Research on Resilience of Maritime Distributed Combat Network Under Targeted Attacks

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Abstract—The structure of the Maritime Distributed Combat network and its emergent characteristics of efficiency and resilience are the core issues in the design of the system. Drawing on the typical characteristics of Social-Ecological networks, the paper proposes that the system should adopt a Multiplicity of Heterogeneous Core structure, use core nodes to aggregate clusters, realize network widely-interaction through cross-community hubs, and design multiple core nodes at the central level to achieve redundant backup. Experiments show that the network structure proposed in this paper has better adaptability in the context of Maritime Distributed Combat system.

Keywords-Resilience; Distributed Combat Network; Multiplicity; Heterogeneous Core; Network Structure

1. INTRODUCTION

With the integration of new combat units such as unmanned clusters into the combat system, the organization of maritime combat resources has undergone profound changes. In new situation, distributed deployment and organizational structure of operation units, has gradually become the prime mode of maritime combat system to adapt to the new warfare environment. The crucial point of Maritime Distributed Combat System is the decentralized deployment of various types of platforms and units, and then relying on high-speed communication networks, a resilient and reconfigurable network system is constructed with a specific topology to efficiently implement various combat operations, and thus gain the advantage of system confrontation. The concepts are shown in Figure 1.

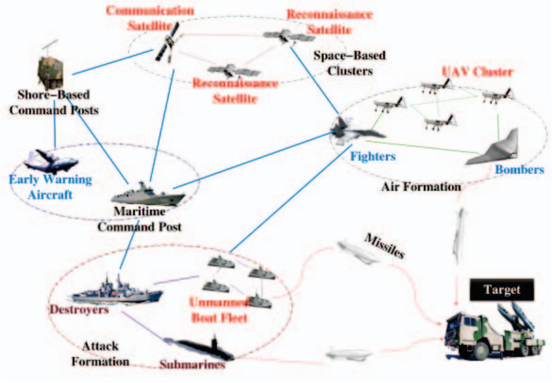

Figure 1. Schematic of Maritime Distributed Combat Concept

In this context, the architecture, morphological characteristics and emergent resilience of maritime distributed combat network, as well as reconfigurability under destruction, are fundamental theoretical issues that need to be urgently addressed in the study of distributed operations. Reference to research results of typical Social-Ecological Networks, the architecture and resilience is explored in this paper, and then theoretical basis of decisions is provided for organization of Distributed Combat Network.

2. THEORETICAL FOUNDATION AND RESEARCH STATUS

2.1. Distributed Combat

Since the 1990s, the U.S. military has demonstrated and validated high-tech equipment and advanced combat concepts in foreign wars, successively proposing "Rapid Decisive Operations," "Network-Centric Warfare," "Mosaic Warfare," etc., gradually forming a "Distributed Strike" as the core of the combat concept system [1]. In 2016, the U.S. Navy also proposed concept of "Distributed Kill", which creates an intractable targeting problem for the enemy through the distributed deployment of a large number of naval vessels that can threaten enemy ships, aircraft, or coastal facilities to achieve the overall effect of "Spatially Decentralized, Efficiency focused" [1][2].

In recent years, the U.S. military has conducted a large number of Distributed Combat Concept validations and experiments, and the basic modes and effects of U.S. Distributed Combat can be glimpsed through some public data. However, there is no reliable intelligence to support its maritime combat force formation pattern, system structure, and the mechanism of system capability emergence based on topology of operation network.

2.2. Socio-Ecological Complex Networks

Currently, scholars in the field of Complex Networks [3] have conducted extensive research on Social-Ecological Network Systems, such as Shipping Networks and Scientific Collaboration Networks [4]. Research shows that Complex Social-Ecological Networks can self-organize to emerge strong resistance to destruction and high efficiency, and these properties are closely related to the topology of the network.

It is found that Socio-Ecological Networks exhibit a typical hierarchical modular structure, and the degree distribution of nodes shows a Non-Power-Law Distribution and tends to be

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Log-normally Distribution. This indicates that unlike centralized Scale-Free Networks, such Socio-Ecological Networks do not rely too much on few core nodes, but exists a more complex central core structure [5]. Measured in terms of robustness, such networks have better resistance to deliberate attacks against the hub nodes. And even if some of the hub nodes lose functions, it will not lead to a destruction of the overall system in a collapsed manner. Overall, Socio-Ecological Networks present a structure and performance that can provide lessons for research on the architecture of Maritime Distributed Combat Network.

