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SIR rumor spreading model in the new media age

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Abstract

With the prevalence of new media, e.g., microblogging, rumors spread faster and wider than ever before. On the basis of prior studies, this paper modifies a flow chart of the rumor spreading process with the SIR (Susceptible, Infected, and Recovered) model, and thus makes the rumor spreading process more realistic and apparent. The authors believe that ignorants will inevitably change their status once they are made aware of a rumor by spreaders; the probabilities that a spreader becomes a stifler are differentiated in accordance with reality. In the numerical simulation part, the impact that variations of different parameters have on the rumor spreading process will be analyzed.

Highlights

► Ignorants will inevitably change their status once they know a rumor. ► The probabilities that a spreader becomes a stifler are differentiated. ► The rumor spreading process is more realistic and apparent. ► The steady state of rumor spreading is analyzed.

Previous Next

Keywords

SIR model; Rumor spreading; Numerical simulation

1. Introduction

A rumor, in general, refers to an unverified account or explanation of events circulating from person to person and pertaining to an object, event, or issue of public concern[1]. As an important part of people's lives, rumor spreading can shape public opinion[2], and cause social panic and instability afterward[3], [4]. The way rumors have spread has changed substantially in the last 150 years: initially from mouth to mouth and then by telephone, short messages (SMS), emails, blogs, podcasts, microblogs, and social networks[5], [6]. With the increasing prevalence of new media, which make it possible for anyone to create, modify, and share content by means of relatively simple tools, people can acquire and disseminate more information with faster velocity; hence the spreading of rumors is faster and wider than ever before. For example, the 2011 Tohoku earthquake and subsequent nuclear leakage accidents caused a number of rumors in China, the United States, Europe, Korea, the Philippines, and surrounding countries. Rumors said that taking materials containing iodine could help ward off nuclear radiation, which led to a public rush for everything containing iodine, such as Chinese people snapping up iodized salt, Americans rushing for iodine pills, Russians hoarding iodine, and Koreans rushing for seaweed. From the afternoon of 16 March 2011, crazy rumors propagated in the coastline cities of China. Residents started to buy and hoard iodized salt. The next day, this irrational behavior of storing up iodized salt swept the whole country, owing much to new media[7].

Daley and Kendall[8], [9] proposed the basic DK model, the beginning of rumor spreading modeling, in the 1960s. In their model, the population is subdivided into three groups: those who are unaware of the rumor (ignorants), those who spread the rumor (spreaders), and those who are aware of the rumor but choose not to spread it (stiflers). Maki[10] later modified the DK model and developed the MK model, in which rumors propagate through direct contact between spreaders and others. Newman et al.[11], Ebel et al.[12], Csanyi and Szendroi[13], and Wang et al.[14] believed that the DK and MK models were not suitable for the study of rumor spreading processes in large-scale social networks. Moreno et al.[15] studied the MK model on scale-free networks and documented the interplay between network topologies and MK model rules. Nekovee et al.[16] and Isham et al.[17] built a new model by combining the MK model with the SIR (Susceptible, Infected, and Recovered) epidemic model on complex networks and, furthermore, derived the rumor spreading mean-field equations and investigated the steady state of rumors on general complex networks. Zhao et al.[18], [19] analyzed the dynamics of rumor spreading on homogeneous networks considering the forgetting mechanism, and concluded that the final state of stiflers depends greatly on the average degree of networks.

The studies about rumor spreading mentioned above were carried out from a group view, which did not consider individual choice properly. These studies (with the exception of those of Zhao et al.[7],

[18], [19]) did not construct flow charts of rumor spreading in their papers, while the flow charts of rumor spreading that Zhao provided also did not reflect the rumor spreading process adequately. Moreover, there is an unreasonable point of view in the above-mentioned studies, in the assumption that ignorants would stay ignorant if they did not turn into spreaders after they heard about a rumor from spreaders, because, in this case, those who are aware of the rumor but choose not to spread it should be stiflers, according to the definition. In addition, there is a consensus in the above studies that the probabilities of spreaders changing into stiflers are the same by different methods, which is not in accordance with reality, as the impact that stiflers have on spreaders should differ from the impact that spreaders have on spreaders. On the basis of previous studies, this paper furthers the study of the SIR rumor spreading model in the following aspects. First, the flow chart of rumor spreading provided in Ref.[18] is developed to align better with reality. Furthermore, the probability that a spreader becomes a stifler by contacting a stifler or another spreader is differentiated in the paper. Finally, rumor spreading mean-field equations are derived and numerical simulations are carried out.

