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Node importance evaluation in multi-platform avionics architecture based on TOPSIS and PageRank

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Abstract

With the development of avionics industry, it is difficult for traditional combat equipment node evaluation method to meet our requirements under complex combat system. This paper presents a method of node importance evaluation which is suitable for modern avionics field and can be used for reference in other combat fields. In order to make better use of the different features of the node itself and the different connections between nodes, we use TOPSIS algorithm to model the characteristics of the node itself, and PageRank to measure the interdependence of all nodes. Therefore, a novel node contribution evaluation algorithm based on TOPSIS and PageRank is proposed in this paper. In addition, after the evaluation of node contribution, we found that there was also a functional relationship between the operational information entropy in the whole graph and the contribution of these nodes. On this basis, information entropy evaluation algorithm of the overall combat map is further proposed. After a lot of experiments, the reliability of our algorithm is evaluated on the indexes of the node's destruction-resistant performance and information transfer efficiency. Compared with the traditional universal algorithm, our proposed algorithm shows more interpretable and robust results in the field of avionics.

Keywords: PageRank, Network influence algorithm, Entropy, TOPSIS

1 Introduction

Due to the development of various communication equipment, problems such as low information transmission efficiency and difficult recovery of network after attack often exist in the redeployment of complex networks. In the field of wireless sensors, Yin et al. [1] proposed a multi-attribute decision-making node importance evaluation method and achieved good results. Nguyen et al. [2] discussed the network robustness algorithm based on degree in the context of social network evaluation. In addition, Singh et al. [3] proposed a nodal weighted centrality evaluation method in public transport networks, which used clever function mapping to make traditional node centrality indexes more reasonable. This work greatly inspired the method in this paper and extended a test of auxiliary experiment. More far-reaching, De Clerck et al. [4] took the view of information communication and used the index of information entropy to analyze the social network data of Twitter, and the experimental results correctly reflected the popular mode of social network. This is of great reference significance for the follow-up work of this paper after the evaluation of node importance—the establishment of a perfect combat capability index.

However, we have to realize that the traditional node evaluation is often limited to the sensor, social network, and transportation fields, and there is a gap in the node evaluation in the aviation field. More importantly, due to the particularity of the characteristics of aviation nodes and the high cost of connection, the traditional evaluation method may not be suitable for aviation scenarios. In the face of complex networks under formation, with the concept of cooperative combat system proposed, we pay more and more attention to the value of nodes in the system. Therefore, we propose a novel node evaluation method, considering the need of cooperative combat of aviation nodes, and create a comprehensive evaluation method of node importance evaluation and combat map information entropy evaluation in the combat domain.

According to the modern warfare cycle theory, a complete combat process is a set of OODA (observation, orientation, decision, action)—a circular process of integration. Based on the theory of the OODA ring, the concept of an operational ring is put forward. The standard operational ring is composed of the reconnaissance, command, and control, influence nodes abstracted from one's equipment system and the target nodes of the other side. In the process of modeling, the equipment in the system has a single function by default. Still, with the continuous progress of science and technology [5], combat aircraft usually have two or more functions, such as multi-purpose fighter aircraft with reconnaissance and strike functions; if it is simply abstracted as a certain type of node, its evaluation is not comprehensive enough.

To make the evaluation of aircraft nodes more reflective of reality, this paper evaluates the contribution of nodes according to the different functions of nodes and the various links between different nodes. We first introduce the existing evaluation methods of node importance [6]:

1. *Methods based on the centrality of neighboring nodes* This kind of method is the simplest and most intuitive, which evaluates the influence of nodes according to their position in the network. Degree centrality examines the number of direct neighbors of a node in the network, and semi-local centrality examines the information of four layers of neighbors of a node in the network, and Cluster Rank [7]. The degree and clustering coefficient of nodes in the network are also considered.
2. *Approach based on path centrality* This kind of method examines the ability of nodes to control information flow and characterizes the importance of nodes. Such methods include subgraph centrality and number centrality (some evolutionary algorithms include route betweenness centrality, flow betweenness centrality, connected betweenness, random walk betweenness center, etc.) and other path-based mining methods.
3. *Iterative optimization sequencing method* These methods not only consider the number of neighbors of nodes in the network but also consider the impact of the quality of neighbors on the importance of nodes, including the centrality of feature vectors, cumulative nomination, PageRank algorithm, and its variants.

