Difficulty-and-Beauty Network Evaluation with Interval Number Eigenvector Method

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Abstract. In consideration of the complexity and difficulty of network evaluation, we propose a "difficulty & beauty" network evaluation framework based on the interval number eigenvector method. In the proposed framework, we adopt the interval number eigenvector method to calculate the weight of each indicator, while its score is obtained from the network test results or expert recommendations. The weighted product and weighted sum methods are used for the aggregation of quantitative indicators and qualitative indicators to obtain the final score of the network. Finally, the feasibility and effectiveness of the proposed framework is verified by numerical experiments.

Keywords: Network evaluation · Difficulty & beauty · Interval number eigenvector method

1 Introduction

With the development of network information technology, the importance of evaluation for network information systems keeps increasing [1]. In order to assess the performance of network information systems more precisely, it is urgent to establish scientific and reasonable network evaluation frameworks.

For different network information systems, the corresponding evaluation methods are different, which are usually combination of weight calculation methods and indicator aggregation methods. There are mainly two weight calculation schemes, namely analytic hierarchy process (AHP) and information entropy method. AHP was first proposed by T. L. Saaty as a multi-criteria decision-making method combining qualitative and quantitative evaluation [2]. Then Lee proposed an improved AHP to evaluate the

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operational potential of the Army's network information system [3]. Manik Chandra Das and others adopted an improved model of AHP, i.e., fuzzy analytic hierarchy process, to evaluate the network system of Indian scientific research institutions [4, 5]. AHP usually uses ordinary numbers to express the judgment, but in practice, there may be some uncertainty for the judgement. In order to handle this issue, interval numbers should be applied to define the elements in the judgment matrix and calculate the weights more objectively. On the other hand, in information theory, information entropy [6] is usually used to describe the uncertainty of random variables. Wang in [7] analyzed the relevant factors affecting the combat effectiveness of the C^4ISR system, and used the method of combining Shannon information entropy and graph theory to put forward a new idea for the C^4ISR system combat effectiveness evaluation. However, if the value of indicator changes very little or suddenly becomes larger or smaller, information entropy method will have some limitations. As for indicator aggregation, the authors in the literature [8, 9] proposed to the arrogate the lower-level indicators to the upper-level indicators by means of weighted sums, ignoring the decisive influence of individual lower-level indicators. Hence it cannot faithfully reflect the actual situation of the object to be evaluated.

In this paper, we propose a novel "difficulty & beauty"-based network evaluation method using interval number eigenvector scheme. Firstly, due to the aforementioned advantages of using interval numbers and information entropy method, the weight of each indicator is calculated by the interval number eigenvector method. Then the score of the quantitative indicator and the qualitative indicator are obtained through the test results of the network or the score from the experts on the network performance. Furthermore, the final score of the network is calculated by the aggregation method combining the weighted product and the weighted sum, wherein for the lower-level indicators that have decisive influence, the weighted product method is applied. Finally, the overall evaluation of the network performance is taken as the average of the final score which is an interval number.

2 "Difficulty & Beauty" Network Evaluation System

We first introduce the "difficulty & beauty" network evaluation system considered in this paper, which is divided into four layers from top to bottom, including 2 first-level indicators and 8 s-level indicators. Under the second-level indicators, a total of 56 appropriate indicator parameters are selected to form the third-level indicators. The specific affiliation is shown in Fig. 1 and Fig. 2 below.

