Complex Network Function Evaluation Algorithm Based on Node Efficiency

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Abstract: The current complex network evaluation model ignores the global influence, so this paper proposes complex network function evaluation algorithm based on node efficiency. The algorithm overall consider the global influence of node failure, and use the efficiency of the node on network to define the load of each node, Limit load and failure model, with the rate of striking the ultimate failure nodes on network to measure the functionality of the network, the result of robustness experiment proofs: the algorithm is suitable for assessing the robustness of large-scale and small-world network function, the complexity of algorithm time is O(n2).

1. INTRODUCTION

There are many complex systems with the form of complex network. These networks can be converted into complex networks in the real world, such as the personal relationships in social system, collaborative network of scientists and spread net of epidemics, neuronal network in ecosystem, gene regulation network and protein interaction network, telephone network in IT systems, Internet, the World Wide Web and so on. The complex networks generally exist some basic statistical properties, such as the "small world effect" reflecting the length of short path and the characteristics of the high clustering coefficient; the nodes reflecting the complex network obeys the 'non -standard degree characteristics' of the distribution of the power rate; Also the description complex network generally exist the characteristics of 'the characteristics of community structure' of 'closely connected nodes within the same community, sparse connected nodes between different communities' [1-3].

Complex network is the abstract of the complex systems, which exit everywhere; many real systems can use abstract as the network model for researching. Complex network researches the core issue that is the relationship between the structure of complex system and the functions. Therefore the function of optimizing the network structure and improving the system has attracted the attention of many scholars in the field of complex networks. On the current research of complex network optimization, different scholars have different needs for different networks and the optimization objectives are not the same [4, 5]. Some scholars have focused on improving network robustness. Jing WP et al proposed topology optimization method in wireless sensor network based on Kleinberg model; through the optimization fault tolerance

and reliability of the network can be significantly improved [6-8]; Fan W et al through the discovery and improvement of the existing topologies key nodes in complex network, the connectivity and robustness of P2P network are improved [9-11]. Some scholars have focused on improving the network topology features: Wang LF studied the network edge reconnection algorithm; through the reconnection of the edges the synchronism of the network is improved [12, 13]; Ouveysi I *et al.* proposed a LCM-WP ways optimizing fiber optic network from the current research situation and other fiber-optic network in order to reduce the network traffic flow and congestion and optimize the robustness of network, by considering the network topology optimization and survival strategies [14, 15]. Many scholars only focus on the purposes of complex network optimization, while the need cost of network optimization is ignored.

What method to evaluate the invulnerability of complex networks? Currently the research method of survivability of complex network based on graph theory attracts the attention of many scholars. Under a certain attack strategies (random attack or deliberate attack), Nira A uses distribution of shortest path between the rate of connected node and node pair to measure the network reliability [16]. The larger scale value of connected node, and the shorter path between nodes, the greater reliability the network has. Wang B puts forward a scale-free network invulnerability optimization method y to deal with random attacks based on entropy. He thinks that network distribution entropy is lager, the network invulnerability is stronger; He S uses network connectivity to measure the robustness of the network, and thinks that network connectivity is not only affected by topology, but also affected by the information transmission capacity of node [17]. Once the network information transfer leads to blockage, it is likely to cause the collapse of the entire network; Wang JW aims at the remove of nodes or edges on network, proposed measurement network cascading failures model, and thinks that failure node will assign its load to an adjacent node and lead
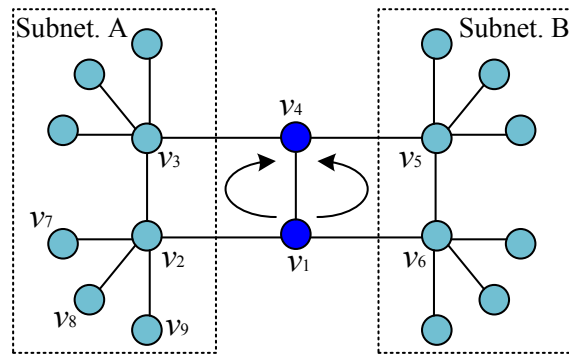
Fig. (1). Schematic About Distribution of Simple Communication Network Information Flow.

to failure of the adjacent nodes. But they all exist room for improvement: Barabasi AL only consider the impact of the network topology to the network robustness, although considering the network functions robustness and topology robustness, but only consider the impact that load on the failed node to adjacent nodes, but ignore its global impact [18-22]. So, in this paper we consider the overall impact of the failed node in the network, and propose a algorithm which uses node efficiency to measure the node function robust. This paper first use original network node to define each node loads and load limits, according to the situation before and after network attack and the change of load node to determine the node function failure model; then give out network features robust assessment algorithm, and optimize it; finally, use experimental analysis to verify its effectiveness and feasibility.