4. *Sorting Algorithm Based on Node Position* [8] The most remarkable feature of this kind of method is that the algorithm does not define the importance of computing nodes but determines the importance of nodes by determining the location of nodes in the network. The node at the core of the network is relatively important. On the contrary, if the node is at the edge of the network, its importance will be relatively low. Recommendation algorithms based on node location and different application scenarios have important research significance.

The methods and steps of node importance evaluation used in this paper are introduced here. Firstly, (1) TOPSIS was used to evaluate the overall contribution of nodes under different indicator scales. (2) Secondly, a PageRank evaluation method combined with the overall contribution is proposed; that is, the PageRank algorithm combined with TOPSIS weight is integrated to evaluate the local contribution of nodes. (3) Finally, the information entropy method is used to evaluate the overall combat capability.

The algorithm proposed in this paper has three main contributions and purpose:

1. TOPSIS algorithm is used to evaluate the characteristics of the aircraft node itself, such as stealth coefficient, initial speed, firepower capability, and other indicators serving for combat. Man–machine and individual combat equipment are evaluated under a framework to measure their contributions in the system.
2. The PageRank algorithm was used to abstract the intricate connections between aircraft nodes into an adjacency matrix, and then, the node orientation relationship was scored to obtain the role of each node in the degree of network connectivity;
3. Finally, we unify the above two algorithms and combine them with linear functions, so that the evaluation of nodes can consider the characteristics of the aircraft itself and the overall aircraft combat network, which is more instructive to the current combat system and can be extended to other combat fields.

The rest of paper is organized as follows: In Sect. 2, we introduce the background and related work. Our model and novel algorithms are presented in Sect. 3, with experimental results and evaluations discussed in Sect. 4. Finally, Sect. 5 gives the conclusions and future work.

2 Research methods

2.1 Evaluation of global aircraft combat ring node contribution based on topics

In order to evaluate the importance of nodes in the field of avionics, the first part of our work starts from the indicators of nodes themselves to analyze their own local weights. To achieve this purpose, we use TOPSIS algorithm, which is mainly used to solve evaluation problems and determine the final scores of each scheme layer. The advantage [9] is that it can make full use of the information of the original data and the results can accurately reflect the gap between the evaluation schemes. This algorithm is more suitable to solve the situation where the original data are sufficient and can be used for quantitative analysis. Therefore, this method is applied to the avionics node evaluation in this paper.

TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) [10] is a ranking method based on the closeness of limited evaluation objects to the ideal goal, and it is a relative evaluation of the advantages and disadvantages of the existing objects. As a sequence optimization technique of ideal target similarity, it is a very effective method in multi-objective decision analysis. Through the normalized data matrix, the optimal target and the worst target in multiple targets were found, and the distance between each evaluation target and the positive ideal solution and negative ideal solution was calculated, respectively, to obtain the closeness degree of each target to the ideal solution. According to the closeness degree of the ideal solution, the targets were sorted, which was used as the basis for evaluating the quality of the targets. The value of closeness is between 0 and 1. The closer the value is to 1, the closer the corresponding evaluation target is to the optimal level, and vice versa.

In the evaluation of aircraft combat ring nodes, it is not difficult to know that there are the following types of nodes [11]:

(1) *Target Node (T Node)* The target that needs to be attacked, destroyed, jammed, or intercepted during combat, which can be an aircraft node or an armed facility on the blue side.
(2) *Reconnaissance and early warning node (S node)* equipment or facilities that collect various types of information on the battlefield, mainly referring to aircraft nodes or other entities that conduct reconnaissance, early warning, or monitor blue targets on the battlefield.
(3) *Command and control node (D node)* the unit that makes decisions and commands combat equipment and personnel in the combat system, such as command posts at all levels and command and control systems.
(4) *Impact node (type I node)* an entity that can directly interfere with or damage the target node, mainly referring to the strike and jamming weapon system.

For different types of nodes, there are obvious differences in their measurement indicators. Taking the following quantitative table of capability indicators as an example, we can easily find that the evaluation of these nodes should first be on the same scale, abandoning the difference in the order of magnitude. Secondly, we should reasonably evaluate the importance of different indicators, so in this paper, we use the TOPSIS method to model this multi-index evaluation task. Some typical aircraft indicators are presented in Table 1.