2.3. Combat Network Architecture

In the early days, the highly centralized command structure, which formed a “single-chain” command model, was basically sufficient to satisfy combat requirements. As the dynamic and uncertainty of war environment increases, the highly centralized hierarchical organizational structure, in the high-dimensional distributed operations, exposes weaknesses such as the vulnerability of core nodes to attack and poor resistance to destruction.

Currently, research on combat network systems is gradually becoming the focus of the field. The paper [6] proposes a command-and-control organizational structure model that models elements, relationships and processes, and divides the system by central and edge. Sun [7] presents the concept of edge warfare in the context of “Mosaic Warfare”, and validates the organizational effectiveness of an operational system architecture where the “Edge-Structure” is integrated with the “Center-and-Edge Structures”.

In summary, the Maritime Distributed Combat System is abstracted as a large-scale clustered adaptive heterogeneous network in the research process. Combined with relevant research results in the field of Complex Networks, the architecture of Distributed Combat System is studied through typical network performance indicators.

3. Method Complex Network Structure Analysis

3.1. Basic Network Characteristic

The topology of a network is usually denoted by $G = (V, E)$, where $V = \{v_1, v_2, \cdots, v_N\}$ is the set of nodes and $E = \{e_1, e_2, \cdots, e_M\}$ denotes the set of edges. The basic properties of the network can usually be measured by the following characteristic.

- Node Degree: The node degree is the average value of the number of edges owned by the nodes in the network:

$$K = \frac{\sum_{i \neq j, i,j \in V} e_{ij}}{N} \tag{1}$$

Where: N is the number of network nodes; v_i, v_j is any two nodes in the network; e_{ij} is the edge between v_i, v_j, when the edge between v_i, v_j exists take $e_{ij} = 1$, otherwise take 0.

- Graph Density: The graph density is the actual number of edges divided by the maximum number of possible edges, calculated as follows:

$$d = \frac{2 \times N_e}{N(N-1)} \tag{2}$$

Where: N is the number of network nodes; N_e is the number of actual edges in the network. A larger graph density indicates the network has a more tightly connected nodes.

- Network Diameter: Assume that the distance d_{ij} is the number of edges connecting the shortest path between node pair v_i, v_j. The network diameter is the maximum value of the distance:

$$D = max\left(d_{ij}\right) \tag{3}$$

- Average Path-length: the Average Path-length of the network is defined as the average value of distance between any two nodes:

$$L = \frac{\sum_{i \neq j, i,j \in V} d_{ij}}{N(N-1)} \tag{4}$$

The average path-length of a network reflects the degree of association between nodes. The shorter the path, the more closely related the network nodes are to each other.

- Clustering Coefficient: Clustering Coefficient is the probability that connected edges between the neighbors of the node in the network, which reflects the density of the network. The Clustering Coefficient of a network is the average of the Clustering Coefficients of all nodes:

$$C = \frac{1}{N} \sum_{i=1}^{N} \frac{M_i}{T_i} \tag{5}$$

where C denotes the Clustering Coefficient of the network; M_i denotes the number of triangles that actually exist with v_i as the vertex, T_i denotes the number of fully connected triangles with v_i as the vertex; $T_i = N_i(N_i - 1)/2$, and N_i is the number of neighbors of node v_i.

3.2. Community Modularization

Social-Ecological networks are often characterized by modular communities. Nodes in a local area are closely connected to each other to form communities, while the connections between different communities are relatively sparse. The Louvain algorithm is commonly used for community division in related studies [8]. The core of the algorithm is to calculate the modularity of communities:

$$Q = \frac{1}{2m} \sum_{i,j} \left[A_{ij} - \frac{k_i k_j}{2m}\right] \delta\left(c_i, c_j\right) \tag{6}$$

Where: A is the adjacency matrix, which represents the node-to-node edge weights, and the undirected network takes 0 or 1; c is the function to determine whether a node belongs to a community and the value takes 0 or 1. m, δ calculated as:

$$m = \frac{1}{2} \sum_{i,j} A_{ij} \tag{7}$$

$$\delta(x, y) = \begin{cases} 0 & x \neq y \\ 1 & x = y \end{cases} \tag{8}$$

Louvain's algorithm maximizes the Q-value by two iterations [8]. The computation starts by placing each node within the community that increases the Q-value, and keeps iterating until the Q-value cannot be increased. Then, each community is considered as a node and the previous steps are repeated until the Q-value cannot continue to increase in the second round. At this point, the Q-value is the modularity of the network, and the current network community division strategy is the best division.

