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Task-oriented Evaluation Algorithm of Node Importance for Operation Network

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Abstract. In order to solve the problem that the existing operation network model is too abstract and the network function complexity is not enough researching, a node importance evaluation algorithm for the converged network is proposed. Firstly, this paper considers the node capability attributes in the operation system fusion complex network model, and integrates the node capability attributes into the function chain analysis method. Then, this paper defines the function path and function path capabilities. Finally, this paper combines node function attributes with capability attributes according to the topology rules, then proposes a kind of task-oriented dynamic node importance evaluation algorithm. The experiment result shows that the algorithm can distinguish the importance difference between nodes briefly, and can find task-independent nodes.

1. Introduction

The confrontation of traditional warfare primarily happened in ground and air space between firepower. Nowadays, the battlefield has expanded to all-dimensions (land, sea, air, space, and electromagnetic), and the participant has expended to all-fields (scout, decision, fire and logistical support). In comparison, modern warfare is more complex. Therefore, it is particularly important to analyze the overall capability of the system accurately. In 2004, J.R. Cares of the United States proposed a model of warring parties under informationized conditions, defined the concept of combat loop[1], which became the basic idea of studying the modeling and analysis of operation networks. Since then, researchers have continued to explore the application of complex network in military field. Theories such as local area connection[2], super network[3][4], fusion network[5] et al. had been put forward, which promoted the development of operational network modeling and analysis. However, most of the existing research still focuses on the topological complexity of network, without the functional complexity. Shi[6][7] proposed the concept of function chain at the information level, and studied on the invulnerability of network based on the information function chain. Zhang[8] proposed the concept of function chain in the weapon and equipment system, and defined the measurement of function chain characteristics such as timeliness, reliability, and firepower index. The theory of function chain has opened up a new way to analyze the function complexity of operation network, through combining the function attributes of nodes with the topologic attributes of network. Moreover, the function complexity of the operation network also comes from the versatile units, which cannot be classified as one single type. Yang and Fu proposed the concept of the fusion complex network. The former studied on fusion network evolution model, while the other studied on the node’s importance. Based on the existing studies on function chain, this paper considers the influence of node capability on the overall performance of the network, proposes task-oriented function chain capability evaluation...
algorithm for function chain and node importance evaluation algorithm.

The first section of this paper introduces the complex network model and related basic theories of operation system integration. The second section defines the functional chain, proposes the functional chain capability evaluation algorithm and the node importance evaluation algorithm. The third section carries out case verification and experimental analysis. The last section summarizes this whole paper and prospects the future work.

2. Network model and related theory

The complex network was first systematically studied by the Hungarian mathematicians Erdos and Renyi[9] in the 1960s and entered a new era at the end of the 20th century[10][11]. The complex network G=(V, E) is an abstraction of complex system in the real world, consisting of a set of points V and an edge set E. A point is the abstraction of a member of system, and an edge is the abstraction of a relationship between members.

2.1 Fusion node

The fusion node is node unique to the fusion network. It is a shared node of different kinds of networks and has multiple functions. The presence of the fusion node increases network efficiency by reducing the number of connected edges in the network and the network diameter. Generally, the higher the degree of network convergence is, the higher the network efficiency is. Fu Kai et al. use the fusion node ratio and the fusion node distribution description as the fusion parameters of the network. The proportion of the fusion node is defined as

$$cnp = \frac{M}{N}$$

(1)

Where: $M$ is the number of fusion nodes, and $N$ is the total number of nodes. The fusion node distribution is defined as

$$cnd = \frac{D_{avg}}{D_{nd}}$$

(2)

Where: $D_{avg}$ is the maximum distance between the fusion nodes, and $D_{nd}$ is the network diameter.

2.2 Overview of Fusion Complex Network Models

An operation network is a complex heterogeneous network with nodes that has different functions. Existing research usually regards the operation network as a multi-layer network. However, nodes in the operation network often can not be classified into a single functional category. What’s more, multi-layer network analysis is more difficult. As shown in Figure 2, the multi-layer network and the fusion network can be transformed into each other, but each part of the multi-layer network are still not independent but are coupled to each other.
Figure 1. Warfare system fusion network model

In this model, the node attributes are divided into functions and capabilities, denoted as \( F_n = \{f_1, f_2, \ldots, f_m\} \) and \( C_n = [t_d, p_e, f_x] \) respectively. The function set \( F_n \) indicates that there may be one or more functions. The three items in capability vectors \( C_n \) are command delay (in milliseconds), intelligence accuracy, and firepower coefficient. The edge only has the capability attribute, expressed as \( C_e = [t_e, p_e] \), \( t_e \) indicates communication delay and \( p_e \) indicates error rate. Table 1 shows all the types of functions and descriptions that appear in the network.

