Dynamic Complex-Net-Based Info-Transmission Model

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Abstract. In order to explore the information flow, we contract and analyze the Dynamic Complex-Net-Based Info-Transmission Model. Simulate the realistic information transmission network utilizing the model.

Considering the characters of information transmission, we employ the SIR-Based Info-Transmission Model at first. Then we utilize the Complex-Net- Based Info-Transmission Model mainly researching the information transmission model from the degree of nodes. Finally we creatively establish the Dynamic Multi-Layer-Network Info-Transmission Model and simulate the information transmission network through the programs.We analyze the breadth and deepness of information transmission by studying the density of the network and the average degree of nodes. The three recurring models fundamentally but creatively explore the information transmission model.

1. Introduction

We are living in the contemporary era of information explosion. Researching social network of the contemporary is prevailing. People generally achieve information through the social network. So exploring the information flow of the networks have significance for us.

In order to understand the evolution of the methodology, purpose, and functionality of societies networks, we analyze the relationship between speed/flow of information and its inherent value. We establish an info-transmission model to simulate the information flow in reality.

2. General Assumptions

We make the following assumptions about modeling process in this paper.

- The data we have collected is enough and accurate and the sources of data are reliable.
- We consider there exist forgetting rate in the processes of information transmission, and the rate approximate to some value.
- We suppose the total amount of people is constant in the small range we research.
- We don’t take other transmission medias with low probability into consideration.
- To simplify our model, we suppose that when clustering coefficient is one, any node in the network connects with each other.
- To simplify the model, we assume the same nodes entering into the all sub-networks at the same time per time step and the time interval is same.
- The elements we use to value news have been taken into consideration play a vital role in our models.
- The ignored characters of information do not influence the evaluation of news.

3. Our Model: Dynamic Complex-Net-Based Info-Transmission Model

Basic Model: SIR-Based Info-Transmission Model. We use the SIR model as the base of our model since information transfer in the similar way with virus. We classify $\boldsymbol{N_I}$ into $\boldsymbol{i}$, $\boldsymbol{s}$ and $\boldsymbol{r}$. Then we adopt Differential Calculous Equation Method to solve problems.

3.1.1 The parameters we define are as Table 1.

The Weighted Analysis Method of λ Information is spread quickly mainly because its inherent value, and the information finding its way to network nodes that accelerate its spread through social media. Considering the flow of the information relative to the inherent value of information, we define λ–the probability of successful transmission per day in theory–to calculate as follow.

Table 1 The Parameters in This Model

Parameters	Definitions
N_I	The total number of people in region or country I.
$i_I(t)$	The function of the ratio of people who know the news/N_I
i_0	The initial ratio of people who know the news/N_I .
$s_I(t)$	The function of the ratio of people who don't know the news/ N_I .
s_0	The initial ratio of people who don't know the news/N_I .
$r_I(t)$	The function of the ratio of people who heard the news but don't transfer it to others/N_I .
r_I	The initial ratio of people who heard but forget the news/N_I .
λ	The probability of successful transmission per day in theory.
μ	The ratio of people who heard but forget the news.
δ	The increment of people who know the news per day in fact.

We use the single factor analysis method to grade 5 levels by the inherent value of information itself. The level-table is as Table 2:

Table 2 The Level-Table

Level	$\boldsymbol{p}$
Ⅰ	$0.8<\boldsymbol{p}\leq 1$
Ⅱ	$0.6<\boldsymbol{p}\leq 0.8$
Ⅲ	$0.4<\boldsymbol{p}\leq 0.6$
Ⅳ	$0.2<\boldsymbol{p}\leq 0.4$
Ⅴ	$0<\boldsymbol{p}\leq 0.2$

The probability value $\boldsymbol{p}$ is the percentage of this kind of information when the spread speed and other factors is defined in a random information set . For example, there is an information set in 19th century containing less than 20 % of some category information, then we say this category is the V-level information, which is to say that its inherent value is extremely low.

According to the statistics, we obtain the spread speed $\boldsymbol{v}$ of different media in different time.

In the basic of analyzing how $\boldsymbol{p}$ and $\boldsymbol{v}$ impacting information transmission, we standardize $\boldsymbol{p}$ and $\boldsymbol{v}$ and determine their weight, then we can obtain λ.