This paper mainly made expanded and innovative work in the following areas:

(1) In order to overcome the existing complex network robust research model which only considers the local impact of the node failure and defects of the network topology robustness, we propose complex network function evaluation algorithm based on the node efficiency. This algorithm considers the node failure overall impact, and uses the efficiency of the network nodes to define the load of each node: maximum load and failure mode. Through the rate of attached final network invalid nodes to measure the shock robustness of the network functions, and gives the evaluation and optimization algorithm.

(2) In order to verify the correctness and validity of the complex networks function evaluation algorithm based on node efficiency, we did a simulation experiment, simply use the topology robustness to assess the robustness of the real network is not enough, but also need to consider node load. By increasing the resources of the information processing nodes to improve the reliability of the actual network system; to measure the actual network system functionality robustness, should use conditions of maintaining the normal function of system to restrain. Under conditions of maintaining normal function, scale-free network in response to a deliberate attack is very fragile, but has a strong fault tolerance to random attack; when a node hit is smaller, different ways of attack has little effect on random networks, and there is same

classic conclusion with complex network robustness study. The simulation results show that: the assessment of this algorithm which considers the complex network functionality robust of node load is feasible and effective, and for large complex networks, can get a good computing power.

2. THEORETICAL BASIS OF COMPLEX NETWORK

2.1. Introduce the Question

The current methods of studying complex network robustness include the method which based on the shortest path of nodes, and the largest connected subnets scale of network, and network connectivity, etc., but they are based on the research of network topology, but ignored the robustness of the network functions, since the operation of actual network system is not only affected by the topology, but also constraints by the capacity of node itself, e.g., the information transmission on the communication network needs to consider the traffic load information of each node; traffic congestion in transport network need to consider evacuation traffic capacity of the transportation hub. Once node information transmission on communication network is overloaded or traffic flow is over the transport hub of evacuation capacity on traffic network, it will also lead to the collapse of the entire network. Refer to the simple communication network shown in Fig. (**1**) (the right side of the adjacent nodes are l), if the node: 1 is failure, it will make the traffic load which connect subnet A and B superimposed on 4v, once 4v is overloaded, the connectivity of the communication network will be destroyed.

Thus, in the actual course of the study the robustness of complex networks, consider the network topology alone is not enough, because removing nodes or edges can lead to redistribution of the flow of information throughout the network and the load of node in the information transmission process will change. For the actual network system, the network node failure is on global, rather than an impact on the neighbor node. For example in Fig. (**1**), the failure of v1 will affect v4. Network connectivity is not just the physical communication, and should consider the range of node load and node capacity constraints. Even if physical side suffered a blow, as long as the node has sufficient resources, it will

maintain its existing functionality by other means. However, if the node is overloaded, it will also lead to the collapse of the network, it is shown in Fig. (**1**). Accordingly, in the research process of the robustness of complex networks, considering the global impact of the load node function and robustness is essential.

2.2. Basic Knowledge

Suppose Figure $R(v,k)$ is a no-circle and undirected connected network. In it, $v = \{v_1, v_2, ... v_n\}$ is the set of all nodes in the network; $k = \{k_{10}, k_{11}, ... k_m \ partial\}$ and $k \subseteq v_x$ is the set of edges between nodes. w_{ij} represents the weight connecting nodes v_i and v_j edge field.

Definition 1 For Figure $R(v,k)$, with a_{ij} represents weights of edge between nodes v_i and v_j in R, when v_i and v_j directly adjacent, $a_{ij} = w_{ij}$, otherwise $a_{ij} = \infty$, then n order matrix $A = (a_{ij}) n_{xn}$ is called the weight side matrix of G.

