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Research on transmission load balancing algorithm and application of tactical communication data chain network based on timing computational analysis

Shuang Geng[1,*] and Xiaoqiong Zhang[1]
[1] North Automatic Control Technology Institute, Taiyuan, Shanxi, 030006, China
Corresponding authors: (e-mail: 18003439323@163.com).

Abstract Tactical communication datalink, as an important part of networked national defense informatization construction, is more difficult to quantitatively assess its effectiveness and transmission load balancing. In this paper, the natural connectivity of tactical communication datalink network is introduced, and an interference effectiveness assessment method based on weighted natural connectivity is proposed to realize the time sequence analysis of tactical communication datalink network. The AGCH algorithm is used to group and cluster the nodes of the tactical communication datalink network, and the adaptive genetic algorithm is used to solve the established model to improve the load balancing effect of network transmission. Relying on the tactical communication datalink network simulation system architecture, the transmission load balancing test of tactical communication datalink network is carried out. The transmission load balancing algorithm proposed in this paper has a convergence speed of 340s, and when the number of tasks increases from 50 to 300, its corresponding task completion time grows from 68s to 275s, and the load balancing differential value decreases from 0.4 to 0.34, which is always the lowest when comparing with other algorithms, such as ACO, ICA, PSO, PSO-ACO, and so on.

Index Terms natural connectivity, AGCH algorithm, adaptive genetic algorithm, tactical communication datalink network

I. Introduction

In recent years, the U.S. military has continued to innovate its operational theories, successively proposing new combat concepts such as "multi-domain warfare", "mosaic warfare", "cyberspace and electronic warfare", and "joint all-domain operations", and accordingly leading the development and capability improvement of equipment systems, and constantly building new combat forces such as precision-guided weapons, hypersonic weapons, and directed energy weapons [1]-[4]. In particular, unmanned systems represented by unmanned aircraft, unmanned vehicles, unmanned boats, etc. have been rapidly developed, promoting the continuous evolution of war patterns towards intelligent warfare. Under intelligent combat conditions, the manned-unmanned combat units distributed ubiquitously in the multi-domain battlefield are seamlessly hinged and dynamically organized through tactical communication networks to build a killing chain from sensor nodes to accusation nodes and then to fire nodes, so as to respond to future new threats and attempt unexpected tasks quickly, accurately and efficiently [5]-[8].

The change of combat style will also promote the development of battlefield communication mode in the direction of more efficient, flexible and intelligent, and routing technology plays a key role in guaranteeing the transmission of combat services in tactical communication networks, supporting the mission decision-making among combat units, and improving the quality of service [9]-[12]. Under intelligent combat conditions, the number of battlefield elements, heterogeneity, and especially the degree of intelligence grows rapidly, making the battlefield communication environment show high complexity and strong confrontation. Therefore, the tactical communication network supporting intelligent combat mainly has the following characteristics: on the one hand, there are more than five types of heterogeneous services carried in the tactical communication network, including voice, image, video, etc., and each type of service has differentiated needs for quality of service such as delay, bandwidth, packet loss, and so on. On the other hand, there are more than 10 heterogeneous link types in tactical communication networks3 , including shortwave, microwave, fiber optic, etc., with link transmission rates ranging from the kbps level to the hundred Mbps level, and the link state is more complex and variable, and the impact on the network transmission performance should not be ignored [13]-[16]. Therefore, the combat environment of strong confrontation and high mobility brings new challenges to the design and deployment of routing algorithms.

In global network transmission path planning algorithms, traditional routing algorithms usually calculate the shortest path to realize service transmission based on limited link state information, which leads to the network being difficult to adapt to the rapid changes in service traffic, and thus fails to meet the service quality of service requirements [17], [18]. In addition, the continuous growth of service traffic and the diversity of application scenarios in complex tactical communication networks have led to the escalation of the difficulty of load balancing for data link network transmission, which also makes the efficiency and accuracy of traditional routing algorithms based on limited information decision-making greatly reduced [19], [20]. It is due to the importance of tactical communication networks, more and more military forces through electronic reconnaissance and other technologies to lock the enemy communication nodes or links and then the communication equipment to carry out precision strikes, node and link damage will inevitably bring its neighboring nodes of the traffic congestion, which leads to the entire data chain network traffic sustained turbulence, and load-sensing delays caused by the collapse of the network [21]-[24]. Therefore, the network to ensure stability, destruction resistance, reliability and survivability, while also taking into account the quality of service indicators such as real-time network, the above issues have become a hot topic of discussion in recent years and the urgent need to solve the difficult problem.

In order to meet the requirements of tactical communication datalink network performance evaluation and transmission load balancing, this paper firstly constructs a tactical communication datalink network simulation system architecture, which simulates the battlefield network communication process in the real environment. Aiming at the problem that it is difficult to quantitatively evaluate the effectiveness of tactical communication datalink network, the “natural connectivity” of the network is used to judge the destructive capability of the communication network. The corresponding adjacency matrix of the tactical communication datalink network is introduced, and the weighted natural connectivity is calculated to measure the jamming effect of the tactical communication datalink network by adopting the change of weighted natural connectivity before and after jamming. Facing the problems of low throughput of tactical communication datalink network, high node transmission delay and etc., the load balancing cluster algorithm for tactical communication datalink network based on adaptive genetic algorithm is proposed. The AGCH algorithm is used to group and cluster the nodes of tactical communication datalink network, from which the cluster head node is obtained, the resource scheduling model is constructed, the resources in the cluster head node are allocated by using the model, and the adaptive genetic algorithm is used to solve the established model, so as to improve the load balancing effect of the tactical communication datalink network and to realize the load balancing of the tactical communication datalink network. We continue to evaluate the performance and topology analysis of the tactical communication datalink network, and test the transmission load balancing algorithm of the tactical communication datalink network proposed in this paper to explore the effectiveness of the performance evaluation method and load balancing algorithm.

II. Tactical communications data link network simulation system architecture design

The tactical communication datalink network simulation system designed in this chapter is a comprehensive tactical network simulation system, which consists of a variety of heterogeneous simulation platforms, aiming to simulate the battlefield network communication process in the real environment, and to meet the needs of tactical communication datalink network performance evaluation and load balancing.