3.3. Network Efficiency

Network efficiency is a valid measure of the ability of nodes to interact with each other [9]. The shorter the average path between nodes in a network, the more efficient the network presents.

- Global Efficiency: Global efficiency is defined as the sum of the inverse of the Average Shortest Path-length between nodes. As the Shortest path-length increases, the efficiency value decreases and is calculated in the following model:

$$E_G = \frac{1}{N(N-1)}\sum_{i,j\in V}\frac{1}{d(v_i,v_j)} \tag{9}$$

where $d(v_i, v_j)$ is the value of the shortest path-length between nodes v_i, v_j; N is the number of network nodes.

- Local Efficiency: The Local Efficiency, which is the global average efficiency of the subgraph composed of the neighbors of the node. Disregard the current node, the Local Efficiency denotes the average value of Global Efficiency of the network composed of its neighboring nodes.

$$E_L = \frac{\sum_{i=1}^{N_{i\_sub}} E_G^{i\_sub}}{N_{i\_sub}} \tag{10}$$

Where N_{i_sub} is the number of neighboring nodes of v_i ; $E_G^{i\_sub}$ is the global efficiency of the subgraph composed of all the neighboring of the node v_i. Local efficiency reflects the network's ability to resist destruction of small-scale failures. If the local efficiency is relatively high, small-scale local destruction has almost no effect on the network, and it has a better ability to compensate for it. If the local efficiency is relatively low, the network will be too dependent on the core nodes and less resistant to destruction.

3.4. Club Coefficient

Socio-ecological networks generally present the structure of modular communities. Among these communities, the club is a special kind, which plays an important supporting role in maintaining the stability of the whole structure and in coordinating the functions of its parts [5]. Current research shows that two types of clubs can be defined based on the ordering of different connectivity characteristics of nodes, namely, Rich Club [10] and Diverse Club [5][11]. A Rich Club is a small set of densely connected nodes with node degree values above a threshold. The Diverse Club refers to the set of nodes with high cross-community participation and deeply connected to each other.

Alstott J. et al. [10] proposed a unified framework to calculate the club coefficients of network nodes, which is calculated as follows:

$$\theta_{norm} = \frac{\theta}{\theta_{rand}} = \frac{2C}{N(N-1)}\Big/\frac{2C_{rand}}{N(N-1)} = \frac{C}{C_{rand}} \tag{11}$$

where θ_{norm} is the normalized club coefficient; θ is the club coefficient of the network; N is the number of nodes; C is the sum of the edge weights of the club nodes; θ_{rand} and C_{rand} are Club Coefficient and the sum of edge-weights of ER Random Network.

3.5. Maximum Connected Subgraph Measurement

The Maximum Connected Subgraph, defined as the connected branch with the highest number of nodes in the graph G:

$$m(G) = \max_{1\le i\le N}\|V(Z_i)\| \tag{12}$$

Where $Z_i = G(V_i, E_i)$ is the connected subgraph containing node v_i 。

Maximum Connected Subgraph Measurement, defined as the largest connected branch in the network with the number of nodes as a percentage of the whole network [12]:

$$S = \frac{m(G)}{N} \tag{13}$$

Where $m(G)$ denotes the number of nodes in the maximum connected subgraph; N is the total number of network nodes; $0 \le S \le 1$, $S = 1$ when and only when the network is fully connected; S gradually decreases towards 0 as the network nodes are attacked and fail; $S = 0$ at which point all set points are completely isolated and the network is completely destroyed.