3.1.2 Modeling Progress

$$\delta=\lambda/\mu \tag{1}$$

$$s(t)+i(t)+r(t)=1$$

$$N[s(t+\Delta t-i(t))]=\lambda Ns(t)i(t)\Delta t-\mu Ns(t)i(t)\Delta t$$

$$N[s(t+\Delta t)-s(t)]=-\lambda Ns(t)i(t)\Delta t \tag{2}$$

$$\begin{cases} \dfrac{di}{dt}=\lambda si-\mu i \\ \dfrac{ds}{dt}=-\lambda si \\ i(0)=i_0,\ s(0)=s_0 \end{cases} \tag{3}$$

while $i_0 + s_0 \approx 1$, and $r(0)=r_0$ is extremely small.

The arithmetic solution of our model.

$$\begin{cases} \dfrac{di}{dt}=\lambda si - \mu i \ , \quad i(0)=i_0 \\ \dfrac{ds}{dt}=-\lambda si \quad , \quad s(0)=s_0 \end{cases} \tag{4}$$

3.1.3 Solutions and Analysis

We use the differential equation method processing data. We get the change curves of $s(t)$ and $i(t)$ of the info-transmission model in five years.

According to Fig.1, we learn

1.The change of $i(t)$ is rising then declining to a stable value. The change of $s(t)$ is monotone decreasing to a stable value.

2.The peak value of $i(t)$ becomes larger and time to reach peak becomes shorter from 1998 to 2006. That means the spread speed and range of information developing with change of era and the development of trans- mission media.

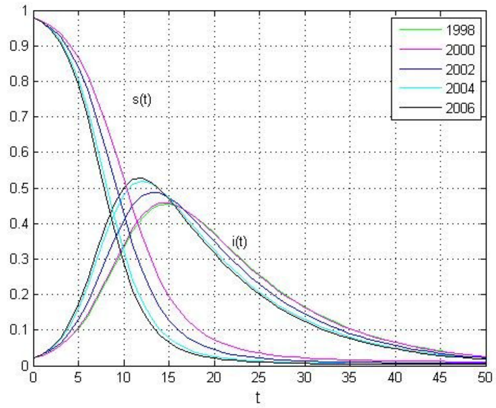

Fig.1: The Change Curve of $s(t)$ and $i(t)$

3.2 Complex-Net-Based Info-Transmission Model

3.2.1 Develop the Complex-Net-Based Model

Complex-Net-Based Transmission Model is hot in recent years. Complex network model is optimized based on SIR model. There have been some mature models such as Small-world network, regular network model, random-network model and scale-free network model. Representative research is Newman and others raise some generating function characterization methods in [1,2,3], and the impact of network structure on the spread of virus in [4,5,6]. Volz and others model side-based network SIR model[7].

We creatively model the question of information flow based on SIR model by complex network theory and information flow to deep explore information flow.

We classify the nodes in information network into three parts, I is set of trans- mission nodes , S is set of nodes that haven't get information, R is set of nodes that get the information but are unable to transfer it to others. The rules are as follows:

- If $node_1$ from I touch $node_2$ from S, then the probability of $node_2$ trans to I is p_1.
- If $node_3$ from I touch $node_4$ from R, then the probability of $node_3$ trans to R is p_2.
- $Node_5$ from I won't transfer infinitely, it trans to R at a speed of v.

We suppose that a node j belongs to S at t, $pj\ ss$ is the probability of j still belonging to S at $[t, t+\Delta t]$, $pj\ si$ is the probability of j transferring to I and $pj\ si = 1-pj\ ss$,while $pj\ ss = (1-\Delta\mu_1)^g$,$g=g(t)$ is the amount of nodes belonging to I close to j at t. Suppose j has k edges, g is a random with a binomial distribution as below:

$$\prod(g,t)=\begin{pmatrix} k \\ g \end{pmatrix} \omega(k,t)^g (1-\omega(k,t)^{k-g}) \tag{5}$$

$\omega(k,t)$ is the probability of a node with k edges from S touch another node from I at t.

$$\omega(k,t) = \sum_{k'} p(k'|k)p(i_{k'}|s_k) \approx \sum_{k'} p(k'|k)\rho^i(k',t) \qquad (6)$$

$p(k'|k)$ is a degree correlation function, it's the conditional probability of a node with degree k touching a node with degree k'. $p(i'_k|s_k)$ is the probability of a node with k' edges belonging to S. $\rho^i(k,t)$ is the density of nodes with degree k' at t.

