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A Novel Approach for Effective Rumor Blocking on Online Social Network

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ABSTRACT

When a rumor breaks out in online social network (OSN), it can lead to significant negative impact on human society, especially in the context of public emergencies, such as pandemic. Toward restraining rumor outbreak in OSN, one of the effective containment measures is to block influential users to minimize the spread of rumors. However, most of previous efforts ignore the imbalance between the cost and effect of rumor suppression. To fill this gap, from the perspective of public opinion crisis, a dynamic rumor spread model called PISIR model is established, which takes into account the overall popularity and individual tendency of rumors. Based on this model, two rumor blocking algorithms considering outbreak threshold and user experience, called 1-Hop and 2-Hop RBOTUE algorithms, are proposed, respectively. In the algorithms, a hyperbolic discount effect-based user experience mode is introduced as the constraint to ensure the user experience in OSN, then the blocking strategy is implemented on the selected subset of nodes to keep the rumor spread scale always below the outbreak warning line. The proposed algorithms can achieve better blocking performance with less restraining cost of rumors in mainstream social networks, and the two algorithms also have different adaptability for different OSNs.

Index Terms : Online social network (OSN), outbreak threshold, public opinion crisis, rumor blocking, user experience.

I. INTRODUCTION

SOCIAL media, such as Twitter, Facebook, Sina Weibo, and WeChat, have become the main platforms for users
to access information, spread information, and communicate with friends [1]. Users establish connections with each other through the platforms provided by social media, and then form an online social network (OSN) [2]. However, the popularity and openness of OSN platforms, unfortunately,turns out to bea double-edged sword,

which not only provides people with convenient channels of information interaction, but also reduces the costs of spread misinformation and then become the breeding.

A rumor is commonly defined as a malicious, unverifiable, or deliberately false statement relevant to an event [3]. For firms,the spread of rumors can result in the misalignment of business investments [4], [5], confusion in operation, undermining pro-ductivity [5], or loss of brand value [6], [7], and for the whole social system, rumors can drive the misallocation of resources during terror attacks and natural disasters, misinformed elec- tions, and even social disorder [4]. For instance, in 2013, a falsetweet about Barack Obama injured in an explosion led to wiping out $130 billion in stock value [4]. In January 2020, a rumor that the base station of 5G could cause the spread of the 2019 novel coronavirus pneumonia epidemic (COVID-19) became the hot topic on Twitter within the United Kingdom. Instigatedby this rumor, some panicked people torched a large numberof 5G masts, causing huge economic losses to enterprises and mobile phone users [8]. In 2008, the fake news about Steve Jobs suffering a heart attack was forwarded, causing Apple's shares to fall 10% in 10 min [7]. During COVID-19 [9], [10], the People's Daily reported on January 31, 2020 that Shuang- Huang-Lian oral liquid can inhibit the COVID-19. Overnight, the medication was sold out, and even veterinary medication ofthe same name came in a climax of sales [11]. Meanwhile, theflooding of various negative public opinions throughout OSN platforms, which had a negative impact on epidemic prevention and control, is also called Infodemic (Information+Epidemic) by World Health Organization [12]. The phenomenon of "rumors flooding" in OSN greatly tests capabilities of social governance of government agencies and crisis response of corresponding firms [13]. Identifying rumorsand restraining the spread of rumors are not only the critical issue for government agencies to govern cyberspace [13], but also the important factors affecting firms to formulate brand and engineering management strategies [6], [7]. Therefore, it is a key challenge for OSN platforms to implement effective measures to identify rumors and restrain the spread of rumors [14].