Edge weight matrix A is used to indicate the distance that each node in the network can get by one step. When $a_{ij} = \infty$, indicating the nodes v_i and v_j can not arrive by one step, and they are not adjacent. Edge weights on network used to represent the degree of difficulty about information flow between nodes, the greater the value, the more consumption of resources.

Definition 2 node distance is the minimum sum of edge weights of all paths between two nodes, represented by d. If there is no path between v_i and v_j, then $d_{ij\infty}$. The maximum value between network nodes in the network is diameter R. When the network is not entitled, m represents the number of edges on the shortest path between two nodes.

$$m_{ij} = \min \left\{ \sum_{pq} w_{pq} \right\}, v_p, v_q \in r_{ij} \in Rt \quad (1)$$

m_{ij} represents the distance between nodes v_i and v_j, r_{ij} represents a path connecting nodes v_i and v_j, R_t represents the path collection connects node v_i, v_j.

Definition 3 network efficiency w is the average value of reciprocal sum of the distance between all nodes pair on the network.

$$w = \frac{1}{n(n-1)} \sum_{i \neq j} \frac{1}{d_{ij}} \quad (2)$$

In the form, n is the number of nodes in network, m_{ij} is the distance between nodes i and j.

From the definition of network Efficiency w, we can see that E expresses the average degree of closeness between all nodes in the network. The node pair in the network is closer, the shorter distance there will be, and the efficiency value of the network is greater. In order to measure the average proximity between in one node and other nodes in the network, based on the definition of network efficiency, we propose the concept of node efficiency i.

Definition 4 nodes efficiency i_k is the average value of the reciprocal about the sum of distance between nodes k and the other nodes in the network.

From form (3) we can see

$$E = \frac{1}{n(n-1)} \sum_{i \neq j} \frac{1}{d_{ij}} = \frac{1}{n} \sum_{k=1}^{n} \left(\frac{1}{n-1} \sum_{j=1, j \neq k}^{n} \frac{1}{d_{kj}} \right) \quad (3)$$

Therefore, this article defines i_k as follows:

$$I_k = \frac{1}{n-1} \sum_{i=1, i \neq k}^{n} \frac{1}{d_{kj}} \quad (4)$$

From the definition of i_k we can see, the average of all nodes efficiency in the network is the network efficiency E, the efficiency of a node express the average difficulty from this node to other nodes in network. The node efficiency on the network is higher in the network, indicates that the node transmits information more easily to other nodes, and the fewer resources consumed.

3. FUNCTIONAL ROBUSTNESS ASSESSMENT MODEL AND ALGORITHM

3.1. Model

The robustness of the network we study is the network is attacked by outside world or face the random failures itself, the ability that complex network system can maintain its function. In this paper, the complex network function robust assessment model considers the network topology node connectivity and the load of node to determine the probability of node failure by the change of node load, then to achieve the aim the assessment of the robustness of the network function. The concept of node load in this article is proposed from the actual network resource distribution process, and it is the abstract representation of the load of node itself, it is characterized by a node to maintain the existing functionality. If the node load is greater, indicating that the more severe the node resource consumption, and the ability to maintain existing functionality is weaker.

For information transmission on network, if the distance between node pair is larger, but need to maintain the

integrity of the information transmission, so the resource consumption information transmission between the nodes is less; if the resource of node information processing is limited, then the loads it bear is larger. Due to network efficiency characterize the average closeness of nodes in the network, so the network efficiency to some extent reflects the load of the entire network. If the network efficiency is higher, indicating that the distance between nodes pairs is shorter, and the network information flow more easily, and information transmission network load is smaller.

Since the average value of all nodes efficient in the network is network efficiency w, thus the efficiency of the node also reflects the sustainable load on the node. To the node whose resources for the information processing is fixed, if its efficiency is higher, it means that it is closer to the other nodes on network, and the flow of information is easier, the fewer resources consumed by the information transmission, and the smaller load imposed on the nodes. So, in this paper, we use node efficiency to characterize the load of node LD, and define the load node k as follows:

$$LD_k = \exp(-I_k) \quad (5)$$

The communication network shown in Fig. (**1**), there are four communication paths exists between node v_1 and v_5. When v_1 is invalid, if v_2 and v_5 have sufficient resources to let them follow the path of $v_2 - v_3 - v_4 - v_5$ to communicate, then v_2 and v_5 will not fail, and the entire network can maintain its existing capabilities. Therefore, for the node, as long as it has a certain amount of resources to maintain its existing capabilities, it can withstand a certain load. This article defines the load of nodes in the network as the tolerance of the load B.