4. DISTRIBUTED COMBAT NETWORK STRUCTURE

4.1. Central-Edge Structure

Socio-Ecological Networks and Research Collaboration Networks show obvious community-based and hierarchical structural features. Take the Linux Kernel Developer Collaboration Network as an example [13], horizontally it shows a relatively independent local cluster aggregation and community-based structure. While vertically, a Hierarchical Central-Edge Structure emerges, as shown in Fig2.

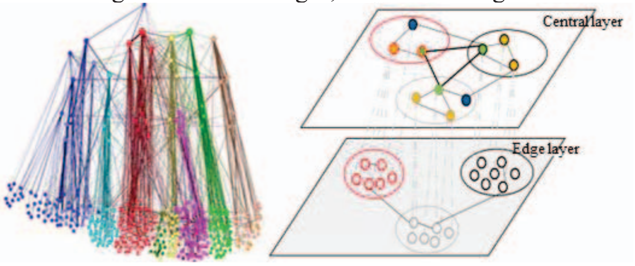


Figure 2. Central-Edge Structure of Linux Collaborative Community Network

In the figure, community is relatively independent with strong internal connections, while different communities show loose coupling and relatively few correlations. In the community, the core nodes are tightly coupled and efficiently collaborate with each other to form the central layer. The edge nodes at the bottom tend to establish association with the nodes at the central layer, and the connection between the edge nodes is low-frequency and sparse. As a whole, the structure inside the community is similar to a Scale-Free Network. with a radial expansion from the center to the edges, a small number of core nodes aggregating a large number of resources. Most of the edge nodes with low degree values are dependent on central core nodes. The central layer nodes are at the core of the network and play a key role in the stable operation of the whole network.

The Central-Edge Structure is an efficient operational pattern formed by developers in Linux community network, which is self-organized to adapt to the Development Environment. With the integration of a large number of clustered unmanned combat platforms, the design of Maritime Distributed Combat Architecture can be based on the Central-Edge Structure: 1. Homogeneous combat units or platforms with the same mission can be organized to form clustered communities, such as UAV swarms, unmanned boat clusters, air and space reconnaissance satellite clusters, etc., to emerge local combat functions with a clustered community structure. 2. Inside the cluster, based on the Central-Edge Structure, deploying multiple central layer core nodes, with close linkage between central nodes to stabilize the internal structure of the cluster community, and other edge nodes accepting command and control from the central-nodes in one direction to reduce ineffective edge layer interactions.

Under the control of the Central-Edge Structure, the network system emerges the overall operational ability through the synergy and interaction of different community clusters. Since most of the nodes belong to the edge layer, random attacks hardly affect the network system effectiveness; however, the central layer nodes are still relatively vulnerable and can easily cause system crashed in the case of targeted attacks.

4.2. Multiplicity of Heterogeneous Core Structure

It was found that the central core is the key to network resilience against destruction. Taking a collaborative network of researchers in the field of physics as an example, Liu [5] studied the function of node roles and found that the "club" coefficient can detect nodes with significant community clustering ability in the network, forming a "Rich" Club Structure, as shown in figure3. These "Rich" Club nodes aggregate most of the resources in the community and form a stable cluster structure.

At the same time, communities interact with each other through multiple types of Cross-Community Collaboration Hub nodes for different types of resources, forming a "Diverse" Club, also shown in figure3.This kind of hub nodes are responsible for cross-collaborative community information integration and resource coordination at the global level, forming a stable structure of the whole system.

