Modeling Information Propagation Driven by Attraction and Drag on Social Network

Jun Cao, Fuzhong Nian and Yabing Yao

January 10, 2020

Modeling Information Propagation Driven by Attraction and Drag on Social Network

Jun Cao
School of Computer & Communication
Lanzhou University of Technology
Lanzhou 730050, China
cjun_ambition@163.com

Fuzhong Nian*
School of Computer & Communication
Lanzhou University of Technology
Lanzhou 730050, China
gdnfz@lut.edu.cn

Yabing Yao
School of Computer & Communication
Lanzhou University of Technology
Lanzhou 730050, China
yaoyabing@lut.edu.cn

***Abstract*—The information propagated on the social network is affected by the intimate degree of the relationship among individuals. It's found that the different relationship exists in individuals according to analyzing the social network. In this study, a network model, including explicit (intimate) edge and implicit (non-intimate) edge, is constructed. Based on this network model, an information propagation mechanism driven by the attraction and drag is proposed, the explicit attraction and implicit attraction generated by the infected individuals to ignorant individuals during the process of the information propagation is studied, so is the explicit drag and implicit drag generated by the recovered individuals to ignorant individuals researched. The simulation experiment found that the major factor of information propagation affected is the explicit attraction and drag, and implicit attraction and drag have few effects on information propagation. Based on the above results, a rumor propagation restrained strategy, which reduces the explicit attraction and increases explicit drag of ignorant person, is designed in this paper. The experimental results clearly revealed the effectiveness of the proposed strategy and its important practical significance for realistic society.**

Keywords—Information Propagation, Explicit and Implicit, Attraction and Drag, Rumor Restrain Strategy

I. INTRODUCTION

Universal gravitation is a general law of mutual effect among objects[1-3], for instance, the falling apples and the moving planets. Actually, except for objects, certain attraction and drag, similar to the universal gravitation, exists in the human relationship, which leads people to tend to certain state. The information propagation in the social network is a phenomenon where the attraction and drag are existed. For example, when you find that intimate friends in your social circle are forwarding and following a certain topic, there is an invisible attraction generated for you, and you are driven to forward and follow the topic. However, ordinary friends have few attraction to you unless you are interested in this topic. On the contrary, if your intimate friends in social circle know the information and do not spread, and only ordinary friends forward the information, you will tend to not pay attention to this information or reprint after you understand. This phenomenon is closely concerned with social contact. The core value in this paper is to research the propagation mode of mutual attraction and drag, and to excavate the social problem corresponding to the model.

The research of the information propagation and rumor control in the social network is a popular topic and various researchers have had in-depth research on the study[4-7]. [8-10] analyzed the characteristics of the social network, studied the properties of the network topology and discovered various topological characteristics, which affected the information propagation. [11-13] studied the spread of information on social networks, which is found that the effects of special nodes in the network on the information propagation. Afterwards, strategies to curb the spread of rumors are proposed from the perspective of infectious disease immune strategies[14-16]. The information propagation is not only related to individuals, but the relationship between individuals is also an important factor to measure the ability of information propagation. [17-19] studied the strength of connected edges and the weight of connected edges between network nodes to analyze the importance of connected edges to propagation. Of course, there are various scholars who have studied the information propagation mechanism and rumor control, and have proposed high-quality information propagation and rumor control models such as ILSR[20-23]. In the process of information propagation, the factors that determine the radius of information propagation are not only the network topology and the propagation mechanism, but also the inherent attributes of the individuals involved in the information propagation. [24-28] studied the influence of factors based on the mass-following psychology and the memory rule of Hermann Ebbinghaus such as the dynamic propagation probability and dynamic recovery probability on information propagation. According to the network data mining[29-31], the nature of potential community structures in social networks is studied and the process of predicting network structure evolution is proposed. Although the above scholars have made outstanding contributions to the research of information propagation and rumor communication in social networks, the impact of different social relationships on information propagation is still not considered, and the invisible attraction and drag between individuals are not found, which have affected on information propagation. Furthermore, the control strategy based on rumors spread from intimate friends is not considered. Not only the influence of intimacy and alienation on information propagation are studied in this paper, but also considers the information propagation mechanism driven by attraction. Moreover, an effective rumor propagation restrained strategy is

* Corresponding Author

proposed and has made significant contributions to the research on information propagation in social networks.

The contributions in this paper are summarized as follows. (1) a novel network model with explicit and implicit edge is proposed in section 2. (2) the model of information propagation driven by the explicit acting force and comprehensive acting force are established, respectively. Furthermore, the propagation process of the two acting forces for information is simulated with experiment. (3) an effective rumor propagation restrained strategy is designed in section 3 and the effectiveness of the strategy is verified.

II. NETWORK MODELING

Interpersonal social network is not a network with the identical connection attributes. For example, there are family relationships, friend relationships, and colleague relationships among individuals. A kind of network model of relationships, including intimate and non-intimate relationship, is constructed based on the differences of relationships existed in the individuals in this paper. In the network, the intimate relationship is named the explicit relationship and the non-intimate relationship is named the implicit relationship.

Definition 1. Let $G=(V,E)$ represents an explicit-implicit network with two types of edges.

Where, $V=\{v_1,v_2,v_3,\cdots,v_n\}$ represents the set of nodes of G. $E=E_E\bigcup E_I$ represents the set of edges of G and the number of E is $|E|$. $E_E=\bigcup_{v_i,v_j\in V,\widehat{(v_i,v_j)}=0}(v_i,v_j)$ represents the set of explicit edges consisted with 30% edges of each node degree, and the number of E_E is $|E_E|$. $E_I=\bigcup_{v_i,v_j\in V,\widehat{(v_i,v_j)}=1}(v_i,v_j)$ represents the set of implicit edges consisted with 70% edges of each node degree, and the number of E_I is $|E_I|$. $\widehat{(v_i,v_j)}\in\{0,1\}$ represent the edge marks of node i to neighbor node j. The network G_E is composed of explicit edges and linked nodes by explicit edges. The network G_I is composed of implicit edges and linked nodes by implicit edges. The explicit-implicit network schematic diagram is showed following Fig. 1.