2. SIR rumor spreading model with forgetting mechanism

As mentioned in the previous section, a population is subdivided into three groups, ignorants, spreaders, and stiflers (represented by I, S, and R, respectively), according to the perception and reaction of a individual to a rumor. Rumors spread and fade away through contact between different individuals. The SIR model for the rumor spreading process is shown in Fig. 1.

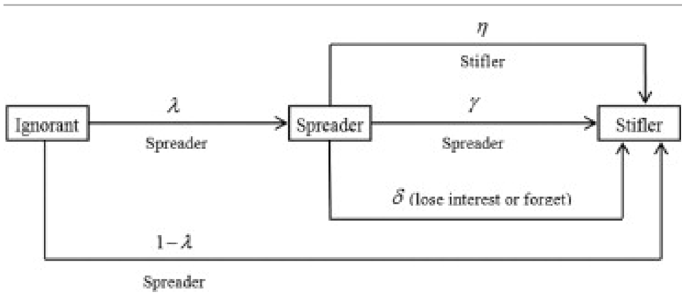

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Fig. 1. Structure of the SIR model for the rumor spreading process.

As shown in Fig. 1, from the spreader's point of view, in time t, a spreader spontaneously loses interest in or forgets about a rumor with probability δ. Stiflers have an negative effect on a spreader when the spreader tries to disseminate a rumor to a stifler. Suppose that stiflers choose not to propagate a rumor because of disbelief or uninterest; in this case, a spreader turns into a stifler with probability η when he/she contacts a stifler. If a spreader contacts another spreader in the rumor spreading process, they may have different versions of the rumor as a result of individual modification and representation of the rumor; in this situation, the initial spreader may change into a stifler with a probability γ because he/she may doubt the credibility of the rumor. In keeping with reality, here γ is restricted to be smaller than η, i.e.,$\gamma < \eta$.

From the ignorant's point of view, an ignorant can only and will inevitably change status upon hearing a rumor from spreaders, because he/she cannot be an individual who is unaware of the rumor once he/she has heard it. In time t, if an ignorant has had contact with spreaders, then there is a probability of λ that he/she disseminates the rumor and changes into a spreader, or a probability of $1-\lambda$ of becoming a stifler.

An undirected graph $G=(V,E)$, where V is a set of vertices and E edges, can be obtained from a social network consisting of N individuals, if individuals and contacts between them are considered as vertices and edges, respectively. As we all know, a general social network is not a regular network; nevertheless, it should be noted that the number of people that each individual directly contacts in reality is substantially close, and the number approximates a Poisson distribution. Hence, rumor spreading based on the SIR model will be discussed on a homogenous network in this paper. In the light of the SIR rumor spreading process elaborated above, the mean-field equations can be acquired as follows:

$$\frac{\mathrm{d}I(t)}{\mathrm{d}t}=-\bar{k}I\left(t\right)S\left(t\right), \tag{1}$$
$$\frac{\mathrm{d}S(t)}{\mathrm{d}t}=\lambda\bar{k}I\left(t\right)S\left(t\right)-\bar{k}S\left(t\right)\left(\gamma S\left(t\right)+\eta R\left(t\right)\right)-\delta S\left(t\right), \tag{2}$$
$$\frac{\mathrm{d}R(t)}{\mathrm{d}t}=\left(1-\lambda\right)\bar{k}I\left(t\right)S\left(t\right)+\bar{k}S\left(t\right)\left(\gamma S\left(t\right)+\eta R\left(t\right)\right)+\delta S\left(t\right). \tag{3}$$

Here $\bar{k}$ denotes the average degree of the network; $I\left(t\right)$, $S\left(t\right)$, and $R\left(t\right)$ denote the density of ignorants, spreaders, and stiflers at time t, respectively; and, obviously, $I\left(t\right)+S\left(t\right)+R\left(t\right)=1$.

In the initial period of rumor spreading, there are very few people who know the rumor; therefore, they become spreaders, as everyone has the desire to disseminate the rumor. So here is a hypothesis that there is only one spreader at first, and all the other people are ignorants, i.e.,the initial condition for SIR rumor spreading is