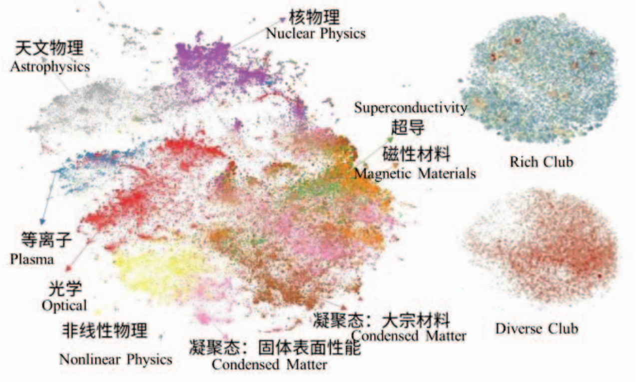


Figure 3. Club Structure of Physics Collaboration Network

Research collaboration networks in Physics form a Multiplicity of Heterogeneous Core Structure Network through two typical "Club" effects. In the network, a few hub-nodes with high cross-community connectivity bridge different communities on the one hand, and are closely connected to each other on the other hand, aggregating different communities in the network as a whole and forming a cohesive network structure. In addition, there are some nodes with high intra-community degree values, whose connections are tightly clustered within the community, and which is able to ensure the integration and aggregation within local area. Structurally, these two types of hub nodes together ensure the stability and flexibility of the network. Functionally, nodes with high degree of cross-community connectivity bridge and integrate knowledge and resources in different communities, while nodes with high degree of intra-community connectivity consolidate and strengthen the inner-exchange and information dissemination within local communities.

The Multiplicity of Heterogeneous Core Structure in the Physics Research Collaboration Network reflects the self-organized "local centrality and global decentrality" of the system, which makes the system emerge economically and functionally efficient at the same time. The Socio-Ecological Network of Multiplicity of Heterogeneous Core Structure provides a reference for the design of the architecture of Maritime Distributed Combat Network. A central type of command node is designed in the local community and supplemented with redundant nodes to back up the core command and decision-making functions. At the same time, the communication hub nodes with exclusive cross-community connections are designed in the central layer of the community to link different functional communities and form the linkage of the system as a whole.

4.3. Maritime Distributed Combat Network

Referring to the research results of Socio-Ecological Network, it provides new ideas for Maritime Distributed organization model. Under the demand of "global integration and local aggregation" of network structure, how to maintain the stability of network form and reconfigurability of the system is the key to the structure design.

To ensure that the Distributed Combat Network has high resilience, cross-domain coordination and dynamic adaptation of the overall Combat Effectiveness, the study concluded that: in the design of the Distributed Network architecture, two combat nodes with different coordination functions should be constructed separately, one combat node is responsible for aggregating local combat resources, forming a local center and emerging local functions as a nuclear within the community, such as the black battlefield unit in Figure 4; the other node is responsible for cross-community coordination, integrating different modules from a global perspective and acting as an interaction hub between different communities, such as the red node in the Figure. Considering the robustness of the overall network, the two types of hub nodes need to avoid overlapping.

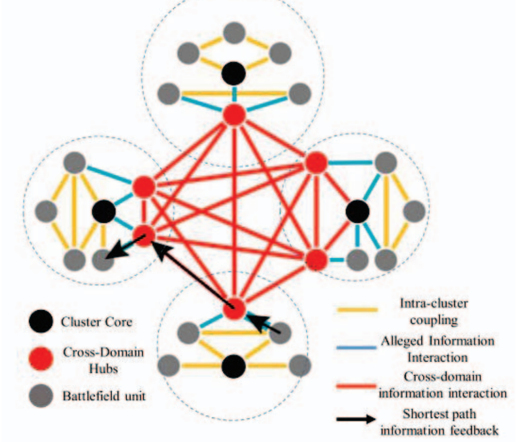


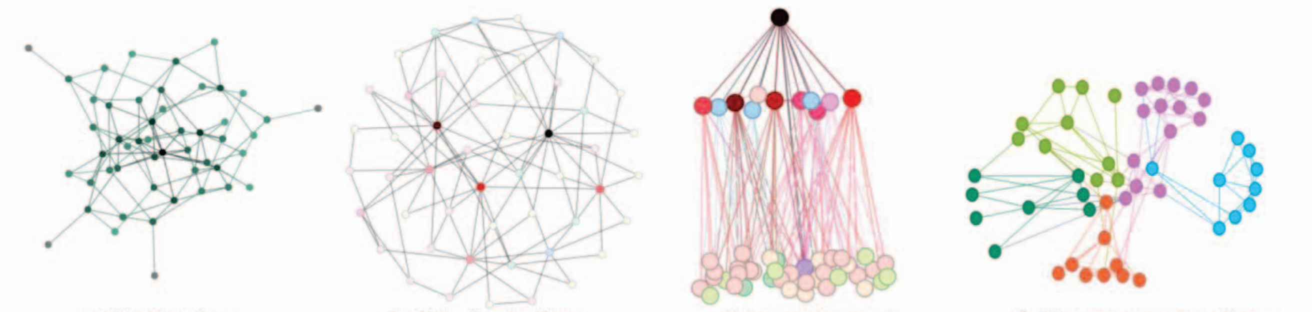
Figure 4. Schematic diagram of the network structure form of the distributed combat system