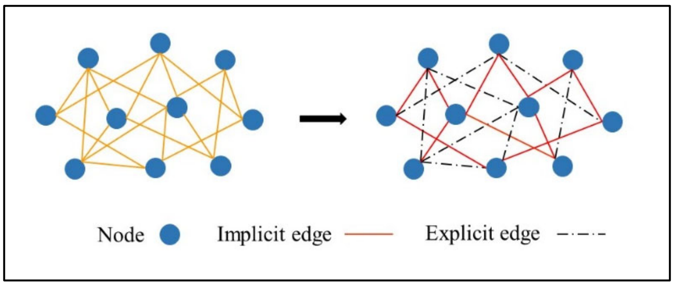

Fig. 1 The schematic diagram of an explicit-implicit network

III. THE PROCESS OF PROPAGATION

A. SIR Model Driven by Explicit Attraction and Drag

During the process of the information propagation in the social network, information is usually initiated by certain individual or intimate circle. After propagated for a while, the number of the people who know the information in the intimate circle is accumulated to a certain number, the influence of the information is gradually increased and burst to affect the entire social network. For example, the academic cheating by some celebrities on February 2019 was early focused on and propagated in the academic circle. Then, with the people who knew the information reaching a certain number, the event was propagated and sensationalized in the social network. In a word, the process of the information propagation is the accumulated procedure of network scale. When an information is propagated by fewer people, implicit relationship is not activated to participate in the propagation, namely, $\rho^E<\rho^0$, $G=G_E$. When an information is propagated by most people, implicit edge is activated to participate in the dissemination, namely, $\rho^E\geq\rho^0$. $G=G_E\cup G_I$, where ρ^E represent the density of spreaders in the explicit network and ρ^0 is a density threshold for implicit edge activated.

When the information is propagated, individual is always affected by the surrounding neighbors, especially the intimate friends, which drive the individual to accept and propagate the information or reject and stagnate the information. In this paper, nodes in the network are marked into three states. Ignorant state means that the node is ignorant of the information, infected state means that the node knows the information and propagate it, and recovered state means that the node knows the information and is ignorant of propagating it. Whether the implicit relationship is activated by the propagation, the intimate friends who are infected state around individual have attractive to individual and the individual is driven to accept and propagate information. Therefore, the close friends are considered to generate explicit attraction on individual. On the contrary, the close friends who are recovered state around individual prevent individual from accepting and propagating information. Thus, the close friends are considered to generate explicit drag on individual. The individuals who are ignorant of information are subjected to explicit attraction and drag. The model of explicit attraction and drag is shown in Fig.2.

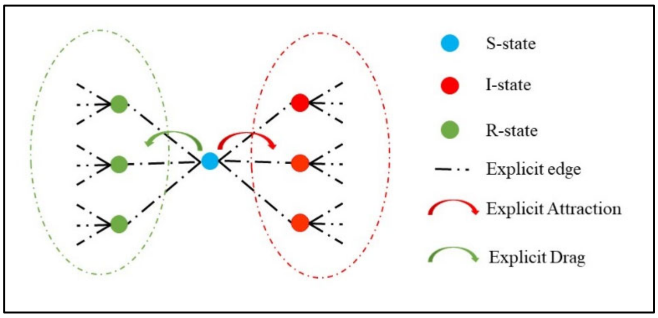

Fig. 2 Model of Explicit Attraction and Drag

Definition 2. Let

$$\beta_{i,E}=\sum_{j=1}^{n_{i,E}}\binom{n_{i,E}}{j}\left(\frac{d_{I,E}}{d_{i,E}}\right)^{j}\left(1-\frac{d_{I,E}}{d_{i,E}}\right)^{n_{i,E}-j} \tag{1}$$

represents the explicit attraction of explicit spreaders j to individual i unknown information at time t.

Definition 3. Let

$$\gamma_{i,E} = \sum_{k=1}^{n_{i,E}} \binom{n_{i,E}}{k} \left(\frac{d_{R,E}}{d_{i,E}}\right)^{k} \left(1-\frac{d_{R,E}}{d_{i,E}}\right)^{n_{i,E}-k} \tag{2}$$

represents the explicit drag of explicit silencer k to individual i unknown information at time t.

Where $n_{i,E}$ represents the number of explicit neighbors of node i, j represents the number of the explicit infected node among explicit neighbors of node i, $d_{i,E}$ represents the sum of explicit degree of all explicit neighbors linked by node i, $d_{I,E}$ represent the sum of explicit degree of all explicit infected node linked by node i. k represents the number of the explicit recovered node linked by node i, $d_{R,E}$ represents the sum of explicit degree of all explicit recovered linked by node i.

The information propagation mechanism is similar to the infectious disease propagation mechanism. According to the classical mathematical models of epidemic diseases, SIR model[32, 33], the dynamic model of information propagation based on the explicit attraction and the explicit drag is obtained.

$$\begin{cases} \dfrac{ds(t)}{dt} = -\left(\beta_0 + \beta_{i,E}\right) s(t) i(t) \\ \dfrac{di(t)}{dt} = \left(\beta_0 + \beta_{i,E}\right) s(t) i(t) - \left(\gamma_0 + \gamma_{i,E}\right) i(t) \\ \dfrac{dr(t)}{dt} = -\left(\gamma_0 + \gamma_{i,E}\right) i(t) \end{cases} \tag{3}$$

Where $s(t)$ represents the proportion of ignorant individual at t moment， $i(t)$ represents the proportion of infected individual at t moment, $r(t)$ denotes the proportion of recovered individual at t moment. β_0 is the initial infectious proportion of individual, $\beta_{i,E}$ is the infectious proportion driven by the explicit attraction, γ_0 is the initial proportion of individuals who have no interests and forget the information, $\gamma_{i,E}$ denotes the obstructive proportion caused by the explicit drag acted on the information propagation.

