Modeling and Analysis of Information Propagation Model of Online/Offline Network Based on Coupled Network

Wanting Qin and Tongrang Fan(✉)

School of Information Science and Technology, Shijiazhuang Tiedao University, Shijiazhuang 050043, China
fantr@stdu.edu.cn, fantr2009@126.com

Abstract. Currently, more and more scholars believe that most networks are not isolated, but interact with each other. Internet-based social network (online network), and physical contact networks (offline network) are a coupled network that interact with each other. Person have online virtual identity and offline social identity. In this paper, the double SIR information spreading model with unilateral effect is constructed according to the characteristics of online and offline information dissemination. And two typical types of coupled networks, BA_BA network and WS_WS network, are used to simulate. The experimental results show that the online information propagation can inhibit the scope of offline. This inhibition is slightly weaker for the BA_BA network that the inter degree-degree correlation (IDDC) is positive. At the same time, it is found that the increase of the interlayer influence rate can enhance the synchronization of information transmission on online and offline so that effectively promote the information propagation of online/offline.

Keywords: Online/offline · The coupled network · SIR · The inter degree-degree correlation · Interlayer influence rate

1 Introduction

The evolution of the Internet is from a single network to the "Super Network" [1]. Once a network fails, cascading failures may result in other networks. Most of real networks are a more complex system formed by the interaction of various types of networks. Such as in power system, power network and computer control system composed of coupled network [2]; in the social network, the interpersonal network formed in real life and the interpersonal network formed in the virtual world can produce coupled network [3]; in the traffic network, the road network and railway network presents a kind of coupled cooperation system [4]. Research on information propagation dynamics only from single network tends to ignore some important factors that affect the spread, for example the interaction of the inter-layer communication in multiplex network. In the real world, the channels

M. Xu et al. (Eds.): CTCIS 2017, CCIS 704, pp. 16–25, 2017.
https://doi.org/10.1007/978-981-10-7080-8_2

of receiving and spreading messages have physical contact networks (offline), such as face to face or telephone, and Internet-based social network (online), such as MSN or twitter. These two channels, online and offline, not only have the relationship of mutual collaboration but also have competition relationship. Study on this information dissemination process which is different from single network has a great significance to more really response the regulars and features of information propagation and to maintain network security and stability. This paper researches online/offline information propagation model based on coupled network.

2 Related Work

At present, Network of networks, Multiplex network and Multiplex network and interdependent networks [1,5] are presented at international. These concepts have become one of the most important areas of complex network. In 2010, Buldyrev et al. [6] proposed a cascading failure model of interdependent networks and found that robustness was lower in interdepend networks. Since then more and more scholars pay attention to multiplex networks, and study various dynamic process based on multiplex networks. Dickison et al. [7] who investigated SIR epidemics on the coupled network found that the diseases spread over a large area in the strong interconnection coupled network and the virus more likely spread one side of the weak interconnection coupled network. Min et al. [8] extended the SIS, SIR model to the coupled or multiplex network and found that the critical values of disease broken out was significantly different from single network. Zhao et al. [9] researched immunization strategy on the multiplex network. They presented two immunization strategies, Multiplex node-based random (targeted) immunization and Layer node-based random (targeted) immunization. They found that these both types of random immunization strategy can effectively control the disease for multiplex consisting of ER and ER network but targeted immunization strategy effect was better than random for multiplex consisting of BA and BA. Granell et al. [10] researched asymmetric transmission dynamic characteristics on coupled network composed of information diffusion network and disease spreading network. Yu [11] constructed on the online/offline BCN information dissemination model based on symmetric transmission mechanisms and asymmetric transmission mechanism. Dong et al. [12] studied the robustness of partial dependence on the N interdependent network. It was found that the N layer ER network will undergo a process which was from the two-order phase transition to the first-order phase transition. Wang et al. [13] studied asymmetrically spreading dynamic on information epidemic network and found that the increase in the rate of information transmission can increase the threshold of disease outbreaks. Therefore, not only the network but also the related network should be considered to maintain the stability of the network.

3 Information Propagation and Coupled Network

3.1 Analysis of the Characteristics of Online/Offline Information Propagation

The Information propagation often both occur simultaneously on these two communication networks, online/offline, but there are obvious differences. Online communications network can span geographical limitations [14]. Such as, one in China and the other person in United States can completely real-time communicate through online network. This phenomenon is impossible on offline network. Cooperation and competition mechanism embodied in coupled network [15]. Online communication network and offline communication network not only exist cooperative relations that promote the information spreading, but also exit competitive relations because of different media. Both cooperation and competition existing in online/offline network, make the information spreading on the coupled network different from on single network. The event happened will trigger online network and offline network at the same time and then transmit the message. But because of the development of internet technology, online has wider range and efficiency on information spreading than offline. Information dissemination process generally radiate message from the online to the offline [16]. Because online radiate message to offline, the double SIR information dissemination constructed in this paper is unilateral effect.