We now briefly introduce one of the third-level indicators, i.e., "Processing" (B3) as an example. Its lower-level indicators are as follows. "Processing error rate" indicates the ratio between the amount of error information and the total amount of information processed; "Access node physical looping ratio" indicates the ratio of the number of physically looped nodes to the total number of access physical nodes; "Access node dual homing rate" indicates the ratio of the number of returned dual homing nodes to

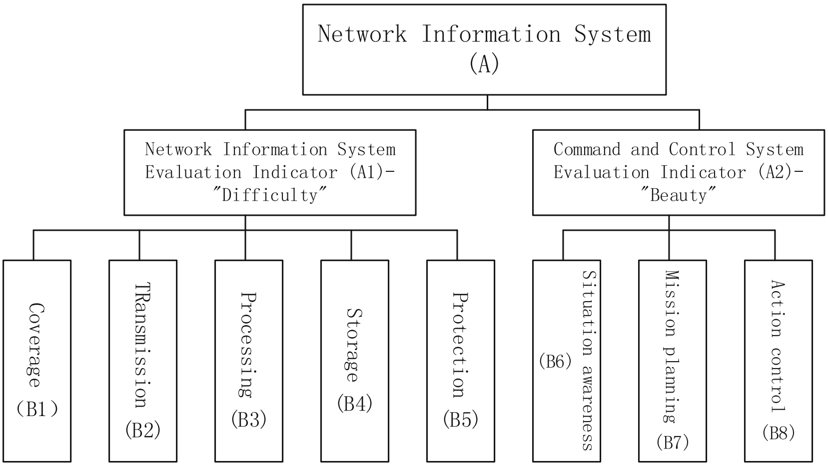

Fig. 1. "Difficulty & beauty" network evaluation system (First and Second levels)

the total number of access nodes; "Processing delay" indicates the time interval between the first bit of a data packet entering the router and the last bit output from the router; "Processing delay jitter" indicates the change of delay.

