Survivability optimization for the networked C^4ISR system structure

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Abstract. An optimization method for the survivability of networked C4ISR system structure is proposed. The strategies of selecting the key nodes to backup, determining the number of the backups, and optimizing the backups processing are given in the proposed method. Based on the computation method for the importance of the information flow betweenness, the survivability optimization problem with the constraints on backup processing and transmission cost is given. The validity of the proposed method is verified by an example of survivability optimization for a networked regional joint air defense system structure.

Introduction

The future war is the battle among System of Systems (SoS). The battle focuses on sticking the vital point of enemy with deadly accuracy, destroying the SoS of enemy and weakening the enemy ability to strike our SoS. To weaken enemy ability of striking, it needs to improve own protection ability by survivability optimization.

A networked C4ISR system[1] is a typical SoS composed by kinds of resources such as information-based detection equipment, weapons equipment, command and control (C2) system, and so on. Currently, the redundant backups for the key nodes in networked C4ISR system, such as the local cluster and long distance double backup, are the main methods employed to improve the survivability. However, to obtain the strategies of selecting the key nodes to backup, determining the number of the backups, and optimizing the backups processing, there are only some easy methods based on the artificial experiences and proximity principle for backups but no optimization method can be used at present.

In order to guide the optimization of survivability for the networked C4ISR system scientifically, this paper proposes a survivability optimization method based on the layer of system structure. The method employs the structure model of the networked C4ISR system in [2] and the survivability analysis method in [3]. Based on the structure model and the survivability analysis method above, this paper proposes the analysis method for the key nodes of system structure and analysis method for the optimal key node backup strategy. Finally, as an example, the optimization for survivability of a certain regional joint air force defense system structure is analyzed. The validity of the proposed method in this paper is verified though the example.

Related Research

The existing researches on the survivability of system structures mainly focus the analyses of survivability[4] and failure reasons[5]. However there is little research on the survivability optimization. In [6], the authors firstly present the structure characters (such as Bimodel degree distribution character) corresponding to the optimal survivability based on experiment analysis. Then the optimization problem of survivability is reduced to the problem of generating the structure with optimal topology character. The survivability optimization method in [6] is only suitable for the simple structure with homogeneity nodes and homogeneity edges. In [7], the survivability of the structure is optimized and the globe optimal survivability is obtained through an iterative algorithm including the operation of edge exchange. However, some constraints on the aspects, such as the space distribution and function, for each element in the C4ISR system are not considered in [7]. In [8], a local optimization algorithm for survivability is studied. The local structure that includes at least R paths and at most k paths is extracted firstly. Then the 0-1 integer programming algorithm is employed to obtain the optimal survivability of the local structure with the lowest construction cost. The method in [8] focuses on the survivability optimization of the system structure with single function but not the C4ISR system structure with multiple functions such as intelligence support, command and control, weapon collaboration, and so on. The methods in [9] and [10] improve the structure survivability indirectly by using the strategy of optimizing the survivability of each node. The optimization problem for survivability of the whole structure is not considered in the methods in [9] and [10].

The foundation of method

The system structure model of networked C^4ISR

The model of system structure is the basis for the analysis and optimization of system structure. This paper employs the OPDAR model in [2] to model the networked C^4ISR system structure. Based on the original attributes of the elements in system structure, some new attributes related to the survivability optimization of the system structure are added, as shown in Table 1.

Table 1 The elements of system structure and the corresponding added attributes

Elements of structure	Name	New attributes related to the survivability optimization
System Units	Intelligence collection unit	• Backup nodes list
	Intelligence processing unit	• Backup mode (mode)
	Decision control unit	• Processing ability (*pro*)
	Response operating unit	• Synchronous data volume (*syn*)
Relationships(R) between two elements	Relationships of intelligence support and share	• Information transmission volume (vol)
	Relationships of command and control	
	Relationships of state synchronization and feedback	

The evaluation method for system structure survivability

The effect of survivability optimization for system structure needs to be quantified analyzed by using an evaluation method for system structure survivability. The survivability evaluation method in [3] is used in this paper. In the evaluation method, the survivability of the system structure can be defined by the maximum tolerance ratio of the damaged system units to the attacked system units. In addition, the attack model of system structure in condition of incomplete information and the Monte Carlo method are used to improve the accuracy and robustness of the analysis results.

