SATURATION MODEL OF NETWORK INFORMATION DIFFUSION

Jinlou Zhao, Zhibin Liu
School of Economics and Management, Harbin Engineering University, Harbin, China

Jiannan Yu
School of Science, Harbin Engineering University, Harbin, China

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Abstract: This paper first put forward information diffusion mode under the framework of network dimension-force, then analyzed the influence of information diffusion dynamic & resistance on information saturation under this mode，later this paper established information saturation model using non-homogeneous Poisson Process, at last simulated information saturation model based on practical data, which proved the effectiveness of this model.

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1 INTRODUCTION

Since the theory of network dimension-force was brought forward in 2004, some scholars have done some primary theoretical research on network information diffusion based on this theory. The key of network dimension-force theory is the information's time-quantity effectiveness, from this view network information diffusion can be viewed as a process in which information's time effectiveness and quantity effectiveness changes with time. In this process information's value increases with the increase of the relative quantity of information which information destination obtains. Therefore information destination is always looking forward to obtain more sufficient information. This sufficient degree of information that information destination obtains can reflect quantity change of information diffusion sufficiently, and it is more intuitional and easy to description and modeling. In order to make research more convenient we called sufficient degree of information as information saturation. The research of network information diffusion saturation can help us find information saturation model, which can help us find time-quantity relation of information diffusion. Using them, we can optimize network information diffusion better. It is of great practical and theoretic significance.

2 THEORETICAL ANALYSIS

2.1 Information Diffusion Mode under the Framework of Network Dimension-force

Information transfers from node to node in the process of information diffusion. Obviously the relevance of two nodes' information is a decay process during information transfer process. In realistic space information transfer process is influenced by some related factors such as distance and time (Sinan & Don, 2007), so information diffusion follows node-to-node mode which is two-dimensional mode of information diffusion obviously. While in network space information diffusion can go without considering related influencing factors such as distance and time under the effect of network dimension-force, information diffusion follows node-to-surface mode, which is more stereotyped than information diffusion in realistic space. This mode belongs to three-dimensional mode of information diffusion as figure 1 shown.

In ideal state after $\Delta t(\Delta t \to 0)$ time the information from source information node transfers to thousands of information destination node explosively. These thousands of nodes can form a

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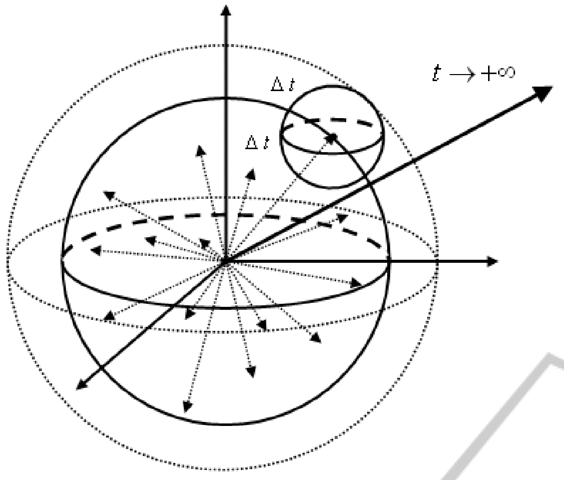

Figure 1: Information Diffusion Mode in Network Space.

sphere which radius is Δt. The surface area of this sphere is information of all information destination nodes from source information through Δt time. And after next period of Δt time all information destination nodes on the first sphere will turn into source information nodes and then information on these nodes will transfers to thousands of new information destination node explosively. Every original node also forms a sphere which radius is Δt. Because the length of Δt time is infinitesimal, we can understand that the first sphere form a new sphere which has the same center of sphere and radius is $2\Delta t$. When the length of Δt time tends to infinity, we can understand thousands of spheres which has the same center of sphere and radius is $n\Delta t$ are formed. So after $t = n\Delta t$ time a sphere which radius is $t = n\Delta t \rightarrow \infty$ will be formed. The process of this sphere changes with time is the process of information diffusion under the effect of network dimension-force. This node-to-surface three-dimensional mode of information diffusion is information diffusion mode under the framework of network dimension-force.

2.2 Information Saturation Analysis based on Dynamic & Resistance

In the theory of network dimension-force the dynamic of information diffusion in network space can be divided into the endogenous powers and the exogenous powers as figure 2 shown (Deng, 2006). The endogenous powers derive from diffusion subject, diffusion object and their interaction in diffusion system. The exogenous powers derive from the effect of the network transmission media to diffusion subject and diffusion object. These two powers act on information diffusion through push and pull effect on information. Obviously the process of information quantity's increase under the action of information diffusion's dynamic, which is the process of information saturation increase, can be viewed as the process of sphere's surface area increase under three-dimensional mode of information diffusion. Information saturation threshold is the biggest surface area of this increasing sphere because of the existence of diffusion resistances.

