Research and Application of a Fast Recovery Strategy for Complex Structure Networks Based on Sorting Multi-objective

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Abstract—With the development of information technology, the scale of data centers and the number of equipment are experiencing explosive growth, and the network structure of data centers has also continued to develop and mature. The more complex network structure increases the possibility of network failures and the difficulty of operation and maintenance. When an unpredictable failure occurs in the network, in order to quickly recover the network, a multi-objective complex structure network rapid recovery strategy is proposed. Under the goal of the shortest failure time, minimum reduction of safety protection, and maximum possible restoration of the original method, a restoration plan is given.

1. Introduction
With the development of technologies such as cloud computing and big data, the scale and number of data centers are experiencing explosive growth, and the network structure of data centers has also continued to develop and mature[1]. With the emergence of the three-layer switching technology, the network bottleneck problem caused by the low speed and complexity of the traditional routers in the local area network has been solved, and it has gradually become the main structure for constructing the data center network. The network security situation has become more severe, and the security equipment in the network architecture has become more and more complex[2]. While improving security, it also increases the risk of network abnormalities.

Long-term practice shows that the network failure rate will increase rapidly as the number of system nodes increases. At present, network failures in data centers can be roughly divided into four categories: software failures, hardware failures, network configuration failures, and failures of unknown cause. The respective ratios are 21%, 18%, 38%, and 23%, respectively. It can be seen that network configuration faults account for the largest proportion, followed by unexplained faults. With the expansion of the network scale, the interconnection between nodes has become more and more complex, making network operation and maintenance more difficult.
Compared with the single-objective optimization problem that only considers one goal, the multi-objective optimization problem optimizes multiple goals at the same time, which is closer to the actual problem, so it has practical application significance. Multi-objective optimization problems generally do not have a single complete solution. It is a solution set composed of a series of non-inferior solutions, usually called the Pareto optimality. In most cases, the various sub-goals are in conflict with each other, and it is impossible for multiple sub-goals to reach the optimal value at the same time. Therefore, it can only be coordinated and compromised to make each sub-objective as optimal as possible. Since Pareto proposed the Pareto optimal principle in 1896, the research and application of multi-objective optimization has gradually matured. In 1997, Zhao summarized several simple multi-objective decision-making problems and their solutions[3]. In 2011, Jiang proposed a switch-oriented and intelligent service restoration strategy of shipboard power network using the nature multiobjective evolutionary algorithm that effectively solve the fault recovery of the ship's power grid[4]. In 2014, Zhou proposed a multi-objective evolutionary algorithm based on decomposition and mixture Gaussian models while that can promote the evolution of the population faster[5]. In 2015, Xiao proposed a new kind of many-objective evolutionary algorithm that consistently provides good convergence as the number of objectives increases, outperforming five state-of-the-art MOEAs[6].

When a network failure or network abnormality occurs, the network administrator needs to deal with it as soon as possible to recover from the failure. Assuming that there is not enough monitoring means, or there is not enough warning information, then the administrator may not be able to start. At this time, it is necessary to develop a strategy to quickly restore the network.

This paper proposes a fast recovery strategy for complex structured networks based on sorting multi-objective algorithms[3], which recovers the network under the shortest processing time, minimum reduction of security protection, and the greatest possible restoration of the original method.
2. Algorithm
The problem of multi-objective strategy is often encountered in reality\cite{7-22}. The various goals of this type of problem generally affect each other, and sometimes some goals contradict each other.

For a multi-objective strategy problem with r goals, it can be written as follows:

\[
(P) \quad \min \left[ f_1(X), f_2(X), \cdots, f_r(X) \right]^	op
\]

Its constraints are:

\[
g_i(X) \geq 0 \quad i = 1, 2, \cdots, N
\]

where \(X = (x_1, x_2, \cdots, x_N)^T\), \(f_1(x), f_2(x), \cdots, f_r(x)\) is an indicator to measure the pros and cons of the plan.

The ranking method is to sort the \(r\) goals of the problem \((P)\) in order of importance. Assume that the order of importance of each goal from large to small is: \(f_1(x), f_2(x), \cdots, f_r(x)\).

Solve first:

\[
(P_1) \quad \min f_1(X) \quad g_i(X) \geq 0 \quad i = 1, \cdots, N
\]

Set the optimal value to \(f_1^*\) and solve the problem:

\[
(P_2) \quad \min f_2(X) \quad g_i(X) \geq 0 \quad i = 1, \cdots, N
\]

\[
f_1(X) \leq f_1^*
\]

By analogy, the solution to the \(r\)-th problem is:

\[
(P_r) \quad \min f_r(X) \quad g_i(X) \geq 0 \quad i = 1, \cdots, N
\]

\[
f_1(X) \leq f_1^* \quad f_j(X) \leq f_j^* \quad j = 1, \cdots, r - 1
\]

The optimal solution of the problem \((P_r)\) will be the effective solution of the original problem \((P)\).

The solution idea is to first find the solution set of the first goal, find the solution set of the second goal in this solution set, find the solution set of the third goal in the solution set of the second goal, and finally find the solution set of the \(R\)-th goal Solution set.