Use (5) and (6), we know

$$\bar{p}_{ss}(k,t)=(1-p_1\Delta t\sum_{k'} p(k'|k)^i(k',t))^k \qquad (7)$$

In the same way, we know that $p^j_{ii} = (1-\Delta tp_2)^g(1-v\Delta t)$.

And the average transition probability of the node with degree k belonging to I at $[t,t+\Delta t]$ is

$$\bar{p}_{ii}(k,t) = (1-\Delta t\, p_2\sum_{k'} p(k'|k)\rho^r(k',t))^k \times (1-v\Delta t). \qquad (8)$$

Then the transition rate of a node from I to R is $\bar{p}_{ir}(k,t) = 1-\bar{p}_{ii}(k,t)$.

We suppose $N(k, t)$ is total amount of nodes with degree k at t in the network. $I(k, t)$, $S(k, t)$ and $R(k, t)$ are the amount of nodes belonging to I, S, R with degree k at t, then

$$I(k, t) + S(k, t) + R(k, t) = N(k, t). \qquad (9)$$

Hence the change in the amount of nodes belonging to S with degree k at $[t, t +\Delta t]$ is

$$S(k, t + \Delta t) = S(k, t) - S(k, t)(1 - \bar{p}_{ss}(k, t))$$

$$= S(k, t) - S(k, t) \times [1 - p_1\Delta t \textstyle\sum_{k'} \rho'(k,t)p(k'|k))^k]. \qquad (10)$$

In the same way, we can get the change of the nodes with degree k of I and R.

$$I(k, t + \Delta t) \quad =I(k, t) + S(k, t) \times [1 - (1 - p_1\Delta t \times \textstyle\sum_{k'} \rho'(k,t)p(k'|k))^k]$$

$$- S(k, t)[1 - (1 - p_2\Delta t \times \textstyle\sum_{k'} \rho^r(k't,t)p(k'|k))^k(1 - v\Delta t)]. \qquad (11)$$

$$R(k, t + \Delta t) \quad =S(k, t)[1 - (1 - p_2\Delta t \times \textstyle\sum_{k'} \rho^r(k',t)p(k'|k))^k \times (1 - v\Delta t)] + R(k,t).$$
(12)

From (8) and (9) we know

$$\frac{S(k,t+\Delta t) - I(k,t)}{N(k,t)\Delta t} = - \frac{I(k,t)}{N(k,t)\Delta t}[1-(1-p_i\Delta t \times \textstyle\sum_{k'} \rho^i(k',t)p(k'|k))^k]. \qquad (13)$$

when $\Delta t \to 0$, Taylor expand (10)

$$\frac{\partial\rho^s(k,t)}{\partial t} = kp_2{}^s(k,t) \textstyle\sum_{k'} \rho^i(k',t)p(k'|k) \qquad (14)$$

In the same way we learn

$$\frac{\partial\rho^i(k,t)}{\partial t} = -kp_1\rho^i(k,t) \textstyle\sum_{k'} \rho_i(k',t)p(k'|k) - kp_2\rho(k,t) \textstyle\sum_{k'} \rho(k',t)p(k'|k) - v\rho^i(k,t). \qquad (15)$$

$$\frac{\partial\rho^r(k,t)}{\partial t} = -kp_2\rho^i(k,t) \textstyle\sum_{k'} \rho^r(k',t)p(k'|k)+ v\rho^s(k,t). \qquad (16)$$

By considering (12),(14) and (15), we gain an information transmission equation group, that can describe the change relation of the density of set I, S and R.

3.2.2 The Analysis of Results

By the above way of modeling information transmission and change in value, we can get a figure of the density of nodes with same variation tendency with Fig.1. What's more, we further analyze the degree of the nodes, degree distribution and clustering coefficient in the network. Finally we get two conclusions:

• The bigger the degree of initial nodes, the more easily for information to transfer in the network.

• Central nodes have more social influences than others. The nodes with degree various occupy different proportion in the network and they appear the same variation tendency.

3. 3 Dynamic Network Info-Transmission Model

3.3.1 Modeling the Dynamic Network

Information flow network is related with graph theory. Nodes represent message senders or receivers, edges mean the transmission relation in some way. The valuable information with media that can accelerate its spread speed is easily to be transfer, that means these information can be transfer more deeply and broadly. In the information transmission network, influential and central nodes will generate. The newspaper, radio and televisions are all represent of central nodes. Most of the message receivers are noncentral nodes.

