Research and Simulation of a Weibo-Based UVFR Rumor Propagation Model: Postprint

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Abstract

The rapid development of social networks has rendered the control of online rumors increasingly critical. This study investigates the propagation mechanism of rumors on the Weibo network. Based on their propagation characteristics, Weibo rumor audience users are classified into four categories: unknowns, browsers, forwarders, and commenters, thereby constructing a UVFR network rumor propagation model. This model is utilized to analyze the influence of key parameters on the propagation process and to propose corresponding control strategies. The principal feature of the model lies in the redefinition of rumor propagation rules and propagation dynamics equations, rendering the description of the propagation process more consistent with Weibo user behavior. A multi-agent simulation platform is employed to conduct simulation studies on rumor propagation behavior within scale-free network structures. By comparing the simulation results with real data from Sina Weibo, the rationality and effectiveness of the obtained conclusions are validated. The simulation experimental results demonstrate that the greater the number of initial propagation nodes, the faster the rumor spreads; and the larger the forwarding probability, the wider the scope of rumor propagation.

Full Text

Preamble

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Research and Simulation of UVFR Rumor Propagation Model Based on Microblog

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Abstract: With the rapid development of social networks, controlling online rumors has become increasingly important. This paper investigates the dissemination mechanism of rumors on microblog networks. Based on propagation characteristics, microblog rumor audiences are divided into four categories: Unknown, Viewer, Forwarder, and Reviewer, thereby constructing a UVFR network rumor propagation model. The model analyzes the influence of key parameters on the propagation process and proposes corresponding control strategies. The main features of the model are the redefinition of rumor propagation rules and dynamic equations, making the propagation process description more consistent with microblog user behavior. Multi-agent simulation platform is used to study rumor propagation behavior on scale-free network structures. By comparing simulation results with real Sina Weibo data, the rationality and effectiveness of the conclusions are verified. Simulation results show that more initial propagation nodes lead to faster rumor spread, and higher forwarding probability results in wider propagation range.

Keywords: microblog; scale-free network; rumor propagation; multi-agent simulation

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0 Introduction

In the era of information explosion, the emergence of new media such as online social networks has made rumor propagation increasingly low-cost. A rumor refers to unverified descriptions and explanations about events, social or natural phenomena that people care about—uncertain information transmitted between individuals. As the primary public opinion platform, microblog has become an important channel for people to publish and obtain the latest information due to its timeliness and casual nature. However, characteristics such as rapid propagation speed, wide coverage, and lax supervision make microblog a breeding ground for various rumor incidents. According to the 40th "Statistical Report on China' s Internet Development," as of June 2017, China' s internet user population reached 751 million, with an internet penetration rate of 54.3%; mobile internet users reached 724 million, with mobile internet permeating every aspect of people' s lives [1]. This poses significant challenges for protecting information security and maintaining a healthy public opinion environment in social networks. The "2017 Weibo Rumor Refutation Data Report" statistics show that in 2017, Weibo officially processed over 28,000 pieces of false information and marked 1,064 as false [2].

The essence of microblog information propagation mechanism lies in its integration of human social relationships into information dissemination, making social relationships a crucial factor affecting propagation effectiveness. Since microblog propagation relies heavily on social networks as a medium, information propagation behavior on microblog is not merely an information activity but reflects netizens' social relationships and underlying cultural identity at various levels, including values and psychology. Therefore, studying rumor propagation characteristics in online social networks, understanding their propagation patterns, and implementing effective immunization and control is a highly noteworthy issue.