II. A.Network Planning Federal Members

The network planning federation member is the starting point of the tactical Internet simulation system, and its role is mainly to plan and design the tactical network organization scheme according to the operational mission requirements and network organization and communication requirements. In this simulation system, the network planning federation member carries out network planning according to the tactical network composition information and communication requirement information inputted into the system. After the planning is completed, the planning scheme is released to the tactical countermeasures federal member and the tactical communication data chain network federal member through RTI, and the initialization and network configuration of the network nodes in the network topology of the two federal members are carried out. The design objective of the network planning federation member is to generate a network planning scheme that meets the requirements of tactical communication services in a shorter time, shorten the planning cycle and improve the efficiency of network planning.

II. B.Tactical Confrontation of the Members of the Intended Confederation

Tactical confrontation conceptualization federation member is one of the core federation members in the process of system simulation, and its role is to provide virtual battlefield situation information for the federation members of tactical communication data chain network. In the process of system simulation, it can simulate according to the preset operational scenario, generate tactical communication services, and at the same time update the position and state information of the nodes in the scenario to the members of the tactical communication data chain network and the members of the terminal simulation federation, so as to provide battlefield situational support for the tactical communication data chain network, and promote the operation of the system simulation.

II. C.Federated members of the Tactical Communications Data Link Network (TCDLN)

Tactical communication datalink network federation member is the core of tactical Internet simulation system, which has the ability to simulate communication networks of different scales such as brigade, battalion and company. In this simulation system, the network planning information released by the network planning federation member is received through RTI and mapped to form the tactical communication data chain network topology. In the process of network simulation, the network structure is dynamically adjusted according to the movement and operation state of the tactical nodes in the tactical countermeasures planning, and the tactical communication service request information issued by the federal members of the tactical countermeasures planning is received and transmitted in the communication simulation network. At the same time, it periodically collects network performance data and releases them to the performance evaluation federation members to prepare for the final network performance evaluation process of the simulation system.

II. D.Members of the Federation for the Assessment of Effectiveness

The function of the Performance Assessment Federation member is to quantitatively analyze the performance of the communications network constructed by the Tactical Communications Data Link Network Simulation Federation member. In the tactical Internet simulation federation, the federation member receives network performance data from the tactical communication data chain network federation member. Based on the specific tactical scenarios and operational requirements, the performance evaluation index system is constructed to comprehensively evaluate the simulation performance of the tactical communication datalink network, locate the network bottlenecks that do not meet the system requirements based on the results of the evaluation, give warnings, analyze the reasons that may affect the performance, and give the corresponding modification suggestions.

II. E.Terminal simulation federation members

Terminal simulation federation members work in the tactical design simulation stage, simulating the operation of a tactical node in the design scenario, the node's position, operation status, movement speed, situational awareness and other information in the form of visualization to the user.

III. Methodology for assessing the effectiveness of the tactical communications datalink network

Tactical communication datalink network is an important part of the research and development of countries in the military field. At present, the anti-jamming and survivability of tactical communication datalink networks have been challenged as never before, and the evaluation of the effectiveness of tactical communication datalink networks has also become a key link in the development of tactical communication datalink network construction.

III. A. Natural connectivity of the tactical communications datalink network

The tactical communication datalink network is reduced to a graph $G(V,E)$ consisting of nodes and links, where G is an undirected connected graph representing the network consisting of nodes V alternating with links E, and any N-node tactical communication datalink network can be represented by using its adjacency matrix $A(G)=(a_{ij})_{N\times N}$ Denote that if a direct communication link exists between any two neighboring nodes v_i, v_j in graph G, then $a_{ij}=1$, otherwise $a_{ij}=0$. Define the sequence $w=v_0e_1v_1e_2v_2\cdots e_kv_k$ as the pathway and k as the pathway length, and call the pathway with the same starting and terminating nodes as a closed pathway. From the example, it can be seen that the destruction resistance is positively correlated with the number of alternative pathways between the same start and end nodes, and the measure of the destruction resistance of a communication network can be summed over the number of pathways n_{ij}^k of arbitrary length k between all pairs of nodes (v_i, v_j) in the communication network:

$$S=\sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{+\infty}n_{ij}^{k} \tag{1}$$

$$S'=\sum_{k=0}^{+\infty}\frac{n_k}{k!} \tag{2}$$

Equation (1) is difficult to apply directly because of the large amount and difficulty of calculation, so it adopts the method of the number of closed paths in the communication network and weighting to measure the redundancy of alternative paths in the communication network, where n_k is the number of closed paths in the communication network of length k, and nodes and paths are allowed to be repeated in the calculation.

The correction coefficients are chosen to take into account the fact that the longer the pathway is recalculated more often and contributes less to the network's resilience, and to ensure that the arithmetic converges as needed. Proof:

$$S' = \sum_{k=0}^{+\infty} \frac{n_k}{k!} = \sum_{i=0}^{N} e^{\lambda_4} \tag{3}$$

where λ_i is the characteristic root of the adjacency matrix $A(G)$ of the tactical communications datalink network, computed by allowing nodes and paths to repeat.

The natural connectivity η of the graph G is defined as [25]:

$$\eta = \ln \frac{S'}{N} = \ln(\frac{1}{N} \sum_{i=0}^{N} e^{\lambda_i}) \tag{4}$$

The natural connectivity is strictly monotonic with respect to adding or removing edges, which means that the natural connectivity is able to characterize the nuances of the perturbation of the communication network, and the results obtained are consistent with intuitive judgments.

III. B. Assessment of interference effects based on weighted natural connectivity

When natural connectivity is used to assess the destruction resistance of a tactical communications data link network, only cases in which the communications link is completely suppressed or physically destroyed are considered. In fact, when the jamming equipment implements jamming on the communication network, part of the communication links may have the situation of incomplete suppression and decreased connectivity probability, which means that the reliability of part of the communication links is affected, considering this situation, the connectivity probability of the links can be induced in the form of weights to the corresponding neighbor matrix of the communication network and the weighted natural connectivity degree can be calculated. It can be seen that the weighted natural connectivity integrally responds to the destruction resistance and reliability of the communication network, and the effect of interference on the communication network can be measured by the change in weighted natural connectivity before and after the interference.