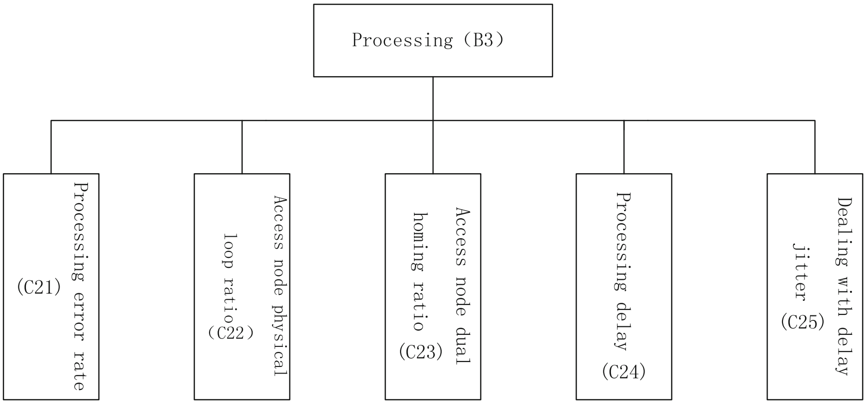

Fig. 2. Third-level indicators under the "Processing" indicator

3 Network Evaluation Based on Interval Number Eigenvector Method

3.1 Overview of the Evaluation Process

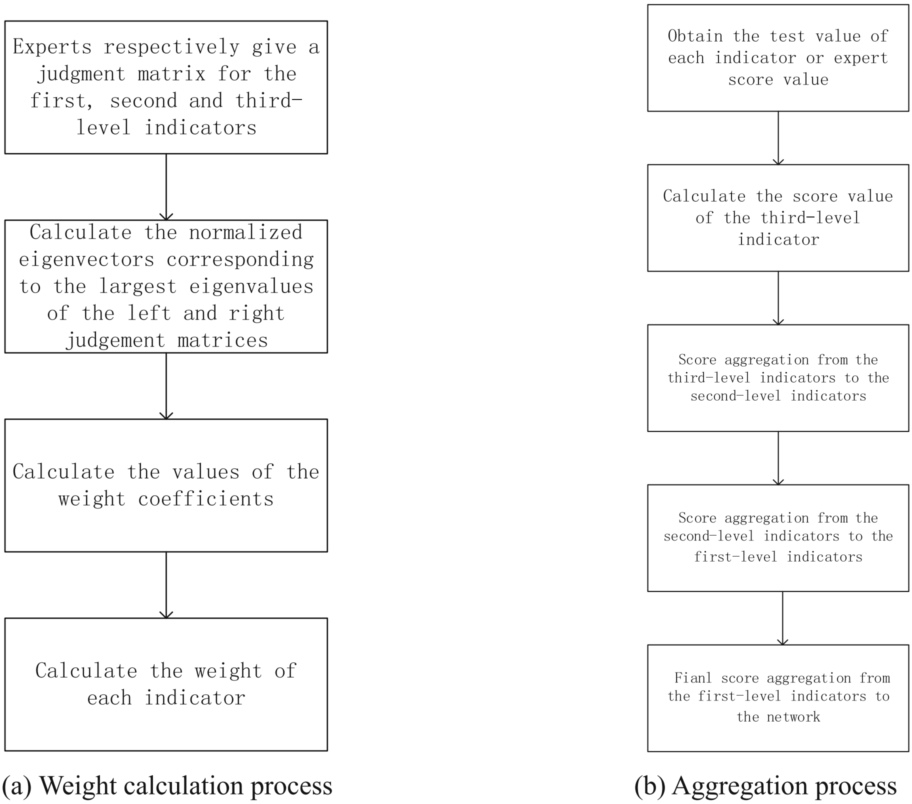

Fig. 3. Flow chart of the evaluation process

The calculation process of the weight of each indicator and the calculation of the final score of the network performance are shown in the above Fig. 3 (a) and (b) respectively.

The weight calculation in Fig. 3(a) is mainly divided into 4 steps. First, the experts give an interval number judgment matrix for the third-level, the second-level indicators and the first-level indicators based on their professional experience. Second, the left and right judgment matrices are processed separately by calculating the normalized eigenvector corresponding to the largest eigenvalue. Then, the value of the weight coefficient is calculated. Finally, the weight of each indicator of the third-level, second-level and first-level is calculated by the data obtained by the above calculations.

Figure 3(b) depicts the score aggregation from lower-level indicators to the upper-level indicators.

3.2 Interval Number Calculation Rules

Due to the introduction of the concept of fuzzy mathematics in the process of the proposed network evaluation method, the weight and the score of an indicator are not given as specific numbers, but in the form of interval numbers. We firstly define an interval number $\hat{x}_i = (x_i^l, x_i^r)$, where the superscript l and r respectively represent the lower and upper bound of interval number. The calculation rules used in this paper are as follows [10]:

Definition 1: Addition rule of two interval numbers:

$$\hat{x}_i + \hat{x}_j = (x_i^l, x_i^r) + (x_j^l, x_j^r) = (x_i^l + x_j^l, x_i^r + x_j^r) \tag{1}$$

Definition 2: Multiplication rule of two interval numbers:

$$\begin{aligned}\hat{x}_{i,j} &= \left(x_i^l, x_i^r\right)\left(x_j^l, x_j^r\right) = \\ &\left(\min\left\{x_i^l x_j^l, x_i^l x_j^r, x_i^r x_j^l, x_i^r x_j^r\right\}, \max\left\{x_i^l x_j^l, x_i^l x_j^r, x_i^r x_j^l, x_i^r x_j^r\right\}\right)\end{aligned} \tag{2}$$

Definition 3: Power operation rule of two interval numbers:

$$\begin{aligned}\hat{x}_i^{\hat{x}_j} &= \left(x_i^l, x_i^r\right)^{\left(x_j^l, x_j^r\right)} \\ &= \left(\min\left\{\left(x_i^l\right)^{x_j^l}, \left(x_i^l\right)^{x_j^r}, \left(x_i^r\right)^{x_j^l}, \left(x_i^r\right)^{x_j^r}\right\}, \max\left\{\left(x_i^l\right)^{x_j^l}, \left(x_i^l\right)^{x_j^r}, \left(x_i^r\right)^{x_j^l}, \left(x_i^r\right)^{x_j^r}\right\}\right)\end{aligned} \tag{3}$$

3.3 Weight Calculation Process

In the evaluation process, whether the indicator weight is reasonable will directly affect the accuracy of the evaluation result. In this following, the process of calculating the weight using the interval number eigenvector method are specifically introduced [11].

