.

Forgetfulness occurs frequently to the individuals of blog, thus the forgetting mechanism greatly influences the process of rumor spreading. Fig. 5 describes the impact of forgetting mechanism on the final size of rumors on LiveJournal. In our study, the whole process of the formation and development of LiveJournal is divided into three stages: in the early development, there are very few people on LiveJournal, so the average degree is very small, in this case, we assume that $\overline{k} = 5$; as the improved network attracted more population, the average degree $\overline{k}$ also increased, then we take $\overline{k} = 15$ as a special case; when LiveJournal reaches its full development, the statistical data shows that the average degree of LiveJournal during this period is $\overline{k} = 29.2944$ [36]. From Fig. 5 we can see that at the end of rumor spreading, the bigger the average degree $\overline{k}$, the more the final size of a rumor R on the network. The forgetting mechanism has different effects on rumor spreading in different stages of LiveJournal. Social networks with small average degree may be easily affected by forgetting mechanism.

4. Conclusions

In this paper, we have analyzed the dynamics of rumor spreading on homogeneous network LiveJournal with consideration of forgetting mechanism. We provide the structure chart of rumor spreading process to describe how spreaders contact with ignorants and stiflers in detail and study the spreading process of rumor on LiveJournal. Novel features and significant results of our models are showed as follows:

(1) The model of rumor spreading studied in this paper is of major practical importance since forgetfulness is a necessary factor to be included. Simulations show that the forget mechanism may weaken the influence of rumor.
(2) The constraint $\alpha + \delta \leq 1$ between stifling and forgetting rate does not exist in previous studies and it is an important factor to decide the behaviors of stiflers and the influence of rumor. We have found some new characteristics that distinguish from the previous studies without consideration of the constraint $\alpha + \delta \leq 1$.
(3) A detailed research on the final size of a rumor changing over the average degree, forgetting rate and stifling rate is discussed in this paper. We find that the impact on the final fraction of nodes R depends greatly on the average degree of LiveJournal and there exists a threshold of the average degree of LiveJournal above which the influence of rumor reaches saturation. These findings shed some light on the effective control of rumor spreading.

Our results could offer some new insights on rumor spreading, thoughts, emotion or motivation involved in decision-making and so on. Equipped with such knowledge, authorities and governments at all levels could avoid or reduce various panics, reduce losses and handle emergencies caused by rumor spreading.

In future we will extend our research to scale-free networks, the degree of which fits the power law distribution. In reality, many ideal networks abstracted from real social networks are quite close to scale-free networks, such as the bio-networks, citation networks and protein interaction networks. On the other hand, further investigation on rumor spreading models and rumor impact on static network will open a new access to revealing the secrets of rumor spreading.

Acknowledgments

This study is supported by grants from the National Natural Science Foundation of China (Nos 90924030 and 70673012) and the ''Shuguang'' project of Shanghai Education Commission (No. 09SG38).