For the general actual communication networks, because during the network formation process, the resources of each node in information processing is fixed, and the resource which can be used in information transmission process is the same, it lends to the loads they can bear are the same, both are B. Therefore, we use the same a to characterize tolerate a load of network nodes, and is defined as

$$B = \alpha \times \max(LD_k, k-1, \cdots, n) \quad (6)$$

In the form, $a \geq 1$ is the tolerance factor of the load node.

In an actual system, some of the overloaded nodes are not invalid immediately, because people will take some measures to increase the capacity of the node, and remit the node load to improve the overall reliability of the network, e.g., the Dynamic Routing Policy in communication network. Thus, the failure of any node in the network has a threshold. Due to the fixed network node information processing resources, lead to the same node failure threshold, which is defined as the node load limit

$$B_\infty = \beta \times C \quad (7)$$

In the formula, $\partial \geq 1$ is the factor of limit load.

According to the node limit load and load tolerance, we can define the failure probability w_k of node k as follows:

$$w_k = \begin{cases} 0, LD_k < C \\ \dfrac{LD_k - C}{C_\infty - C}, C < LD_k < C_\infty \\ 1, LD_k > C_\infty \end{cases} \quad (8)$$

From equation (8) we can see: when $\partial \to \beta \ \alpha \to \infty$, $B \to \infty$, each node has sufficient resources to maintain existing functionality, and is not affected by changes of topology in the network, equal to only study the topology robustness of the network; When β is fixed and $\beta \to \infty$, it means the extreme load of each node is infinite great, and the failure of overloaded node is not entirely dependent on the load of node, but with a certain probability to maintain existing functionality.

When the network is hit in a certain way, the failed node will lead to changes in the pattern of transmission of information and loads of other nodes, once the load of node exceeds the limit load, it will cause the node failure, and in turn affect its load of other nodes. If the network is hit, and the failed node is less, it indicates the ability to maintain the normal operation of the network is stronger.

Therefore, this article measures the functions robust of network via the number of failed node, and gives its normalized expression

$$f = \dfrac{\sum_{i=1}^{Num} f_i}{Num \times n} \quad (9)$$

In the formula, n is the number of nodes in the network, Num indicates the number of the network's hit, f_i represents the number of failure nodes caused by the i hit. Every fight is not only limited to one node fails; it can contain multiple failure modes.

3.2. Evaluation Algorithms

In order to statistic the failed node on the network, here we give the simple steps as follows:

Put: network edge weight matrix $A = (a_{ij}) n \times n, \partial, \beta$

Output: network function robustness w

Begin

l) Algorithm based on A to calculate the shortest distance matrix D is $a = [a_{ij}]$ //Floyd between all nodes:

2) Determine the efficiency and the load of the network node

F or i = 1 to n

{According to D is $a = \begin{bmatrix} a_{ij} \end{bmatrix}$ to determine the l_i, LD i of node v_i}:

3) According to the node load of the original network, to determine the tolerance load w and the limit load $B\infty$ of network node;

4) Determine the function robustness f of the network

According to the method of bit to determine the failure nodes and their number s_w_x;

While ($s\_w_x \succ 0$)

{According to the failed node, amend A ;

Repeat step l), 2) to determine the node load;

According to form (8) to determine the node with functional failure and it number s_w_x};

According to form (9) to determine the function robustness of the network, the output f;