When the optimal solution of one of the problems is unique, it’s impossible to continue to solve future problems. At this point, in order to be able to continue to solve the latter problem, the constraints of the latter problem can be appropriately relaxed. For example, the optimal solution of \((P_1)\) is unique, the target value of \(f_1(X)\) can be relaxed from \(f_1^*\) to a still satisfactory level: \(f_1^* + \varepsilon_1\) (\(\varepsilon_1 > 0\)). The original problem becomes:

\[
(P_k) \quad \min f_k(X) \quad (k = 2, \cdots, r)
\]

\[
g_i(X) \geq 0 \quad i = 1, \cdots, N
\]

\[
f_1(X) \leq f_1^* + \varepsilon
\]

\[
f_2(X) \leq f_2^*
\]

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Solving the above problem will get an effective solution to the original problem.

3. Application

The goal of the fast network recovery problem is

1) the shortest processing time;
2) the minimum reduction of security protection;
3) the greatest possible restoration of the original method.

Therefore, the objective function can be expressed as:

\[
\begin{align*}
(P) \quad & \min \left[ f_1(X), f_2(X), f_3(X) \right] \\
& f_1(X) = \sum_{i=1}^{N} L_i \\
& f_2(X) = \sum_{i=1}^{N} J_i \\
& f_3(X) = \sum_{i=1}^{N} |x_i^b - x_i^p| \\
& X = (x_1, x_2, \ldots, x_N)^T
\end{align*}
\]

where \( f_2(X) \) are fault handling time; \( L_i \) are Emergency response time of \( i \) device; \( f_1(X) \) is the size of the area without security protection; \( J_i \) is number of devices affected by \( i \) device; \( f_3(X) \) is comparison with the original state; \( x_i^b \) is the original state of \( i \) device; \( x_i^p \) is the current state of \( i \) device when the abnormality recovers; \( X \) is the state vector of the emergency operation of each equipment. \( x_i \) is the \( i \)-th component of \( X \), while \( x_i = 1 \) means that the first device has carried out emergency operation; \( x_i = 0 \) means to carry out emergency operations, where \( i = 1, 2, \ldots, N \).

When the objective function components \( f_1(X), f_2(X), \) and \( f_3(X) \) all reach the minimum, it is optimal.

4. Conclusion

This paper proposes a fast recovery strategy for complex structure network based on sorting multi-objective algorithm. When a network failure or network abnormality occurs without sufficient monitoring means and insufficient alarm information, the network can be restored with the shortest processing time, with the minimum reduction of the safety protection and with the maximum protection of the failure site.

This paper provides a solution to network failure recovery, which is to transform the network failure problem into a multi-objective optimization problem to achieve fast and effective failure recovery. Although the idea of sorting multi-objective algorithm is simple, its application effect is still insufficient. In the future, we will thoroughly investigate the existing multi-objective optimization algorithms and design an algorithm to more effectively solve the network failure recovery problem.

References

[1] Wang Binfeng, Su Jinshu, Chen Lin. (2016) Review of the Design of Data Center Network for Cloud Computing. Journal of Computer Research and Development. Beijing 53(9):2085-2106.
[2] Wang Zhe, Li Jianghua, Kang Dong, Ran Haodan. (2020) Review on Strategies Enhancing the Robustness of Complex Network. Complex Systems and Complexity Science. Qingdao, 17(3):1-46.

[3] Zhao Sheng. (1997) Multi-objective Decision-making Problems and Solutions. Journal of Zhengzhou University of Technology. Zhengzhou, 2:41-44.

[4] Jiang Yanjun, Jiang Jiaqiuo, Qiao Shutong. (2011) Intelligent Service Restoration of Shipboard Power Network Using Natre Multiobjective Evolutionary Algorithm. Proceedings of the CSEE. Beijing, 31(31):118-124.

[5] Zhou Aimin, Zhang Qingfu, Zhang Guixu. (2014) Multiobjective Evolutionary Algorithm Based on Mixture Gaussian Models. Journal of Software. Beijing, 25(5):913-928.

[6] Zhao Sheng. (1997) Multi-objective Decision-making Problems and Solutions. Journal of Zhengzhou University of Technology. Zhengzhou, 2:41-44.

[7] Jiang Yanjun, Kang Dong, Ran Haodan. (2011) Intelligent Service Restoration of Shipboard Power Network Using Natre Multiobjective Evolutionary Algorithm. Proceedings of the CSEE. Beijing, 31(31):118-124.

[8] Zhou Aimin, Zhang Qingfu, Zhang Guixu. (2014) Multiobjective Evolutionary Algorithm Based on Mixture Gaussian Models. Journal of Software. Beijing, 25(5):913-928.

[9] Zhao Sheng. (1997) Multi-objective Decision-making Problems and Solutions. Journal of Zhengzhou University of Technology. Zhengzhou, 2:41-44.
[22] Liu Ruochen, Li Jianxia, Liu Jing, Jiao Licheng. (2020) A Survey on Dynamic Multi-Objective Optimization. Chinese Journal of Computers. Beijing, 43(7):1246-1278.