The adjacency matrix of graph G is [26]:

$$A = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix} \tag{5}$$

The weight matrix corresponding to the connectivity probability of each link is defined as:

$$P = \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{pmatrix} \tag{6}$$

The weighted adjacency matrix is defined as:

$$A' = \begin{pmatrix} a_{11}p_{11} & a_{21}p_{12} & \cdots & a_{1n}p_{1n} \\ a_{21}p_{21} & a_{22}p_{22} & \cdots & a_{2n}p_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1}p_{n1} & a_{22}p_{n2} & \cdots & a_{nn}p_{nn} \end{pmatrix} \tag{7}$$

The evaluated value λ of the interference effect on the communication network is calculated as.

$$\lambda = (\eta'_{\text{Before interference}} - \eta'_{\text{After disturbance}}) / \eta'_{\text{Before interference}} \tag{8}$$

IV. Simulation assessment of the effectiveness of the tactical communications datalink network

This chapter will rely on the tactical communication datalink network simulation system architecture to carry out the simulation assessment of tactical communication datalink network effectiveness by applying the tactical communication datalink network effectiveness assessment method proposed in this paper.

IV. A. Network effectiveness assessment

IV. A. 1) Network data settings

After setting up the network topology, OPNET software is used to export the communication data and generate the communication animation. Due to the large amount of network services, the network will be unstable at the beginning of transmission, so it is necessary to set a longer simulation time to make the network performance convergence. The network simulation time is set to 1000 seconds, and the random number seed is 128. In order to compare the state of all communication data transmission, scenario 1, which has no restriction on the communication radius (referred to as "scenario 1"), and scenario 2, which has a restriction on the communication radius (referred to as "scenario 2"), were set up.

IV. A. 2) Analysis of performance indicators

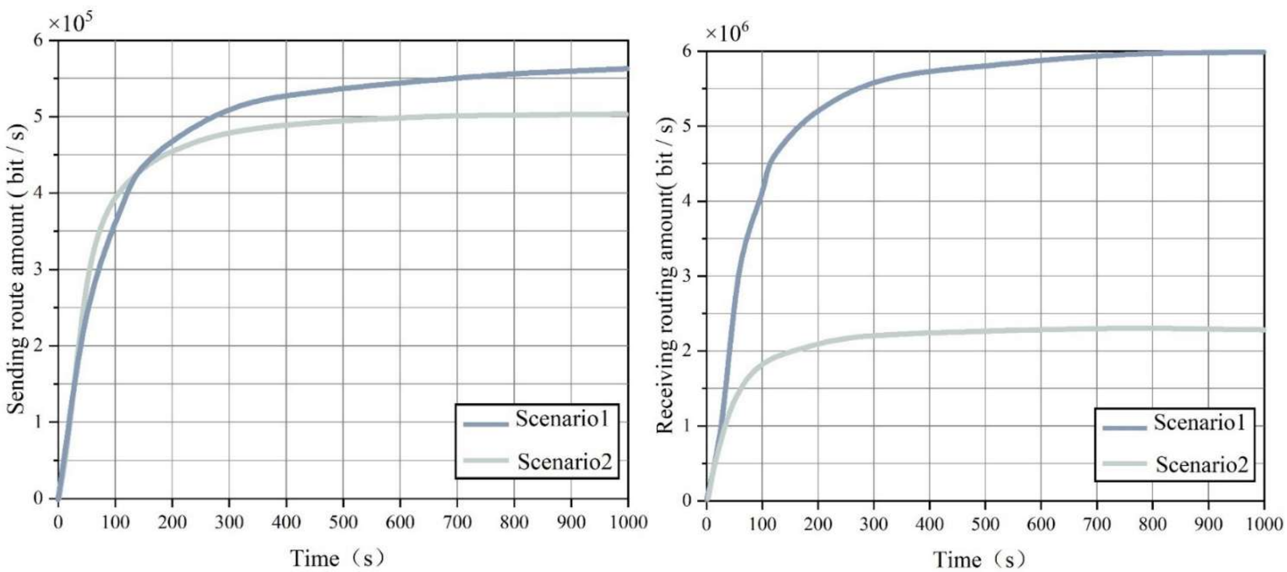
This subsection focuses on evaluating the effectiveness of the tactical communications datalink network by describing the performance indicators in the network through the network global statistics, and then evaluating the overall effectiveness of the network based on a comprehensive evaluation system. The independent metrics analysis is divided into 2 main aspects:

Aspect one, the AODV statistic group allows us to observe the operation of communication protocols.

Aspect two, the Wireless LAN statistics group can observe the impact of network load on network performance.

1) AODV statistics analysis

The entire network uses the AODV protocol to run, you can observe whether the routing volume in the network is stable to determine whether the AODV protocol is running normally in the entire network.The sending and receiving routing volume of the AODV protocol network is specifically shown in Figure 1, in which Figure (a) is the amount of sending routes, and Figure (b) is the amount of receiving routes. It can be seen that both scenarios stabilize after about 60s, indicating that normal transmission is possible using the AODV protocol.



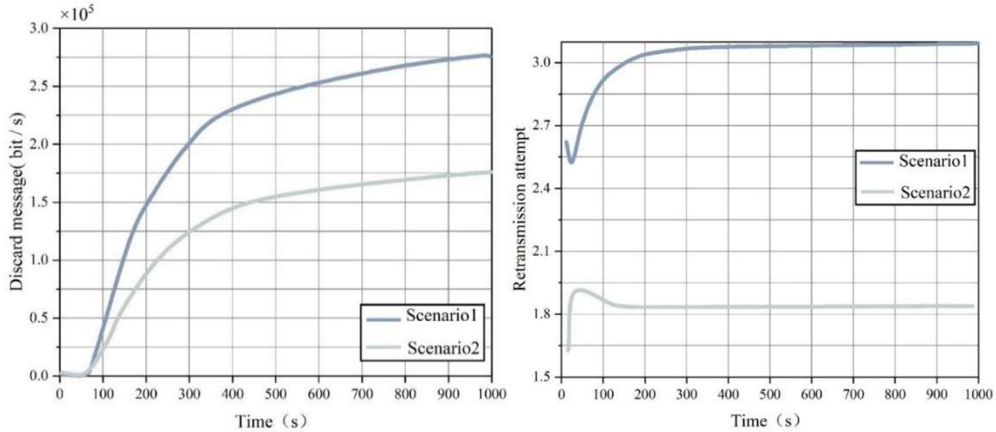
(a) Sending route amount (b) Receiving routing amount