Although in network space information diffusion can go without considering related influencing factors such as distance and time under the effect of network dimension-force, information diffusion will reach stable saturation state at last. This restrictive function comes from diffusion resistances mainly. These resistances hinder diffusion process and decrease diffusion efficiency. The concrete constitutes of information diffusion resistances is as shown in figure 2 (Deng & Xu & Zhao, 2008). Resistances come from reaction force of endogenous powers and nodes' resistances. Firstly, because nodes in network information diffusion affect as sources and information destination each other, sources can act on information destination through endogenous powers. At the same time information destination can change into sources to diffuse information to original sources which now are information destination. Under these circumstances the original endogenous powers from sources will become resistances of information diffusion (Deng & Xu, 2008). So the endogenous powers can change into resistances of information diffusion with the transformation between diffusion subject and diffusion object. Secondly, because nodes are combination points of realistic space and network space, information receiving and sending are inevitably influenced by some resistances in realistic space. Under the influence of some resistances such as node spacing friction force, cultural difference inertia force and the resistance of information asymmetry in realistic space, some information certainly will be lost in the process that nodes process information. It will lend to information losing. Because of these two resistances' influence, the information from sources can't reach every node on the sphere. Some nodes can't be covered though they are relevant with sources. We called these nodes information vanishing points. Information vanishing points varies with information species. A information vanishing point can bring more information vanishing points. So information vanishing points can bring loss of information

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quantity and this loss is random obviously (Davies, 1979). Information vanishing points reflect to sphere model of network information diffusion in form of sphere's surface area decrease at t time. At last the final sphere will be all covered with information vanishing points at $t \to \infty$ time. At that time information diffusion will reach full saturation state.

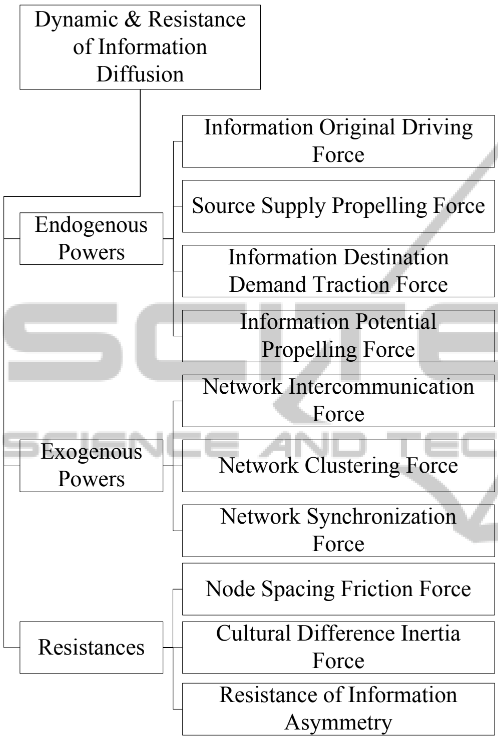

Figure 2: The Sketch Map of Information Diffusion Dynamic & Resistance.

3 MODEL DESCRIPTION

3.1 Model Description of Information Saturation Increase

In the second theoretical analysis part, after $t = n\Delta t$ time the information from source forms a sphere which radius is $n\Delta t$. The information, which all nodes on the sphere received in the last period of $n\Delta t$ time, is the augmenter of information within t time. We suppose that all nodes on the sphere receive information from source completely. In the theory of network dimension-force nodes is equated with information, so the augmenter of information within t time is equated with the quantity of nodes on the sphere. The sphere's surface area at t time is $s(t) = 4\pi(\tau t)^2$, and time intensity parameter is τ. Because $s(t)$ is integrable function in area of $[0, +\infty)$, we can get following function:

$$q(t) = V(t) = \int_0^{+\infty} s(t)dt = \int_0^{+\infty} 4\pi r(\tau t)^2 dt = \frac{4\pi}{3}(\tau t)^3 \qquad (1)$$

In this function $q(t)$ is total quantity of information within t time in ideal condition, and it conforms to the variation of sphere's volume which radius is τt .We can use $q(t)$ to describe the increase of information saturation.