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

3. Steady-state analysis

There are only ignorants and stiflers left when the system reaches the steady state. Define

$$R=\lim_{t\to\infty}R\left(t\right)$$

as the final state of stiflers; it will be deduced in this section. Divide Eq. (3) by Eq. (1), i.e.,

$$\frac{\mathrm{d}R(t)}{\mathrm{d}I(t)}=\frac{(1-\lambda)\bar{k}I(t)S(t)+\bar{k}S(t)(\gamma S(t)+\eta R(t))+\delta S(t)}{-\bar{k}I(t)S(t)}=-\left(1-\lambda\right)-\frac{\gamma S(t)+\eta R(t)}{I(t)}-\frac{\delta}{\bar{k}I(t)}=\lambda-1$$
$$-\frac{\gamma(1-I(t)-R(t))+\eta R(t)}{I(t)}-\frac{\delta}{\bar{k}I(t)}=\lambda-1-\frac{\gamma}{I(t)}+\gamma-\left(\eta-\gamma\right)\frac{R(t)}{I(t)}-\frac{\delta}{\bar{k}I(t)}=\lambda+\gamma-1$$
$$-\left(\gamma+\frac{\delta}{\bar{k}}\right)\frac{1}{I(t)}-\left(\eta-\gamma\right)\frac{R(t)}{I(t)}.$$

Given

$$A=\lambda+\gamma-1,\qquad B=\gamma+\frac{\delta}{\bar{k}},\qquad C=\eta-\gamma,$$

then

$$\frac{\mathrm{d}R(t)}{\mathrm{d}I(t)}=A-\frac{B}{I(t)}-\frac{CR(t)}{I(t)}=\frac{AI(t)-CR(t)-B}{I(t)}.$$

Given $x=I\left(t\right),y=R\left(t\right)+\frac{B}{C}$, then

$$\frac{\mathrm{d}y}{\mathrm{d}x}=\frac{Ax-C\left(y-\frac{B}{C}\right)-B}{x}=A-\frac{Cy}{x}.$$

Let $y/x=u$, so $dy=x\mathrm{d}u+u\mathrm{d}x$, and

$$\frac{\mathrm{d}y}{\mathrm{d}x}=\frac{x\mathrm{d}u+u\mathrm{d}x}{\mathrm{d}x}=A-Cu,$$
$$\therefore x\mathrm{d}u+u\mathrm{d}x=A\mathrm{d}x-Cu\mathrm{d}x,\Rightarrow x\mathrm{d}u=\left[A-\left(C+1\right)u\right]\mathrm{d}x,\Rightarrow\frac{du}{A-(C+1)u}=\frac{\mathrm{d}x}{x},\Rightarrow$$
$$-\frac{1}{C+1}\cdot\frac{\mathrm{d}[A-(C+1)u]}{A-(C+1)u}=\frac{\mathrm{d}x}{x},\Rightarrow-\frac{1}{C+1}\ln\left[A-\left(C+1\right)u\right]=\ln C_1x,\Rightarrow\ln\left[A-\left(C+1\right)u\right]=$$
$$-\left(C+1\right)\ln C_1x,\Rightarrow A-\left(C+1\right)u=\left(C_1x\right)^{-(C+1)},\Rightarrow\left(C+1\right)u=A-\left(C_1x\right)^{-(C+1)},$$
$$\Rightarrow u=\frac{A}{C+1}-\frac{C_2x^{-(C+1)}}{C+1},$$

where C_1 is the arbitrary constant, and $C_2=C_1^{-(C+1)}$.

$$\therefore\frac{y}{x}=\frac{A}{C+1}-\frac{C_2x^{-(C+1)}}{C+1},$$
$$\Rightarrow y=\frac{A}{C+1}x-\frac{C_2}{C+1}x^{-C},\Rightarrow R\left(t\right)+\frac{B}{C}=\frac{A}{C+1}I\left(t\right)-\frac{C_2}{C+1}I(t)^{-C},\Rightarrow R\left(t\right)=\frac{A}{C+1}I\left(t\right)$$
$$-\frac{C_2}{C+1}I(t)^{-C}-\frac{B}{C}.$$

Considering the initial condition $R\left(0\right)=0,I\left(0\right)=\frac{N-1}{N}\approx1$, then

$$\Rightarrow0=\frac{A}{C+1}-\frac{C_2}{C+1}-\frac{B}{C},\Rightarrow\frac{C_2}{C+1}=\frac{A}{C+1}-\frac{B}{C},\Rightarrow C_2=A-\frac{B(C+1)}{C},$$
$$\therefore R\left(t\right)=\frac{A}{C+1}I\left(t\right)-\left(\frac{A}{C+1}-\frac{B}{C}\right)I(t)^{-C}-\frac{B}{C}.$$