Figure 1: The amount of sending and receiving routes of AODV protocol network

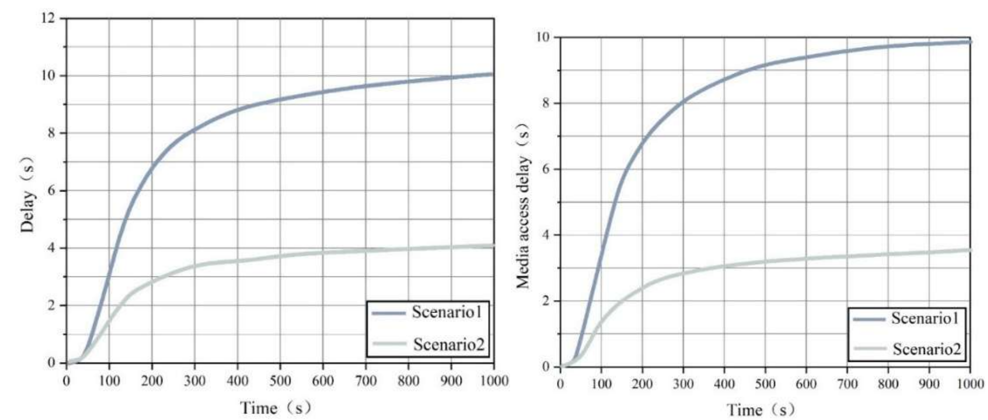
2) Wireless LAN Statistics Analysis

WLAN provides global and node statistics, Wireless LAN contains overall statistics about the performance of WLAN.WLAN statistics are shown in Fig. 2, Figs. (a) to (f) represent dropped messages, retransmission attempts, network delay, media access delay, network load, and network throughput in that order. From the figure, we can see that the number of dropped messages per second in scenario 1 and scenario 2 is about 280,000 bits and

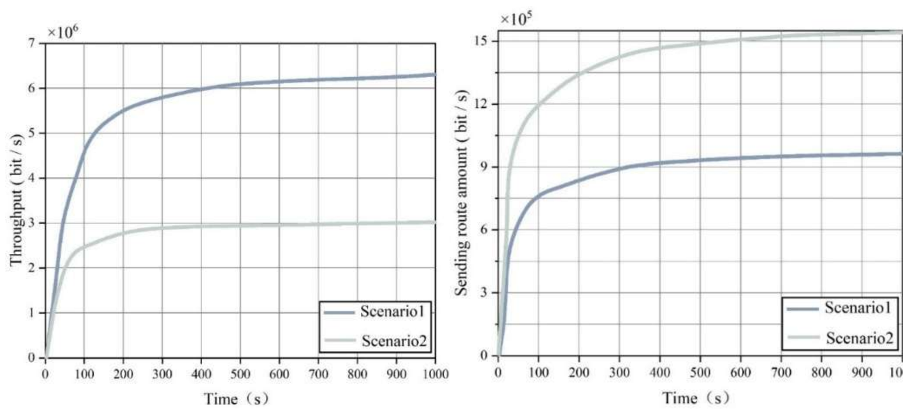
170,000 bits, the number of retransmission attempts is about 3 packets and 2 packets, the end-to-end latency is about 10s and 4s, respectively, the network load is 950,000 bits/sec and 155,000 bits/sec, and the throughput is 6,300,000 bits/sec, respectively, 3,000,000 bits/sec. Overall, the Wireless LAN statistics tend to stabilize with the increase of network simulation time, indicating that the whole tactical communication data chain network is stable.



(a) Discard message (b) Retransmission attempt



(c) Network delay (d) Media access delay



(e) Network load (f) Network throughput

Figure 2: WLAN statistics

3) Analysis of multi-indicator comprehensive performance evaluation system

The indicators are put into the multi-indicator comprehensive effectiveness evaluation system for calculation, and the scores of each indicator are obtained for scenario1 and 2, as shown in Table 1. From the table, it can be seen that scenario 1 has a higher rating in terms of data processing ability, and scenario 2 has a higher rating in terms of effectiveness. The final scores of the two scenarios are obtained by multiplying the scores of the above indicators by the corresponding weights, and the scores of scenario 1 and scenario 2 are 0.46 and 0.539, respectively. Based on the comprehensive network performance scores, it can be concluded that the performance of scenario 2 is better than that of scenario 1, which is due to the fact that the radius restriction of scenario 2 reduces the amount of transmission services of the network, and the whole network is more stable.

Table 1: Multi-index comprehensive effectiveness evaluation system score table

Index classification	Index layer	Weight	Scenario1	Scenario1
Response ability	Upload response time	0.05	0.25	0.75
	Download response time	0.05	0.5	0.5
	Network delay	0.05	0.833	0.167
	Media access delay	0.05	0.75	0.25
Data processing ability	Send routing traffic	0.15	0.25	0.75
	Receive routing traffic	0.15	0.25	0.75
	Business sending traffic	0.1	0.833	0.167
	Business receiving traffic	0.1	0.833	0.167
	Load	0.1	0.167	0.833
	Throughput	0.1	0.167	0.833
Effectiveness	Packets discarded in transmission	0.05	0.5	0.5
	Retransmission attempt	0.05	0.875	0.125

IV. B. Network Expansion Analysis

IV. B. 1) Topological Inference

The original communication data exported by OPNET is used as the reconnaissance data, and the reconnaissance data is randomly intercepted in proportion to the ratio, and three types of reconnaissance data files are generated with the ratios of 70%, 80%, and 90%, respectively.VS2017 reads the reconnaissance data files generated by OPNET for topology inference, and the inferred information includes node name, node location, communication between the starting node and the terminating node, and the link weights. The inferred information includes node name, node location, communication between the start node and the end node, and link weight. For the subsequent display of the topology map, this information needs to be written to the net file. Using Pajek software to read the obtained net file, the inferred network visualization topology can be obtained, as shown in Figure 3. The figure shows the inferred topology result when the probability of interception is 70%. The graph reflects the node names and node locations in the net file.