3.2 The Classic Model of Information Propagation

Most of researches on information propagation model make use of epidemic spreading model. Social network has a close relationship with disease transmission network. In fact, disease spreads through the contact between people. Therefore, it's suitable to make use of epidemic model to study information dissemination in social networks. There are three classical epidemic spreading models, susceptible-infected model (SI), susceptible-infected-susceptible model (SIS) and susceptible-infected-recovered model (SIR). S (susceptible) means that some people is illness and easy to be infected by sick person, which represent the group who do not receive message in this paper; I (infected) means that some people can infect susceptible person, which represent those who get the message and reproduce or transport the message in this paper; R(recovered) means that some people are isolated or immunized, and in this paper, it represents some people who lost interest and will not spread it after getting the message. The classic SIR virus propagation model is shown in Fig. 1:

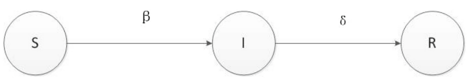

Fig. 1. The classic SIR virus propagation model

3.3 The Topology of Coupled Network

The type of coupled network built in this paper is inter-dependent networks, as shown in Fig. 2. There have two types of edges in this coupled network: (1) Interdependent edge: represents a connection between nodes at different network layers; (2) Intralayer edge: represents a connection between nodes in the same network layer. The general topology of interdependent networks is given by Ref. [17]. This topology introduces the concept of interdependent matrix based on the adjacency matrix of single network. And this topology represents the topology of interdependent edge. The topology of interdependent networks is shown in Eq. 1. In this matrix, A1, A2 represent the adjacency matrix of Layer A and Layer B, and B_{12} is interdependent matrix representing connections between Layer A's node and Layer B's node.

$$\tilde{A} = \begin{bmatrix} A_1 & B_{12} \\ B_{12}^T & A_2 \end{bmatrix} \tag{1}$$

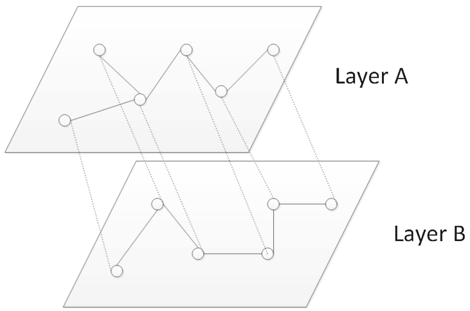

Fig. 2. Interdependent network

3.4 The Inter Degree-Degree Correlation (IDDC)

In the single network, degree correlation describes different degree of nodes in the network preferentially connect. The inter degree-degree correlation describes degree of relevance between different layers in the coupled network. Parshani [18] mentioned the IDDC that based on degree correlation in single network, as shown Eq. 2. The IDDC exits the following three types: (1) The value of IDDC is positive ($r^{AB} \to 1$). Represent a larger degree node of Layer A tends to connect with a larger degree node of Layer B. The greater value of IDDC is, the more obvious the tendency is. (2) The value of IDDC is negative ($r^{AB} \to -1$). Represent a larger degree node of Layer A tends to connect with a smaller degree node of Layer B. (3) The value of IDDC is approximately equal to 0 ($r^{AB} \approx 0$). The nodes between two layers randomly connect with equal probability.

$$r^{AB} = \frac{1}{\sigma^2} \sum_{jk} jk \left(e_{jk} - p_j^A p_k^B \right) \tag{2}$$

Which, e_{jk}, the probability of choosing an interdependent edge that degree of Layer A vertex is j and degree of Layer B vertex is k. p_j^A, p_k^B represent that the probability that degree of Layer A node is and the degree of Layer B node is k. $\sigma^2 = \sqrt{\sigma_A} * \sqrt{\sigma_B}$, which $\sigma_A = \sum_k k^2 p_k^A - [\sum_k k p_k^A]^2$, $\sigma_B = \sum_k k^2 p_k^B - [\sum_k k p_k^B]^2$.

4 The Information Propagation Model of Online/Offline

Virus propagation model in single network does not apply to information spreading on multiplex network. A double SIR information propagation model with unilateral effect is given.

