Grey Theory and AHP Applied in Performance Evaluation of Tactical Communication Network Information System

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Abstract. The tactical communication network is the core technology of digital battlefield communication. Research on the interference effectiveness of tactical communication networks can ensure that the information services of tactical communication can be transmitted in real time and reliably. The article analyzes the interference effectiveness evaluation index system of tactical communication networks, uses indicators such as route discovery time, throughput, delay, and packet loss rate to evaluate network interference effectiveness, and proposes an effectiveness evaluation method based on AHP and gray theory. Finally, the networking software OPNET is used to conduct simulation experiments to obtain the experimental data before and after the interference, so as to obtain the effective evaluation results of the interference effectiveness of the tactical communication network. The research results have theoretical guiding significance for the evaluation of the interference effectiveness.

Keywords: Tactical communication network, grey theory, analytic hierarchy process, interference, effectiveness evaluation

1. Introduction
The tactical communication network is the communication network of the digital battlefields of all countries in the world. It is an important means to realize the mobile command and control, hierarchical situational awareness and seamless communication of troops in a complex electromagnetic environment [1]. The goal of the tactical communication network is to provide communication capabilities to areas with limited or no existing communication infrastructure. In a local war, the research on the interference effectiveness of the tactical communication network is an important part of the army’s combat preparations, and it has a major impact on the improvement of military strength. The significance of the battlefield communication and security often also determine the outcome of the war. Therefore, how to scientifically analyze and evaluate the jamming effectiveness of tactical communication networks is a major research topic for scholars.

2. Selection of Interference Effectiveness Evaluation Index for Tactical Communication Network
The operational effectiveness evaluation of a tactical communication network is a complex system engineering. It is necessary to consider not only the business capabilities of the communication
network, but also the tactical factors after networking. The setting of the index system should follow the principles of objectivity, completeness and rationality: Clarify the connotation and interrelationship of each factor index, distinguish the priority and ensure the objectivity of the evaluation; under the conditions of information warfare, the characteristics of the tactical communication network shall be examined from different angles and aspects. This article evaluates the effectiveness of communication service capability indicators in three aspects: reliability, data processing capability, and data response capability of the tactical communication network, reflecting the number and quality of communication services handled by the tactical communication network and the ability of the network to rationally utilize resources [2]. Specific evaluation indicators are shown in Figure 1.

![Image](image.png)

**Figure 1. Evaluation Index of Tactical Communication Jamming Effectiveness**

3. Evaluation Method of Tactical Communication Jamming Effectiveness

3.1. AHP (analytic hierarchy process)

AHP refers to a decision-making method that decomposes the relevant elements of a decision-making problem into goals, criteria, plans and other levels, and performs qualitative and quantitative analysis on this basis [3]. Its characteristic is to construct a hierarchical structure model after in-depth analysis of the nature, influencing factors and internal relations of complex decision-making problems, and then use less quantitative information to mathematicize the thinking process of decision-making, so as to solve more problems. Complex decision-making problems with criteria or unstructured characteristics provide a simple decision-making method [4]. Specific steps are as follows:

1) Construct a comparison judgment matrix

According to the expert’s experience and judgment, the judgment matrix $M = (M_{ij})_{n \times n}$ is constructed based on the relative importance of each sub-item in AHP. In the judgment matrix (Equation 1) $n$ is the number of indicators, which represents the importance of the i-th index relative to the j-th index. The scale definition of the judgment matrix is shown in Table 1.

$$
M = 
\begin{bmatrix}
M_{11} & M_{12} & \cdots & M_{1n} \\
M_{21} & M_{22} & \cdots & M_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
M_{n1} & M_{n2} & \cdots & M_{nn}
\end{bmatrix}
$$
Table 1. Scale value table of judgment matrix

| Intensity of importance | Explanation                                                                 |
|-------------------------|-----------------------------------------------------------------------------|
| 1                       | $i$ is as important as $j$                                                  |
| 2                       | $i$ is a little more important than $j$                                     |
| 3                       | $i$ is more important than $j$                                              |
| 4                       | $i$ is strongly more important than $j$                                     |
| 5                       | $i$ is extremely more important than $j$                                    |
| 2, 4, 6, 8               | Represent the intermediate values of the above adjacent judgments           |
| Reciprocals of above     | If $i$ has one of the above nonzero numbers assigned to it when compared with $j$, then it has the reciprocal value when compared with $i$, $M_{ij} = 1/M_{ji}$ |

2) Sorting under the single criterion

The information basis of AHP is the comparison judgment matrix. Since each criterion dominates several factors in the next layer, a comparative judgment matrix can be obtained for each criterion and the factors it dominates. Therefore, the process of obtaining the relative ranking weight of each factor for criterion $A$ according to the comparison judgment matrix is called the ranking under the single criterion.

Matrix $M$ has two characteristics: $M_{ij} > 0$ and $M_{ji} = \frac{1}{M_{ij}}$ ($j, i = 1, 2, ..., n$) where $M_{ii} = 1$, eigenvector $(M\omega)$ and maximum eigenvalue $\lambda_{\text{max}}$. The judgment matrix is calculated according to the square root method (Equation 2 and 3).

$$
\lambda = \frac{1}{n} \sum_{i=1}^{n} \frac{(M\omega)_i}{\omega_i}
$$

$$
\omega_i = \left( \frac{\prod_{j=1}^{n} M_{ij}}{\sum_{j=1}^{n} (\prod_{i=1}^{n} M_{ij})^{\frac{1}{n}}} \right)^{\frac{1}{n}}
$$

3) Consistency check under single criterion

The normalized eigenvector corresponding to the maximum eigenvalue of the judgment matrix is used as the weight vector of all the sub-items in the objective function, but the actual judgment matrix is usually inconsistent. In this case, use the calculation of $CR$ (consistency ratio) to verify whether the matrix $M$ is in the acceptable range.