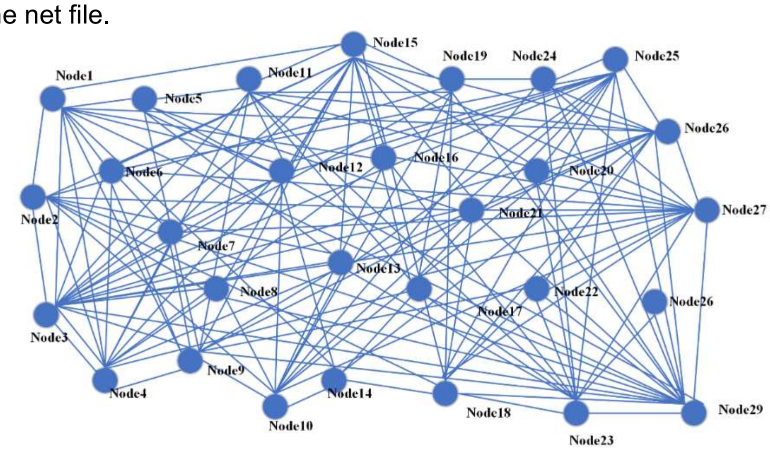


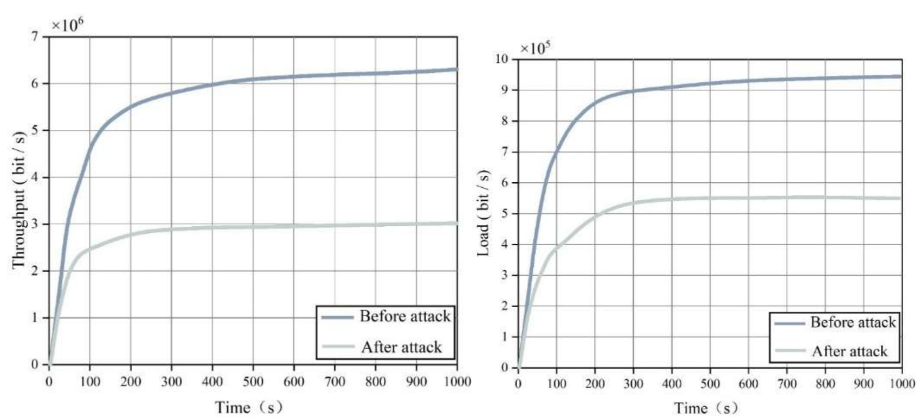
Figure 3: Topology results

IV. B. 2) Key Node Identification

Using the network topology in the case of 70% interception ratio as the object of analysis, the importance ranking of the network nodes obtained by three comprehensive evaluation algorithms, namely, fuzzy comprehensive evaluation (FCE), gray comprehensive evaluation (GCE), and hierarchical analysis (AHP), is shown in Table 2. The ordering in the table is descending order, the higher the node's importance is. In this paper, the top five nodes in terms of importance are selected as the key nodes of the network, the key nodes obtained by AHP are node 2, node 9, node 5, node 3, node 7, the key nodes obtained by FCE are node 2, node 10, node 22, node 9, node 6, and the key nodes obtained by GCE are node 2, node 9, node 12, node 5, and node 10. The data in the table shows that the key nodes obtained by three evaluation methods are roughly the same. Data in the table, it can be seen that the key nodes obtained by the three evaluation methods are approximately the same.

Table 2: Importance ranking of network nodes

Sort	AHP	FCE	GCE
1	Node 2	Node 2	Node 2
2	Node 9	Node 10	Node 9
3	Node 5	Node 22	Node 12
4	Node 3	Node 9	Node 5
5	Node 7	Node 6	Node 10
6	Node 10	Node 11	Node 22
7	Node 12	Node 8	Node 25
8	Node 1	Node 24	Node 29
9	Node 4	Node 25	Node 19
10	Node 22	Node 4	Node 21
11	Node 6	Node 1	Node 13
12	Node 29	Node 27	Node 14
13	Node 8	Node 19	Node 7
14	Node 19	Node 13	Node 18
15	Node 20	Node 18	Node 1
16	Node 25	Node 21	Node 27
17	Node 21	Node 28	Node 6
18	Node 14	Node 26	Node 3
19	Node 17	Node 29	Node 20
20	Node 11	Node 20	Node 8
21	Node 13	Node 16	Node 11
22	Node 26	Node 15	Node 17
23	Node 15	Node 17	Node 15
24	Node 27	Node 23	Node 24
25	Node 28	Node 7	Node 23
26	Node 23	Node 3	Node 4
27	Node 18	Node 5	Node 26
28	Node 24	Node 12	Node 16
29	Node 16	Node 14	Node 28



(a) Network throughput (b) Network load

Figure 4: Network statistics after attack

Node 10, node 22, node 2, node 9, and node 21 are selected as the key nodes of the tactical communication datalink network in this paper and attacked. The network statistics after being attacked are specifically shown in Fig. 4, Figs. (a) and (b) show the network throughput and network load, respectively. It can be seen that the network throughput drops from 6200000 bits to 4300000 bits and the load drops from 950000 bits to 750000 bits after the attack. Based on the statistics results, it can be seen that attacking the key nodes of the network can effectively reduce the communication efficiency of the network.

V. Tactical communications datalink network transmission load-balancing algorithms

Tactical communication datalink network often fails to ensure network load balancing as the number of tasks increases during transmission. Aiming at this problem, this chapter will propose a cluster algorithm for load balancing of tactical communication datalink network based on adaptive genetic algorithm, and utilize adaptive genetic algorithm to solve the model and realize the load balancing of tactical communication datalink network.

V. A. Load Balancing Clustering Algorithm Based on AGCH Algorithm

In order to be able to realize the tactical communication data chain network load balancing, the AGCH algorithm is used to divide the tactical communication data chain network nodes into two phases, which are the grouping phase and the cluster phase, from which the cluster head nodes are obtained to realize the tactical communication data chain network load balancing into clusters.