(1) Experts give judgment matrix $\mathbf{A} = \left(\widetilde{\mathbf{a}}_{ij}\right)_{n\times n} = \left[\mathbf{A}^-, \mathbf{A}^+\right]$ based on their own experience, where $\widetilde{\mathbf{a}}_{ij} = (a_{ij}^-, a_{ij}^+)$, $\mathbf{A}^- = \left(a_{ij}^-\right)_{n\times n}$, $\mathbf{A}^+ = \left(a_{ij}^+\right)_{n\times n}$, and a_{ij} represents the importance of the i-th indicator compared with the j-th indicator.

(2) Calculate the normalized eigenvectors $\mathbf{x}_i^-$ and $\mathbf{x}_i^+$ corresponding to the largest eigenvalues of the matrices $\mathbf{A}^-$ and $\mathbf{A}^+$:

$$\mathbf{x}_i^- = \frac{1}{\sum\limits_{j=1}^{n} \mathbf{b}_j^-} \boldsymbol{b}_j^-, \tag{4}$$

$$\mathbf{x}_i^+ = \frac{1}{\sum\limits_{j=1}^{n} \mathbf{b}_j^+} \mathbf{b}_j^+, \tag{5}$$

where $\mathbf{b}_j^- = (b_1^-, b_2^-, \cdots, b_n^-)^T$ and $\mathbf{b}_j^+ = (b_1^+, b_2^+, \cdots, b_n^+)^T$ are the eigenvector corresponding to the largest eigenvalue of matrix $\mathbf{A}^-$ and $\mathbf{A}^+$,respectively.

(3) Calculate the weight coefficient values for $\mathbf{A}^- = \left(a_{ij}^-\right)_{n \times n}$, $\mathbf{A}^+ = \left(a_{ij}^+\right)_{n \times n}$, which is given by

$$k = \sqrt{\sum_{j=1}^{n} \frac{1}{\sum_{i=1}^{n} a_{ij}^+}}, \tag{6}$$

$$m = \sqrt{\sum_{j=1}^{n} \frac{1}{\sum_{i=1}^{n} a_{ij}^-}}, \tag{7}$$

(4) Calculate the weight of each indicator, i.e., $\widetilde{\delta}_i = \left(\delta_i^-, \delta_i^+\right) = \left(k\mathbf{x}_i^-, m\mathbf{x}_i^+\right)$, where δ_i^- and δ_i^+ respectively represent the lower and upper bound set of weights.

3.4 Calculation of the Score for Each Indicator

In this section, we will introduce the method to obtain the score of each third-level indicator. The indicator is classified into qualitative indicator and quantitative indicator.

(1) The score of a qualitative indicator is based on the expert's rating on the actual performance of the network which is mapped into an interval number. Among them, 'excellent' rating corresponds to the interval (0.85, 1), 'good' rating corresponds to the interval (0.75, 0.85), 'qualified' rating corresponds to the interval (0.6, 0.75), and 'unqualified' rating corresponds to the interval (0, 0.6).

(2) The score of a quantitative indicator is based on the test results of the network performance, and the calculation method is as follows. Consider a quantitative indicator evaluation standard, i.e., 'excellent' mapping to the interval (c, d), 'good' (b, c), 'qualified' (a, b), 'unqualified' (0, a). Let the test result of an indicator be an interval number (x^-, x^+), then the corresponding score $\left(y\left(x^-\right), y\left(x^+\right)\right)$ is obtained by the formula given by

$$y(x) = \begin{cases} \frac{0.6}{a} \cdot x, 0 \le x < a \\ \frac{0.15}{b-a} \cdot (x-a) + 0.6, a \le x < b \\ \frac{0.1}{c-b} \cdot (x-b) + 0.75, b \le x < c \\ \frac{0.15}{d-c} \cdot (x-c) + 0.85, c \le x \le d \end{cases}, \tag{8}$$

wherein the score interval for 'excellent', 'good', 'qualified', 'unqualified' are consistent with that of qualitative indicators as given in (1).