4.1 Model Definition

Definition 1. *SIR virus transmission dynamic process in single network simultaneously exist in Layer A and Layer B.*

Definition 2. *The interlayer effect is unilateral. In other word, infected node from Layer A can infect susceptible node from Layer B which can't reverse.*

Definition 3. *Interlayer influence rate, the probability that the infected node from Layer A can infect susceptible node of Layer B into infected state, and (1) interlayer symmetrical transmission mechanism, if the node of Layer A is I, the corresponding node of Layer B will become I from S. (2) interlayer asymmetric transmission mechanism, if the node of Layer A is I, the corresponding node of Layer B will become R from S. (3) spread between layers for the random state. The node of Layer A and Layer B is randomly mapping.*

Definition 4. *What the node of Layer A lose interest for information will lead to the corresponding nodes of Layer B losing interest. If Layer A node is recovered, the corresponding node of Layer B will be recovered. The double SIR information propagation model with unilateral effect is shown in Fig. 3.*

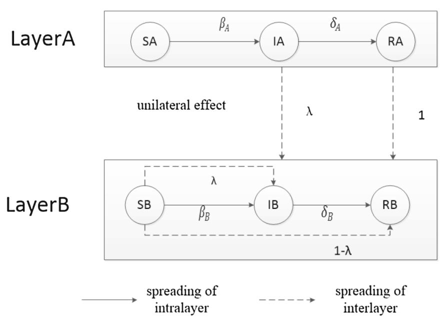

Fig. 3. The double SIR information propagation model

4.2 Algorithm Description Based on Double SIR Information Propagation Model

Node status information is asynchronous update on spreading of intralayer and synchronous update on spreading of interlayer. When the initial $t = 0$, it means that a node was selected as infected node from Layer A randomly, and the corresponding node of Layer B is also infected node. When $t = t_i$, it means that the status of node B_i is determined by its own state and its neighboring node status at $t = t_i - 1$ and corresponding layer node at $t = t_i$.

1. The spreading of intralayer in Layer A (principle of asynchronous update) (1) At $t_i - 1$, if node A_i is S, then judge whether the neighbor of A_i exist I status node. If don't have, node A_i will keep S status at $t = t_i$ and if the number of node I is m, node A_i will become I with probability $1-(1-\beta)^m$ at $t = t_i$. (2) If node A_i is I at node A_i will become R with probability δ at $t = t_i$. (3) If node A_i is R at $t_i - 1$, node will keep R status at $t = t_i$.
2. The spreading of intralayer in Layer B is similar with Layer A.
3. The spreading of interlayer between Layer A and Layer B (principle of synchronous update): (1) If node A_i is S at $t = t_i$, corresponding node B_i of Layer B will keep status at $t = t_i$. (2) If node A_i is I and corresponding node B_i is S at $t = t_i$, node B_i will change to I with probability λ. (3) If node A_i is R at $t = t_i$, the node B_i will change to R at $t = t_i$.
4. When there is no node I on the coupled network, the process of propagation will be end.

5 The Simulation of Information Propagation Process on Online/Offline

5.1 The Construction of Coupled Network

Based on Matlab, the double SIR information propagation process is run. First, construct two classic types of online/offline network, BA_BA network and WS_WS network, which the subnetworks attributes is shown in the following Table 1. For convenience, the interlayer connection is one-to-one in this paper. Sort the nodes of Layer A and Layer B according to the size of degree: $k_1^A \geq k_2^A \geq k_3^A \geq \cdots \geq k_N^A$,$k_1^B \geq k_2^B \geq k_3^B \geq \cdots \geq k_N^B$. If the way of interlayer connection is $k_1^A \leftrightarrow k_1^B, \cdots, k_N^A \leftrightarrow k_N^B$, the value of IDDC is maximum; if the way of interlayer connection is $k_1^A \leftrightarrow k_N^B, \cdots, k_N^A \leftrightarrow k_1^B$, the value of IDDC is minimum.

5.2 The Settings of Experiment and Results

The value of IDDC is approximately set to 1, −0.2, 0 for BA_BA network; the value of IDDC is approximately set to 1, −0.9, 0 for WS_WS network. The interlayer influence rate λ is 0.1, 0.5, 0.9; the infection rate of Layer B is set to $\beta_B = 0.3$. In order to accelerate the process of experiment; the recovery rates

Table 1. The two types of subnetworks attributes

Types	Number	Average path length	Average degree	Clustering coefficient	Connectivity
WS	1000	3.3846	10	0.094672	Yes
BA	1000	2.975	10	0.042318	Yes

of Layer A and Layer B are both set to $\delta_A = \delta_B = 0.8$. Select one node of Layer A as infected node and corresponding node of Layer B is also infected node and then run the double SIR information propagation process on the constructed coupled network, BA_BA network and WS_WS network. After end of each process, statistic the proportion of infected nodes to the total nodes (I/N), and average value of 20 groups of experimental data.