Domestic scholars began researching microblog rumor propagation in 2010. Many studies analyze microblog rumor propagation from perspectives of user psychology and information dissemination, with few involving quantitative model research. Due to similarities between rumor propagation in microblog networks and infectious disease spread, most rumor research borrows methodologies from SI, SIS, and SIR epidemic models [3–5]. With the rise of complex network research, Zanette [6] first applied complex network theory to rumor propagation research, establishing rumor propagation system dynamics models based on static and dynamic small-world networks, confirming the existence of rumor propagation thresholds. Zhu et al. [7] considered the global information characteristics of rumors in social networks, individual differences in conformity effects, and the impact of network scale and topological properties (homogeneous and heterogeneous networks) on rumor propagation. Moreno et al. [8] established a rumor propagation model based on scale-free networks, confirming that different individuals have varying probabilities of believing rumors and that different network topologies affect rumor propagation. Shen Xian [9] studied rumor propagation characteristics on scale-free networks, proposing an HKASI model and establishing dynamic equation groups based on it.

As an emerging social network platform, microblog' s unique information propagation mechanism and user relationship network have become major factors affecting rumor propagation. Song et al. [10] analyzed microblog user behavior in obtaining and propagating rumors, considering unconventional channels for rumor acquisition and propagation lag, and constructed an SCCIR rumor propagation model applicable to microblog networks based on epidemic dynamics. Wang et al. [11] studied the internal characteristics of microblog user relationship networks based on complex network theory, proposing an evolution model for microblog user relationship networks and analyzing its topological statistical characteristics using mean-field theory. Liu et al. [12] extended audiences into five categories (ignorant, contactor, disseminator, stifler, and uninterested) based on fundamental epidemic models, introduced interest decay coefficients to describe reduced forwarding interest when individuals encounter rumors multiple times, and considered the realistic scenario where individuals only forward once. As is well known, rumor propagation is a social phenomenon and a typical manifestation of social group psychological behavior. Tan et al. [13] borrowed gravitational mechanics concepts, modeled user influence and rumor influence from both user and rumor information perspectives based on inter-user relationships, information propagation relationships, rumor contact rates, and forwarding rates, quantified rumor information propagation, and fully considered user personalization characteristics to build corresponding modeling and analysis functions. Wang et al. [14] fully considered users' skeptical characteristics, proposed an SIQR rumor propagation model more consistent with social reality, and analyzed model stability. Wang et al. [15] studied the influence of forgetting mechanisms on rumor propagation according to Ebbinghaus forgetting curves, establishing a rumor propagation model with exponential function-form forgetting rates.

However, many current SIR-like rumor propagation models make assumptions that differ greatly from reality, such as permanently immune individuals and perpetual rumor propagation by disseminators. These assumptions fail to reflect netizens' true psychology toward rumors. In reality, rumors produce cumulative effects on individuals that are history-dependent, and such realistic public psychology should be reflected in models [16]. Additionally, due to differences among microblog network users in lifestyle and knowledge background, traditional SIR models cannot fully characterize all user states in microblog network rumor propagation [17]. Therefore, it is necessary to improve the classic SIR epidemic model according to reality and reclassify rumor audiences and infection states in microblog networks.

In summary, this paper constructs a new microblog rumor propagation model based on microblog user behavior characteristics, rumor propagation mechanisms, and network topology, introducing four states: Unknown, Viewer, Forwarder, and Reviewer. Considering the scale-free network environment, we conduct simulation research on rumor propagation mechanisms in microblog networks through computer multi-agent simulation experiments, analyze the impact of key parameter variations on propagation processes and state peaks, and propose corresponding control strategies.

1 Microblog Rumor Propagation Mechanism

Through continuous social network development in recent years, microblog has become one of the mainstream applications for Chinese netizens, with its massive user base further consolidating its core position in online public opinion propagation. Mobile terminal usage frees microblog from time and location constraints, greatly enhancing user authenticity, regional characteristics, and real-time interaction [18]. Sina' s Q3 2017 microblog financial report shows that as of September 2017, microblog had 376 million monthly active users, a 27% year-over-year increase, with mobile accounting for 92%; daily active users reached 165 million, a 25% year-over-year increase [1]. Binding microblog terminal software with mobile phone numbers ensures user authenticity; selectively introducing location information provides diverse social network services including regional information; mobile terminals leverage mobility and portability features of mobile communication devices (e.g., smartphones), enabling users to communicate anytime, anywhere within network coverage. The "always online" characteristic provides real-time information interaction, allowing users to forward and comment on rumor information promptly.