End

As can be seen from the above algorithm steps, the time complexity of the algorithm depends on the shortest distance between all node pair on calculation of the matrix $Ds_i = \begin{bmatrix} d_{ij} \end{bmatrix}$. Because the time complexity of the floyd algorithm is O (n3), so the time complexity of this algorithm in the worst situation is O (n4). According to the feature that floyd algorithm calculate the shortest distance between node pair, so in order to reduce the complexity of its time, this paper can optimize it. Due to Floy d algorithm in the process of calculating the shortest distance matrix $Ds_i = \begin{bmatrix} d_{ij} \end{bmatrix}$ needs n cycles for the right side of the matrix, but when the shortest distance between all nodes on the network have been found, we will find $Ds_i = \begin{bmatrix} d_{ij} \end{bmatrix}$ maintains unchanged in the subsequent recycling process. Therefore, in process of solving $Ds_i = \begin{bmatrix} d_{ij} \end{bmatrix}$, if blindly do n cycles, will inevitably lead to a waste of computing resources, and improve time complexity of the algorithm. Based on this, in the process of using Floyd algorithm to calculate $Ds_i = \begin{bmatrix} d_{ij} \end{bmatrix}$, this paper sets the identity matrix to determine if the shortest distance between nodes has been found, once you find it out, then jump out of the loop , thus reducing running time and improve the efficiency of the algorithm. According to random matrix theory, we know that any the shortest distance between nodes can be got by side weight matrix $A = \begin{pmatrix} a_{ij} \end{pmatrix} n \times n$. If the shortest distance between nodes pairs has been identified, it means the maximum value (network diameter R) of distance between network nodes pairs has also been identified. We can know,

after optimization, the time complexity of this algorithm becomes 0 (Mn3), M represents the number of cycles that the network diameter R determination required. When the network has a small-world characteristics, and $M \leq n$, the time complexity of the algorithm can achieve O(n5), the evaluation of the functionality robustness of small-world and large-scale network can get a good computing power.

4. SIMULATION EXPERIMENT AND ANALYSIS

4.1. Experiment Environment and Setup

Assume the scale-free communication network and random communication network with the number of nodes are 512 and the number of sides is 1504.

In order to analyze the efficiency of the algorithm, use of the optimization algorithm to run MATLAB programs on the Intel Core 2 Duad 2.86 GHz computer, and assess the functional robustness for the different sizes and small-world network whose weight side is 1 (each node is connected to an adjacent six nodes, the probability of side reconnection is 0.3).

4.2. Effectiveness Analysis of Model

For simple communication network shown in Fig. (**1**), the paper treats network connectivity and maximum connectivity subnet as indicator, when the network assesses topology robustness and functional robustness while k_1, k_1 and k_2 are both failure, the assessment result is shown in Table **1** (multiple emulation average).

As can be seen from Table **1**, when $\partial = \infty$, the result of network function robustness is consistent with the topology robustness assessment result; When $\partial = 1, \beta = 1.6$, the evaluation results of network function robustness is different from the robustness of the topology. Analyze the reason, it is due to the assessment of network function robustness considers the tolerated load of communication network node. Once node overload, it will also lead to the destruction of network connectivity and reducing the size of the largest connected subnet, such as edge node k_5, k_6, k_7 overload. We can see, simply use the topology robustness to assess the robustness of actual network is one-sided, only overall consider the network topology, the capacity of the node, and the sustainable load to make the assessment of network robustness is more accurate.

About the study of complex networks robustness, generally consider that in the random attack, scale-free networks have a stronger fault tolerance than random network; but in a deliberate attack, scale-free network seems extremely fragile, use mentioned method in this article to assess the robustness. After simulation (average of multiple sampling), the assessment results of function robustness about random communication network and non-standard communication network are shown in Figs. (**2**, **3**).
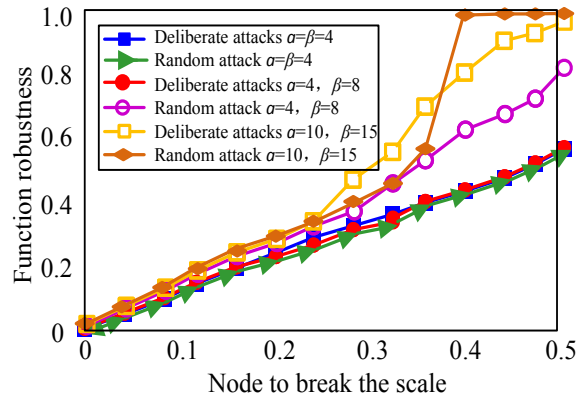
Fig. (2). Schematic of Functionality Robust of Random Communication Network.

Table 1. The Result of Simple Communication Network Robustness Assessment.