When λ the is 0.1, 0.5, 0.9, the simulation results of I/N change with infected rate β_A of Layer A for BA_BA network and WS_WS network is shown in Figs. 4, 5 and 6. In the following simulation results graph, the solid red line represents I/N of Layer A; black dotted line represents I/N of Layer B. And the star-shape, triangular-shape and square-shape separately represent the value of IDDC is positive, negative or 0.

From Figs. 4, 5 and 6, both for BA_BA network and WS_WS network, when the β_A of Layer A increases, the I/N of Layer A is gradually increasing, however, the I/N of Layer B is gradually decreasing. This phenomenon shows there is a competing relation between Layer A and Layer B. The spreading of Layer A can inhibit Layer B. With the β_A of Layer A increases, the difference of I/N between Layer A and Layer B is becoming larger and larger. In other word, online information spreading has an impulsion on the scope of offline. The bigger the propagation rate of online is, the stronger the effect of inhibition is. From Figs. 5a and 6a, when the value of IDDC is 1, the I/N of Layer B is higher than that the value of IDDC is -0.2 or 0. The value of IDDC more tend to maximum, and the I/N of Layer B will be higher which means that IDDC has slightly effect on BA_BA network. From Figs. 3b, 4b and 5b, different IDDC don't have obvious influence on WS_WS network. This inhibition is also consistent with the spreading characteristics of information disease network. The information spread more quickly on information layer so that people will early receive the disease messages. The infected number of person will be reduced because people have received the message and take appropriate measures to protect themselves.

Both the infected rate of Layer A and Layer B are set to $\beta_A = \beta_B = 0.3$, both the recovery rate of Layer A and layer B are set to $\delta_A = \delta_B = 0.3$. The simulation results of I/N of Layer A and Layer B change with the influence rate is shown in Fig. 7.

From Fig. 7, both for BA_BA network and WS_WS network, the I/N of Layer B increases with λ the increasing, and finally tends to Layer A's. That means Layer A and Layer B will become more synchronously when λ increases. When λ tends to 1, this is symmetrical transmission mechanism. Layer B is more

(a) BA_BA network (b) WS_WS network

Fig. 4. $\lambda = 0.1$, the proportion of infected nodes (I/N) change with infected rate β_A of Layer A

(a) BA_BA network (b) WS_WS network

Fig. 5. $\lambda = 0.5$, the proportion of infected nodes (I/N) change with infected rate β_A of Layer A

(a) BA_BA network (b) WS_WS network

Fig. 6. $\lambda = 0.9$, the proportion of infected nodes (I/N) change with infected rate β_A of Layer A

synchronous with Layer A, so the proportion of infected nodes is bigger in this situation. Conversely, when λ tends to 0, this is asymmetrical transmission mechanism, and the synchronization of Layer A and Layer B is weaker. Symmetric dissemination mechanisms contribute to dissemination of information. The partnerships between layer and layer are highlighted at this time and synchronicity is more noticeable. However, asymmetric transmission mechanisms would highlight competition. The above analysis show that the transmission of online/offline has broader range than single way transmission. However, because online/offline are substitute so that they have a competitive relationship. For example, Traditional media and new media will spread information with broader scope and efficiency, however the high efficiency of new media will have a bad impact on traditional media.

(a) BA_BA network

(b) WS_WS network

Fig. 7. The proportion of infected nodes (I/N) change with interlayer influence rate λ

6 Conclusion

At present, the research of information dissemination model is based on single layer network. In this paper, the research object is to take the online/offline as an interdependent coupled network. This is more conform to the process of information propagation of online/offline. The information dissemination and public opinion can be better controlled and guided through study information propagation on online/offline. Especially, when face unexpected events, be able to guide public opinion and stop the spread of rumors. Therefore, the study of information transmission from the coupled network can better maintain the flow of information security in the network.