As shown in the figure, the design of Multiplicity of Heterogeneous nodes makes network connectivity more economical and efficient. First, the intra-community center nodes, as black nodes in the figure, are able to maintain the stability of self-organized combat operations in local functional areas, enabling the network to produce a modular structure of functional partitioning; second, the cross-community hub nodes, as red nodes in the figure, further share the interaction pressure of local core nodes and are able to integrate multiple functional areas, enabling different clusters to organize and operate effectively in the system as a whole. This network system organization form balances the stability of local-functions of Maritime Distributed operations and the flexibility of cross-community collaboration, which can emerge a better performance in the whole.

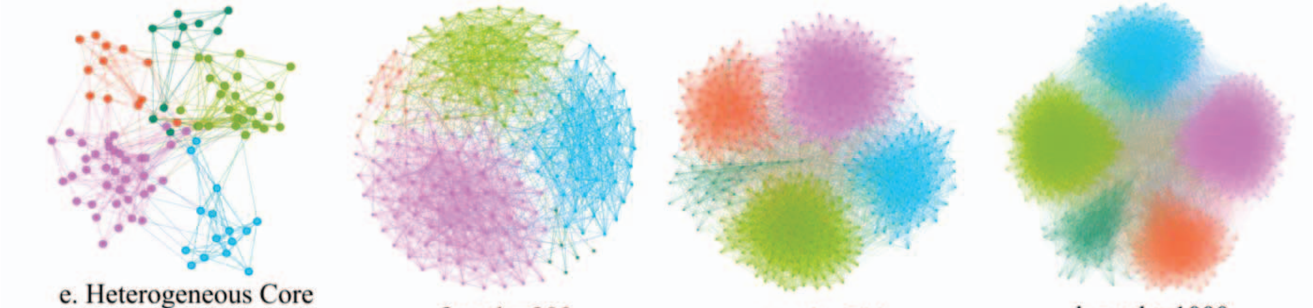
5. EXPERIMENTS

5.1. Experimental Network Formation

Four typical network structures were designed during the experiment of this research. The four networks with gradually increasing number of nodes and edges are used to study the emergence pattern of network performance, as shown in Fig 5.



a. ER-Random b. BA-Scale Free c. Centre-Control d. Heterogeneous Core



e. Heterogeneous Core (node=100) f. node=200 g. node=500 h. node=1000

Figure 5. Schematic diagram of the network structure form of the distributed combat system

The experimental objects are four typical networks mentioned above. As in the figure, sub-figure ***a*** is an ER random network, in which associations between nodes are generated completely randomly. Sub-figure ***b*** is a scale-free network, in which the aggregation of key nodes at the center is obvious and the degree distribution of the network is clearly power-law distributed. Sub-figure ***c*** is a hierarchical center network, which has similarity with the current centralized pattern of command and control for Maritime operation resources. Sub-figure ***d, e, f, g, h*** are multiplicity of heterogeneous core structure networks proposed in this paper, difference is the number of nodes and edges. Through the rich club and diverse club, the network achieves agglomeration within the community and also maintains the convenience of cross-community association.

5.2. Network Characteristics Statistics

Statistical calculations of network metrics yielded the data shown in Table 1.