In a combat ring, there are usually m evaluation nodes D_1, D_2..., D_m, and each target has n evaluation indexes X_1, X_2... X_n. Firstly, experts are invited to score the evaluation index, and then, the scoring results are expressed in the form of a mathematical matrix to establish the following characteristic matrix:

$$D = \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix}$$

In the above matrix, m row represents m nodes to be evaluated, and n column means that each node has n indicators. For the purpose of the following explanation, we abstract this matrix into a row matrix. We further write:

$$D = \left[X_1(x_1), \ldots, X_j(x_i), \ldots, X_n(x_m)\right]$$

Table 1 Example table of multiple indicators of aircraft

Capability indicators	Value range
Coefficient of survivability	[0.75, 0.82]
Warning time/s	[0.4, 0.9]
Maneuvering speed/knots	[0, 40]
Stealth coefficient	[0.18, 0.63]
Initial distance/km	[500, 2000]
Relative interception capability	[0.5, 0.9]
Anti-optical coefficient	[0.44, 0.74]
Anti-radar coefficient	[0.2, 0.71]
Anti-infrared coefficient	[0.44, 0.68]
Response time/s	[5e−4, 1e−3]
Decision error	[0, 1e−7]

The characteristic matrix is normalized to obtain a normalized vector, and a normalized matrix about the normalized vector is established:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$$
$$i = 1, 2, \ldots, m, j = 1, 2, \ldots, n$$

By calculating the weight normalization value of the corresponding indicator l_j, establishing a weight normalization matrix with respect to the weight normalization values:

$$v_{ij} = l_j r_{ij}, i = 1, 2, \ldots, m, j = 1, 2, \ldots, n.$$

The ideal solution and the anti-ideal solution are determined according to the weight normalization values:

$$A^* = \left(\max_i v_{ij} j \in J_1\right), \left(\min_i v_{ij} j \in J_2\right), \middle| i = 1, 2, \ldots, m = v_1^*, v_2^*, \ldots, v_j^*, \ldots, v_n^*$$
$$A^- = \left(\min_i v_{ij} j \in J_1\right), \left(\max_i v_{ij} j \in J_2\right), \middle| i = 1, 2, \ldots, m = v_1^-, v_2^-, \ldots, v_j^-, \ldots, v_n^-$$

Calculate the distance scale; that is, calculate the distance from each target to the ideal solution and the anti-ideal solution. The distance scale can be calculated by the n-dimensional Euclidean distance. The target is at a distance S^* from the ideal solution and a distance S^- from the anti-ideal solution.

$$S^* = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - v_j^*\right)^2}$$
$$S^- = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - v_j^-\right)^2}$$
$$i = 1, 2, \ldots, m$$

According to the closeness degree of the ideal solution, the higher the closeness degree of the sorting result is, the better the target is.

$$C_i^* = \frac{S_i^-}{\left(S_i^* + S_i^-\right)}, \quad i = 1, 2, \ldots, m$$

Define the hierarchical weight of a node w_i^1 for

$$w_i^1 = \alpha_i C_i^*$$

2.2 Aircraft node contribution evaluation based on the TOPSIS-PageRank multi-index fusion algorithm

After we obtain the importance ranking information of the attributes of nodes through TOPSIS algorithm, we hope to naturally integrate this information into the global importance evaluation of nodes. Therefore, we use the commonly used PageRank algorithm to evaluate the role played by each node in the whole connected graph based on the pointing relation of nodes. The results of TOPSIS are linearly combined. The combination of these two results reflects the importance of the node itself and the comprehensive performance of the network in the field of avionics [12]. The local weights of the nodes are evaluated, and then, the TOPSIS hierarchical weights proposed above are used for weighted fusion. Finally, the comprehensive weight based on the TOPSIS-PageRank multi-index fusion is obtained [13].

PageRank is a common algorithm to evaluate the relevance and contribution of aircraft nodes, which can be transferred to the research of node importance. In 1998, Sergey Brin and Lawrence Page proposed PageRank to solve some problems in search engines [14]. In this paper, we proposed a new algorithm for network link analysis, which is based on the random surfer model. Specifically, if a command node follows the link for several steps of information transfer, then it turns to a random starting point, and the aircraft node follows the link again for information transfer, and then, the value of an aircraft node is determined by the frequency with which the aircraft node is visited by the command node.