Sina Weibo adopts a one-way following relationship, where follow and followed relationships between users form a unique information sharing and propagation pattern [19]. Users become each other' s followers by "following" one another, achieving interaction and communication through messages, comments, and forwarding. Microblog propagation generally has two paths: a "fan-based path" where all followers receive information when a followed user posts; and a "forwarding path"where user A forwards user B's microblog, and A's followers receive the information in real-time, enabling near-fission-style information propagation. This propagation method contains enormous public opinion power. Users curious or confused about rumor information leverage microblog's rapid propagation to quickly exchange personal opinions and viewpoints on the platform. These exchanged opinions form common group opinions, creating group-level public opinion that further exchanges, discusses, and communicates with other groups' opinions to form broader public opinion [20]. Recent incidents such as the "Secretary Yan' s Daughter," Hongmao Medicinal Wine, nationwide crackdown on chess rooms arresting everyone under 60, flight attendant Didi murder, rabies-infected boy barking like a dog, and WeChat payment code screenshot theft have seen microblog become the primary venue for topic generation and propagation, with platform propagation volume exceeding 80.00%, demonstrating its immense influence.

When users encounter a rumor microblog, they may take one of four actions: forward, comment, forward with comment, or neither forward nor comment. Forwarding directly propagates rumor information and is the most efficient propagation behavior. Commenting does not directly propagate rumors but increases rumor heat and may stimulate conformity psychology among some viewers, indirectly affecting rumor propagation. Users who forward with comment use the forwarded rumor microblog as background, add their own comments, and forward it, creating new rounds of propagation while adding information value. Forwarding volume and comments enhance propagation effects and influence. Users who neither forward nor comment cannot transmit rumor information and have no propagation effect, so they are temporarily not considered. Figure 1 [Figure 1: see original paper] illustrates microblog rumor propagation.

2.1 Basic Model Assumptions

Using network rumors propagated on the Sina Weibo platform as the research object, this paper makes the following assumptions regarding software/hardware conditions, audience users, and interaction rules:

a) During microblog rumor propagation, we assume no hardware or network environment issues such as microblog lag or crashes.

b) During microblog usage, due to numerous and 杂乱 followings, users may group their followings and can only view messages from one group at a time, potentially missing some rumor information. Therefore, we assume microblog users do not set up following groups and can browse content from any followed user with a certain probability.

c) In reality, when users post or forward microblog information, they can set the information as public (visible to all followers) or visible only to selected users. Since users post microblogs to record their views on events, share their truest thoughts, and communicate through followers' messages and comments, the vast majority are willing to post publicly. Therefore, we assume all user-posted (or forwarded) microblog information is in public status.

d) Based on microblog network rumor propagation mechanisms and characteristics, we divide microblog network rumor audiences into four states: Unknown state U (not yet exposed to microblog rumors), Viewer state V (has viewed microblog rumors), Forwarder state F (forwards and propagates microblog rumors), and Reviewer state R (comments on microblog rumors but does not temporarily propagate). The propagation process is shown in Figure 2 [Figure 2: see original paper].

The interaction rules of the microblog network rumor propagation model described in Figure 2 are as follows:

a) After registering, microblog users follow interesting users through software prompts or search their contact lists, and can choose to follow contact list users who have registered on microblog. After following, users see followed users' microblog information on their homepage. We assume that within unit time, Unknown U browses rumors in the microblog following list with probability , at which point Unknown U converts to Viewer V.

b) We assume Viewer V's reaction after seeing rumors is to forward/propagate or comment, ignoring rumor-ignoring scenarios. Viewers may immediately forward rumor information or, with doubts, first write comments to express attitudes but temporarily not forward, observing other users' reactions. At this point, within unit time, Viewer V converts to Forwarder F with probability or to Reviewer with probability .