Table 1. Statistical calculations of network metrics

	Network Structure							
Network Metrics	***ER Random Network (N=50)***	***Scale-Free Network (N=50)***	***Hierarchical Center Network (N=50)***	***Multiplicity Heterogeneous Network (N=50)***	***Multiplicity Heterogeneous Network (N=100)***	***Multiplicity Heterogeneous Network (N=200)***	***Multiplicity Heterogeneous Network (N=500)***	***Multiplicity Heterogeneous Network (N=1000)***
Graph Density	0.0816	0.0816	0.0816	0.0816	0.0808	0.0804	0.0802	0.0801
Network Diameter	7	5	**4**	6	6	5	3	3
Average Path-length	2.9690	**2.6367**	2.7502	3.4580	2.6927	2.3658	2.1522	1.9970
Clustering Coefficient	0.0883	0.1530	0.0707	**0.3498**	0.3006	0.2829	0.2999	0.2956
Community Modularity	0.4010	0.3890	0.3420	**0.5940**	0.5500	0.5050	0.5790	0.6030
Global efficiency	0.3997	**0.4313**	0.4241	0.3629	0.4259	0.4676	0.5014	0.5272
Local Efficiency	0.0916	0.1667	0.0889	**0.4034**	0.4329	0.4247	0.5315	0.5857
Club Coefficient Degree=1	0.0928	0.0816	0.1030	0.0868	—	—	—	—
Club Coefficient Degree=3	0.1379	0.2333	0.2762	0.1594	—	—	—	—
Club Coefficient Degree=7	—	0.5333	0.2857	**1.0000**	—	—	—	—
Club Coefficient	—	**0.6666 Degree=10**	**0.6666 Degree=12**	—	—	—	—	—

From the table, it is easy to see that the four compared network structures have the same number of nodes and edges with a same network size. With the network diameter comparison, the Hierarchical Center network structure has the shortest diameter, shows a smaller expansion, and the maximum communication distance between nodes is relatively small. However, the network diameter describes the special cases in the structure, while the average-shortest-distance can better reflect the distance property between nodes. From this attribute, the average-shortest-path between nodes of Scale-Free network is the smallest, and its average convenience of information interchange is the highest in theory.

In the comparison of the two indicators of Clustering Coefficient and Community Modularity, the Multiplicity of Heterogeneous Core structure proposed in this paper gives the best community aggregation effect, and the nodes within the community are most closely connected, which is also in line with the features of large-scale homogeneous combat nodes aggregating into a group in maritime distributed combats.

In terms of efficiency, the Scale-Free network is the most efficient in terms of Global Efficiency, which is mainly because the core nodes aggregate a large number of nodes with low degree values; in terms of Local Efficiency, the Multiplicity of Heterogeneous Core Structure has the highest Local Efficiency, which indicates that the network can have better tolerance in small-scale attacks and better substitution effect between combat nodes. In fact, in Distributed Combat system, most nodes within the cluster do not need to interact extensively with the global or other communities, so the Global Efficiency metric is not exactly be applicable with the assessment of the Maritime Distributed Combat network. Instead, the Local Efficiency is more reflective of the cluster's resilience kernel robustness.

In terms of Club Coefficients, the ER-Random network does not show Club characteristics, and the Scale-Free network and the Hierarchical Central network emerge with certain rich club characteristics only in nodes with degree values up to 10 and 12, indicating that the central-edge hierarchical structure of these two networks is not obvious. In the Multiplicity Heterogeneous Network proposed in this paper, the network shows a very typical Club feature in nodes with degree value above 7. This part of nodes takes on the main function of network cluster aggregation and community interaction, and the vast majority of other nodes are aggregated to Club and Hub nodes, which reduces the ineffective information interaction among low-degree nodes and Enhances network simplicity.

The Multiplicity Heterogeneous Network is compared with the number of nodes set at 100, 200, 500 and 1000, as shown in Figure 5 and Table 1. The Multiplicity Heterogeneous Network maintained good stability under the expansion of the network-scale. With the gradual increase in size, the network improved in diameter and average-shortest-distance metrics, and remained basically flat in terms of community degree and clustering coefficient. The improvement in both Global Efficiency and Local Efficiency indicates that the quantitative change in network size leads to significant network efficiency growth.

5.3. Network Evaluation Under Targeted Attacks

In this paper, Targeted Attacks are performed on each of the four networks. Node Between Centrality and Edge Between Centrality are used to arrange nodes and edges in order respectively. During the experiments, the nodes and edges in the sequence are gradually invalidated, and then the Maximum Connected Subgraph Size, Global Efficiency, Clustering Coefficient and Local Efficiency of the networks are calculated and compared, as shown in Fig6.