A simple description of the PageRank algorithm migrating to aircraft nodes is as follows: u is an aircraft node, $F(u)$ is the set of aircraft nodes pointed to by node u, $B(u)$ is the set of aircraft nodes pointed to u, $N(u) = F(u)$ is the number of links pointed out by u, and c is the normalization factor (generally 0.85).

The PR value of the importance of a node is formulated as follows; that is, the importance of a node is mainly determined by the importance that points to its node and the links that it points outward to:

$$\mathrm{PR}(u) = c \sum_{v \in (B(u))}^{n} \frac{\mathrm{PR}(v)}{N(v)}$$

However, considering that there is no direct subordinate relationship between some nodes; that is, there are fewer external links, this does not mean that the combat node is not important, so in this combat system, it is necessary to introduce a new node weight evaluation method.

We add an increment to prevent the node from being too low; that is, we add a damping coefficient called d (generally normalized to 0.85), which is like the paranoia in the neural network, to avoid sinking to 0 when calculating the weight, that is, to avoid some nodes not being considered.

$$\mathrm{PR}(u) = (1-d) + d\sum_{v\in(B(u))}^{n}\frac{\mathrm{PR}(v)}{N(v)}$$

In the case of more data, we can improve it from the perspective of the damping coefficient. In the classical PageRank algorithm, the transition probability of the aircraft node is equally distributed to the out-link aircraft node, and the PR value of the new aircraft node is generally low due to fewer links. The classical PageRank algorithm calculates the PR value by linking without considering the practical significance of aircraft nodes, which has the problems of command weight drift and aircraft node weight equalization. Therefore, an authority degree $p(vi)$ is introduced, which is determined by the ratio of the pointed links to the pointed links of the aircraft nodes:

$$p(vi) = Q\left(\frac{\text{Linkin}}{\text{Linkout}}\right)$$

After the introduction of the Ratio variable $p(vi)$:

$$\mathrm{PR}(u) = (1-d) + d\sum_{v\in(B(u))}^{n}\frac{\mathrm{PR}(v)\cdot p(v)}{N(v)}$$

Finally, combined with the TOPSIS algorithm mentioned above, we integrate the weight meaning of the node itself with the node orientation relationship obtained by the PageRank we define the overall weight evaluation of the node as:

$$w_u = k_1 * w_u^1 + k_2 * \mathrm{PR}(u)$$

where w_u^1 is the TOPSIS weight of the layer in which the u node is located, as represented above, and k_1 and k_2 represent normalization coefficients.

2.3 Evaluation method of combat capability based on information entropy

The ability to complete combat tasks is often uncertain, and information entropy can well describe the uncertainty of information, so the operational network capability of the weapon equipment system can be measured by information entropy [15].

The combat process can usually be decomposed into multiple nodes and edges, and each node and edge often have many factors that affect the combat capability. The smaller the uncertainty of these factors to meet the requirements of combat capability, the higher the combat capability. Conversely, the greater the uncertainty of meeting the capability requirements, the lower the combat capability. The uncertainty of various influencing factors in combat can be measured by the importance of its nodes. The greater the overall contribution of the nodes and the more distributed, it shows that the whole network has better invulnerability and better robustness in information transmission, and the more it can meet the needs of combat capability, the less uncertainty it brings to combat. Transforming the entropy function to obtain the weighted self-information quantity of the node, namely:

$$I_u = \frac{w_u}{N}$$

Among W_u represents the comprehensive contribution of nodes evaluated in Sect 2.2, and N is the number of nodes in the entire battle graph. We evaluate the amount of information of nodes in a way like K-shell, but we need to evaluate the information entropy. Further, we integrate the amount of information of other nodes about a node to obtain the information entropy function of a node:

$$e_u = -\sum_{j \in \Gamma(u)} I_u \cdot \ln I_u$$

where J $(j \in \Gamma(u))$ is the set of neighbors of node V_u. The information entropy of a node considers the propagation effect of its neighbors, and the greater the information entropy of a node, the greater its influence.