The final state of stiflers can be obtained in view of

$$\lim_{t\to\infty}I\left(t\right)=1-\lim_{t\to\infty}R\left(t\right)=1-R$$

as

$$R=\frac{A}{C+1}(1-R)-\left(\frac{A}{C+1}-\frac{B}{C}\right)(1-R)^{-C}-\frac{B}{C}=\frac{A}{C+1}-\frac{A}{C+1}R-\frac{A}{C+1}(1-R)^{-C}$$
$$+\frac{B}{C}(1-R)^{-C}-\frac{B}{C}=\left(\frac{B}{C}-\frac{A}{C+1}\right)(1-R)^{-C}-\frac{A}{C+1}R+\frac{A}{C+1}-\frac{B}{C}.$$

Given

$$f(z)=z-\left(\frac{B}{C}-\frac{A}{C+1}\right)(1-z)^{-C}+\frac{A}{C+1}z-\frac{A}{C+1}+\frac{B}{C}=\left(\frac{A}{C+1}+1\right)z$$
$$+\left(\frac{A}{C+1}-\frac{B}{C}\right)(1-z)^{-C}-\frac{A}{C+1}+\frac{B}{C},$$

where $0\le z<1$, then

$$f'(z)=\frac{A}{C+1}+1+\left(\frac{A}{C+1}-\frac{B}{C}\right)\cdot C\cdot(1-z)^{-C-1},$$
$$f''(z)=\left(\frac{A}{C+1}-\frac{B}{C}\right)\cdot C\cdot(C+1)\cdot(1-z)^{-C-2}=[AC-B(C+1)](1-z)^{-C-2}$$
$$=[(A-B)C-B](1-z)^{-C-2}$$
$$=\left[\left(\lambda+\gamma-1-\gamma-\frac{\delta}{\bar{k}}\right)(\eta-\gamma)-\left(\gamma+\frac{\delta}{\bar{k}}\right)\right](1-z)^{-C-2}$$
$$=\left[\left(\lambda-1-\frac{\delta}{\bar{k}}\right)(\eta-\gamma)-\left(\gamma+\frac{\delta}{\bar{k}}\right)\right](1-z)^{-C-2}.$$
$$\because \lambda-1-\frac{\delta}{\bar{k}}<0,\qquad \eta-\gamma\ge 0,\qquad \gamma+\frac{\delta}{\bar{k}}>0,\qquad 1-z>0.$$
$$\therefore f''(z)<0.$$

That is to say, $f(z)$ is a concave function on the interval $[0,1)$. Also

$$f(0)=\frac{A}{C+1}-\frac{B}{C}-\frac{A}{C+1}+\frac{B}{C}=0,$$
$$f'(0)=\frac{A}{C+1}+1+\left(\frac{A}{C+1}-\frac{B}{C}\right)\cdot C=A+1-B=\lambda+\gamma-1+1-\gamma-\frac{\delta}{\bar{k}}=\lambda-\frac{\delta}{\bar{k}},$$
$$\lim_{z\to1^-}f(z)=\lim_{z\to1^-}\left[\left(\frac{A}{C+1}+1\right)z+\left(\frac{A}{C+1}-\frac{B}{C}\right)(1-z)^{-C}-\frac{A}{C+1}+\frac{B}{C}\right]=\frac{A}{C+1}+1$$
$$+\left(\frac{A}{C+1}-\frac{B}{C}\right)\lim_{z\to1^-}(1-z)^{-C}-\frac{A}{C+1}+\frac{B}{C}=1+\frac{B}{C}+\frac{AC-B(C+1)}{C(C+1)}\lim_{z\to1^-}(1-z)^{-C}=1$$
$$+\frac{\gamma+\frac{\delta}{\bar{k}}}{\eta-\gamma}+\frac{\left(\lambda+\gamma-1-\gamma-\frac{\delta}{\bar{k}}\right)(\eta-\gamma)-\left(\gamma+\frac{\delta}{\bar{k}}\right)}{(\eta-\gamma)(\eta-\gamma+1)}\lim_{z\to1^-}(1-z)^{-(\eta-\gamma)}=1+\frac{\bar{k}\gamma+\delta}{\bar{k}(\eta-\gamma)}$$
$$+\frac{\left(\lambda-1-\frac{\delta}{\bar{k}}\right)(\eta-\gamma)-\left(\gamma+\frac{\delta}{\bar{k}}\right)}{(\eta-\gamma)(\eta-\gamma+1)}\lim_{z\to1^-}(1-z)^{-(\eta-\gamma)}<0.$$

So, when $f'(0)>0$, i.e. $\frac{\lambda}{\delta}>\frac{1}{\bar{k}}$, which can be easily satisfied, there has to be a $v\in(0,1)$ that can make $f(v)=0$ (Fig.2). In other words, as is shown in Fig.3, if $\frac{\lambda}{\delta}>\frac{1}{\bar{k}}$, then spreaders can promote the rumor dissemination and let the system reach equilibrium; rumors cannot disseminate the other way round.