Evaluation Index	Failure Node	k_1	k_1, k_2
topology robustness	network connectivity	connected	unconnected
	scale of Max connected subnet	18	14
function robustness	network connectivity	unconnected	unconnected
	scale of Max connected subnet	15	0
function robustness	network connectivity	connected	unconnected
	scale of Max connected subnet	18	14
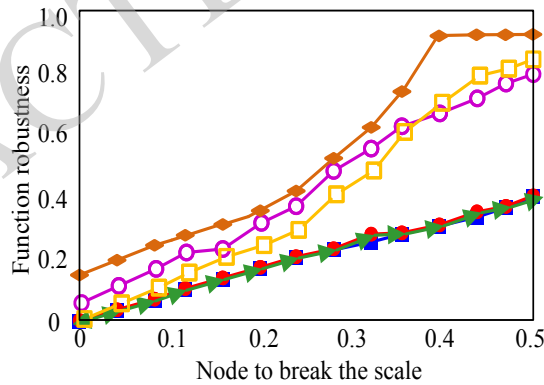
Fig. (3). Schematic of Functionality Robust of Scale-Free Communication Network.

As can be seen from Figs. (**2**, **3**), with the increase of tolerance factor and limit factor of the load of network node, the function robustness of the communication network gradually increased. When α, the curve of function robustness of communication network is a straight line whose slope is 1, indicating that there is no communication network as a result of overload function failure node, except the hit node, other nodes can maintain its existing communication function, then the function robustness of the communication network is the strongest. We can see, to the actual network system of different topology, in order to increase reliability, reduce the number of function-failure node caused by overload, we can add a node of the information processing resources to increase the capacity of the node, then reduce the failure probability of node function, and let the network has a strong functional robustness.

When the value of α and β is certain, on the whole: scale-free communication network in response to a deliberate attack on its functional robustness is low , but has strong
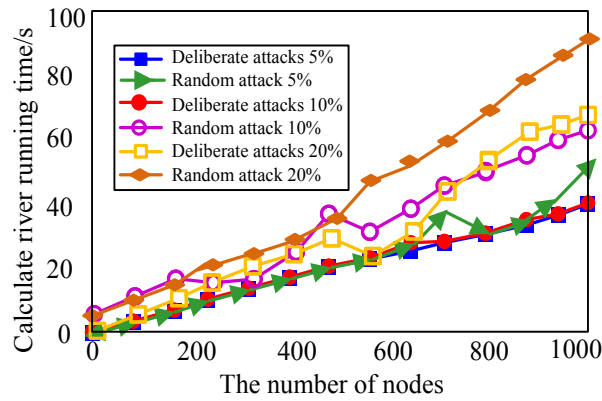
Fig. (4). Execution Efficiency Charts of Different Size and Small World Network Algorithm.
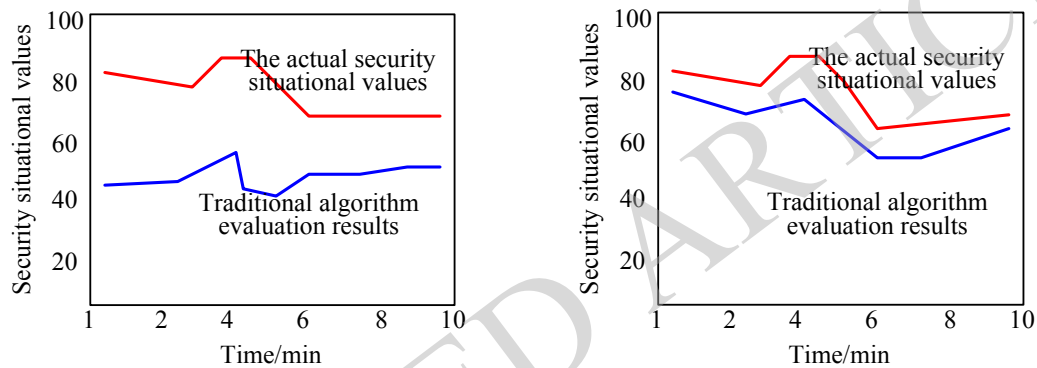

Fig. (5). Comparisons about Assessment of Our Algorithm and Traditional Algorithm.