Table 1. Type and description of functions

| Identifier of function type | Description               |
|-----------------------------|---------------------------|
| S                           | Air-based radar           |
| Sa                          | Land-based radar          |
|                             |                           |
| D                           |                           |
| Da                          | Air force command         |
| De                          | Army command              |
| Ds                          | Naval command             |
| Dw                          | Joint command             |
|                             |                           |
| F                           |                           |
| Faa                         | Land-to-land blow         |
| Fae                         | Land-to-air blow          |
| Fsa                         | Sea-to-air blow           |
| T                           | ---                       |
|                             | Communication             |

3. Node importance evaluation algorithm based on function chain

Node importance indicates the relative importance of a node in the network. The significance of its research in military is to concentrate its superior resources to protect key units of our own side or to attack enemy’s key units. Unlike most networks, the node importance of a operation network is not only related to the topology nature of the nodes in the network, but also to the attributes of the nodes themselves. Moreover, the importance of nodes in a operation network is not static, but varies according to current tasks.
3.1 Function chain
At present, complex network analysis is chiefly based on network topology. After recognizing that the operation network has its unique functional complexity, some studies attempt to combine the node's own attributes with the network topology characteristics in a weighted form. However, the results have strong subjective factors. The function chain is based on the topology of the network, and connects nodes of different functions in a path manner. A function chain is an organic combination of network topology characteristics and node function attributes. This paper defines a function chain as a structure that combines different functions in a certain order and emerges new functions for a given operation task, a function path is a specific implementation in the network of a kind of function chain. Taking FIG.3 as an example, the path "1→2→6" in (b) constitutes the function chain "S1→D2→F1"; the path "4→2→7→5" in (c) constitutes the function chain "S2→D2→F3". Since there is no edge between "D2" and “F3” in (a), it is necessary to use the terminal function of the node 7; the path "1→7" in (d) constitutes the function chain "S1→D1→F2", that utilizes the fusion node, is shorter than the function chain. The following definitions are made here.

Definition 1: Redundant function path. When node fusion is utilized in the process of constructing the function chain path, each different functional step is recorded. The path in Figure 3(d) should be written as "1→1→7".

Definition 2: Simple function path. When node fusion is utilized in the process of constructing a functional chain path, the same fusion node is only recorded once. The path in Figure 3(d) should be written as "1→7".

![Figure 2. Several different ways of constructing a functional path](image)

3.2 Capability analysis of function path
The attributes of function chain are mainly divided into timeliness $\rho_t$, credibility $\rho_d$, and firepower index $f_2$, which are defined as follows
\[
\rho_i = \begin{cases} 
1 - \frac{\Delta_t + t_d + \sum_{j=1}^{t} t_{e_j}}{\lim}, & \Delta_t + t_d + \sum_{j=1}^{t} t_{e_j} < \lim \\
0, & \text{others}
\end{cases}
\]

\[
\rho_d = \rho_v \prod_{i=1}^{l} (1 - p_{e_i})
\]

\[
f_z = \sum_{j=1}^{d} f_{C_i}
\]

Where \(\Delta_t\) is the task update time limit, \(t_d\) is the command decision time consuming, \(t_{e_i}\) is the delay of the i-th side to transmit information, \(t_{lim}\) is the longest time limit for completing the task; \(p_{es}\) is the intelligence accuracy of the scout node, \(p_{e_i}\) is the communication error rate of the i-th side; \(f_{i}\) is the firepower index in the i-th space, and \(c_i\) is the weight coefficient. Comprehensive timeliness, credibility, and firepower index, defining functional chain capabilities as

\[
C_i = \rho_i \rho_d f_z
\]

3.3 Evaluation algorithm of node importance

After searching all the function paths corresponding to given function chain, the node importance is related to the number of function paths involved, the degree of participation in function path, and the capacity of the function path involved. Therefore, the definition of node importance in this paper is

\[
I_i = \frac{\sum_{j=0}^{m_p} J_{ij} C_j}{m_p}
\]

Where \(m_p\) is the total number of function paths in the network, \(J_{ij}\) is the degree of participation of i-th node in j-th function path, defined as \(J_{ij} = t_{ij} / l_{c_j}\), \(t_{ij}\) is the number of jobs held by i-th node, and \(l_{c_j}\) is a function. The redundant length of j-th path.

4. Case analysis

This paper analyzes an operation network with 50 nodes and 200 edges. Figure 4 shows the network structure. Table 2 shows the four function chains designed for experiment in this paper.
Table 2. Function chain for experiment

| NO. | Describe | Description       |
|-----|----------|-------------------|
| 1   | Se→De→Fea | Air defense       |
| 2   | Sa→Da→Faa | Air confrontation |
| 3   | Se→Da→Fae | Bombing          |
| 4   | Se→Dw→Fsa | Maritime air defense |

The result of experiment is shown in 0. In the four simulation experiments, the most critical nodes respectively are nod NO.36, NO.44, NO.41, and NO.24. It can be seen in the experiment’s results that the evaluation algorithm proposed in this paper can mine the most critical nodes in the given task mode, and can reveal the difference in importance between nodes obviously. Moreover, the experiment’s results show that half of the nodes have no importance, indicating that this evaluation algorithm can exclude units that are not related to the task, so that a large amount of guaranteed resources can be saved. It is consistent with the actual situation.

(a) Analysis result of air defense  
(b) Analysis result of Air confrontation  
(c) Analysis result of bombing  
(d) Analysis of maritime air defense

Figure 4. Distribution of node importance

5. Conclusion

1) Aiming at the problem that existing models is over abstracting in the field of operation network analysis, this paper establishes the operation system fusion complex network model, and further classifies the node functions. When applied to practice, a more accurate and detailed classification can be used.

2) In this paper, the function attributes and capability attributes of different nodes are merged by network topology rules, and the importance of nodes is dynamically analyzed according to the new
capability attributes emerged. The results of the experiment are convincing.

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