Consistency index:

$$
CI = \frac{\lambda_{\text{max}}}{n-1}
$$

Consistency ratio:

$$
CR = \frac{CI}{RI}
$$

Generally speaking, the larger the CI, the stronger the inconsistency of the matrix $M$, and the RI is the random consistency index. Generally, when $CR < 0.1$, it can be considered that the evaluation model has achieved partial satisfactory consistency at this level.
3.2. Grey Whitening Weight Cluster Evaluation Model

The gray clustering evaluation method is a multi-dimensional gray evaluation method based on the gray number white function. The white number is summarized into different gray types. These gray types are the clustering objects having different clustering indicators, and then determine the cluster type to which the class object belongs [5]. Specific steps are as follows:

1) According to the evaluation requirements and the quantitative value of the index, determine the number of gray classes and the value range of the corresponding gray classes. Divide the interference degree into s gray classes to describe, respectively: 1, 2, 3, s, set the corresponding interference intensity value grouping vector $C= [λ_1, λ_2, λ_3, ..., λ_s]$.

2) Establish a triangular whitening weight function, and determine the membership degree of the corresponding gray class according to the quantified value of each index. The expression of the constructed triangular whitening weight function is as follows:

$$f^k_j(x) = \begin{cases} 
\frac{x - λ_{k-1}}{λ_k - λ_{k-1}}, & (x ∈ [λ_{k-1}, λ_k]) \\
\frac{λ_k - λ_{k-1}}{λ_{k+1} - λ_k}, & (x ∈ [λ_k, λ_{k+1}]) \\
0, & (x ∈ [λ_{k-1}, λ_{k+1}])
\end{cases} \quad (6)$$

From equation 6, the degree of membership $f^k_j(x)$ of the gray category $k (k = 1, 2, 3, ..., s)$ can be calculated.

3) Determine the gray class of the evaluation object based on the weight of each indicator in the clustering model and the principle of maximum membership degree. Combining the weighting of the AHP in section 2.1 to obtain the weight $ω_i, i = 1, 2, ..., n$. Calculate the comprehensive clustering coefficient $σ^k_i$ of the object $i (i = 1, 2, ..., n)$ with respect to the gray class $k$.

$$σ^k_i = \sum_{j=1}^{m} f^k_j(x_{ij}) \odot ω_j \quad (7)$$

From $\max_{1≤i≤n} \{σ^k_i\} = σ^k$, we can determine the gray category of the interference effectiveness of the tactical communication network.

4. Simulation experiment analysis

The OPNET simulation platform is used to simulate the tactical communication network [6], and the battlefield interference electromagnetic environment is simulated at the same time [7]. The battlefield size is 10km*10km, and 30 mobile network nodes (mobile_node_1 to mobile_node_30) are randomly distributed in the scene. Rx Group Config is the configuration node Effective communication distance, Mobility Config module is to configure the moving speed of the node.

As shown in Figure 2 (a-f), respectively reflect the comparative analysis of route discovery time, route cost, packet loss rate, delay, load, and throughput before and after interference.
• (a) Route Discovery Time 
(b) Total Delay 
(c) Packet loss probability 
(d) Load 
(e) Throughput 
(f) Routing cost

Figure 2. Comparison analysis diagram of each indicator before and after interference

The entire simulation simulation time is 300 s. The simulation results of each index are taken every 3 seconds to obtain 100 sets of data, from which 4 sets of data are randomly selected to obtain the interference front-to-back ratio, and then the maximum value normalization process is performed to obtain the data as shown in Table 2.

**Table 2. Tactical Communication Network Interference Performance Evaluation Sample Sheet**

| Number | Load | Routing cost | Throughput | Packet loss probability | Route Discovery Time | Total Delay |
|--------|------|--------------|------------|-------------------------|----------------------|-------------|
| 1      | 0.888| 1            | 0.89       | 0.964                   | 0.67                 | 0.199       |
| 2      | 0.8  | 0.88         | 0.805      | 0.991                   | 1                    | 0.35        |
| 3      | 1    | 0.942        | 0.843      | 1                       | 0.761                | 1           |
| 4      | 1    | 0.527        | 1          | 0.729                   | 0.823                | 0.167       |

This paper evaluates the indicators based on the method of expert consultation, and constructs the judgment matrix as follows:
According to the AHP, the upper and lower index weights are obtained, \( \omega = (0.12, 0.56, 0.32) \), \( \omega_1 = (0.2, 0.8) \), \( \omega_2 = (0.33, 0.67) \), \( \omega_3 = (0.86, 0.14) \), the random consistency index \( CR=0.016<0.1 \), which meets the consistency test standard. This paper divides the gray number of interference levels into three categories: "light interference", "Moderate interference", "severe interference", the corresponding interference intensity value grouping vector \( C = [90, 60, 30] \), determine the whitening weight function according to Equation 6, and then get the interference efficiency value of 69.43, which is in the gray category of "moderate interference" Therefore, the interference is moderate interference.

5. Conclusions
Based on the use of OPNET networking software to simulate the tactical communication network, the battlefield electromagnetic interference environment was simulated, and the original experimental data of the comparative analysis before and after the interference of each evaluation index were obtained. At the same time, the maximum value of the data was normalized to obtain the evaluation sample. Furthermore, combining gray theory and analytic hierarchy process method to evaluate the interference effectiveness of tactical communication network, an effective interference evaluation value is obtained. The experimental results show the rationality and effectiveness of the method applied to the evaluation of the interference effectiveness of the tactical communication network. The next step will be to further explore the selection of indicators and the determination of weights, and compare this method with other machine learning effectiveness evaluation methods.

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