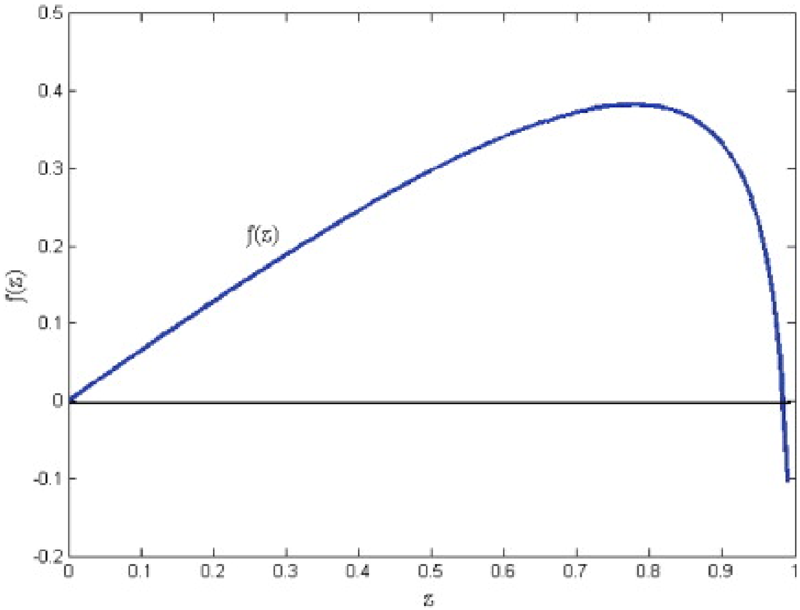


Fig.2. Graph of the function $f(z)$.

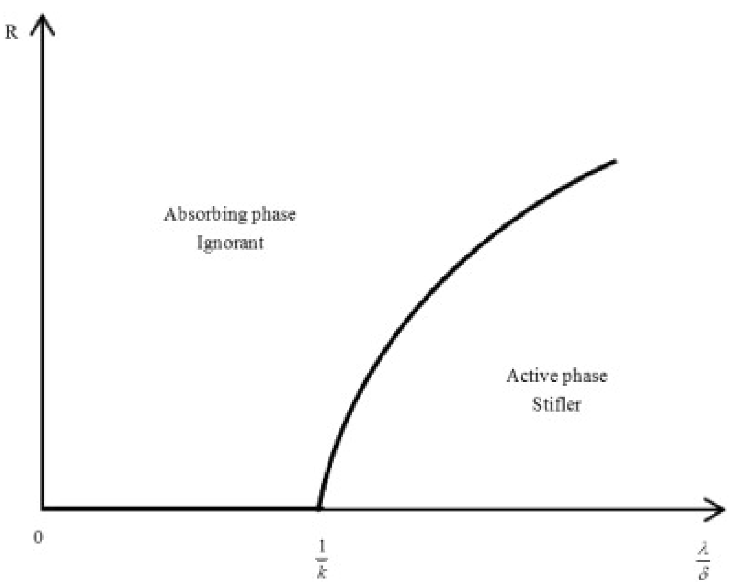
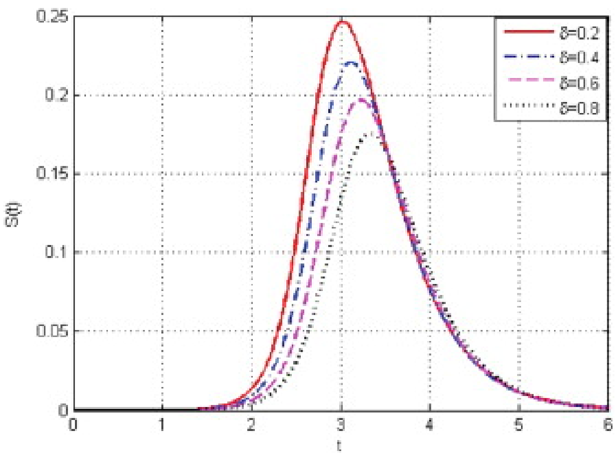


Fig.3. SIR phase diagram in a homogeneous network.