1) Tactical communication data chain network load balancing grouping

When grouping the tactical communication data chain network phase, it is necessary to divide the network nodes into several groups with the same distance, and after a cycle, the network can be grouped again.

Firstly, the distributed distance competition algorithm is utilized to use the tactical communication datalink network node ID as a basis for comparison, and then it is grouped, and the specific grouping process is expressed as follows:

Generate a random number from 0 to 1 in each tactical communication datalink network node and set up a probability threshold T , if the random number is going to be lower than T , then the node can be the head of the candidate group to participate in the tactical communication datalink network equalization node competition.

Set N represents the total number of nodes in the tactical communication datalink network, and the area of the region where the network equalization nodes are monitored is described by A , whereas k is the total number of nodes in the tactical communication datalink network.

And k is the optimal number of clusters in the network nodes. The radius of the competitive area at the head of the selected group is labeled by $u*R$, where u is labeled as the regulating factor and R is labeled as the radius. Then R is computed using the following equation, denoted as:

$$R = \sqrt{\frac{A}{k\pi}} \tag{9}$$

Assuming that the set of competing nodes is described by Scp, then the Scp of the candidate group head i can be defined as:

$$i.Scp = \{ j \mid j \text{ Represents the head of the candidate group } (i,j) < u*R \} \tag{10}$$

2) Tactical communication data chain network load balancing into clusters stage

Based on the above grouping of network nodes, a cluster head is selected within each grouping and an energy consumption model is constructed, which is used to divide the intra-cluster energy consumption of the tactical communication datalink network nodes into two parts: the first part is the energy consumed to deliver the data, and the second part is the energy consumed by the cluster head to merge the data after it is received.

Then the intra-cluster communication cost of the tactical communication datalink network node i is described by the following equation:

$$\cos t(i) = \sum_{j=G(i), j\neq i} d(i,j)^2 \tag{11}$$

Where $\cos t(i)$ describes the communication cost, $G(i)$ describes the set of nodes in each grouping, and $d(i,j)$ describes the distance between node i and node j .

When the density of the load-balanced node distribution of the tactical communications datalink network is more uniform, $2R+h$ is the maximum distance of the nodes and $2R-h$ is the minimum distance of the nodes. The final equation expression for this node is defined as:

$$\cos t(i) = (2R+h)^2 + (2R-h)^2 = 2(4R^2 + h^2) \tag{12}$$

Setting the cluster heads in the load balancing node group of the tactical communication datalink network to be described through EV and using EV as the primary selection basis, the equation expression for the EV cluster heads is defined as:

$$EV(i) = RE(i) * cost(i) / \overline{cost}(i) \tag{13}$$

Where RE describes the residual energy.

After grouping and clustering the nodes of tactical communication datalink network based on AGCH algorithm, the cluster head node of tactical communication datalink network is obtained from it to complete the clustering of tactical communication datalink network.

V. B. Load Balancing Based on Adaptive Genetic Algorithm

V. B. 1) Modeling resource scheduling

With the cluster head nodes obtained above, a resource scheduling model is constructed, which is utilized to allocate and schedule the resources in the cluster head nodes. In order to be able to effectively realize the load balancing of the tactical communication data chain network, the shortest scheduling time of the resource scheduling of the cluster head nodes is used as the main factor. Considering the total resource scheduling of the cluster head node, the objective function and constraints of the cluster head node need to be established.

Since the resources in the cluster head nodes are different, the demand for resource scheduling and allocation is also very different, so set a_j to mark the scheduling time and cost coefficients of the cluster head node EV, and β_i to mark the penalty cost coefficients of the EV, and add the set coefficients to the resource scheduling, then the objective functions of resource scheduling of the cluster head nodes are all expressed as as:

$$\begin{cases} W_1 = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{l=1}^{q} a_j + t_{ij} + x_{ij}^l \\ W_2 = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{l=1}^{q} a_j + p_l + x_{ij}^l \\ W_3 = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{l=1}^{q} \beta_i + (d_j^l - x_{ij}^l) \end{cases} \tag{14}$$

where W_1 describes the total scheduling time, W_2 describes the total scheduling cost, W_3 describes the total penalization cost, t_{ij} describes the minimum scheduling time, p_i describes the unit scheduling cost, x_{ij}^l describes the cluster head The number of node resources, m,n,q all describe the node coefficients, and d_j^l describes the resource scheduling requirements.

And there are two constraints to construct the resource scheduling model:

1) The total amount of resources scheduled for cluster head node EV cannot be more than the scheduling demand of cluster head node EV;

2) The total amount of scheduling allocation to the cluster head node EV cannot exceed the usage of the allocated node resources.

Based on the establishment of the above objective function and constraints, the resource scheduling model of the tactical communication data chain network is constructed, and θ is set to represent the time-cost conversion coefficient, then the established resource scheduling model is defined by the equation expression as:

$$\min W = \theta \cdot (W_1 + W_2 + W_2) \tag{15}$$

V. B. 2) Adaptive Genetic Algorithm Based Model Solving

Using the constructed resource scheduling model, the acquired tactical communication datalink network cluster head nodes are allocated and scheduled, and the adaptive genetic algorithm is used to solve the model, so as to improve the effect of load balancing of the tactical communication datalink network, and realize the load balancing of the tactical communication datalink network.

Adaptive genetic algorithm can generate a new population by performing various operations on the population, and repeat the process until the optimal solution is generated within the population. Therefore, adaptive genetic algorithm is used to solve the constructed resource scheduling model to achieve the tactical communication datalink network load balancing [27].

Firstly, the adaptive genetic algorithm's fitness function, crossover and mutation rate are optimized and adjusted.

1) Optimization of fitness function

In the adaptive genetic algorithm, the fitness value of the fitness function is an important basis for the genetic algorithm to search, when the fitness value is larger, the probability of evolving to the next generation will be improved, so when the genetic algorithm is optimized, the fitness value needs to be increased as a way to facilitate the solution of the model. Then the fitness function of the adaptive genetic algorithm is expressed as follows:

$$F=\begin{cases}C_{\max}-f & f<C_{\max}\\ 0 & \text{other}\end{cases} \quad (16)$$

Where $C_{\max}$ describes the constant, f describes the function after constraints and F describes the fitness function.