There are several ways to identify rumors in OSN. First, a family of effective rumor detection algorithms have been pro- posed which can automatically detect rumor by computational approach [15], [16] and machine learning techniques [17], [18]. Second, government agencies also can release evidence to clarify some rumors by official channels. Besides, some independent fact-checking organizations, such as snopes.com, politifact.com, factcheck.org, truth or fiction.com, hoax-slayer.com, and ur- banlegends.about.com, can provide valuable resources to verify news or claims and then report rumors on their websites [4]. In view of this, the implementation of rumor restraining measuresis based on the premise that the news has been judged as a rumor.To deal with the serious negative effects brought by rumors, OSN platforms have explored various interventions, both preventive (i.e., restraining rumors from the source) and corrective (i.e., detecting and removing rumors already in circulation)[19], and the specific measures range from labeling or cen-soring articles that have been identified as containing false information [5] to blocking or removing "dangerous accounts" [20], [21].

Rumor blocking, which refers to cutting off the spread link of rumors by removing the user nodes or the connections between users in OSN, is regarded as an effective measure to restrain the spread of rumors. Therefore, in the field of cyberspace gover- nance, it has become a critical issue that designs a scientific and reasonable rumor blocking strategy in OSN, and most of existing rumor blocking strategies have faced a major challenge to deal with the imbalance between the cost and the effect of rumor restraining. Aiming at this problem, this article presents two rumor blocking algorithms in OSN, and the main contributions of the article are as follows:

1) Based on SIR model, a dynamic rumor spread model, called PISIR model, is constructed considering both the overall popularity of rumors at macro-level and the indi- vidual spread tendency of rumors at micro-level. Based on the analysis of a large number of rumor data, it is found that the overall popularity of some rumors has multipeak char- acteristics. Therefore, a multipeak Gaussian distribution is proposed to simulate the overall popularity of rumors, which conforms to the actual situation of rumor spread in OSN.
2) Combined with individual characteristics of online users and structure characteristics of OSN, a hyperbolic dis- count utility function is proposed to construct the user experience model. Taking the user experience model as constraint, a subset of blocked nodes is selected, and then all connections between the blocked nodes and other nodes are removed.
3) From the perspective of public opinion crisis, the outbreak threshold of rumor spread is proposed as a constraint of the rumor blocking algorithm. The proposed outbreak threshold is a new evaluation methodology in an orig- inal perspective. Under the constraint conditions, two rumor blocking algorithms are proposed, called 1-Hop and 2-Hop RBOTUE algorithm, respectively. The two algorithms can ensure that the rumor spread range is always lower than the rumor outbreak threshold within the observation time window.
4) The performance of the proposed RBOTUE algorithms is verified by simulation experiments in various OSNs, and the influence of different factors on the performance of the RBOTUE algorithms is further analyzed which can provide the decision-making basis for firms, government agencies, and OSN platforms to effectively control rumor spread.

II. RELATED WORKS

It is the basis of designing effective rumor blocking strategies to construct a rumor spread model which can reveal the mech- anism of rumor spread. At present, the study of rumor spread model is separated into two general classes: the macro level and the micro level. At the macro level, some studies indicate that the spread of rumors have a similar global tendency with general topics. Yang et al. [22] proposed the K-SC clustering algorithm to analyze the topic popularity in OSN. Regardless of the various network platforms, the positive and negative polarity of topics, and the different scales of time series variation, they believed that the topic spread curve in OSN had a similar shape with three stages of rise, peak, and decline. Based on the statistical analysis of microblog information data, Liu et al. [23] thought that the life cycle of a tweet basically divided into the boom period and decline period, in addition to the incubation period and secondary growth. The above studies reflect the global popularity and evolution pattern of rumors in OSN. However, they ignore the state transition process of individual at the micro level, so it is impossible to effectively reveal the dy- namic mechanism of information spread and evolution in OSN. At the micro level, empirical studies showed that the process of information spread in social networks was very similar to epidemic process [24]. Based on this fact, some scholars built various information spread models based on epidemic dynamics to reveal the diffusion patterns of information in social networks [25], [26]. Epidemic dynamics simulates the user's state transi- tion process by constructing differential equation models, and then to predict the outbreak and spread laws of epidemics. The classic epidemic models include SIR, SI, SIS, and SIRS. In 1965, Daley and Kendall [27] pioneered the application of epidemic dynamics in homogenous network to the study of rumor spread. Subsequently, scholars proposed a series of rumor spread models based on homogenous networks, and analyzed the influence of different parameters in the model on the popularity of rumors [28]. However, a large number of empirical studies showed that OSN was not a homogeneous network, but a networkwith typical heterogeneous characteristics [29]. In view of this, scholars applied complex network theory to the study of rumor spread dynamics in OSN, and put forward a large number of rumor spread models in complex network environments, and focused on analyzing the comprehensive impact of the basic model parameters and network structure on the spread process of rumors [30], [31]. However, the above models are mainly based on the rough mean field theory to analyze the dynamics of rumor spread, that is, differential equations are applied to calculate the number of infected nodes in the network, and often ignore the influence of the infection probability among individuals on the spread process of rumors. Therefore, the above models cannot determine the "when" and "which" nodes need to be controlled in order to effectively restrain the spread of rumors [32].