Definition 4. Let $\lambda_{i,E}(t)$ represents the explicit effective attraction of node i at time t. Let λ_E represents the average explicit effective attraction of ignorant node of G.

When the information is propagated, explicit effective attraction acted on the node i at t moment is $\lambda_{i,E}(t) = \dfrac{\beta_0 + \beta_{i,E}(t)}{\gamma_0 + \gamma_{i,E}(t)}$. Since each node has an identical β_0 and γ_0, the explicit effective attraction acted on node i at t moment is approximate to $\lambda_{i,E}(t) = \dfrac{\beta_{i,E}(t)}{\gamma_{i,E}(t)}$, the network average explicit effective attraction acted on all ignorant individuals in the network is $\lambda_E = \dfrac{1}{N}\sum_{i=1}^{N} \dfrac{\sum_{j=1}^{n_{i,E}} \frac{(jp_i)^{n_{i,E}}}{n_{i,E}!} e^{-jp_i}}{\sum_{k=1}^{n_{i,E}} \frac{(kq_i)^{n_{i,E}}}{n_{i,E}!} e^{-kq_i}}$, which represents that there have averagely λ_E explicit infected node around ignorant node to attract it and prompt it to accept and propagate information. N is the number of ignorant nodes, $p_i = \dfrac{d_{I,E}}{d_{i,E}}, q_i = \dfrac{d_{R,E}}{d_{i,E}}$.

Proof:

From (1) and (2):

Let $\dfrac{d_{I,E}}{d_{i,E}} = p_i, \dfrac{d_{R,E}}{d_{i,E}} = q_i$,

The explicit effective attraction of node i is:

$$\lim_{t\to\infty} \lambda_{i,E}(t) = \lim_{t\to\infty} \frac{\beta_{i,E}(t)}{\gamma_{i,E}(t)}$$

$$= \lim_{t\to\infty} \frac{\sum_{j=1}^{n_{i,E}} \binom{n_{i,E}}{j} \left(\frac{d_{I,E}}{d_{i,E}}\right)^{j} \left(1-\frac{d_{I,E}}{d_{i,E}}\right)^{n_{i,E}-j}}{\sum_{k=1}^{n_{i,E}} \binom{n_{i,E}}{k} \left(\frac{d_{R,E}}{d_{i,E}}\right)^{k} \left(1-\frac{d_{R,E}}{d_{i,E}}\right)^{n_{i,E}-k}}$$

$$= \frac{\sum_{j=1}^{n_{i,E}} \frac{(jp_i)^{n_{i,E}}}{n_{i,E}!} e^{-jp_i}}{\sum_{k=1}^{n_{i,E}} \frac{(kq_i)^{n_{i,E}}}{n_{i,E}!} e^{-kq_i}}$$

The explicit mean effective attraction of network is:

$$\lambda_E = \frac{1}{N}\sum_{i=1}^{N} \lambda_{i,E}(t) = \frac{1}{N}\sum_{i=1}^{N} \frac{\sum_{j=1}^{n_{i,E}} \frac{(jp_i)^{n_{i,E}}}{n_{i,E}!} e^{-jp_i}}{\sum_{k=1}^{n_{i,E}} \frac{(kq_i)^{n_{i,E}}}{n_{i,E}!} e^{-kq_i}}$$

B. *SIR Model Based on Comprehensive Attraction and Drag*

Above contents has studied the attraction and drag of intimate friends to individual. In fact, after the implicit edge is activated by the information propagation, not only are the close friends affected at the information propagation, but also the other friends have an impact on it. The influence is not ignorant. In this section, the implicit relationship activated by the information propagation in the social network, the explicit and implicit comprehensive attraction and comprehensive drag acted on the individual in the social network are studied and the influence to the information propagation is discussed. The model of comprehensive attraction and drag acted on the ignorant individual is shown in Fig.3.

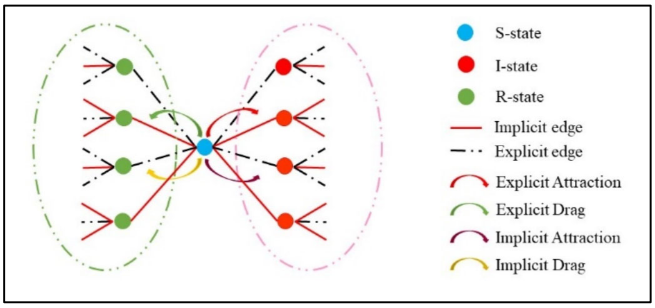

Fig. 3 Model of Comprehensive Attraction and Drag

Definition 5. Let

$$\beta_{i,I} = \sum_{m=1}^{n_i - n_{i,E}} \binom{n_i - n_{i,E}}{m} \left(\frac{d_{I,I}}{d_{i,I}}\right)^{m} \left(1-\frac{d_{I,I}}{d_{i,I}}\right)^{n_i - n_{i,E} - m} \tag{4}$$

represents the implicit attraction of implicit infected node m to ignorant individual i at time t

Definition 6. Let

$$\gamma_{i,I} = \sum_{m=1}^{n_i - n_{i,E}} \binom{n_i - n_{i,E}}{n} \left(\frac{d_{R,I}}{d_{i,I}}\right)^{n} \left(1-\frac{d_{R,I}}{d_{i,I}}\right)^{n_i - n_{i,E} - n} \tag{5}$$

represents the implicit drag of implicit recovered node n to ignorant individual i at time t.

Where n_i represents the number of all neighbors of node i, $n_{i,E}$ represents the number of explicit neighbors of node i, m represents the number of the implicit infected node linked by node i, $d_{i,I}$ represents the sum of implicit degree of all implicit neighbors linked by node i, $d_{I,I}$ represent the sum of implicit degree of implicit infected node linked by node i. n represents the number of the implicit recovered node linked by node i, $d_{R,I}$ represents the sum of implicit degree of all implicit recovered node linked by node i.