c) When commenting on rumor information, Reviewers will see others' comments and attitudes on the event. Assuming positive social reinforcement effects exist—where an event' s occurrence and development are stimulated by social behavior to promote its positive development—as comment numbers increase, within unit time, some Reviewers R will convert to Forwarder F with probability due to conformity or curiosity psychology after seeing others' comments.

d) Under massive information bombardment, Forwarders and Reviewers may forget or lose interest in the rumor information, or see similar rumors posted by other followers. Therefore, we assume that after forwarding/propagating and commenting on rumors for some time, due to forgetting effects and interest decay, or upon re-encountering similar content rumors, Forwarders and Reviewers will convert back to

Unknown and rejoin the network rumor propagation process. At this point, Forwarder F converts to Unknown U with probability within unit time, and Reviewer R converts to Unknown U with probability within unit time.

2.2 Model Construction

Based on the above basic assumptions and interaction rules of the microblog rumor propagation model, the dynamic model of microblog network rumor propagation is constructed as:

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where , , , and represent the numbers of Unknowns, Viewers, Forwarders, and Reviewers at time , respectively; , , , , , and represent the probabilities of Unknown converting to Viewer, Viewer converting to Forwarder, Viewer converting to Reviewer, Reviewer converting to Forwarder, Forwarder converting to Unknown, and Reviewer converting to Unknown, respectively. Specifically, when Unknown U converts to Viewer V, considering network topology, the conversion amount at time is . Assuming the total number of users in the microblog network is , then at any time, .

3 NetLogo-Based Simulation Experiments

Based on the above basic assumptions and propagation characteristics of microblog network rumors, we conduct multi-agent simulation experiments using NetLogo software. Each agent represents a microblog user, with four possible states: Unknown (U), Viewer (V), Forwarder (F), and Reviewer (R). In the initial state, all agents are in the Unknown state.

For microblog network construction, this paper uses a scale-free network growth model to first construct a scale-free network with 1,000 nodes. Figure 3 [Figure 3: see original paper] describes the scale-free network growth process. Figures 3(a)–(e) clearly show the preferential attachment and "rich-get-richer" characteristics of scale-free networks.

The core algorithm for generating scale-free networks is as follows:

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while(n<1000)
    Create a node a, set as Unknown state (white);
    Create connection from node a to node i with probability w, set as green;
    Preferential attachment: probability that a new node connects to an existing node is ,
    where  is the total number of nodes in the network.
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The microblog network rumor propagation simulation experiment rules are: a) Randomly select nodes as initial Viewers. b) At each time step, Viewers accept rumors and become Forwarders with probability or become Reviewers with probability . Reviewers become Forwarders with probability . Then, Forwarders propagate rumors to all connected Unknowns, who become Viewers with probability after browsing the rumor. c) Forwarders and Reviewers convert to Unknowns with probabilities and , respectively. d) Repeat rules b) and c) until no Unknowns remain around any Forwarder.

3.1 Comparison with Real Cases

Sina' s public opinion analysis of Weibo posts about "Jing Tian" from March 27 to April 11, 2018, shows the forwarding volume trend as the red line in Figure 5 [Figure 5: see original paper]. Initially, there were 2 posts on March 27, after which forwarding propagation began. The period from March 27 to 30 was the rapid outbreak phase of rumor propagation, with forwarding numbers increasing rapidly, slowing down after 30 days and gradually stabilizing. For comparison experiments, parameters were set as , and initial propagators were set to 2 based on March 27 propagation volume. The comparison results are shown in Figure 5 [Figure 5: see original paper]. The real data forwarding trend basically matches the simulated data forwarding trend, indicating that the model can better describe real-world network rumor propagation processes, thus demonstrating certain effectiveness.