tolerance on random attack; but different ways of attacking random communication has little effect on the network, which is consistent with the classic conclusion of assessment of the robustness of the network, it illustrates the effectiveness of this method, however, the assessment of considering the function robust of complex communications network of the load node, you should use the actual maintain the normal function of the communication system in response to a different mode of attack under constraint. For example: if there is 12% node on communication network is failed, it will make the network collapse, when the size of node is more than 12%, the conclusion of complex network robustness assessment is not true, because in this case the impact of random attacks and deliberate attacks on the communications network is the same, so if the actual network system maintains normal function, scale-free network in response to a deliberate attack is very fragile, However, has a strong tolerance by random attack, which is shown in Fig. (**3**); when the scale of node attack is small, attack in different ways has small influence on random networks, when the size exceeds a predetermined threshold value, deliberate attacks on random network is also very fragile, it is shown in Fig. (**2**).

4.3. Algorithm Efficiency Analysis

In the current study on complex network robustness, the reason why scholars consider only local effects of node

failures while ignoring its global impact is due to complexity time if consider the robustness assessment algorithm of global information network, for large-scale network, it is not apply, so this paper proposes the robustness of complex networks function optimization algorithm.

Assume $\partial = 3$, $\beta = 8$, the running time (the average of several sampling) shown in Fig. (**4**).

As can be seen from Fig. (**4**), the assessment time of optimized algorithm is no more than 104s on small-world network features robust whose number of nodes is 1000, and the scale of deliberate attacks is 20%, and with the size of the node hit is reduced, its computing power is better, it shows that the proposed algorithm is effective. Because the actual system is mostly has small-world characteristic, so use this method for the assessment of large-scale and small-world function robustness network can obtain ideal computing power.

4.4. The Convergence Rate of Algorithm

Use traditional algorithms for complex network assessment and use our algorithm for security situation assessment of complex network, and the obtained experimental results can be described by Fig. (**5**).
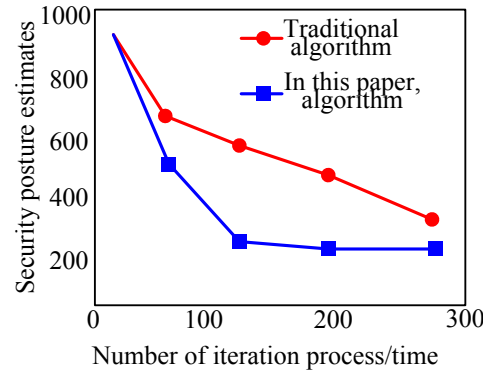
Fig. (6). Comparisons about Convergence Rates of Different Algorithms.

We can know from the above experimental results that the evaluation curve we obtained by using our algorithm for complex network assessment, is closer to the real complex network. It represents that in the process of assessment of complex network, our algorithm has better performance. During the process of assessing complex network by using different algorithms, the convergence rate of evaluation result we obtained can be described by Fig. (**6**). According to the comparing result of convergence rate of different algorithms, we can be informed that the convergence rate of our algorithm is faster, greatly reduces the learning time, thereby improving the accuracy of the assessment of complex network.

CONCLUSION

For today's complex network robustness evaluation model only consider the robustness of the network topology and the defect of local effect of the failed node, so this paper proposes complex network function evaluation algorithm based on node efficiency. The algorithm overall consider the global influence of node failure, and use the efficiency of the node on network to define the load of each node, Limit load and failure model, with the rate of striking the ultimate failure nodes on network to measure the functionality of the network, the result of robustness experiment proofs: the algorithm is suitable for assessing the robustness of large-scale and small-world network function, the complexity of algorithm time is O (n2).

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

REFERENCES

[1]   R. Andrew, G. P. Peters, and J. Lennox, "Approximation and regional aggregation in multi-regional input-output analysis for national carbon footprint accounting," *Economic Systems Research*, vol. 21, no.3, pp. 311-335, 2009.

[2]   J. P. Boyd, W. J. Fitzgerald, M. C. Mahutga, and D. A. Smith, "Computing continuous core/periphery structures for social relations data with MINRES/SVD," *Social Networks*, vol. 32, no.2, pp. 125-137, 2010.

[3]   E. Dietzenbacher "More on Multipliers," *Journal of Regional Science*, vol. 45, no.2, pp. 421-426, 2005.