Then, we define the operational capability of the operational graph u as Ku, which can be measured by the amount of self-information, and we define the operational capability as the sum of the information entropy of nodes on all operational rings in the operational graph:

$$K_u = \sum_{i=1}^{M} \sum_{j \in \sigma(i)} e_j$$

Among σ_i is the set of nodes contained in the combat ring I, and M is the number of combat rings owned by the combat graph.

Then, the combat capability F of the joint combat system for the multi-target combat mission is

$$F = \sum_{i=1}^{M} q_i K_i$$

In the formula, q_i represents the weight value of each target, and the target weight is determined mainly based on the following aspects:

(1) The urgency of the military task (the threat level of the target to our side).
(2) The importance of the target in the enemy equipment system (the key node in the enemy system).

3 Experimental result and discussion

3.1 Different node contribution evaluation methods are used to evaluate the operational nodes

We start from a simulated avionics network, carry out case analysis, and do relative comparative experiments and performance evaluation.

Table 2 Explanation table of figure terms

Node name	Meaning
LD	Manned lead aircraft
UL	Unmanned lead aircraft
WM	A manned plane to protect the leader plane
UM	An unmanned plane to protect the leader plane
EL	Nodes with electronic warfare capability
RD	Nodes equipped with a radar reconnaissance unit

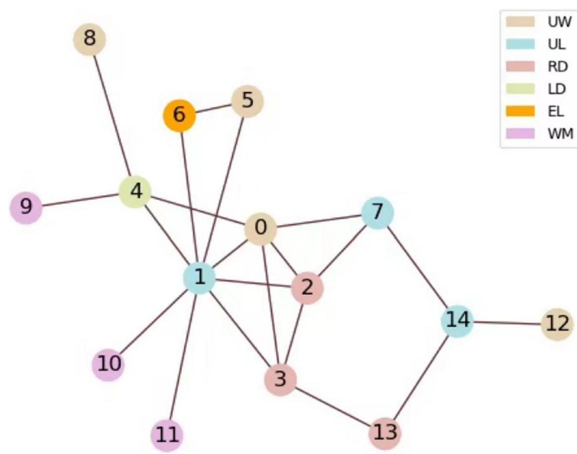

Fig. 1 Typical aircraft node battle chart

First, the practical significance of each node is explained in Table 2:
The following figure mainly includes.

1. LD 5.
2. WM 10, WM 11, WM 12.
3. UL 2, UL 15.
4. UM 6, UM 1, and UM 12, 13.
5. Other electronic warfare and radar warfare equipment.

To facilitate analysis, Fig. 1 shows an example of how nodes of different types are related to each other. We can see that the human aircraft in the picture are relatively few and in a lead state, and the radar and detection units will work with it to accomplish the assigned task.

To measure the efficiency of the integrated algorithm, it combines the TOPSIS global level weight node contribution algorithm and the PageRank node local contribution algorithm. We adopt the K-Shell [16], degree centrality [17], closeness centrality, VoteRank [18] and other common node contribution evaluation methods, combined with our own algorithm to carry out experiments. For the example shown above, the algorithm importance evaluation is shown in Table 3. After the experiment, the data obtained under the evaluation of these different algorithms have been normalized and presented in the following table on a unified scale.

We continue to carry out the experiment and measure the rationality of this evaluation algorithm through network survivability. After the removal of several key nodes, the network becomes several disconnected sub-networks, which greatly damages the control communication between aircraft nodes. We define that the communication performance of the network is evaluated by the connection between manned node 5 and manned wingman nodes 10, 11, and 12. When the network damage reaches 100%, it shows that after the key nodes are attacked, the information communication capability of the combat network will also be destroyed. In Table 4, the order of node importance under this algorithm is as follows:

Next, we introduce network efficiency [19]. This index is used to evaluate the efficiency of network nodes under different rankings. Between two nodes in a network V_i and V_j, a simple path with the least number of edges (different edges) is called a geodesic.

The number of edges of the geodesic d_{ij} is referred to the shortest path length between two nodes.

$1/d_{ij}$ called the efficiency between V_i and V_j, written as ε_{ij}, is often used to measure the speed of information transfer between nodes. When there is no path communication between V_i and V_j, $d_{ij} = 0$, and $\varepsilon_{ij} = 0$. Therefore, the efficiency is very suitable for measuring non-fully connected networks.