3.5 The Aggregation Process

In this section, we will introduce how to aggregate the scores of the lower-level indicators to obtain the scores of the upper-level indicators according the corresponding weights, while qualitative indicators and quantitative indicators adopt different aggregation methods.

The third-level indicators under the quantitative indicators are aggregated by the weighted product method to obtain the scores of the corresponding second-level indicators. On the other hand, the third-level indicators under the qualitative indicators are aggregated by the weighted sum method to obtain the scores of the corresponding second-level indicators.

The weighted product aggregation method [12] is given by

$$\hat{x}_i = \prod_{j=1}^{m} \left(\hat{x}_{ij}\right)^{\hat{\delta}_{ij}}, \tag{9}$$

where $\hat{x}_i$ is the score of the i-th indicator, $\hat{x}_{ij}$ represents the score of the j-th indicator under the i-th indicator, and $\hat{\delta}_{ij}$ is the weight of the j-th indicator under the i-th indicator. Note that $\hat{\delta}_{ij}$ needs to meet the normalization condition $\sum_{j=1}^{m} \hat{\delta}_{ij} = [1, 1]$.

The weighted sum aggregation method [12] is given by

$$\hat{x}_i = \sum_{j=1}^{m} \hat{x}_{ij}\hat{\delta}_{ij}. \tag{10}$$

4 Numerical Results

In the simulation, we consider a communication network consisting of multiple cellular networks and a core network. Then we conduct simulation tests on this network, and calculate the weight and score for each indicator. The specific calculation process of weight follows Sect. 3.3, and the specific calculation process of score can be found in Sect. 3.4.

According to the test results, we select some indicators to illustrate their influence on the overall score of the network.

Figure 4 plots final score of the network versus the score of “Task completion benefit” (C55). Indicator C55 represents the weighted sum of the percentage of completed tasks of different levels to the total number of task goals. Since C55 is a third-level indicator under “Action control” (B8) which is a qualitative indicator, it is aggregated upward with other indicators in the same level by the weighted sum method. Note that the weight of C55 is relatively small. As shown in the figure, when its score is 0, the score of the network is high, which means that it has little effect on the score of the entire network. Considering the final score of the network under different scores of C5, it can be observed from Fig. 4 that when the score of C5 is high, the score of the network is high.

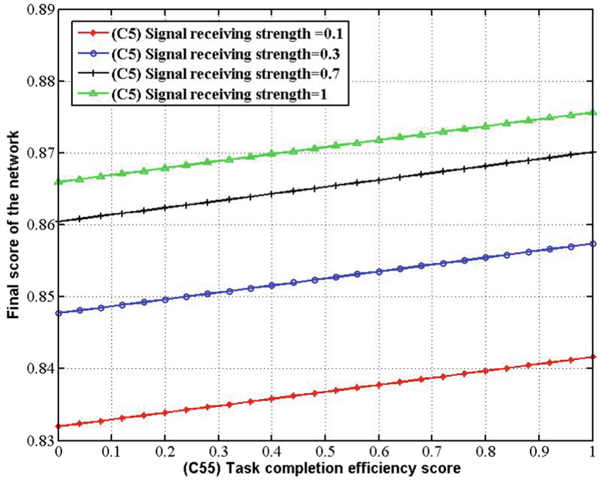

Fig. 4. Overall network score versus the score of "Task completion efficiency" (C55)