Rumor blocking is an effective measure to minimize the im- pact of malicious rumors, which mainly limits the spread range of rumors in the network by deleting some links between nodes or removing some nodes, that is, deleting all the relationship links between the target node and other nodes in the network. Therefore, the rumor blocking is usually equated to the problem of minimizing negative impact of rumors, and finding the most influential node is the key point to the design of blocking strategy [33]. In recent years, scholars mainly applied static measurement methods, e.g., network topology, to determine the influence of nodes in the spread process of rumors. For example, Yang and Leskovec [34] used the degree of nodes as a measurement index in terms of influential identification, Zhang et al. [35] used the betweenness centrality of nodes to characterize the spread ability of rumors,

and Yang and Leskovec [36] deployed the location of blocked nodes based on the kernel number. Basaras et al. [37] simulated the process of malicious information diffusion based on SIR model, and adopted continuous dynamic block- ing to minimize the range of malicious information diffusion. Yan et al. [38] defined the rumor effect minimization prob- lem(MIR), which aims to minimize the sum of the activa- tion probabilities of rumor source nodes by selecting the set of blocked nodes, and then proposed a two-stage method to generate the candidate set and select the set of blocked nodes (GCSSB). Hosni et al. [39] gave a multirumor propagation model HISBM, and proposed a dynamic blocking period method to minimize the impact of multiple rumors in OSN by blocking the most influential nodes on rumor propagation. Zhang et al.
[40] proved that rumors spread is mainly driven by browsing behaviors, so they constructed a rumor spread model based on the random walk model, and then proposed a rumor blocking algorithm (BUK) considering users' browsing behaviors.