Considering a network with nodes $\boldsymbol{N(t)}$, nodes are connected by two kinds of edges, which respectively represent transmission and contact relation.The sub-network under these two relations are transmission networks and contact networks, which are homologous the $\boldsymbol{f}$ -layer and $\boldsymbol{c}$-layer of multi-layer information network. Note $\boldsymbol{N}$ is the set of all nodes in the network, $\boldsymbol{E_f}$ and $\boldsymbol{E_c}$ respectively mean the set of sub-network of $\boldsymbol{f}$ -layer and $\boldsymbol{c}$-layer. So $\boldsymbol{E_f}$ is the edge set of the transmission network, if there exist edge between two nodes ,the two nodes are transmission relation mutually; And $\boldsymbol{E_c}$ is the edge set of contact network, and if there exist edge between two nodes ,the two nodes are contact relation mutually. Hence a double-layer network with the two relation can be $\boldsymbol{G = (N, E_f , E_c)}$.

The double-layer information transmission network with transmission and contact networks' construction algorithm is as follows:

1.Initial condition: The $\boldsymbol{f}$-layer and $\boldsymbol{c}$-layer networks have the same edge set when the initial network is a double-layer network with $\boldsymbol{m}_0$ nodes, that is $\boldsymbol{E_c = E_f}$ and the amount of edges of the two sub-network is $|\boldsymbol{E_c}| = |\boldsymbol{E_f}| = \boldsymbol{e}_0$. In other word, the $\boldsymbol{f}$ -layer and $\boldsymbol{c}$-layer networks are total isomorphic.

2.Growth: A new node $\boldsymbol{v}$ enter $\boldsymbol{f}$ -layer and $\boldsymbol{c}$-layer networks at the same time and respectively connect $\boldsymbol{m_f}$ and $\boldsymbol{m_c}$ nodes in $\boldsymbol{f}$ -layer and $\boldsymbol{c}$-layer networks, while $\boldsymbol{m_f} \leq \boldsymbol{m}_0$, $\boldsymbol{m_c} \leq \boldsymbol{m}_0$.

3.Priority connection weights of degree: Define function $\boldsymbol{F^{\alpha}_{\omega}(k^c_{\omega} ,k^f_{\omega})}$ is the weight of degree of node $\boldsymbol{\omega}$ on the $\boldsymbol{\alpha}$-layer sub-network ($\boldsymbol{\alpha}$=$\boldsymbol{f}$ or $\boldsymbol{c}$). $\boldsymbol{F^{\alpha}_{\omega}(k^c_{\omega} ,k^f_{\omega})}$ is related with the node $\boldsymbol{\omega}$'s degree $\boldsymbol{k^c_{\omega}}$ and $\boldsymbol{k^f_{\omega}}$ on the $\boldsymbol{f}$-layer and c-layer networks, and the rate of the new node v connecting with $\boldsymbol{\omega}$ on the $\boldsymbol{\alpha}$-layer sub-network is proportional to the weight $\boldsymbol{F^{\alpha}_{\omega}(k^c_{\omega} ,k^f_{\omega})}$ on the sub-network.

4.Renew the $\boldsymbol{c}$-layer network: Randomly select $\boldsymbol{n_p r}_0$ couples of nodes on the $\boldsymbol{c}$-layer network and connect them per time step, so the rate of each couple to be selected is $\boldsymbol{r}_0$; Then break $\boldsymbol{n^c_e(t) r}_1$ edges randomly of the $\boldsymbol{c}$- layer network, so the rate of each edge still having contact relation is 1- $\boldsymbol{r}_1$.

5.Renew the $\boldsymbol{f}$ -layer network: Randomly select $\boldsymbol{s_0 k^c_i}$ adjacent nodes that's not transmission nodes of $\boldsymbol{i}$ and connect the new nodes with $\boldsymbol{i}$ for each node $\boldsymbol{i}$ of the $\boldsymbol{f}$-layer network per time step; Then break $\boldsymbol{n^f_e(t)s_1}$ edges randomly of the $\boldsymbol{f}$-layer network, so the rate of each edge still having transmission relation is 1 - $\boldsymbol{s_1}$; Finally we randomly select $n^f_m s_2$ nodes, the rate of random node j to be selected is proportional to $\boldsymbol{k^f_j(t)(k^f_j(t)} - 1)$. For each node selected choose a couple nodes from its adjacent nodes without edges and connect them, that means two nodes with a common transmission relation node having transmission relation.

Repeat (2)-(5) until the network reaches the scale of multi-layer network we need.