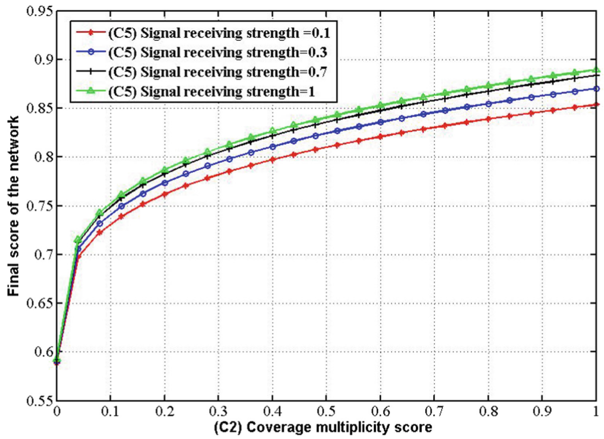

Fig. 5. Overall network score versus the score of "Coverage multiplicity" (C2)

Figure 5 plots final score of the network versus the score of "Coverage multiplicity" (C2). Indicator C2 means the degree of redundancy of coverage in a certain area. If this area is within the coverage of K nodes, then its coverage multiplicity is K. Since C2 is a third-level indicator under "Coverage" (B1) which is a quantitative indicator, it is aggregated upward with other indicators in the same level by the weighted product method. Note that the weight of C2 is relatively large. As shown in the figure, when its score is 0, the score of the network is low, which means that it has a greater impact on the score of the entire network. Considering the final score of the network under different scores of C5, it can be observed from Fig. 4 that when the score of C5 is high, the score of the network is high.

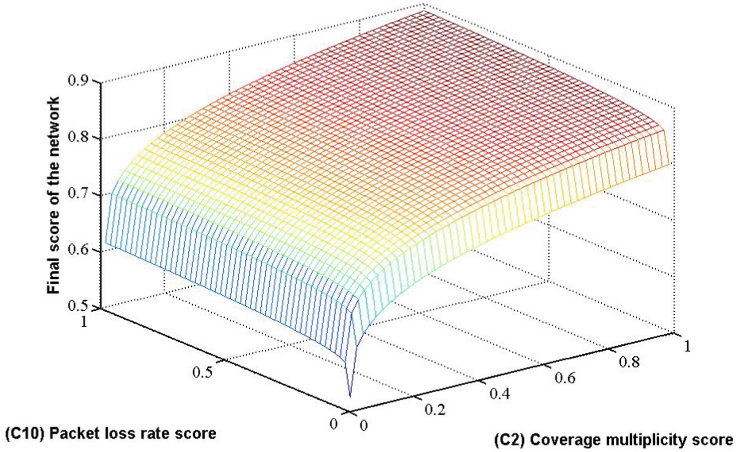

Fig. 6. Overall network score versus the score of "Coverage multiplicity" (C2) and "Packet loss rate" (C10)

"Packet loss rate" (C10) indicator represents the percentage of packets that cannot be forwarded by the network device due to lack of resources in the router under a stable load state, i.e., the ratio of the lost data packets to the total number of transmitted data packets. It can be seen from Fig. 6 that "Coverage multiplicity" has a greater impact on the score of the network than the "Packet loss rate". When the score of the two indicators both change from 0 to 1, the final score of the network changes greatly with "Coverage multiplicity", because the weight of "Coverage multiplicity" is larger than that of "Packet loss rate", which means the corresponding impact to the network rating is more notable.

5 Conclusion

In this paper, we have proposed a "difficult & beautiful" network evaluation framework based on the interval number eigenvector method. In this framework, the judgement matrix is given from the recommendation of experts, and the weight of each indicator can be obtained through the processing and calculation of the judgement matrix. The scores of third-level indicators are obtained through the results of network test or advice of experts, and the scores of second-level indicators and first-level indicators are obtained by aggregation of the weights and scores of the lower-level indicators. For qualitative indicators and quantitative indicators, the weighted sum and weighted product methods are used for aggregation, respectively. The final score of the network is obtained through the level-by-level aggregation. Experimental results show that the proposed framework can evaluate multi-indicator networks appropriately and objectively.

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