A double SIR information propagation model based on the spreading characteristics of online/offline is put up in this paper. Simulation results show that as the inflected rate of Layer A increases, it has an inhibitory effect on Layer B. The inhibitory effect will slightly weaken for BA_BA network with larger value of IDDC. However, this effect has no clear distinction with different IDDC of WS_WS network as the inflected rate of Layer A increases, and will conduct a follow-up study. Layer A and Layer B tend to sync with the interlayer influence rate increase. It needs to increase cooperation between the different transmission routes and lessen competition, if want to expand dissemination of information. The increase of interlayer influence rate can make online and offline partnerships highlight and the competitive relationship weakened so that online/offline can be in sync. Epidemic spreading model is used to study information spreading in this paper. Due to the information dissemination process is different from the spread of the virus, the process of information propagation can reflect the characteristics of the information itself. In the subsequent work, the above imperfections should be taken into account. And the double SIR information propagation model should be refined further and will be more prefect.

Acknowledgements. This work was supported by the National Natural Science Foundation of China (61373160,61402300) and the Founded Projects for Introduction of Overseas Scholars of Hebei Province, and the Funds for Excellent Young Scholar of Shijiazhuang Tiedao University.

References

1. Nagurney, A., Dong, J.: Supernetworks: Decision-Making for the Information Age. Edward Elgar Publishers, Cheltenham (2002)
2. Shi-Ming, C., Xiao-qun, Z., Hui, L., Qing-Gang, X.: Research on robustness of interdependent network for suppressing cascading failure. Acta Phys. Sin. **63**(2), 432–441 (2014)
3. Yiran, G., Huang, Z.: Analying and modeling of student communication behavior based on bilayer network. J. Nanjing Univ. Posts Telecommun. (Nat. Sci. Ed.), **36**(2), 41–48 (2016)
4. Wen-ju, D., Li, Y.-Z., An, X., Ma, C.-X.: A new class of two layers public traffic coupled network model. J. Transp. Syst. Eng. Inf. Technol. **16**(4), 131–138 (2016)
5. Yang, L.S., Junde, W., Liang, B.: Review of interdependent networks. J. Nat. Univ. Defense Technol. **1**, 122–128 (2016)
6. Buldyrev, S.V., Parshani, R., Paul, G., Stanley, H.E., Havlin, S.: Catastrophic cascade of failures in interdependent networks. Nature **464**(7291), 1025–1028 (2010)
7. Dickison, M., Havlin, S., Stanley, H.E.: Epidemics on interconnected networks. Phys. Rev. E Stat. Phys. Plasmas Fluids Relat. Interdisc. Topics **85**(2), 1380–1404 (2012)
8. Min, B., Goh, K.I.: Layer-crossing overhead and information spreading in multiplex social networks. In: APS March Meeting 2014. American Physical Society (2013)
9. Zhao, D., Wang, L., Li, S., et al.: Immunization of epidemics in multiplex networks. Plos One **9**(11), e112018 (2014)
10. Granell, C., Gmez, S., Arenas, A.: Dynamical interplay between awareness and epidemic spreading in multiplex networks. Phys. Rev. Lett. **111**(12), 1–7 (2013)
11. Yu, K.: Research on information spreading model on bilayer coupled network. Dalian University of Technology (2015)
12. Dong, G., Tian, L., Zhou, D., et al.: Robustness of n interdependent networks with partial support dependence relationship. EPL **102**(102), 68804 (2013)
13. Wang, W., Tang, M., Yang, H., et al.: Asymmetrically interacting spreading dynamics on complex layered networks. Sci. Rep. **4**(7502), 5097 (2014)
14. Ming, D.: Research on model online/offline network and information spreading. University of Electronic Science and technology of China (2016)
15. Kai-Jun, L.I., Chang-Gui, G.U., Yan-Qing, Q.U., et al.: Onset of co-operation in some real world layered networks. Complex Syst. Complex. Sci. **9**(2), 79–83 (2012)
16. Hengmin, Z., Liu, Y., Jing, M., Jing, W.: Study on public opinion propagation model based on coupled network under online to offline interaction. J. Intell. (0.2), 139–144+450 (2016)
17. Wang, H., Li, Q., D'Agostino, G., Havlin, S., Stlanely, H.E., Van, M.P.: Effect of the interconnected network structure on the epidemic threshold. Phys. Rev. E Stat. Nonlinear Soft Matter Phys. **88**(2), 279–311 (2013)
18. Parshani, R., Rozenblat, C., Ietri, D., Ducruet, C., Havlin, S.: Inter-similarity between coupled networks. EPL **96**(6), 2470–2484 (2011)

http://www.springer.com/978-981-10-7079-2

Trusted Computing and Information Security
11th Chinese Conference, CTCIS 2017, Changsha, China, September 14-17, 2017, Proceedings
Xu, M.; Qin, Z.; Yan, F.; Fu, S. (Eds.)
2017, XIII, 410 p. 133 illus., Softcover
ISBN: 978-981-10-7079-2