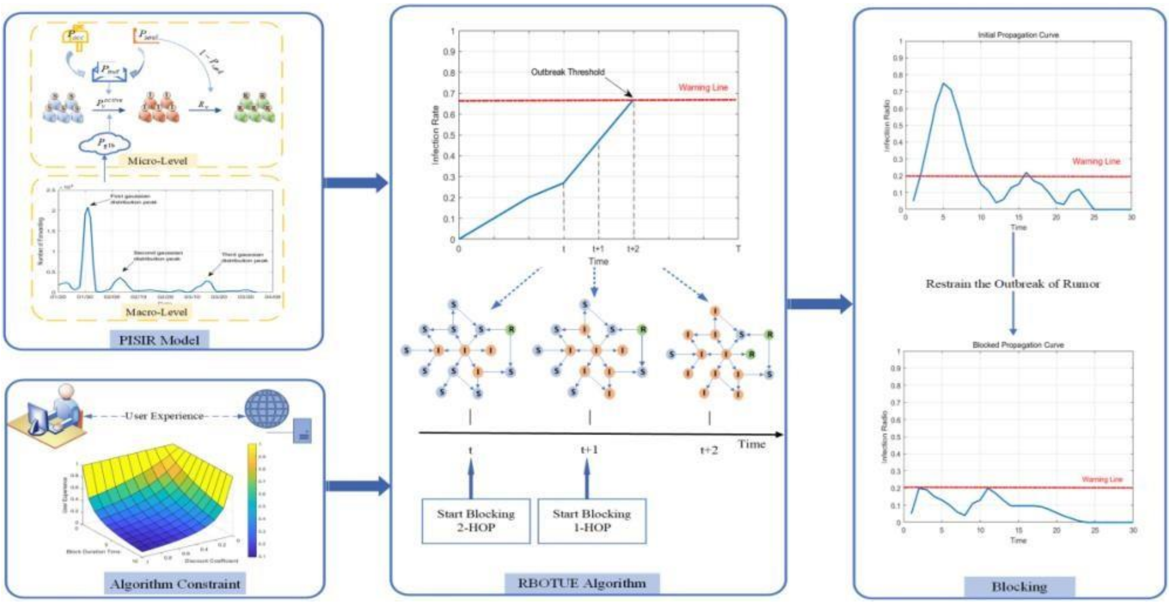

Fig. 1. RBOTUE algorithm framework

III. ALGORITHM FRAMEWORK AND MOTIVATION

A. Algorithm Framework

The RBOTUE algorithm framework is described, as shown in Fig. 1. RBOTUE algorithm aims to dynamically establish the blocked node set and block them. In establishing the blocked node set, PISIR model is used to calculate the rumor infection rate at the next moment, and the appropriate blocked nodes are selected according to the user experience model.

B. Motivation

The classic SIR model is one of the most widely applied rumor spread models. However, with the development of OSN, many new features of rumor spread have emerged. Therefore, many scholars are still committed to studying the rumor spread model based on SIR, in order to more accurately characterize the rumor spread process in OSN [24]–[26], [30]–[33], [41], [42]. According to the analysis of rumor spread models in Section II, we find that the existing rumor spread models either analyze the change tendency of rumor from a macro perspective, ignoring the individual state transition process at the micro-level [22], [23], or analyze the influence of different influencing factors on individual rumor forwarding from a micro perspective, ignoring the overall evolution law of rumor spread [24]–[31]. To this end, based on SIR model, a dynamic rumor spread model is constructed, considering both overall popularity of rumors at macro-level and individual spread tendency of rumors at micro-level. In order to more accurately characterize the overall popularity of rumors, we have fitted the collected COVID-19 rumor data, and found that the multipeak Gauss distribution can more accurately simulate the overall popularity of rumors. The proposed model lays the foundation for design of rumor blocking strategies.

The main purpose of this article is to provide scientific and reasonable rumor governance measures and managerial impli- cations for the relevant government departments or firms. In Section II, the importance of rumor blocking algorithms has been introduced, and the existing rumor blocking algorithms have been listed and analyzed. The existing studies all equate the rumor blocking to the problem of minimizing the influence of rumors [33]–[40]; however, they have lost sight of the restraining costs of implementing various blocking strategies. Actually, the implementation of coercive measures for blocking users in OSN can easily arouse users' resentments and complaints, which not only reduces the information transmission performance of the OSN platform, but also reduces the user's satisfaction and stickiness for OSN platforms [43], [44]. Including OSN plat- forms, the firms attach great importance to user's satisfaction and stickiness, which are regarded as the basis for firms to create value [45]. Moreover, the user experience is the decisive factor for user's satisfaction and stickiness. Therefore, for users who do not know that the information is a rumor, how to balance the cost and the effect of restraining rumor is a very critical issue.

Moreover, in the OSN platform, the characteristics of open- ness, interactivity, and convenience make it difficult to com- pletely eliminate rumors by using mandatory intervention mea- sures. The underlying aim of cyberspace governance is to curb the diffusion of rumors or negative public opinions on a large scale in a short time period, so as to avoid triggering public opinion crisis. Motivated by this fact, we assume that rumors need to reach a certain amount of diffusion in order to "break out" in OSN, and then the warning line for the outbreak of rumors is introduced, called outbreak threshold in this article. Inspired by the idea of greedy algorithm, two rumor blocking algorithms,

1-Hop and 2-Hop RBOTUE algorithms, are presented in this article, which aim to restrain the rumor spread range below the outbreak threshold.