And considering the constraints of resource scheduling of cluster head nodes, then the adaptation degree function based on the constraints is defined by the equation expression as follows:

$$f=p_{lom}+\sum_{j=1}^{N}\alpha_j+(I_j-I_{j\lim})+\sum_{k=1}^{N}\beta_k(U_k-U_{k\lim}) \quad (17)$$

where $I_{j\lim}$ describes the current limit, $U_{k\lim}$ describes the voltage limit, α,β both describe the tactical communication datalink network coefficients, and p_{lom} describes the network loss.

2) Adaptive Genetic Algorithm Adjustment

In the traditional genetic algorithm, if the crossover rate and mutation rate are low, then it will affect the efficiency of the algorithm itself and reduce the performance of the algorithm. So here it is necessary to adaptively adjust the crossover rate and mutation rate in the tactical communication datalink network, so that the crossover rate is linearly reduced and the mutation rate is exponentially increased, and the set crossover rate and mutation rate are represented by the equation expression as follows:

$$\begin{cases}P_c(t+1)=P_{cinitial}+(t+1)/T_{\max}+(P_{cfinal}-P_{cinitial}+e^{-1/\Delta f(t)})\\ P_m(t+1)=P_{\min itial}+(P_{mfinal}-P_{\min itial}+e^{-(t+1)/T_{\max}\cdot\Delta f(t)})\end{cases} \quad (18)$$

where $P_c(t+1)$ describes the crossover rate in the $t+1$ th generation, $P_m(t+1)$ describes the mutation rate in the $t+1$ th generation, $P_{cinitial},P_{cfinal}$ both describe the initial crossover and mutation rates, and $P_{\min itial},P_{mfinal}$ both represent the final crossover and variance rates. $T_{\max}$ describes the maximum number of evolutionary generations, and $\Delta f(t)$ describes the mean difference in fitness.

VI. Tactical communications data chain network transmission load balancing tests

In this chapter, convergence performance, task completion time, energy consumption and load balancing degree will be used as the performance evaluation metrics of the experimental algorithms, and CloudSim software will be used to test the tactical communication datalink network transmission load balancing algorithms proposed in this paper, and the selected algorithms for comparison are ACO, ICA, PSO, and PSO-ACO.

VI. A. Test environment setup

In this paper, the open source simulation platform CloudSim is used to complete the simulation of resource scheduling strategy for improving ACO-ICA. In the simulation tool, five virtual machines are configured to simulate the service nodes in the ship, corresponding to five edge servers, and their performance is expressed in terms of computational power F, bandwidth and memory, and the specific parameter settings are shown in Table 1. Six groups of experiments are conducted, each group of experiments performs 50 tasks, and a total of 300 tasks are performed. Each task is run 10 times to take the average value, in which the length of the task instruction is a random value within 1000~5000, and the size of the task is a random value within 100~1000.

VI. B. Analysis of test results

VI. B. 1) Convergence properties for different number of iterations

To test the performance of the algorithms in this paper in terms of convergence speed, the experimental environment is set to 300 tasks, and 5 virtual machines simulate the internal edge server responsible for data processing. The convergence speed of each algorithm is compared, and each group of algorithms is averaged over 10 trials, and the convergence characteristics of different algorithms are shown in Figure 5. As can be seen from the figure, all the tested algorithms basically complete the task when the number of iterations is 50 ~ 70, and the task completion time of this paper's algorithm is about 340s, which is better than that of ACO(540s), ICA(465s), PSO(416s) and PSO-ACO(380s).

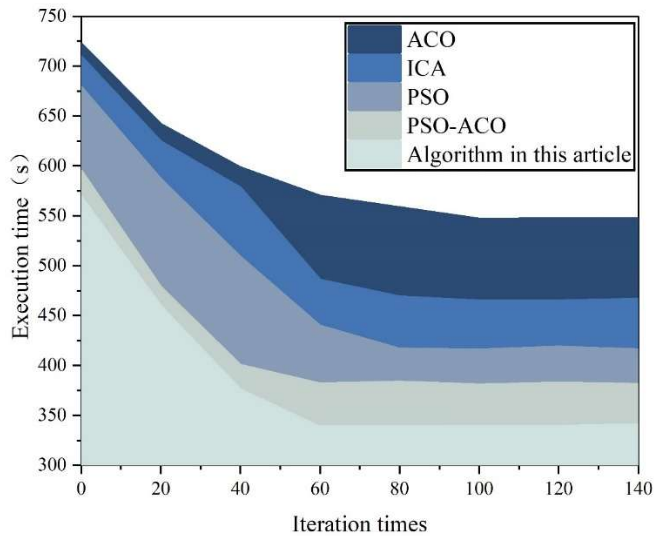


Figure 5: The convergence characteristics of the algorithm under different iterations

VI. B. 2) Task completion time

The task completion time is the sum of time spent by the inner edge server nodes from the beginning of the first task assignment to the completion of the last task. The task completion time for different number of tasks is shown in Fig. 6. The task completion time for different number of tasks is shown in Fig. 5.The completion time of this paper's algorithm is shorter than the other algorithms in all cases where the number of tasks is the same. When the number of tasks increases from 50 to 300, this paper's algorithm grows from 68s to 275s in completion time, and the completion time is always the lowest among all algorithms.