The information, which is started to propagate, is that the initiator of the information first spreads the information to close circles, that is, $\rho^E < \rho^0$, $G = G_E$. The formula of the propagation mechanism is revealed in (3). The implicit relationship is activated until the number of people who obtain the information in the close circle is rise to a certain number and the information is burst and propagated, namely, $\rho^E \geq \rho^0$, $G = G_E \cup G_I$. At the moment, not only are the explicit attraction and drag considered in the information dissemination mechanism, but also the implicit attraction and drag are considered. The node is subjected to two types of attractive and drag. The formula of propagation mechanism based on the comprehensive acting force is shown in (6).

$$\begin{cases} \dfrac{ds(t)}{dt} = -\beta s(t) i(t) \\ \dfrac{di(t)}{dt} = \beta s(t) i(t) - \gamma i(t) \\ \dfrac{dr(t)}{dt} = \gamma i(t) \end{cases} \left| \begin{array}{l} \rho^E < \rho^0, \begin{cases} \beta = \beta_0 + \beta_{i,E} \\ \gamma = \gamma_0 + \gamma_{i,E} \end{cases} \\ \rho^E \geq \rho^0, \begin{cases} \beta = \beta_0 + \beta_{i,E} + \beta_{i,I} \\ \gamma = \gamma_0 + \gamma_{i,E} + \gamma_{i,I} \end{cases} \end{array} \right. \tag{6}$$

where $s(t)$ represents the proportion of ignorant individuals at t moment, $i(t)$ represents the proportion of infected individuals at t moment, $r(t)$ denotes the proportion of recovered individuals at t moment. β is the infectious proportion under the combined force, γ is the obstructive proportion under the combined force, β_0 is the initial infectious proportion of individuals, $\beta_{i,E}$ is the infectious proportion driven by the explicit attraction, $\beta_{i,I}$ is the infectious proportion driven by the implicit attraction, γ_0 is the initial proportion of individuals who have no interests and forget the information, $\gamma_{i,E}$ denotes the obstructive proportion caused by the explicit drag acted on the information propagation, $\gamma_{i,I}$ is the obstructive proportion caused by the implicit drag acted on the information propagation.

Definition 7. Let $\lambda_i(t)$ represents the comprehensive effective attraction of node i at time t. Let λ represents the average comprehensive attraction of ignorant node of G.

When the information is propagated, nodes are affected by the comprehensive acting force after the implicit edge is activated in the network. The comprehensive acting force of the node i is $\lambda_i(t) = \dfrac{\beta_0 + \beta_{i,E}(t) + \beta_{i,I}(t)}{\gamma_0 + \gamma_{i,E}(t) + \gamma_{i,I}(t)}$ at t moment. Similarly, the β_0 and γ_0 of each node are ignored, the comprehensive acting force of the node i approximates to $\lambda_i(t) = \dfrac{\beta_{i,E}(t) + \beta_{i,I}(t)}{\gamma_{i,E}(t) + \gamma_{i,I}(t)}$. Therefore, the average comprehensive effective attraction acted on susceptible node at t moment is

$$\lambda=\frac{1}{N}\sum_{i=1}^{N}\frac{\sum_{j=1}^{n_{i,E}}\frac{(jp_i)^{n_{i,E}}}{n_{i,E}!}e^{-jp_i}+\sum_{m=1}^{n_i-n_{i,E}}\frac{(ma_i)^{n_i-n_{i,E}}}{(n_i-n_{i,E})!}e^{-ma_i}}{\sum_{k=1}^{n_{i,E}}\frac{(kq_i)^{n_{i,E}}}{n_{i,E}!}e^{-kq_i}+\sum_{n=1}^{n_i-n_{i,E}}\frac{(nb_i)^{n_i-n_{i,E}}}{(n_i-n_{i,E})!}e^{-nb_i}}$$

, that is, ignorant nodes in the network are attracted to infected nodes on average to receive and propagate information, where $a_i=\frac{d_{I,I}}{d_{i,I}}$, $b_i=\frac{d_{R,I}}{d_{i,I}}$ and the other parameters are consistent with the above section.

Proof:

From (4) and (5):

Let $a_i=\frac{d_{I,I}}{d_{i,I}}$, $b_i=\frac{d_{R,I}}{d_{i,I}}$

The comprehensive effective attraction of node i is:

$$\lim_{t\to\infty}\lambda_i(t)=\lim_{t\to\infty}\frac{\beta_{i,E}(t)+\beta_{i,I}(t)}{\gamma_{i,E}(t)+\gamma_{i,I}(t)}$$

$$=\lim_{t\to\infty}\frac{\sum_{j=1}^{n_{i,E}}\beta_{i,E}(t)+\sum_{m=1}^{n_i-n_{i,E}}\beta_{i,I}(t)}{\sum_{k=1}^{n_{i,E}}\gamma_{i,E}(t)+\sum_{n=1}^{n_i-n_{i,E}}\gamma_{i,I}(t)}$$

$$=\frac{\sum_{j=1}^{n_{i,E}}\frac{(jp_i)^{n_{i,E}}}{n_{i,E}!}e^{-jp_i}+\sum_{m=1}^{n_i-n_{i,E}}\frac{(ma_i)^{n_i-n_{i,E}}}{(n_i-n_{i,E})!}e^{-ma_i}}{\sum_{k=1}^{n_{i,E}}\frac{(kq_i)^{n_{i,E}}}{n_{i,E}!}e^{-kq_i}+\sum_{n=1}^{n_i-n_{i,E}}\frac{(nb_i)^{n_i-n_{i,E}}}{(n_i-n_{i,E})!}e^{-nb_i}}$$

The average comprehensive attraction of network is:

$$\lambda=\frac{1}{N}\sum_{i=1}^{N}\lambda_i(t)$$

$$=\frac{1}{N}\sum_{i=1}^{N}\frac{\sum_{j=1}^{n_{i,E}}\frac{(jp_i)^{n_{i,E}}}{n_{i,E}!}e^{-jp_i}+\sum_{m=1}^{n_i-n_{i,E}}\frac{(ma_i)^{n_i-n_{i,E}}}{(n_i-n_{i,E})!}e^{-ma_i}}{\sum_{k=1}^{n_{i,E}}\frac{(kq_i)^{n_{i,E}}}{n_{i,E}!}e^{-kq_i}+\sum_{n=1}^{n_i-n_{i,E}}\frac{(nb_i)^{n_i-n_{i,E}}}{(n_i-n_{i,E})!}e^{-nb_i}}$$

C. *The simulation result*

According to analysis of the information propagation model driven by explicit attraction and drag, the simulation experiments are executed on the BA network and WS network of three different average degree with $N=20000$ nodes, respectively. The change for the density of infected node during the process of information propagation is obtained in this paper, as follows.