In rumor blocking algorithms, the critical issue is how to select "dangerous nodes," i.e., the nodes that need to be blocked [37]–[41], [43], [44], [46], [47]. As stated above, the imple- mentation of rumor blocking strategy will prevent users from accessing information normally for a period of time, which in- evitably sacrifices the user experience and limits users' freedom of speech in OSN platform. Hence, user experience and users' freedom of speech needs to be considered as the additional constraints of rumor blocking algorithm. In view of this, in this article, user experience is taken as the constraint of the algorithm, and the aim is to curb the spread of rumors without sacrificing the user's freedom of speech as far as possible. Motivated by the discount effect in Economics, a hyperbolic discount utility function is introduced to characterize user experience combined with individual characteristics of online users and structure char- acteristics of OSN. Finally, in order to verify the effectiveness of the rumor blocking strategy developed in this article, simulation experiments need to be carried out in several different social network environments.

IV. PRELIMINARIES

A. Online Social Network

A large number of empirical studies have shown that OSN is not a homogeneous network, but a network with typical heterogeneous characteristic [29]. In order to be more realis- tic, we regard OSN as a directed heterogeneous network and describe OSN as a directed graph DG = (V, E), where V is a set of user nodes and E represents a set of connected edges between nodes. In the article, a user node refers to a network account. If a person has multiple accounts. However, users react in different ways to the same rumor due to individual differences, resulting in different state transition probabilities. For example, in a heterogeneous network, the greater the appeal of the rumor to the user, the stronger the willingness of user to forward the rumor; and the higher the attention of user to the rumor, or the greater the influence of the neighboring nodes spreading the rumor, the greater the transition probability of the user from S→I. Besides, the transition probability from I R is affected by user's recognition ability and interest in rumors. The individuals with high recognition ability will quickly change their state, and even transform intoR at the beginning of rumor spread. Therefore, in heterogeneous networks, the spread probability and recovery probability in SIR model need to be further analyzed.

C. Energy Model

In the field of physics, annealing and cooling refers to the process that the temperature of a high-temperature object grad- ually decreases, that is, the energy within the object gradually declines, and eventually maintains a stable state [48]. Due to the novelty seeking psychology of the public, malicious rumors will be spread rapidly in the crowd once they are created. These unconfirmed rumors are easy to attract people's attention, and appeal most to the users who exposed to these rumors for the first time, then these users are more prone to forward it. However, over time, the appeal of rumors gradually subsides, which leads to users' willingness to forward rumors fade away. In light of the above analysis, the change in the attraction of rumors to individuals during the spread process can be modeled as a decline process of energy over time. Hence, based on the principle of simulated annealing, an energy model [49] is applied to describe the changing process of rumor attraction when constructing rumor spre ad model, as follows:

At0

$$At(t) = C \times Dout \times lg(10 + (t)) \qquad (1)$$

be regarded as multiple user nodes. In E, (u, v) E indicates the directed edge from the node u to v, where (u, v) = 1 indi-cates that the edge (u, v) exists, that is, there is an information transmission path u→v between the node u and v; (u, v) = 0

indicates that the edge (u, v) does not exist, that is, there is not an information transmission path u v i→n the network. The number of connected edges where the node u directly points to other

nodes is called the out-degree of the node u, which is expressed as Doutu. The number of connected edges where other nodes directly point to the node u is called the in-degree of the node u, which is expressed as Dinu. If the out-degree of node u is larger, it may send information to more neighbor nodes. If the in-degree of node u is larger, it may obtain information from more neighbor nodes.