[4]   H. W. Holub, and H. Schnabl, "Qualitative input-output analysis and structural information," *Economic Modelling*, vol.2, no.1, pp. 67-73, 2012.

[5]   H. W. Holub, and G. Tappeiner, "A general qualitative technique for the comparison of economic structures," *Quality & Quantity*, vol. 22, no. 3, pp. 293-310, 2010.

[6]   J. Kranich, "Agglomeration, vertical specialization, and the strength of industrial linkages," *Papers in Regional Science*, vol. 90, no.1, pp. 159-178, 2011.

[7]   M. J. Mirza, and N. Anjum, "Association of Moving Objects Across Visual Sensor Networks," *Journal of Multimedia*, vol 7, no. 1, pp. 2-8, 2012.

[8]   T. Phakpoom, "Clustering and Industrial Development: Evidence from Thailand," *Nagoya University*, 2011.

[9]   Y. Geng, J. He, H. Deng and K. Pahlavan, "Modeling the Effect of Human Body on TOA Ranging for Indoor Human Tracking with Wrist Mounted Sensor," 16th International Symposium on *Wireless Personal Multimedia Communications* (WPMC), Atlantic City, NJ, 2013.

[10]   S. J. Kwak, S. H. Yoo, J. I. Chang, "The role of the maritime industry in the Korean national economy: an input-output analysis," *Marine Policy*, vol. 29, no.4, pp. 371-383, 2011.

[11]   M. Labaj, "Qualitative input-output analysis and national innovation system in Slovakia," *International Journal of Transitions and Innovation Systems*, vol. 1, no. 2, pp. 105-116, 2011.

[12]   M. L. Lahr, and L. D. Mesnard, "Biproportional Techniques in Input-Output Analysis: Table Updating and Structural Analysis," *Economic Systems Research*, vol. 16, no. 2, pp. 115-134, 2009.

[13]   S. Lee, S. H. Yooka, and Y. Kimb, "Centrality measure of complex networks using biased random walks," *The European Physical Journal*, vol. 68, no. 2, pp. 277-281, 2010.

[14]   P. Midmore, M. Munday, and A. Roberts, "Assessing industry linkages using regional input-output tables," *Regional Studies*, vol. 40, no. 3, pp. 329-343, 2006.

[15]   A. S. G. Muniz, A. M. Raya, C. R. Carvajal, "Core periphery valued models in input-output field: A scope from network theory," *Regional Science*, vol. 90, no. 1, pp. 111-121, 2011.

[16]   J. Oosterhaven, and F. E. Cardenoso, "A new method to estimate input-output tables by means of structural lags," *Tested on Spanish regions. Papers in Regional Science*, vol. 90, no. 4, pp. 829-844, 2011.

[17]   H. Roepke, D. Adams, and R. Wiseman, "A new approach to the identification of industrial complexes using input-output data," *Journal of Regional Science*, vol. 14, no. 1, pp. 15-29, 2000.

[18]   C. J. R. San, and M. V. Biezma, "The mining industry in the European Union: Analysis of inter-industry linkages using input-output analysis," *Resources Policy*, vol. 31, no. 1, pp.1-6, 2006.

[19]   C. J. Sanchez, and R. Duarte, "Production Chains and Linkage Indicators," *Economic Systems Research*, vol. 15, no. 4, pp. 481-494, 2003.

[20]   X. Li, Z. Lv, B. Zhang, W. Wang, S. Feng, and J. Hu. "WebVRGIS Based City Bigdata 3D Visualization and Analysis," In*: IEEE, Pacific Visualization Symposium (PacificVis)*, 2015.

[21]   S. Li, Y. Geng, J. He, and K. Pahlavan, "Analysis of Three-dimensional Maximum Likelihood Algorithm for Capsule Endoscopy Localization," *5th International Conference on Biomedical Engineering and Informatics* (BMEI), Chongqing, China, pp. 721-725, 2012.

[22]   Y. Geng, J. He, H. Deng and K. Pahlavan, "Modeling the Effect of Human Body on TOA Ranging for Indoor Human Tracking with Wrist Mounted Sensor," *16th International Symposium on Wireless Personal Multimedia Communications* (WPMC), Atlantic City, NJ, 2013.