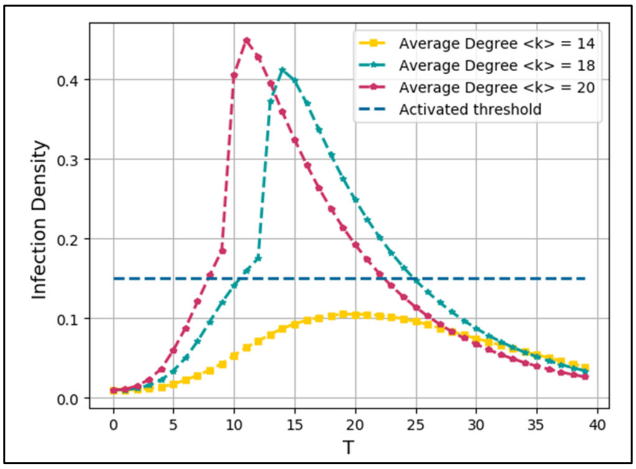

Fig.4 The change of density driven by the explicit attraction and drag in the BA network.

Fig.4 illustrates that the change of propagation density for information driven by the explicit attraction and explicit drag. The diagram is the change graph of infector density for information propagated on the BA network with average degrees of $\langle k\rangle=14$, $\langle k\rangle=18$ and $\langle k\rangle=20$, respectively. The orange curve is the change of density for information propagated by explicit edge at the preliminary stage. During the propagation, there are few explicit neighbors around the point and the explicit attraction is not applied to promote activating the implicit edge. The other two curve represent that the information is subjected to greater explicit attraction and the infection density is up to critical condition, implicit edge is activate to continually propagate the density change.

Fig.5 shows that the change graph of infector density for information propagated on the WS network with average degrees of $\langle k\rangle=18$, $\langle k\rangle=20$ and $\langle k\rangle=22$, respectively. Laurel-green curve is the density change of the implicit edge inactivated to propagate and the change of value is tiny. The remaining two curve are driven by the explicit attraction, the information infection density is up to the awakened threshold and the information is propagated by the implicit edge.

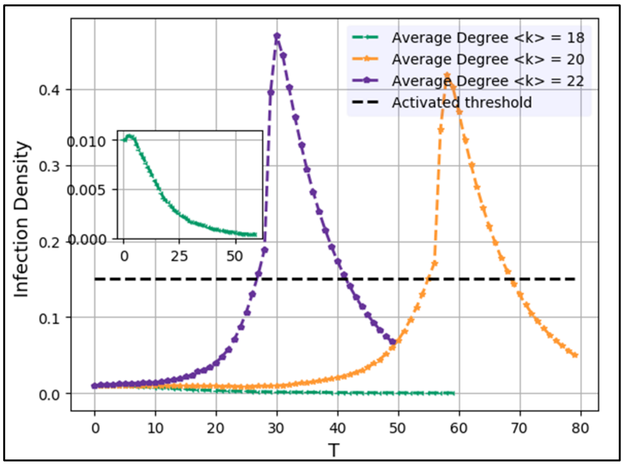

Fig.5 The change of density driven by the explicit attraction and drag in the WS network.

According to analyze the modeling of the information propagation driven by comprehensive attraction and drag, the simulation experiments are executed on the BA network and WS network of three different average degree with $N = 20000$ nodes, respectively. In the experiment, the information propagation at the preliminary stage is only affected by the explicit attraction and drag. When the information is propagated for a while and the infection density exceeds the density threshold set in the experiment, the implicit edge is activated and individual is initially affected by the comprehensive attraction and drag. Therefore, the change for the density of population who propagate information during the process of information propagation is obtained.

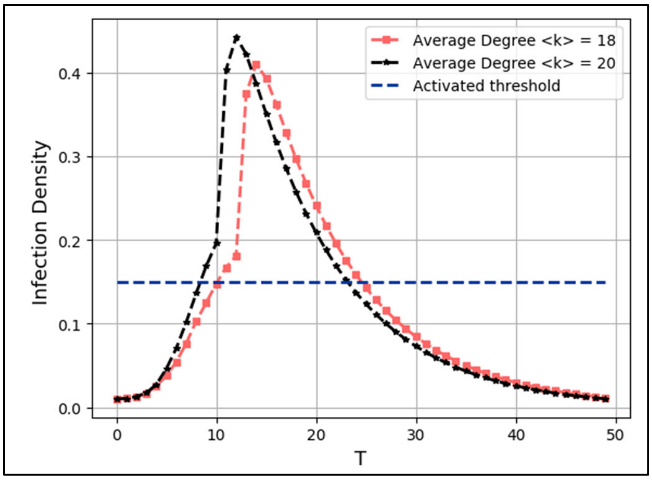

Fig.6 The change of density driven by the comprehensive attraction and drag in the BA network.