3.2 Impact of Initial Propagation Node Quantity on Propagation Process

We conducted sensitivity comparison simulation experiments on initial propagation node values, setting initial propagation node quantities to 10, 50, and 100, respectively, conducting three experiments each and recording curves of the four user state transformations. UVFR model propagation results under different initial propagation node quantities in scale-free networks are shown in Figure 6 [Figure 6: see original paper].

In Figure 6(a), when initial propagation node quantity is 10, propagation stabilization time is approximately 1,550 time steps. In Figure 6(b) with 50 initial propagation nodes, stabilization time is about 1,250 time steps. In Figure 6(c) with 100 initial propagation nodes, stabilization time is only about 900 time steps. These results fully demonstrate the promoting effect of initial propagation node quantity on rumor propagation. The concept of "three people make a tiger" aligns with social psychology perspectives on rumor propagation [21]. This conclusion assists official media in effectively eliminating negative impacts of network rumors in microblog social networks.

3.3 Impact of Forwarding Probability on Propagation Process

Similar to the above experiments, we conducted three comparative experiments with different forwarding probabilities, recording curves of the four user state transformations. Initial propagation node quantity was set to 50, and forwarding probability was set to 0.3, 0.5, and 0.8, respectively. UVFR model propagation results under different forwarding probabilities are shown in Figure 7 [Figure 7: see original paper].

In Figure 7(a), when forwarding probability is 0.3, Forwarder proportion at stabilization is about 34%. In Figure 7(b) with of 0.5, Forwarder equilibrium proportion is about 45%. In Figure 7(c) with of 0.8, Forwarder equilibrium proportion is about 47%. Comparative analysis of data shown in Figure 7 indicates that forwarding probability significantly affects rumor coverage range. Larger forwarding probability results in higher Forwarder proportion at equilibrium and greater social impact range, while forwarding probability has less significant impact on time to reach propagation equilibrium.

4 Conclusion

This paper constructed a UVFR rumor propagation model considering rumor propagation characteristics in microblog social networks. The model' s main features are: a) redefining propagation rules and dynamic equations based on microblog propagation mechanisms and network topology, making propagation formulas more consistent with real microblog user habits; b) considering that microblog users may forget or lose interest in certain rumor information under massive information bombardment, thus Forwarders and Reviewers convert back to Unknowns with certain probabilities, allowing propagation processes to continue. In simulation experiments, the multi-agent simulation platform compared propagation effects of initial propagation node quantity and forwarding probability in scale-free networks. Results show that more initial propagation nodes lead to faster rumor spread, and higher forwarding probability results in wider propagation range. As the saying "rumors stop at the wise" suggests, we can reduce initial propagation node quantity and forwarding probability by publishing complete and accurate information, reducing people' s doubts about rumor information, or providing professional explanations for suspicious points in rumors to reduce curiosity. These measures can effectively control rumor propagation in microblog information management.

However, it should be noted that this study of microblog rumors is not complete and has certain limitations. In reality, a single microblog can involve huge numbers of people. Due to simulation software and hardware limitations, generated network scale is restricted, and we can only approximate microblog network rumor propagation processes based on node proportions. Additionally, rumor forms on social networks are often diverse, making it difficult for users to make rational judgments about accepting or rejecting rumors. The number of times users encounter rumors and propagator weights often become important bases for user decision-making. Furthermore, the scale-free network generated in this paper' s simulation experiments is static, with network nodes no longer changing after reaching 1,000, while real online social networks are dynamically changing and not necessarily strictly scale-free [22]. In future research, we will utilize complex network theory and optimal control theory [23,24] to study rumor propagation dynamics on complex networks and network rumor control strategies based on propagation models. Additionally, we will consider more realistic and detailed user psychological states and random user acceptance thresholds, construct dynamic network environments for microblog rumor propagation, and provide suggestions for microblog platforms and official media in monitoring, suppressing, and refuting rumors.

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Note: Figure translations are in progress. See original paper for figures.