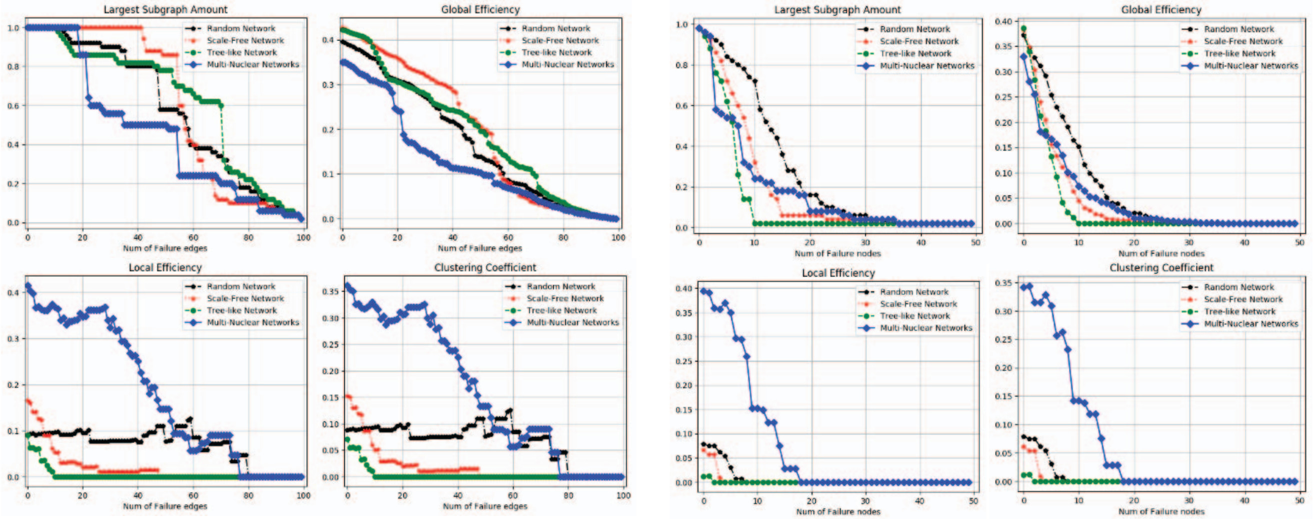


Figure 6. Schematic diagram of the network structure form of the distributed combat system

The experimental results show that the overall effectiveness of the network shows different degrees of decay when subjected to targeted attacks on both nodes and edges. The decay of the Maximum Connected Subgraph indicates that the targeted attack has a similar effect on the disassembly of the systematic network, and different network structures are disassembled similarly into subgraphs. Moreover, the Multiplicity of Heterogeneous Core structure proposed in this paper is still relatively obvious to be disassembled, indicating that the node of bridging role as a hub is a key node for the interaction between network communities. After being split, the Global Efficiency of various networks decreases significantly, and the difference in the degree of decay of this indicator is not obvious.

The Multiplicity of Heterogeneous Core structure has the best resistance to destruction in terms of both Local Efficiency and Clustering Coefficient metrics. The kind of network is able to maintain the maximum local aggregation capacity during the attacks and ensure that the community structure remains stable. This indicates that this structure is able to maintain the stability of local functions better in the long term under targeted attacks. Compared with the other three structures, it is still the optimal choice of structure even when 50% of the important nodes or edges lose effectiveness.

6. CONCLUSION

Distributed Combat is the current hotspot of military research in the field of Maritime operations. The construction and application of Distributed Combat System is the key to the reorganization and Reconfigurability of maritime combat resources under the new situation, and the rapid formation of combat power. In this paper, from the perspective of Distributed Combat Network structure form and related system effectiveness, it is proposed that the system can adopt the network form of central-edge hierarchical and multiplicity of heterogeneous core structure. Finally, an experiment verified that by typical evaluation indicators, all kind of network under targeted attacks will substantially reduce the overall efficiency and stability. However, the Multiplicity of Heterogeneous Core structure proposed in this paper is able to maintain the maximum local stability and aggregation effect in the face of targeted attacks, regardless of the network size. Therefore, the network possesses better tolerance to targeted attacks. In Maritime Distributed Combats, when key nodes are disabled by targeted damage, the system with Multiplicity of Heterogeneous Core structure can still aggregate the cluster force and accomplish the combat tasks.

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