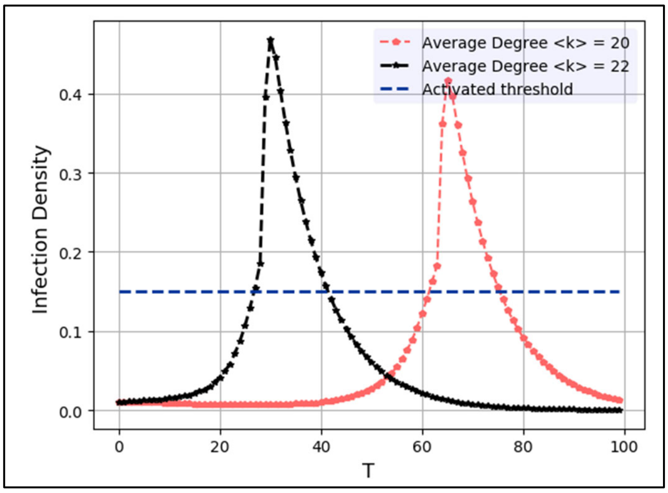

Fig.7 The change of density driven by the comprehensive attraction and drag in the WS network.

Fig.6 is that the change graph of infection density for information affected by the explicit attraction and drag when the implicit edge is activated by the information propagation. The red curve is the infection density change for the scale-free network of the average degree $\langle k \rangle = 18$, the black curve is the density change for the scale-free network of the average degree $\langle k \rangle = 20$. Compared with Fig.4, which is affected by the explicit acting force, there is no significant change for the infection density after the implicit edge is broken down. It's found with observed data that the infection density peak value is greater than the density peak value only affected by the explicit acting force during the information is propagated under the comprehensive action.

Fig. 7 is the infection density change affected by the comprehensive attraction in the small network of the average degree $\langle k \rangle = 20$ and $\langle k \rangle = 22$, respectively. The density change in the WS network is similar to the BA network, the propagation process has no significant change. It is only that the density peak is greater than the information affected by the explicit attraction.

According to analyzing the simulation experiment of the information propagation driven by the explicit acting force and comprehensive acting force, it's clearly seen that the explicit acting force is the important factor to influence the information propagation whether it's a BA network and WS network. The implicit acting force have little influence on the propagation. Whether an information is propagated in the social network is closely related to the scale of the intimate circles.

IV. RUMOR PROPAGATION RESTRAIN STRATEGY

In the section III, the impact of attraction and drag on information propagation in explicit and implicit relationships is discussed. The process of the information propagated for an individual affected by the explicit acting force and comprehensive acting force is simulated in the simulation experiment. The experiment found that when the implicit edge is activated and the information is affected by the comprehensive attraction and drag, the implicit attraction and drag have little influence on the propagation, the radius of the information propagation has almost increased very small. Therefore, a rumor propagation restrained strategy, that is, to control the number of individuals who propagate rumors among intimate friends, is found in this paper.

When rumors are propagated on the social network, the larger the radius of rumor propagated, the more serious the negative social impact, and curbing the propagation of rumors becomes a more important issue. In this paper, when rumors are propagated, the close friends who distribute the rumors are monitored and educated in a timely manner, so that someone who know the rumors not continue to propagate the rumors. The process of rumor propagation restrained is shown in Fig.8.

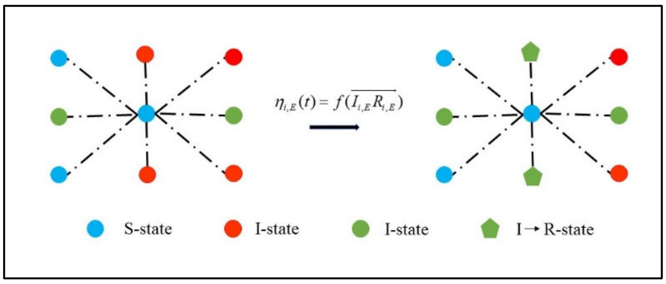

Fig.8 the schematic diagram of restraining the rumor propagation

Definition 8. $\eta_{i,E}(t) = f(\overrightarrow{I_{i,E}R_{i,E}})$ represents the control rate of rumor spread.

Where, $I_{i,E}$ denotes the number of intimate individuals who spread the rumors at time t, $R_{i,E}$ represents the number of intimate individuals who know rumor but do not spread the rumor. $\eta_{i,E}(t)$ denotes control rate of rumor spread, that is to say $I_{i,E}$ becomes $R_{i,E}$ at time t.

When rumors are propagated, the intimate friends who propagate rumors around the individual are controlled to intensify their thought, get them to realize the harm of rumors, let them know rumors without propagating rumors and forget rumors. The formula for the model of the rumor propagation restrained strategy driven by the attraction is shown as follows.

$$\begin{cases} \dfrac{ds(t)}{dt} = -\beta s(t)i(t) \\ \dfrac{di(t)}{dt} = \beta s(t)i(t) - \gamma i(t) - \eta_{i,E}(t) \\ \dfrac{dr(t)}{dt} = \gamma i(t) + \eta_{i,E}(t) \end{cases} \left| \begin{array}{l} \rho^{E} < \rho^{0}, \begin{cases} \beta = -(\beta_0 + \beta_{i,E}) \\ \gamma = \gamma_0 + \gamma_{i,E} \end{cases} \\ \rho^{E} \geq \rho^{0}, \begin{cases} \beta = -(\beta_0 + \beta_{i,E} + \beta_{i,I}) \\ \gamma = \gamma_0 + \gamma_{i,E} + \gamma_{i,I} \end{cases} \end{array} \right. \tag{7}$$

In the model, the change of parameters is consistent with the (6). The different is that the rumor propagation restrained strategy is increased.

According to the above theoretical analysis, simulation experiments are performed in the implicit edge activated by the BA network and WS network in this section. The basic network parameters are identical as the network parameters in section III. In the experiment, different control rate of rumor spread is selected to observe the density change for the propagation of rumors and discuss the effectiveness of rumor removal strategies. The density change of rumor propagation is shown below.