We use the cumulative node efficiency to evaluate in Table 5:

We can see that the TOPSIS-PageRank multi-index fusion approach can stand out in the degree measurement algorithm and achieve the best network efficiency.

Next, we evaluate the survivability of the network. How to evaluate the key nodes has always been a concern in the evaluation of complex networks. We delete the top three nodes one by one according to the importance of different algorithms and calculate the degree of network connectivity, to infer the significance of key nodes to the survivability of the network under different algorithms:

Table 3 Evaluation table of node contribution under different algorithms

Node	K-shell	Degree centrality	Closeness centrality	VoteRank (top 5)	TOPSIS	PageRank	TOPSIS-PageRank multi-metric fusion*
1	0.5	0.35	0.58	1.57	0.44	9.61	0.12
2	2	0.57	0.60	8	0.53	19.4	0.18
3	0.5	0.28	0.51	0.1	0.33	8.42	0.11
4	0.25	0.28	0.51	0.14	0.20	9.59	0.08
5	1	0.28	0.5	2.64	0.48	2.86	0.14
6	0.25	0.14	0.4	0.15	0.30	1.67	0.04
7	0.5	0.14	0.4	0.15	0.34	1.49	0.06
8	0.5	0.21	0.45	0.28	0.34	3.21	0.10
9	0.25	0.07	0.34	0.02	0.27	0.69	0.08
10	0.25	0.07	0.34	0.11	0.34	0.89	0.08
11	1	0.07	0.38	0.04	0.24	4.44	0.05
12	0.5	0.07	0.38	0.11	0.26	5.18	0.04
13	0.13	0.07	0.26	0.11	0.25	0.68	0.07
14	0.13	0.14	0.4	0.2	0.24	6.65	0.05
15	0.13	0.21	0.35	1.24	0.45	7.29	0.15

Table 4 Top 5 nodes of importance

Node importance ranking	K-shell	Degree centrality	Closeness centrality	VoteRank (top 5)	TOPSIS-PageRank multi-metric fusion*
1	2	2	2	2	2
2	5	1	1	5	15
3	11	3	3	1	5
4	1	4	4	15	1
5	8	5	5	8	8

Table 5 Cumulative node efficiency

Algorithm	K-shell	Degree centrality	Closeness centrality	VoteRank (top 5)	TOPSIS-PageRank multi-metric fusion*
Cumulative node efficiency	0.6122	0.5955	0.58	0.76	0.79

As can be seen in the figure below, when we delete the top three important nodes in various algorithms, these networks become fragmented. Here, we mark the branches with the number of connections greater than 1. We can see how the remaining nodes of the whole network communicate if the malicious attacks the important nodes evaluated by different algorithms.

In Fig. 2, we show the connectivity of nodes when the most critical nodes of TOPSIS-PageRank and Centrality are attacked.

In Fig. 3, we show the connectivity of nodes when the top three important nodes of VoteRank and K-Shell are deleted.

As shown in the figure above, we circle the link nodes that still exist after the attack.

As shown in Figs. 2 and 3, we can see that (1) in the TOPSIS-PageRank multi-index fusion method, after deleting nodes 2, 5, and 1, there are two connected branches left, which are the main connected subgraph of length 5 of 1–3–4–8–14 and the 6–7 connected branch; (2) in the degree cent algorithm, after deleting 2, 1, and 3, three connected branches are left, and the length of the longest connecter branch is 5. Because on the first three important nodes, the results of degree centrality and closeness centrality algorithms are node 2, node 1, and node 3, so the experiment is not repeated. (3) In the VoteRank, similarly, after deleting 2, 5, and 1, the main connected subgraph with a length of six is left; (4) in the K-shell, after deleting 2, 5, and 11, there is still a main connected subgraph of length 7 and 6–7 connected branches; below we use the average node connectivity metric [20] and analyze the four graphs after deleting the nodes.

