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Study on Node Importance of Networks Security Defense Based on Complex Network

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Abstract: How to find the key nodes in the networks is critical to distribute the limited networks security resource for the key part in the networks, so that the key parts of the networks can operate effectively under the attack of the network threat. In this study, we divide the network into nodes and edges according to the graph theory and study the node importance of the networks by means of the complex network. First, the topological model of the network is modeled by means of complex networks theory under the base of analyzing the connection feature and the function of the network firstly and then some characteristics of the networks are presented, such as the information distribution amount, distribution efficiency and the information control capability; finally, an evaluating algorithm of node importance for the networks is proposed based on the relation, function of the nodes and the properties of the network. The simulation result shows that the method of node importance proposed in this study is effective and therefore a reference can provided for making network defense decision.

Key words: Node importance, network defense decision, information security

INTRODUCTION

With the development of the information technology, the network is playing a more and more importance role in everywhere. A large amount of information, such as the economy, finance and industry etc., are transmitted by the networks among every network node in the networks. In current research results about the network security mainly focus on network defense strategy dispose and network risk assessment (Strogatz, 2001; Alberts *et al*., 2000) etc., but rarely study the network security defense from the important node defense in the network.

The complex network theory (Latora and Marchiori, 2007; Defense Science Board, 2007) is an analytic approach to describing a variety of network structures developed based on statistical physics and several important features of the network structures around us were discovered (i.e., the Small World, the Scale-Free, etc.). Some of recent studies were focused on the issue of whether the same principles could be applied to the development of the computer-network communication (Gallos *et al*., 2005; Burke, 1999) and also applied in modeling the network (Defense Science Board, 2007; Wang *et al*., 2010; Poulin *et al*., 2000; Trencansky and Cervenka, 2005; Chen *et al*., 2004; Li *et al*., 2010; Ma *et al*., 2010). Because these research results mainly focus on the structure and the properties of the network but rarely pay attention to the function of the information in the network, they can't describe the node importance really and exactly. For this reason, we study the node importance based on the complex network theory and function of the information of the network and propose a method for the evaluation of node importance, to provide a reference for making network defense decision, such as network defense resource distribution.

MODEL OF THE NETWORK

Network structure analyzing: According to the function of the network, the function of the node in the network can be divided into the information distribution node, information relay and information receive and transmit node (Fig. 1) which is composed of a series of nodes based on the function of the node.

Topological model: Based on the network connection feature analyzed above, the topological model of the network can be modeled. Suppose the set of the nodes is

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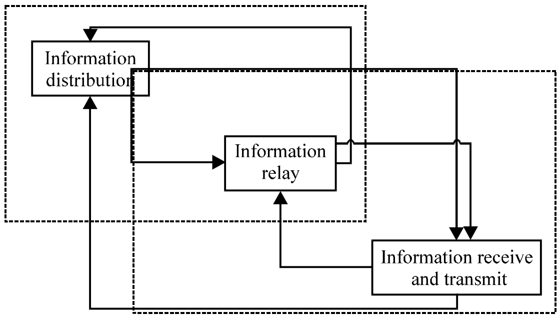

Fig. 1: Function of node

V and the set of the edges is E, the topological structure of the network can be described as an undirected graph, G = (V, E),Where, V = {v_1, v_2, ..., e_m} represent the nodes in the network; E = {e_1, e_2, ..., e_m} represents the information exchange relation between the each pairs of nodes. The adjacency matrix represents the connection between each node, i.e.:

$$\alpha_{ij} = \begin{cases} 1, \text{if } i, j \text{ are connected} \\ 0, \text{otherwise} \end{cases} \quad (1)$$

In order to show the information distribution and transmission function of the nodes in the network, we divide the nodes in the network into three types of node, i.e., information distribution node, v_D, information relay node, v_R and the information receive and transmitting node, v_{CT}. The set of the node is composed of the set of the Decision and that of the Sensor and Operation:

$$V = V_D \cup V_R \cup V_{CT} \quad (2)$$

CHARACTERISTICS OF THE NODE IN THE NETWORKS

Information distribution: In the networks, the amount, transmitting speed and the control capability of the information are critical to the network operation effectiveness,. For a node in the network, its importance in network depends on its information distribution amount, distribution capability and relay capability.