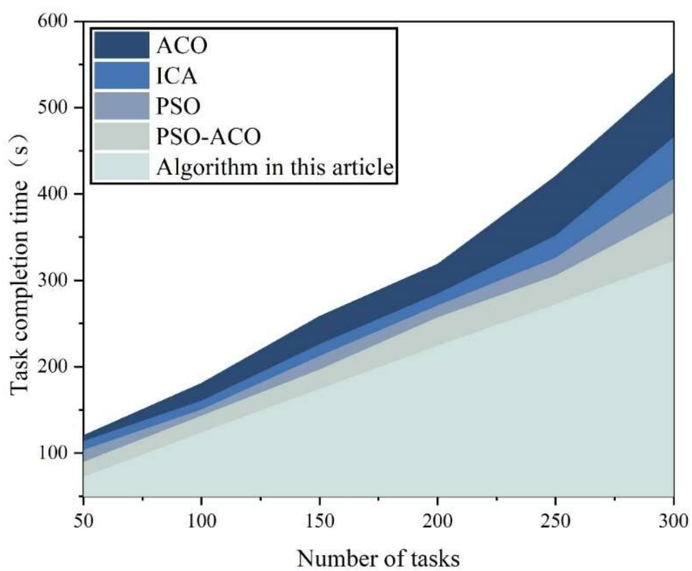


Figure 6: Completion time of each algorithm under different task numbers

VI. B. 3) Energy consumption

The energy consumption comparison of the five task scheduling algorithms at different number of tasks is shown in Table 3. It can be seen that the energy consumption values of the task scheduling schemes of this paper's algorithms are all the lowest. When the number of tasks is 50, the energy consumption value of this paper's algorithm is 8.04% lower than that of ACO. Compared with ICA and PSO ,the algorithm of this paper reduces 9.65% and 8.04% respectively. And when the number of tasks reaches 300, the energy consumption value of this paper's algorithm is reduced by 8.52%, 6.08%, 5.39% and 4.09% compared to ACO, ICA, PSO and PSO-ACO respectively. This indicates that this paper's algorithm has better energy consumption optimization in large-scale task scheduling.

Table 3: Energy consumption comparison of each algorithm

Number of tasks	Algorithm				
	ACO	ICA	PSO	PSO-ACO	Algorithm in this article
50	11.2	11.4	11.2	11	10.3
100	24.1	24	23.3	23.1	22.6
150	38.2	37.6	36.7	36.5	36
200	54.9	52.8	52.8	51.6	50.9
250	69.8	66.8	65.7	64.7	63.4
300	84.5	82.3	81.7	80.6	77.3

VI. B. 4) Load Balancing Degree

The comparison of load balancing degree of different algorithms at different number of tasks is specifically shown in Table 4. With the increase of the number of tasks, the load balancing difference of this paper's algorithm decreases slightly, while the load balancing difference of ACO and ICA increases gradually. The smaller the load balancing difference is, the more balanced the system load is. When the number of tasks increases from 50 to 300, the load balancing differences of ACO, ICA, PSO and PSO-ACO all increase, while the load balancing difference of this paper's algorithm decreases from 0.4 to 0.34. Obviously, the transmission load balancing algorithm for tactical communication datalink network proposed in this paper can effectively improve the load balancing effect and realize the load balancing of tactical communication datalink network.

Table 4: Comparison of load balancing degree of different algorithms

Number of tasks	Algorithm				
	ACO	ICA	PSO	PSO-ACO	Algorithm in this article
50	0.74	0.47	0.47	0.43	0.4
100	0.77	0.49	0.48	0.41	0.38
150	0.79	0.49	0.49	0.43	0.38
200	0.81	0.52	0.49	0.45	0.36
250	0.82	0.53	0.5	0.45	0.34
300	0.83	0.57	0.53	0.46	0.34

VII. Conclusion

In this paper, using the concept of natural connectivity of networks, a tactical communication datalink network effectiveness assessment method based on weighted natural connectivity is proposed. Relying on the tactical communication datalink network simulation system architecture, we carry out the tactical communication datalink network effectiveness simulation evaluation. In scenario 1 (scenario 1), where there is no restriction on the communication radius, and scenario 2 (scenario 2), where there is restriction on the communication radius, the amount of sending and receiving routes of the AODV protocol network is stabilized at about 60s. All the indicators of Wireless LAN statistics tend to stabilize with the increase of network simulation time, indicating the stability of the whole tactical communication datalink network. Putting all the indicators into the multi-indicator comprehensive performance evaluation system, the final scores of scenarios 1 and 2 are 0.46 and 0.539 respectively, and the tactical communication datalink network performance is better in scenario 2, which restricts the communication radius. In the network topology analysis, using the network topology in the case of 70% interception ratio as the object of analysis, when the key nodes of the network, such as node 10, node 22, node 2, node 9, node 21, etc., are attacked, the throughput of the network decreases from 6,200,000 bits to 4,300,000 bits, and the load decreases from 950,000 bits to 750,000 bits after attack, and the communication efficiency of the tactical communication data chain network is reduced by the effect of the attack. The communication efficiency of the data chain network is reduced significantly.

In order to improve the load balancing effect of tactical communication datalink network, the transmission load balancing algorithm of tactical communication datalink network based on adaptive genetic algorithm is proposed, and the transmission load balancing test of tactical communication datalink network is carried out to check the application effect of this paper's algorithm. Comparing with other algorithms such as ACO(540s), ICA(465s), PSO(416s) and PSO-ACO(380s), the task completion time of this paper's algorithm is about 340s, which has the optimal convergence speed. With the same number of all tasks, its completion time is shorter than other algorithms. In terms of energy consumption, when the number of tasks is 50, it is reduced by 8.04%, 9.65% and 8.04%

compared to ACO, ICA and PSO respectively. And when the number of tasks reaches 300, the value of energy consumption is reduced by 8.52%, 6.08%, 5.39% and 4.09% compared to ACO, ICA, PSO and PSO-ACO, respectively. This proves that the algorithm in this paper has better energy consumption optimization in large-scale task scheduling. In addition, the load balancing difference of this paper's algorithm decreases from 0.4 to 0.34, while the load balancing differences of the comparative ACO, ICA, PSO and PSO-ACO algorithms all increase. In conclusion, the proposed transmission load balancing algorithm for tactical communication datalink network has excellent load balancing effect and can well realize the load balancing of tactical communication datalink network.

About the Author

Shuang Geng, Han, member of the Communist Party of China, was born in July 1975. I am a Professor-level Senior Engineer with a bachelor's degree. In June 1997, I graduated from Nanjing University of Science and Technology with a major in Automatic Control. I joined the North Automatic Control Technology Institute in July of the same year and has working there ever since.

Xiaoqiong Zhang, Han, was born in December 1976. I am a Professor-level Senior Engineer with a bachelor's degree. In June 1997, I graduated from Nanjing University of Science and Technology with a major in electronice and applied technology. I joined the North Automatic Control Technology Institute in July of the same year and has working there ever since.

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