In Table 6, we evaluated the seven average connections. Average node connectivity evaluation is after deleting the top three nodes of importance, we measure the connectivity of each node in the figure, for evaluation, which reflects the ability of information exchange to a certain extent. This also reflects the algorithm we used to evaluate

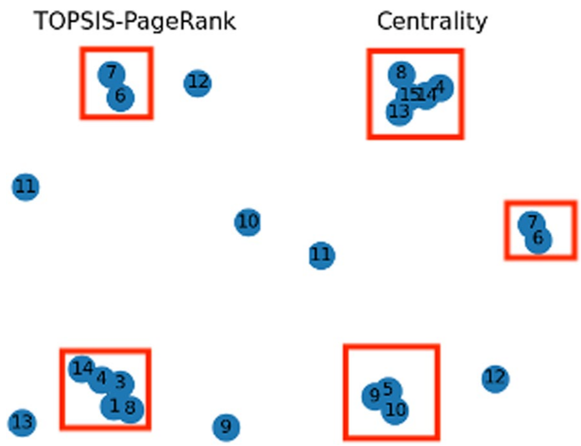

Fig. 2 TOP 3 nodes attack connectivity comparison figure a

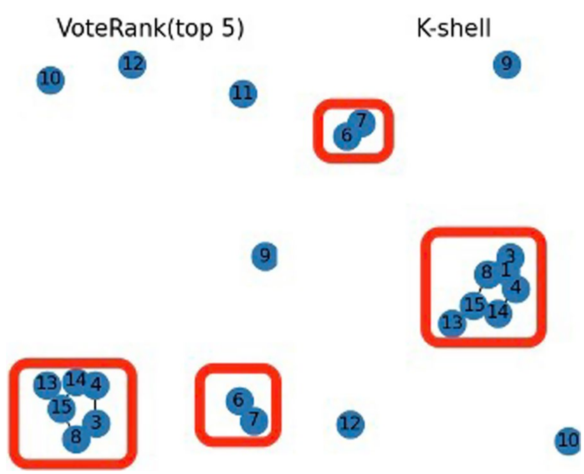

Fig. 3 TOP 3 nodes attack connectivity comparison figure b

Table 6 Connectivity after a key node is delete

Algorithm	K-shell	Centrality	VoteRank (top 5)	TOPSIS-PageRank multi-metric fusion*
Average node connectivity	0.44	0.37	0.27	0.24

the top three nodes of importance, after they were deleted, the index of Average node connectivity degradation is serious, in this evaluation scale, our algorithm is more reasonable and practical significance, let us know which nodes are the most important.

The connectivity performance of the TOPSIS-PageRank multi-index fusion method is relatively the worst, which also shows that the node deleted is the more critical node [21], indicating that our algorithm has some merit in identifying key nodes.

Figure 4 illustrates the network damage after key nodes are attacked under different algorithm measurement criteria.