References

[1] S. Galam, Modeling rumors: the no plane pentagon French hoax case, Physica A 320 (2003) 571–580.
[2] M. Kosfeld, Rumours and markets, J. Math. Econom. 41 (2005) 646–664.
[3] H. Hayakawa, Ryugen no shakaigaku-keishikisyakaigaku karano sekkin (sociology of rumor-approach from formal sociology), Seikyusya, Tokyo, Japan, 2002.
[4] A.J. Kimmel, Rumors and Rumor Control: A Manager's Guide to Understanding and Combatting Rumors, Lawrence Erlbaum Associates, Mahwak, New Jersey, 2004.
[5] A.M. Kermarrec, L. Massoulie, A. Ganesh, HiScamp: self-organizing hierarchical membership protocol, IEEE Trans. Parallel Distrib. Syst. 14 (2003) 248.
[6] A. Oram (Ed.), Peer-to-Peer: Harnessing the Power of Disruptive Technologies, O'Reilly & Associates, Sebastopol, CA, 2001.
[7] Z.L. Zhang, Z.Q. Zhang, An interplay model for rumour spreading and emergency development, Physica A 388 (2009) 4159–4166.
[8] S.A. Thomas, Lies, damn lies, and rumors: an analysis of collective efficacy, rumors, and fear in the wake of Katrina, Sociol. Spectrum 27 (2007) 679–703.
[9] E.R. Danzig, P.W. Thayer, L.R. Galanter, The Effects of a Threatening Rumor on a Disaster-Stricken Community, National Academy of Science-National Research Council, Washington, DC, 1958.
[10] M. Nekovee, Y. Moreno, G. Bianconi, M. Marsili, Theory of rumour spreading in complex social networks, Physica A 374 (2007) 457–470.
[11] Z. Liu, Y.-C. Lai, N. Ye, Propagation and immunization of infection on general networks with both homogeneous and heterogeneous components, Phys. Rev. E 67 (2003) 031911.
[12] J. Zhou, Z. Liu, B. Li, Influence of network structure on rumor propagation, Phys. Lett. A 368 (2007) 458.
[13] H. Kesten, V. Sidoravicius, The spreading of a rumor or infection in a moving population, Ann. Probab. 33 (2005) 2402.
[14] D.J. Daley, D.G. Kendall, Epidemics and rumours, Nature 204 (1964) 1118.
[15] D. Maki, M. Thomson, Mathematical Models and Applications, Prentice-Hall, Englewood Cliff, 1973.
[16] J.D. Murray, Mathematical Modelling in Epidemiology, Springer, Berlin, 1980.
[17] M.E.J. Newman, S. Forest, J. Balthrop, Email networks and the spread of viruses, Phys. Rev. E 66 (2002) 035101.
[18] H. Ebel, L. Mielsch, S. Bornholdt, Scale-free topology of email networks, Phys. Rev. E 66 (2002) 035103.
[19] F. Wang, Y. Moreno, Y. Sun, Structure of peer-to-peer social networks, Phys. Rev. E 73 (2006) 036123.
[20] G. Csanyi, B. Szendroi, Structure of large social networks, Phys. Rev. E 69 (2004) 036131.
[21] N. Smith, Instant messaging as a scale-free network, cond-mat/0206378, 2002.
[22] A. Sudbury, The proportion of population never hearing a rumour, J. Appl. Probab. 22 (1985) 443–446.
[23] D.H. Zanette, Criticality behavior of propagation on small-world networks, Phys. Rev. E 64 (2001) 050901.
[24] D.H. Zanette, Dynamics of rumor propagation on small-world networks, Phys. Rev. E 65 (2002) 041908.
[25] L. Buzna, K. Peters, D. Helbing, Modelling the dynamics of disaster spreading in networks, Physica A 363 (2006) 132–140.
[26] Y. Moreno, M. Nekovee, A. Pacheco, Dynamics of rumor spreading in complex networks, Phys. Rev. E 69 (2004) 066130.
[27] V. Isham, S. Harden, M. Nekovee, Stochastic epidemics and rumours on finite random networks, Physica A 389 (2010) 561–576.
[28] W. Bachnik, S. Szymczyk, P. Leszczynski, R. Podsiadfo, E. Rymszewicz, S. Buraczewska, L. Kurylo, Quantitative and sociological analysis of blog networks, Acta Phys. Polon. B 36 (2005) 2435.
[29] E. Spertus, M. Sahami, O. Buyukkokten, Evaluating similarity measures: a large-scale study in the orkut social network, in: Proc. 11st ACM SIGKDD, ACM Press, New York, 2005, pp. 678–684.
[30] F. Fu, X. Chen, L. Liu, L. Wang, Social dilemmas in an online social network: the structure and evolution of cooperation, Phys. Lett. A 371 (2007) 58–64.
[31] S. Golder, D. Wilkinson, B. Huberman, Rhythms of social interaction: messaging within a massive online network, in: Proc. 3rd Commun. Technol. Conf., Springer, 2007, pp. 41–66.
[32] B.A. Huberman, D.M. Romero, F. Wu, Social networks that matter: twitter under the microscope, First Monday 14 (2009) 1–5.
[33] S. Sathe, Rumor spreading in LiveJournal, Mini-Project Report, Dynamical Networks, July 4, 2008.
[34] J. Gu, X. Cai, The forget-remember mechanism for 2-state spreading, http://arxiv.org/abs/nlin.Ao/0702021vl.
[35] J. Gu, W. Li, X. Cai, The effect of the forget-remember mechanism on spreading, Eur. Phys. J. B 62 (2008) 247–255.
[36] A. Mislove, M. Marcon, K. Gummadi, P. Druschel, B. Bhattacharjee, Measurement and analysis of online social networks, in: Proceedings of the 7th ACM SIGCOMM Conference on Internet Measurement, 2007, pp. 29–42.