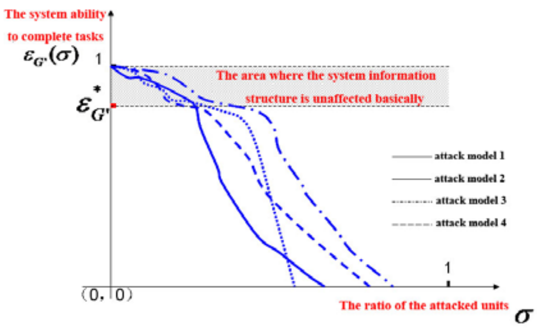

Figure1 The sketch for the system structure survivability with different attack models

As shown in Figure 1, for each attack model, the ability of system to complete the task is reduced with the increasing ratio of the attacked system units. The grey part in Figure 1 shows the area where the system information structure is unaffected basically. The area is related with the assumed tolerance degree ($\varepsilon^{*}_{G'}$) of the system ability to complete the task. The x-coordinate in figure 1 represents the ratio (σ) of the attacked system units and y-coordinate represents the system ability to complete tasks.

The survivability optimization process model for system structure

The survivability optimization process model for system structure is shown in Figure 2.

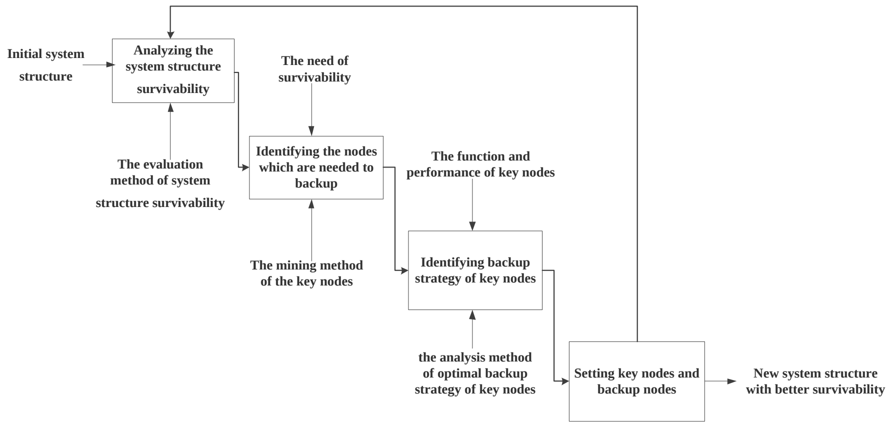

Figure 2 The model of survivability optimization process for system structure

The survivability optimization process of system structure includes the following four key steps:

Step 1: Analyze the initial survivability of the system structure by using the survivability evaluation method;

Step 2: According to the requirements of survivability (for example, the survivability of intelligence support is greater than or equal to 4 such that the intelligence support ability is still acceptable when 4 key nodes are damaged), determine the key nodes which need to be backed up by using the mining method;

Step 3: According to different key node types and different performance requirements, determine the backup strategy of the key nodes by using the optimal method.

Step 4: According to the backup strategy, set the key nodes and backup nodes to form the system structure with optimized survivability.

Step 5: Go back to step 1 until the performance requirement of the structure survivability is achieved.

Based on the above optimization process, the main contribution of this paper is that the mining method for key nodes in step 2 and optimal key nodes backup strategy in steps 3 are proposed in this paper.

The analysis for applications

In the background of a networked regional joint air defense[11], the basic scenario is set as follows. the security state of our airspace is continuously monitored by radar system monitors in real time. Once there are enemy aircrafts intrude into our airspace, the detection, tracking, and identification for targets will be operated by the related radar systems and electronic countermeasures systems. Meanwhile, the interception for enemy aircrafts will be operated by our arms including air force and ground-to-air missile force jointly.

Assume the initial system structure of joint air defense includes 1 air force level command post, 2 air force regional command posts, 4 campaign direction command posts, 1 intelligence processing center, 11 radar signal processing units, and many radar stations and combat platforms. This system structure includes more than 200 units and 700 unit relationships, as shown in Figure 3.

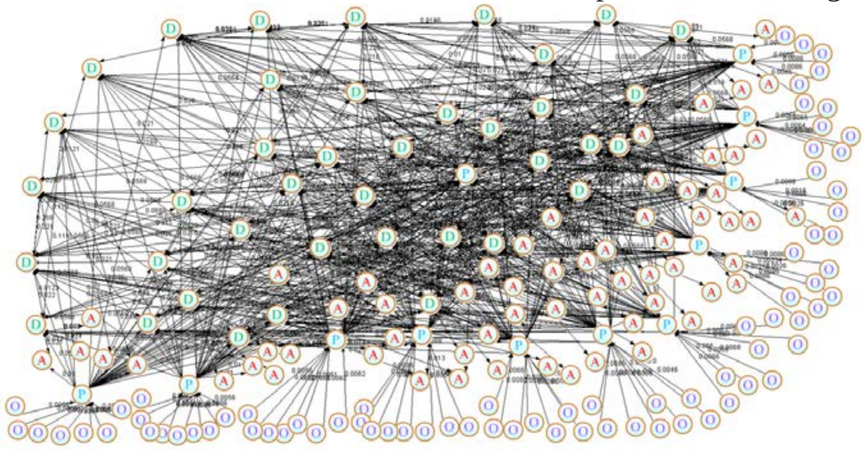

Figure 3 The command information system structure of networked joint air defense

According to the survivability optimization process of system structure above, we optimize this system structure by the following steps:

(1) Analyze the system structure survivability

(2) Determine the key nodes to backup

(3) Determine the key node backup strategy

(4) Set the backup nodes of key nodes and compare the survivability before and after backup

According to the analysis results of the optimal backup number and backup relationship, we set the campaign direction command post 2, air force regional command post 1 and the campaign direction command post 3 to the backup nodes of the campaign direction command post 1. The backup mode of input synchronous is used. Then the survivability of weapon coordination after backup is 3.92, as shown in figure 4. It can be seen that the survivability is improved obviously, indicating the validity of the survivability optimization method proposed in this paper.

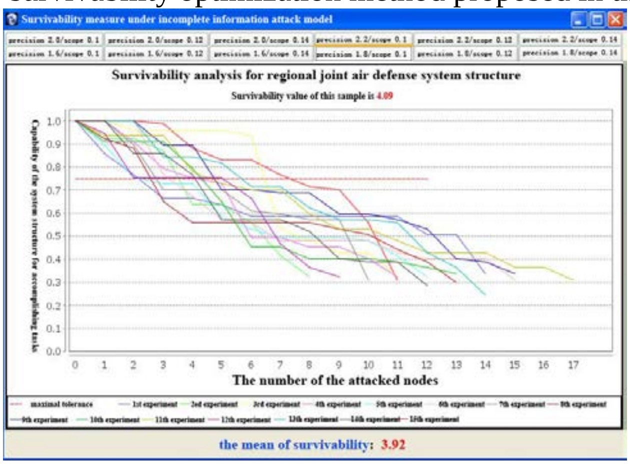

Figure 4 The survivability of weapon coordination after backup

Conclusion

In this paper, the mining method of the key nodes is proposed for the survivability optimization of the system structure. With the constraints on backup process and transmission cost, the optimal backup strategy analysis method for the key nodes is proposed to maximize the survivability. The survivability of the regional joint air defense system structure is optimized as an example. The results verify that the method proposed in this paper can provide the theory support for improving the survivability of the system structure through the scientific and reasonable backups for key nodes.

References

[1] Lan Yushi. Understanding the Network-Centered Command Information System[J]. Command Information System and Technology, 2010, 1(1): 1-4. (in Chinese).

[2] Lan Yu-shi，Yi Kan，Wang Heng，etc., Delay assessment method for networked C~4ISR system architecture [J], System Engineering Electronics, 2013, 35(9):1908-1914

[3] Yi Kan，Wang Heng，etc.. Information Flow based Survivability Assessment Method for Networked C4ISR System Structure [J]. System Engineering Electronics，2014，36（8）：1544-1550.

[4] Jeong H. Albert R., Barabasi A. L.，Error and Attack Tolerance of Complex Networks，Nature，2000，406(6): 378-382.

[5] Zhang Jin-fen,Yi Kan，Wang Heng，Mining Method of Key Nodes in C~4ISR Network System Structure Based on Information Flow [J]. Fire Control & Command Control，2014，39（8）：61-69.

[6] Suto K.,Nishiyama H.,etc., A Method to Construct an Attack and Fault Tolerant Scalable Distributed Network[C]// 4th International Conference on Communications, Mobility, and Computing (CMC 2012), Guilin,China,2012:128-139.

[7] Yazdani N.,Herrmann H.,etc., GA Optimization of Networks Against Malicious Attacks[C]// Evolution Artificielle(EA 2011),Abgers,France:306-317.

[8] Alexander F. Veremyev,Modeling and Optimization Approaches for Ensuring Robustness in Networked and Financial Systems[D], Florida:University of Florida,2012.

[9] SHEN Di,LI Jian-hua,etc., Simulation and Researching of Disaster Backup Strategy of Military Information System[J],Computer Simulation,2013,30(1):23-27.

[10] HU Bin; LI Fang，Repair strategies of scale-free networks under multifold attack strategies[J]，System Engineering Electronics，2010，32（1）:86-89.

[11] Miao D C, Cao Y, Lu J W, et al. Analysis on detecting ability of the early-warning system for joint air-defense[J]. Systems Engineering and Electronics, 2006, 28(2): 253-256.