3.3.2 Results of Simulation

The figures of info-transmission network and the degree of nodes in various years are as Fig.2, Fig.3, Fig.4 and Fig.5.

By contrastively analyzing these figures, we can learn:

1) The density of the info-transmission network becomes bigger from the year 1998 to 2006, that is the clustering coefficient becoming bigger than before. It reflects that the transmission capability becoming stronger and the cover area becoming broader with the development of trans media.
2) Observing and comparing the figures of the degree of nodes, we know that the degree of nodes' density becomes larger and the amount of nodes with degree large becoming more than before.

That is to say that the number of the influential central nodes becomes larger with time going, accelerates the spread of information and plays a vital role innetwork.

3) When clustering coefficient is one, the info-transmission network is a complete graph and the degree of each node reach to the maximum. It reflects that the information cover rate is one, the nodes touch each other totally and information transfer most broadly.

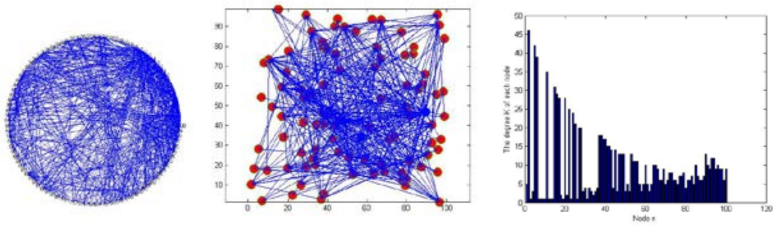

Fig 2: Clustering Coefficient Is 0.34819 In 1998.

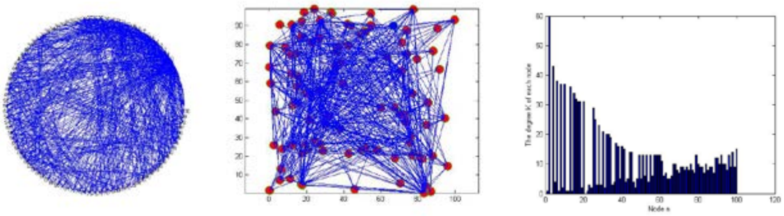

Fig 3: Clustering Coefficient Is 0.37406 In 2002.

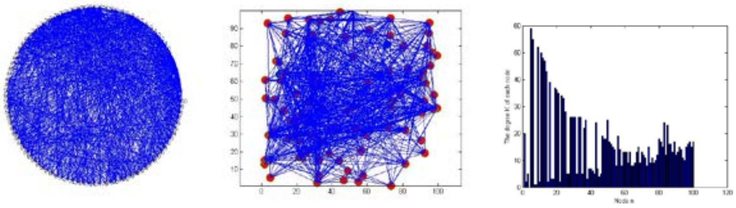

Fig 4: Clustering Coefficient Is 0.39535 In 2006.

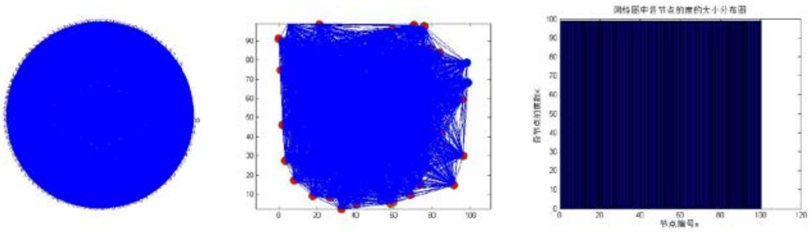

Fig 5: When Clustering Coefficient Is One

4. Summary

According to the results of each model, we analyze info-transmission network deeply and find some characters of information flow.

Analyzing the parameter $\boldsymbol{\delta}$ of SIR-based info-transmission model, we get that when $\boldsymbol{s}_0 \geq \frac{1}{\boldsymbol{\delta}}$. The function of the ratio people knowing the news $\boldsymbol{i(t)}$ rises at first then declines to 0, that means this information is widespread. When $\boldsymbol{s}_0 \leq \frac{1}{\boldsymbol{\delta}}$, the function $\boldsymbol{i(t)}$ decline to 0 monotonously, that means this information is spread in a small range. Hence we know that threshold of information is $\frac{1}{\boldsymbol{\delta}}$.

The progress of communication technology respect the degree of influential and central nodes in the information transmission network becoming bigger than before and the amount of central nodes is increasing in fact.

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