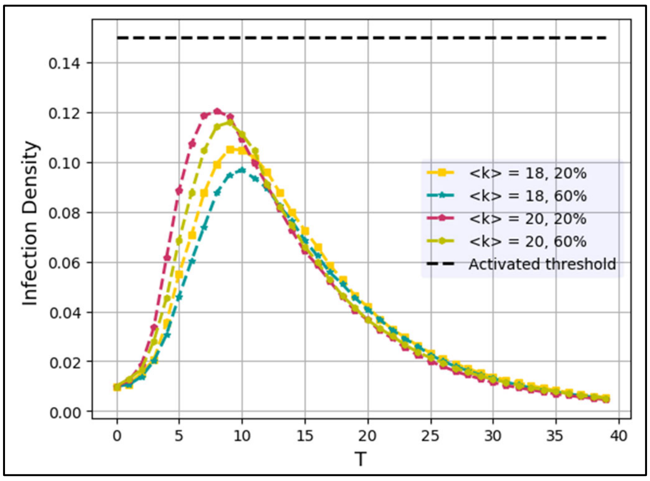

Fig.9 The change of rumor density based on propagation restrain strategy in the BA network

In Fig.9, when considering the comprehensive attraction and drag, based on the change of the propagation density of the rumor restrain strategy, rumor propagated in different networks has chosen to control $\eta_{i,E}(t) = 20\%$ and $\eta_{i,E}(t) = 60\%$ of the explicit rumor spreaders, respectively. The graph is the density change in the BA network. It's clearly seen that, regardless of the average degree of the network, the larger the proportion of explicit rumor spreaders that control the rumor, the slower the rumor spread, and the infection density does not exceed threshold for activating the implicit edge.

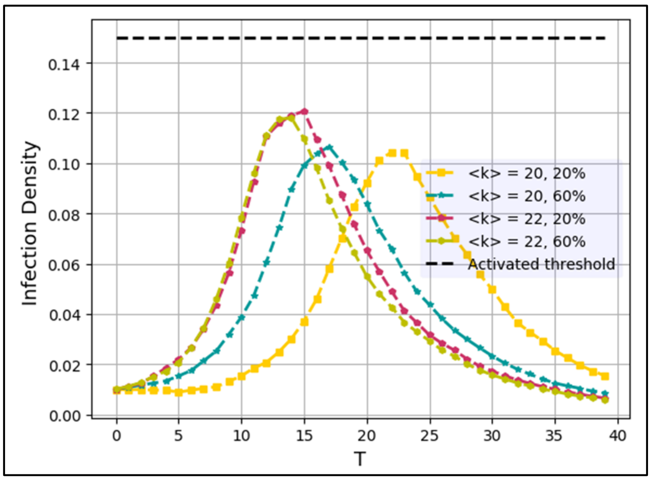

Fig. 10 The change of rumor density based on propagation restrain strategy in the WS network

The density change in the WS network is shown in Fig.10. When the average degree is $\langle k \rangle = 22$, the proportion of controlling the explicit rumor spreaders has no significant influence on the propagation velocity. The propagation radius is smaller when the control rate is larger, vice versa. When the average degree is $\langle k \rangle = 20$, there has few influences on the propagation radius and the propagation velocity is affected. The larger the control rate, the slower the propagation speed.

According to the comparison of the propagation under the rumor control strategy, it is found that the rumor control strategy proposed in this paper is effective. The control rate of rumor spread restrains the spread of rumors both in the BA network and the WS network. The propagation radius of rumor is greatly reduced. The density of rumor spread is not reached the critical condition of activating the implicit relationship. The rumors are launched and gradually extinct until there is no danger in social.

V. CONCLUSION

The relationship difference among individuals in the social network is analyzed in this paper and the relationship of individuals is divided into explicit (intimate) and implicit (non-intimate). Meanwhile, the model of explicit-implicit network is constructed. According to analyzing the process of information interaction in the network, it's found that the information propagation is always initiated in a small explicit circle. When the number of individuals who know information is accumulated up to a certain number, the implicit relationship is activated and the information has an influence on the entire network. When the information is propagated, individuals are likely to accept and forward the information reproduced by their good friends. The closer friends who reproduce the information, the easier it is for individuals to be attracted. The close friends know the information and do not propagate the information, the more difficult it is for individuals to be get. Based on the phenomenon, the model of information propagation driven by the explicit attraction and drag is constructed and the influence of explicit attraction and drag on the information propagation is studied in this paper. Moreover, the ordinary friends have attraction and drag for individuals but the main influence of the information launched to spread comes from the close friends. After the information burst, individuals are subjected to the comprehensive attraction and drag from intimate friends and non-intimate friends. The impact of implicit attraction and drag on information propagation during large-scale dissemination for information is also studied. The simulation experiment found that the explicit attraction and drag, which are the main factors, have an influence on the information propagation and the implicit attraction and drag have few influence on the information dissemination. Therefore, a rumor propagation restrain strategy, which is applied to monitor the intimate friends, is proposed in this paper. The experiment found that when the rumor is spread, it is only necessary to control several intimate friends who know the rumor and let them not spread the rumor, further to control the harm of the rumor to society.

ACKNOWLEDGMENT

This research is supported by the National Natural Science Foundation of China (No. 61263019; No. 61863025), Program for International S & T Cooperation Projects of Gansu Province (No. 144WCGA166), Program for Longyuan Young Innovation Talents and the Doctoral Foundation of LUT.

REFERENCES

[1] Ø. Grøn, "Newton's Law of Universal Gravitation," vol. 772, no. 97, pp. 1-16, 2014.

[2] X. Yue and Y. I. Fan, "Propagation of gravity wave packet near critical level," *Science in China,* no. 5, pp. 538-555.

[3] S. Ren, S. M. Polavarapu, and T. G. Shepherd, "Vertical propagation of information in a middle atmosphere data assimilation system by gravity-wave drag feedbacks," *Geophysical Research Letters,* vol. 35, no. 6, p. L06804.

[4] X. X. Zhan *et al.*, "Coupling dynamics of epidemic spreading and information diffusion on complex networks," (in English), *Applied Mathematics And Computation,* vol. 332, pp. 437-448, Sep 1 2018.

[5] A. Louni and K. P. Subbalakshmi, "Who Spread That Rumor: Finding the Source of Information in Large Online Social Networks With Probabilistically Varying Internode Relationship Strengths," *IEEE Transactions on Computational Social Systems,* vol. 5, no. 2, pp. 335-343, 2018.