3.2 Model Description of Information Saturation Decrease

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In the second theoretical analysis part, the decrease of information saturation is equated with the decrease of nodes which can receive information from source availably. In the theory of network dimension-force nodes is equated with information (Zhao, 2006), so the decrease of available nodes within t time is equated with surface area which consists of information vanishing points. In ideal condition this process is a random process, so there is a stable proportionality constant between surface area $\Delta q(t)$ which consists of information vanishing points and sphere's whole surface area $q(t)$. It can be described as $\Delta q(t) = \alpha q(t)$. We can see that information losing rate is a function on t. Meanwhile the increase of information vanishing points can be seen as a counting process (Hudson, 1972), and the variation of information vanishing points at t time is mutual independent with it at $(t + \Delta t)$ time. So this counting process is also a process with independent increments with a information losing rate function on t. All above proves the process of information vanishing points' increase is a Non-homogeneous Poisson Process which is satisfied with following functions:

$$N(0) = 0 \qquad (2)$$

$\{N(t), t \geq 0\}$ have independent increments (3)

$$p\{N(t+h) - N(t) \geq 2\} = o(h) \qquad (4)$$

$$p\{N(t+h) - N(t) = 1\} = \lambda(t)h + o(h) \qquad (5)$$

We set following condition:

$$m(t) = \int_0^t \lambda(s)ds \qquad (6)$$

We can get following function:

$$p\{N(t+s)-N(t)=n\}$$
$$=\exp\{-[m(t+s)-m(t)]\}\frac{[m(t+s)-m(t)]^n}{n!} \quad (7)$$

It means that $N(t+s)-N(t)$ is of Poisson Distribution with $m(t+s)-m(t)$ average value. Its intensity function is following:

$$\lambda(t)=dp/dt \quad (8)$$

Because $\Delta q(t)=\alpha q(t)$, $\lambda(t)$ is variation Probability of average information vanishing points' appearance with following function:

$$\lambda(t)=dE[N(t)]/dt \quad (9)$$

It is of Weibull Distribution. This function can be described with following function:

$$\lambda(t)=\lambda\beta t^{\beta-1} \quad (10)$$

In this function $\lambda,\beta>0$, β is shape parameter and λ is intensity parameter. So we can describe cumulative information decrease with following function:

$$m(t)=\int_0^t \lambda(t)dt=\lambda t^{\beta} \quad (11)$$

It conforms to the variation of sphere's volume which radius is τt .We can use $q(t)$ to describe the decrease of information saturation.

3.3 Comprehensive Model Description of Information Saturation Variation

In summation saturation function of network information diffusion consists of following functions:

(1) saturation increase function under the action of information diffusion powers:

$$q(t)=\frac{4\pi}{3}(\tau t)^3(\tau>0,t\geq 0) \quad (12)$$

(2) saturation decrease function under the action of information diffusion resistances:

$$m(t)=\lambda t^{\beta}(\lambda<0,\beta\geq 3,t\geq 0) \quad (13)$$

Because information diffusion will reach full saturation state finally, the speed of saturation's increase will fall over time. $\beta\geq 3$ meets this form. So there is following information saturation function under the action of information diffusion dynamic & resistances:

$$Q(t)=q(t)+m(t)$$
$$=\frac{4\pi}{3}(\tau t)^3+\lambda t^{\beta}(\tau>0,\lambda<0,\beta\geq 3,t\geq 0) \quad (14)$$

When we do diffusion experiment this function can be described with following simple function:

$$Q(t)=q(t)+m(t)$$
$$=\tau t^3+\lambda t^{\beta}(\tau>0,\lambda<0,\beta\geq 3,t\geq 0) \quad (15)$$

4 SIMULATION AND RESULTS

4.1 Experiment Simulation

The simulation program of the proposed model is developed in the environment of MATLAB 7.1.

In order to simulate $Q(t)$ in realistic condition, we adopt click-through accumulation of specific information as simulation data. We collect monthly click-through data of iPhone global official website from 2007/1 to 2008/9 as table 1 shown. Because the increase of information saturation is a process of accumulation increase, we adopt click-through accumulation as simulation data. The data after processing is as table 2 shown.

Table 1: Monthly Click-through Data of iPhone Global Official Website from 2007/1 to 2008/9 (unit: hundred million).