Definition 1 (information distribution amount): The amount of information transmitted by the node in the network.

In the network, the type of node is different; the amount of information transmitted is different, e.g. the information distribution nodes transmit more information than that of the information receive and transmitting node. Suppose information amount transmitted by every transmission channel is same. The information transmission amount can be measured by the number of links incident upon a node (i.e., the number of ties that a node has). Supposed the number of the links incident upon the node is N, the information transmission amount can be denoted as N. In order to normalize the information transmission amount, we use the relative information transmission amount to characterize the information transmission amount which is shown as follows:

$$C_d(v) = \frac{N}{N_{max}}, \quad v \in V \quad (3)$$

where, N is the number of the links incident upon the node, N_{max}, the maximum number of the links incident upon the node in whole network.

Information distribution efficiency: Definition 2 (information transmission efficiency): The transmission efficiency means the information transmission speed from one of the nodes in the network, v_s, to another node in the network, v_t.

Supposed the d (vs, vt) means the shortest path length between the node v_s and v_t, the information transmission efficiency Ce(v) can be denoted as:

$$C_e(v) = \frac{1}{\sum_{j=1}^{n} d(v_s, v_t)}, \quad s \neq t, v \in V \quad (4)$$

Information control capability: Definition 3 (information control capability): The information control capability is a measure of a node's centrality in a network equal to the number of shortest paths from all vertices to all others that pass through that node which is a more useful measure of the load placed on the given node in the network as well as the node's importance to the network than just connectivity. It can be written as:

$$C_R(v) = \sum_{s \neq v \neq t \in V} \frac{\sigma_{st}(v)}{\sigma_{st}}, \quad (5)$$

Where, σ_{st} is total number of shortest paths from node s to node t and $\sigma_{st}(v)$ is the number from the node s to node t and pass the node v. To calculate the control capability, the σ_{st} and σ_{st} (v) should be calculated.

The control capability of the node represents its role in the network. If the control capability of a node is equal to zero which is in the edge of the network; if that of a node is equal to one, this node can control all information transmission.

Since, the Operation node in the C^2 network only receives or transmits information, has not information control capability. If the type of the node belongs to the Operation node, the control capability of the information

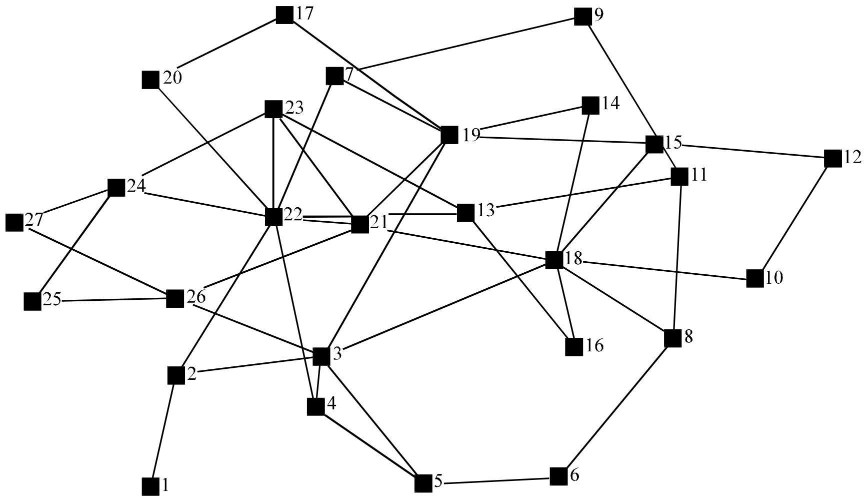

Fig. 2: Network example

is equal to zero. The control capability of the node can be described as follow to decrease the calculating amount.:

$$C_R(v)=\begin{cases}\sum_{s\neq v\neq t\in V}\dfrac{\sigma_{st}(v)}{\sigma_{st}}, & v\in V, v\notin V_O\\ 0, & v\in V, v\in V_O\end{cases} \tag{6}$$

NODE IMPORTANCE OF THE NETWORK

Concept of the node importance: Based on the definition proposed in above section, the more the information amount transmitted by a node, the more important the node is in the network; the higher the information transmission efficiency is, the more important the node is in the network; the greater the information control capability has, the more important the node is in the network.