[6] C. Li, P. Li, and F. Liu, "Research on network rumor propagation model based on combustion theory," in *the 2018 International Conference*, 2018.

[7] X. Yan and J. Ping, "Stability Analysis and Control Models for Rumor Spreading in Online Social Networks," *International Journal of Modern Physics C,* vol. 28, no. 5, 2017.

[8] M. N. Aydin and N. Z. Perdahci, "Dynamic network analysis of online interactive platform," *Information Systems Frontiers,* vol. 21, no. 2, pp. 229-240, 2019.

[9] K. Wang, M. A. Hong, and R. Huang, "Hierarchical Structure Analysis of Social Network Based on Important Nodes Removal Method," *Computer Engineering,* 2018.

[10] A. R. Benson, D. F. Gleich, and J. Leskovec, "Higher-order organization of complex networks," *Science,* vol. 353, no. 6295, p. 163, 2016.

[11] F. Nian, A. Cong, and R. Liu, "Information propagation based on Historical Memory," *International Journal of Modern Physics C,* 2019.

[12] T. Ma and Z. Xia, "An improved label propagation algorithm based on node importance and random walk for community detection," *Modern Physics Letters B,* p. 1750162.

[13] N. E. El-Keltawi and R. Croteau, "Single-node cuttings as a new method of mint propagation," *Scientia Horticulturae,* vol. 29, no. 1, pp. 101-105.

[14] R. Tian and Y. Liu, "Isolation, Insertion, and Reconstruction: Three Strategies to Intervene in Rumor Spread Based on Supernetwork Model," *Decision Support Systems,* vol. 67, no. 2, pp. 121-130, 2014.

[15] Y. Bao, N. Yan, C. Yi, and Y. Xue, "Effective immunization strategy for rumor propagation based on maximum spanning tree," in *2014 International Conference on Computing, Networking and Communications (ICNC)*, 2014.

[16] P. Y. Chen, S.-M. Cheng, and K.-C. Chen, "Optimal Control of Epidemic Information Dissemination Over Networks," *IEEE Transactions on Cybernetics,* vol. 44, no. 12, pp. 2316-2328.

[17] F. Nian, L. Wang, and Z. Dang, "The epidemic network construction and immunization based on node strength," *Modern Physics Letters B,* vol. 32, no. 26, 2018.

[18] S. Hosseini, H. Yin, M. Zhang, Y. Elovici, and Zhou, "Mining Subgraphs From Propagation Networks Through Temporal Dynamic Analysis," in *19th IEEE International Conference on Mobile Data Management*, 2018.

[19] L. I. Yupeng, X. Wang, and L. I. Xiaolin, "Design change impact assessment for complex product based on complex networks propagation dynamics," *Computer Integrated Manufacturing Systems,* 2017.

[20] H. YAO and X. GAO, "SE2IR Invest Market Rumor Spreading Model Considering Hesitating Mechanism," *Journal of Systems Science and Information,* no. 1, 2019.

[21] Z. Tan, Y. Shi, N. Shi, G. Yang, X. Wang, and N. University, "Rumor Propagation Analysis Model

Inspired by Gravity Theory for Online Social Networks," *Journal of Computer Research & Development,* 2017.
[22] S. Hosseini and M. A. Azgomi, "A Model for Malware Propagation in Scale-Free Networks Based on Rumor Spreading Process," *Computer Networks,* vol. 108, no. C, pp. 97-107, 2016.
[23] J. Wang, L. Zhao, and R. Huang, "SIRaRu rumor spreading model in complex networks," *Physica A Statistical Mechanics & Its Applications,* vol. 398, pp. 43-55.
[24] J. Wang, Y. Q. Wang, and M. Li, "Rumor spreading considering the herd mentality mechanism," in *2017 36th Chinese Control Conference (CCC)*, 2017.
[25] T. Pan, A. Kuhnle, X. Li, and M. T. Thai, "Dynamic Propagation Rates: New Dimension to Viral Marketing in Online Social Networks," in *2017 IEEE International Conference on Data Mining (ICDM)*, 2017.
[26] K. Kandhway and J. Kuri, "Campaigning in Heterogeneous Social Networks: Optimal Control of SI Information Epidemics," *IEEE/ACM Transactions on Networking,* vol. 24, no. 1, pp. 1-1, 2014.
[27] E. H. W. Xu, W. Wang, C. Xu, M. Tang, Y. Do, and P. M. Hui, "Suppressed epidemics in multirelational networks," *Physical Review E Statistical Nonlinear & Soft Matter Physics,* vol. 92, no. 2, p. 022812.
[28] A. Moinet, R. Pastor-Satorras, and A. Barrat, "Effect of risk perception on epidemic spreading in temporal networks," *Physical Review E,* vol. 97, no. 1, p. 012313.
[29] T. Luo, C. Zhong, X. Ying, and J. Fu, "Detecting community structure based on edge betweenness," in *Eighth International Conference on Fuzzy Systems and Knowledge Discovery, FSKD 2011, 26-28 July 2011, Shanghai, China*, 2011.
[30] Tzy-Shiah Wang, Hui-Tang Lin, and Ping Wang, "Weighted-spectral clustering algorithm for detecting community structures in complex networks."
[31] R. Liu, S. Feng, R. Shi, and W. Guo, "Weighted Graph Clustering for Community Detection of Large Social Networks," *Procedia Computer Science,* vol. 31, pp. 85-94.
[32] Y. Moreno, R. Pastor-Satorras, and A. Vespignani, "Epidemic outbreaks in complex heterogeneous networks," *The European Physical Journal B - Condensed Matter,* vol. 26, no. 4, pp. 521-529.
[33] T. Harko, F. S. N. Lobo, and M. K. Mak, "Exact analytical solutions of the Susceptible-Infected-Recovered (SIR) epidemic model and of the SIR model with equal death and birth rates," *Applied Mathematics & Computation,* vol. 236, pp. 184-194.