Time	Monthly Click-through Data
2007.1	0.0459
2007.2	0.0667
2007.3	0.3615
2007.4	0.2164
2007.5	0.3537
2007.6	0.5687
2007.7	1.4390
2007.8	1.2285
2007.9	1.5424
2007.10	1.6043
2007.11	1.1045
2007.12	1.6431
2008.1	1.4923
2008.2	0.7961
2008.3	1.0944
2008.4	0.5334
2008.5	0.4847
2008.6	0.1654
2008.7	0.2350
2008.8	0.0933

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Table 2: Monthly Click-through Accumulation of iPhone Global Official Website from 2007/1 to 2008/9 (unit: hundred million).

Time	Monthly Click-through Accumulation
2007. 1	0. 0459
2007. 2	0. 1126
2007. 3	0. 4741
2007. 4	0. 6905
2007. 5	1. 0442
2007. 6	1. 6129
2007. 7	3. 0519
2007. 8	4. 2804
2007. 9	5. 8228
2007. 10	7. 4271
2007. 11	8. 5316
2007. 12	10. 1747
2008. 1	11. 6670
2008. 2	12. 4631
2008. 3	13. 5575
2008. 4	14. 0909
2008. 5	14. 5756
2008. 6	14. 7410
2008. 7	14. 9760
2008. 8	15. 0693

We simulate practical data through Gaussian Fitting as figure 3 shown.

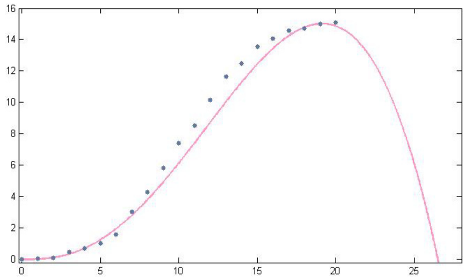

Figure 3: The Fitted Curve of Monthly Click-through Accumulation.

In the function after simulation time intensity parameter $\tau = 0.0459$, intensity parameter $\lambda = -0.02835$ and shape parameter $\beta = 3.147$. So information saturation function after simulation can be described with following function:

$$Q(t) = q(t) + m(t) = 0.0459t^3 - 0.02835t^{3.147} \qquad (16)$$

4.2 Results Analysis

We found information quality pushed by information diffusion powers outweighs it hindered by information diffusion resistances through the observation of figure 3 within $t \in (0,19)$ time. It means that in this period information diffusion powers outweigh information diffusion resistances. When $t = 19$ there is $\frac{d(Q(t))}{dt} = 0$, so it means that information quality pushed by information diffusion powers equals it hindered by information diffusion resistances, information diffusion powers equal information diffusion resistances, and information saturation reaches the maximum. When $t \in (19, 26.5)$, information quality pushed by information diffusion powers is less than it hindered by information diffusion resistances, information diffusion powers are fewer than information diffusion resistances, and information saturation begins to decrease. When $t = 26.5$ there is $Q(t) = 0 (t \neq 0)$, information quality within t time pushed by information diffusion powers equals it hindered by information diffusion resistances, and information saturation dropped to 0.

Through above analysis we can find the time point when $\frac{d(Q(t))}{dt} = 0$ is the turning point of dynamic & resistances variation curve. Before the turning point information diffusion powers occupy leading position (James, 2005). After the turning point information diffusion resistances occupy leading position. Under the framework of network dimension-force we called the time point when $\frac{d(Q(t))}{dt} = 0$ as saturation point of information diffusion, and $Q(t)$ is saturation value. After calculation there are $t = 19.1716$ (unit: month) and $\overline{Q(t)} = 15.0607$ (unit: hundred million).

The results meet market behavior of Apple Corporation. In 2007/10 Apple Corporation declared iPhone would be sold, and it accelerated the speed of information saturation's increase. After 13 months information saturation reached the maximum, and accordingly the sales volume of iPhone was increasing quickly. When information saturation began to decrease in 2008/6, Apple Corporation developed advanced product iPhone3G in the same month to keep the sales volume of its products.

5 CONCLUSIONS

Under the framework of network dimension-force information diffusion mode is node-to-surface

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spherical mode. An information saturation model for information diffusion in network space is constructed in this study. Some dynamic & resistance factors are involved in the model, such as endogenous powers, exogenous powers and diffusion resistances. From the simulation results, we conduct three main conclusions: (a) The tendency of information saturation is ascend in first and descend at last in the process of information diffusion. (b) Information saturation reaches the maximum when information quality pushed by information diffusion powers equals it hindered by information diffusion resistances. (c) Information saturation dropped to 0 when cumulative increase of information equals its cumulative decrease. In order to keep high information saturation we can develop new information in advance before original time reaches full saturation state.

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