4. Numerical simulation

Simulations will be carried out using the Runge–Kutta method and MATLAB in legacy media and new media, respectively. We set mouth to mouth, telephone, and short messages as legacy media, and classify emails, blogs, podcasts, microblogs, social networks, etc., as new media. New media make it possible for anyone to create, modify, and share content, using relatively simple tools that are often free or inexpensive. So a person can contact more people through new media than legacy media; in other words, $\bar{k}$, the average degree of the network, is bigger in new media. Furthermore, we consider that people deal with more information in new media than in legacy media; therefore they are more apt to forget or shift their focuses; that is, we believe that δ is bigger in new media. Suppose that $N = 10^6$, $\bar{k} = 10$ in the legacy media and $\bar{k} = 20$ in the new media, and, given $\lambda = 0.5, \gamma = 0.1$, and $\eta = 0.2$, the density of spreaders and stiflers, respectively, as shown in Fig.4, is analyzed along with the forgetting probability δ in the first place.



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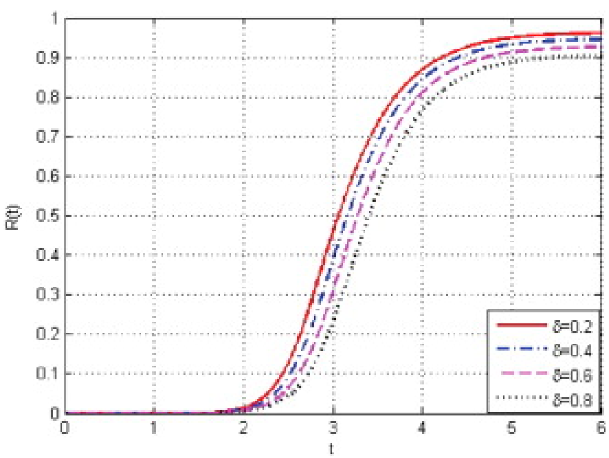
(a) Density of spreaders in legacy media.



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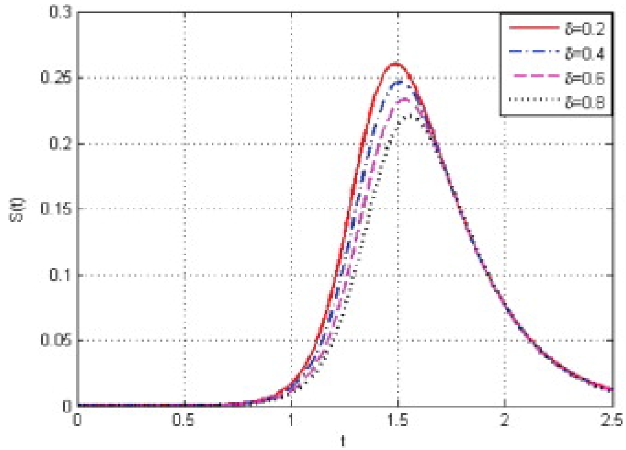
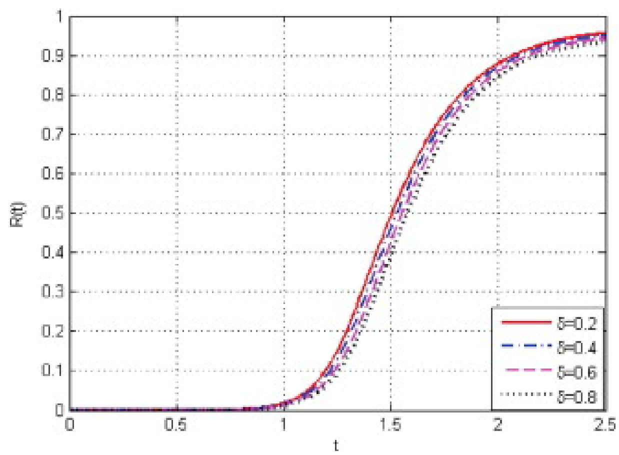
(b) Density of stiflers in legacy media.



(c) Density of spreaders in new media.

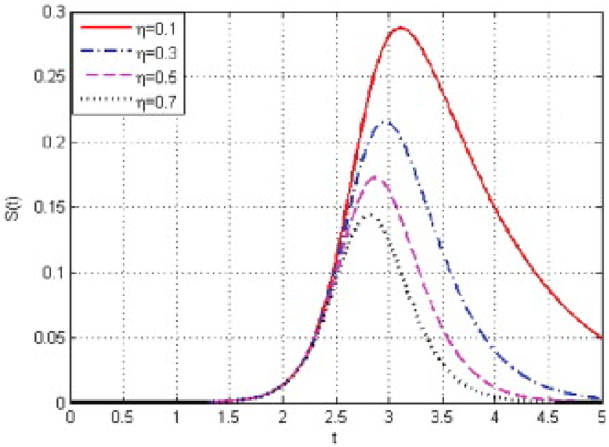


(d) Density of stiflers in new media.