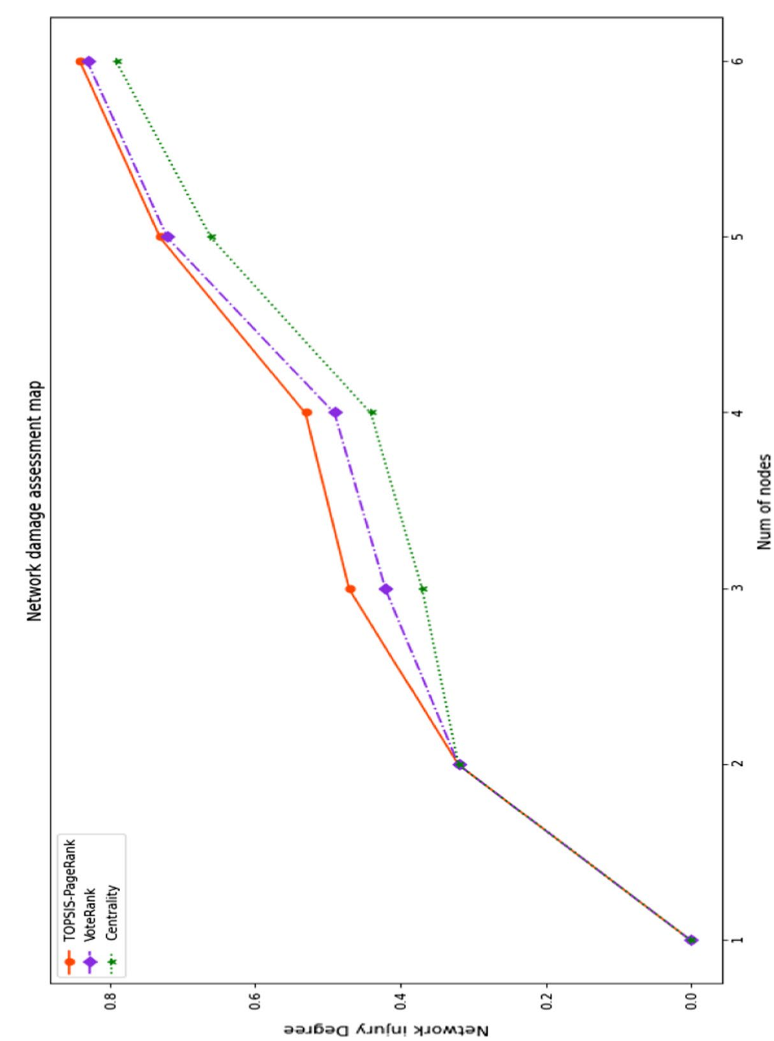

Fig. 4 Network performance impairment graph

We can find different algorithms to delete the top five priority nodes, which has caused a very big blow to the connectivity of the network. However, from the perspective of key nodes, we can see that the PageRank algorithm is more reasonable and more in line with our needs to measure the resilience of the network. In the last graph, we can see that after the top five important nodes of the TOPSIS-PageRank multi-index fusion ranking are destroyed one by one, the performance loss rate of the network has reached about 86%, and compared with other algorithms, the performance loss rate of the network has been reduced. After the first three nodes are destroyed, our model suffers a greater blow, which also shows that our evaluation method is conducive to the protection of key information nodes and the global network.

4 Conclusion

In this paper, we mainly propose a hybrid node contribution evaluation method based on TOPSIS and PageRank algorithm. The experimental results show that in the field of avionics, the method has proved its correctness and effectiveness in improving the anti-destruction performance of the network and maximizing the information transmission efficiency of the nodes. The main advantage is that compared with the common soft voting node contribution algorithm represented by VoteRank, the broken cycle node contribution algorithm represented by K-Shell, and other node centrality contribution algorithms, our algorithm can better measure the survivability of the network and the evaluation of key nodes and provide a new perspective for evaluating the efficiency of the network. It is also helpful to the ability of aircraft nodes to cooperate in combat, and this algorithm still has some randomness. Perhaps in the future, we can hope to add more interpretable models to make the node evaluation area of coordinated operations of wingman, leader, radar, and other combat units reasonable and consistent. Not only that, based on the above node importance assessment, we quantified the information entropy of each node and calculated the information entropy of the whole graph. Thus, a widely applicable algorithm to evaluate the information contained in the battle map was proposed, and through this information entropy evaluation algorithm, we can naturally get the evaluation method of combat capability and information transmission capability.

5 Future works

In this paper, due to time constraints, there are still some related works that can be improved, and more enlightening results can be produced on the topic of node importance evaluation:

(1) Based on this article, perhaps we can use personalized PageRank instead of traditional PageRank. Personalized PageRank means that we can give each node some importance we think it has before PageRank gives the node weight. This initial importance will enter the iteration of random walk, making the whole evaluation method more reasonable and suitable for people's changing needs.
(2) On the basis of node importance evaluation in this paper, considering the characteristics of the graph algorithm itself and the particularity of the avionics system itself, we believe that this node importance evaluation algorithm can be used as the basis for aviation deployment. At the same time, if various connections between nodes can be sorted out and classified into different edges, this algorithm may be

more comprehensive and specific by making edge information a part of the overall importance evaluation. Meanwhile, the method of combining point and edge evaluation is also applicable to other connected graph evaluation problems.

Abbreviations

OODA	Observation, orientation, decision, action
TOPSIS	Technique for Order Preference by Similarity to an Ideal Solution
PR	PageRank weight
TOPSIS-PageRank	An evaluation method combining TOPSIS and PageRank algorithm
UL	Unmanned lead aircraft
WM	A manned plane to protect the leader plane
UM	An unmanned plane to protect the leader plane
EL	Nodes with electronic warfare capability
RD	Nodes equipped with a radar reconnaissance unit
LD	Manned lead aircraft

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In this paper, CL carried out the whole node modeling part, JW carried out the local improvement and experiment, and RX was responsible for the information entropy evaluation algorithm. All authors read and approved the final manuscript.

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Availability of data and materials
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Competing interests
The authors declare that they have no competing interests.

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