B. SIR Model

In SIR model, the individuals in the network are divided into three types of states: susceptible state (S), that is, people who have not heard rumors; infected state (I), that is, people who believe and spread rumors; and recovered state (R), that is, people who are removed from the network and no longer participate in the spread process of rumors, including those who believe in rumors and no longer spread them, and those who are completely uninterested in rumors [27]. In the classic SIR model, the rumor spread probability of S→I and the recovery probability of I→R are usually set to be constants.

where C represents the credibility of rumors; Dout represents the out-degree of node; At0 is the initial attraction of rumor to users; t is the time step; and At(t) represents the attraction of rumor to users at time t. The larger the value of Dout is, the more “fans” the node has in OSN, accordingly, in order to attract the attention of “fans,” the node has a more positive attitude toward sharing information (that is, forwarding rumors). The larger the value of At(t) is, the more attractive the rumors to user has and the stronger the user’s willingness to forward is. At the moment when the user has just changed from the susceptible state S to the infected state I, his/her willingness to express opinions to others (that is, the spread tendency of rumor) is the strongest, and it can be considered that the user’s “energy” is strongest at this time. Being attracted by other “new stories,” the user’s attention will shift, and his/her willingness to forward the rumor will gradually decrease, and eventually the user forgets the rumor. Thus, the user will no longer participate in the spread of the rumor in the network, that is, change from I to R.

D. Ising Model

In OSN, individual rumor spread behavior is not only affected by the attraction of rumor, but also affected by the “overall atmosphere” formed during rumor spread. Therefore, a rumor spread model that combines individual propagation tendency and overall popularity of rumors can describe the process of rumor spread in OSN more realistically.

Ising model is a widely applied model in the field of physics, which briefly describes the ferromagnetic concept in physics.

Specifically, Ising model describes a physics phenomenon that when the atomic spin array is consistent with the way that

the magnetic moments associated with them all point in the same direction, it will create a macroscopic magnetic moment [50]. Ising model contains micro and macro parts: the micro part represents the spin alignment of each atom, that is, local or individual behavior; the macro part represents the external magnetic moment, that is, global or collective behavior. Based on its inherent properties, Ising model can be generalized to other similar scenarios.

In this article, Ising model is adopted to simulate the spread process of rumors in OSN, which combines the spread proba- bility of rumors based on individual tendency at micro level and the overall atmosphere of rumors diffusion at the macro level, so as to determine the probability of successful propagation and recovery of rumors between nodes u and v.

E. Variable Notations and Definitions

The main variable notations and definitions used throughout the article are summarized in Table I.

Among Table I, G represents the candidate set of blocked nodes, including all nodes in the OSN except official media; and RT represents the outbreak threshold, which refers to the rumor outbreak warning line, and its value range is (0, 1).

V. PISIR MODEL

A. Individual Spread Tendency of Rumors

Between neighbor nodes (u, v), the successful spread of rumors includes two steps: I state node u is attracted by the rumor and sends the rumor to its neighbor node v; the neighbor node v in the S state accepts the rumor, and its state changes

from S to I. The specific analysis is as follows:

1) u is a I state node at time t 1−. From the previous analysis,we can see that the attraction of rumors will gradually fade in the spread process as time goes by, so that the probability of nodes forwarding rumors also decreases accordingly.

Hence, according to (1), the probability Pu that the node initial probability of nodes sending a rumor; tu represents time when node u is changed from S to I, whicahct is the infected.

CONCLUSION

Restraining rumor spread in OSN is a crucial issue in the field of online rumors governance in recent years. In order to characterize the spread process of rumors more accurately, weresearched deeply the rumor information in Sina Weibo during the COVID-19 epidemic period, and found that the spread pro- cess of rumors exhibits multipeak characteristic. Therefore, the multipeak Gaussian distribution is used to simulate the overallpopularity of rumors in this paper. Based on SIR model, a dy- namic rumor spread model, PISIR model, is constructed, whichconsiders both macrolevel and microlevel spread processes.To reduce the sudden social and economic impacts of rumor spread on relevant government departments or firms, 1-Hop RBOTUE and 2-

Hop RBOTUE algorithms are proposed from the perspective of public opinion crisis, which take into accountthe user experience in the process of blocking nodes and the balance between the cost and effect of restraining rumors. TheRBOTUE algorithms provide a feasible scheme for OSN sites to restrain rumor spread.

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