Fig.4. Plot of the density of spreaders $S(t)$ and stiflers $R(t)$ versus system time t along with the forgetting probability δ, where $\lambda = 0.5, \gamma = 0.1$, and $\eta = 0.2$.

In Fig.4, given that other parameters are fixed, the bigger the value of δ, the smaller the rumor's influence. In reality, along with the increase of δ, the probability that spreaders lose interest in or forget about the rumor increases if the rumor itself is not absorbing, for example. As a result, the number of spreaders decreases, which decreases the influence of the rumor. Also, we can see in Fig.4 that, compared with legacy media, rumors have more power, the initial spike in spreaders comes up earlier, and the forgetting probability δ has a smaller impact on the rumor in the new media. This reflects the reality that if the media can release valid, timely information to dispel rumors, then the forgetting probability δ will increase accordingly, which leads to a smaller influence of rumors.

Fig.5 shows the density of spreaders and stiflers along with η when $\bar{k}, \lambda, \gamma$, and δ are fixed to 10, 0.5, 0.1, and 0.2 in the legacy media and 20, 0.5, 0.1, and 0.4 in the new media, respectively. Clearly, the bigger the value of η, when other parameters are fixed, the smaller the rumor's influence. In reality, a large η means that stiflers have high credibility; they can make more spreaders change into stiflers, and, therefore, decrease the influence of the rumor. The density of spreaders reaches a peak earlier in new media than in legacy media, but the peak values are almost the same in both. Moreover, the impact of the variation of η on rumor spreading is significant in both kinds of media. This reflects the fact that if the stiflers (such as experts and government officers) have low credibility they cannot greatly influence the general public.



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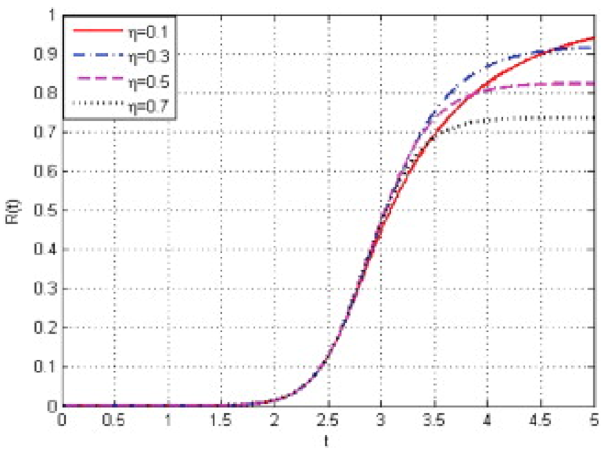
(a) Density of spreaders in legacy media.



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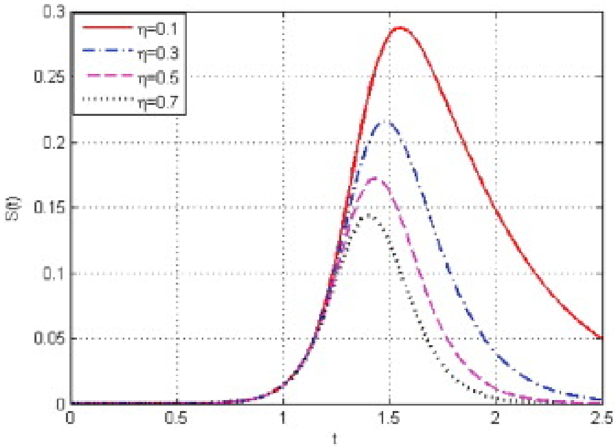
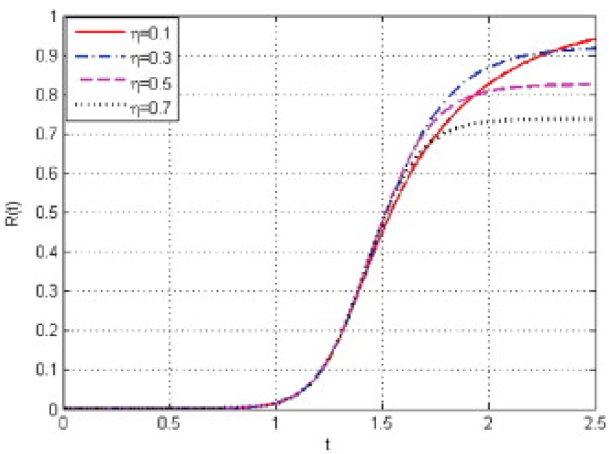
(b) Density of stiflers in legacy media.