The node importance of the network (Ci (v)) can be described as:

$$C_i(v)=C_a(v)\cdot C_e(v)\cdot C_R(v) \tag{7}$$

Evaluation algorithm of node importance: Based on the concept of the node importance and the affect factors of the node importance mentioned above, the Evaluation algorithm of node importance are described as follows:

- For I = 1 to n
- Calculate all the shortest paths from the node v to all other nodes//Dijstra algorithm
- Calculate Ca (v) according to (3)
- Calculate Ce (v) according to (4)
- For each pairs of nodes
  { Calculate $\boldsymbol{\sigma}_{st}$
  Calculate $\boldsymbol{\sigma}_{st}$ (v)}

Table 1: Simulation result

	$C_a(v)$	$C_e(v)$	$C_R(v)$	$C_i(v)$
1	0.166667	0.240741	0	0
2	0.333333	0.313253	0.153846	0.016064
3	1	0.433333	0.855385	0.370667
4	0.333333	0.320988	0.295385	0.031605
5	0.333333	0.25	0.153846	0.012821
6	0.166667	0.20155	0	0
7	0.833333	0.40625	0.683077	0.23125
8	0.333333	0.298851	0.153846	0.015326
9	0.166667	0.232143	0	0
10	0.333333	0.305882	0.295385	0.030118
11	0.333333	0.240741	0.153846	0.012346
12	0.166667	0.195489	0	0
13	1	0.419355	0.904615	0.379355
14	0.166667	0.298851	0	0
15	0.333333	0.305882	0.153846	0.015686
16	0.166667	0.236364	0	0
17	0.333333	0.320988	0.424615	0.045432
18	0.5	0.254902	0.301538	0.038431
19	0.166667	0.204724	0	0
20	0.166667	0.204724	0	0
21	0.833333	0.412698	0.467692	0.160847
22	0.333333	0.302326	0.153846	0.015504
23	0.166667	0.234234	0	0
24	0.5	0.342105	0.424615	0.072632
25	0.5	0.268041	0.301538	0.040412
26	0.166667	0.213115	0	0
27	0.166667	0.213115	0	0

- Calculate $C_R(v)$ according to (6)
- Calculate $C_i(v)$ according to (7)

Simulation result: Based on the evaluation algorithm proposed in this study and take the network example shown in Fig. 2 which is described by the Ucinet 6.0 (a software for analyze complex network).

All node importance are evaluated and the results are shown in Table 1.

From Table 1, we can find that the node importance of the node No. 3, No. 7, No. 13 and No. 19 are maximum and that of No. 1, No. 9, No. 16, No. 23 are minimum. If one of the node No. 3, No.7, No. 13 and No. 19 is destroyed, the network is cut apart into two parts, the information can't be transmitted to every node in the network. If the network defense resource are mainly distributed to these nodes, the security and the operation of the network can be protected. On the contrary, the one of the nodes No. 1, No. 9, No. 16 and No. 23 is destroyed; the operation of the network can't be affected.

In the algorithm proposed in this study, the relay capability of the receiving and transmitting node is taken as zero. The calculating time of the control capability for all nodes by Eq. 6 decreases with the increase of the number of the Operation node than that of by Eq. 5 and the calculating results are same.

CONCLUSIONS

In this study, the node importance of the network is evaluated by means of the information transmission amount, transmission efficiency and the information relay capability of the node in the network. By this way, the functional capability of the node is applied to evaluate the node importance which can provide the reference for making defense decision for the network, such as the network defense resource distribution etc. The simulation result about the network example shows the effectiveness of the algorithm proposed in this study.

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