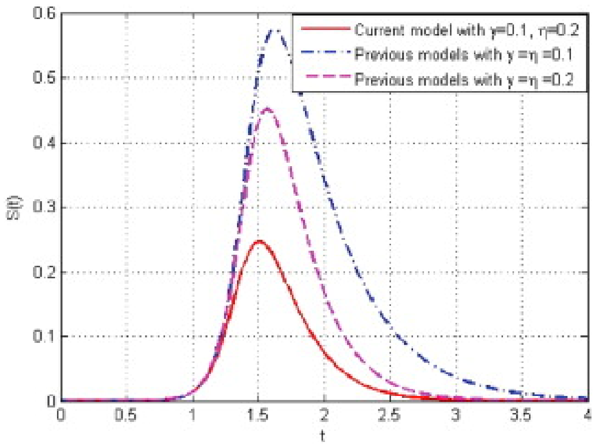
(c) Density of spreaders in new media.



(d) Density of stiflers in new media.

Fig.5. Plot of the density of spreaders $S(t)$ and stiflers $R(t)$ versus system time t along with the probability that a spreader turns into a stifler when he/she contacts a stifler η, where $\bar{k} = 10, \lambda = 0.5, \gamma = 0.1$, and $\delta = 0.2$ in the legacy media and $\bar{k} = 20, \lambda = 0.5, \gamma = 0.1$, and $\delta = 0.4$ in the new media.

Next, a comparison of results of the current model with previous models will be made. Modifications to the previous models in the current model will be canceled out in the following part. First, we consider that, when an ignorant is contacted by spreaders, he/she cannot change into a stifler and only can change into a spreader with probability λ, which is consistent with previous models. Then, according to previous models, let $\gamma = \eta$. The comparisons are shown in Fig.6. We find that the peak value of spreaders in the current model is much smaller, compared with previous models.



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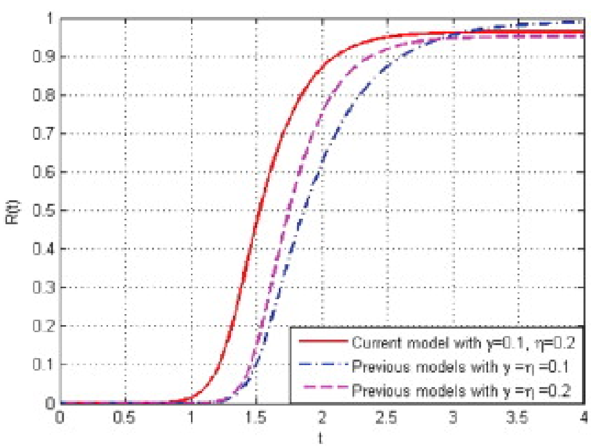
(a) Density of spreaders.



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(b) Density of stiflers.

Fig.6. Plot of density of spreaders $S(t)$ and stiflers $R(t)$ versus system time t under the current model and previous models with $\bar{k} = 20$, $\lambda = 0.5$, and $\delta = 0.4$.

5. Conclusion

In this paper, the SIR rumor spreading process is furthered, based on previous studies about rumor spreading, in the following ways.

(1) The flow chart of rumor spreading provided in Ref.[18] is modified in this paper in light of reality, which makes the rumor spreading process more realistic and apparent.

(2) To differentiate from previous studies, which took the position that ignorants could stay ignorant after they heard a rumor via spreaders, we insist that ignorants will inevitably change their status, to either spreaders or stiflers, once they are contacted by spreaders.

(3) Probabilities that a spreader becomes a stifler by contacting a stifler or another spreader are differentiated into η and γ in this paper; we think that it is realistic that the former probability is bigger than the latter.

(4) Through numerical simulation, parameters like forgetting rate and probability of spreaders changing into stiflers are found to have negative impacts on rumor spreading, and the variation of η has a greater impact on rumor spreading than δ. In addition, compared with legacy media, new media make the rumor spread faster.

We find that, at present, the average degree of a social network is getting much greater owing to the prevalence of new media, which gives rumors chances to disseminate extensively in a short time and, hence, causes social instability. The spreaders' interest in propagating rumors and the stiflers' impacts on the spreaders are both key factors to prevent rumors from spreading.

In the present work, we assumed the underlying network to be homogenous. In reality, however, many social and communication networks have different topologies. In addition, distinct rumors may have influences on one another; for example, people may shift their focus from old rumors when a new one appears, and this might impose some constraints on the model parameters. We aim to tackle these problems in future work.

Acknowledgments

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