Timeliness Optimization Model For Network C^4ISR System Structure Based on Information Flow

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Abstract: In order to adapt to a variety of combat missions and complex environmental situation， how the structure of the network C^4ISR system automatically adjusts the system structure and promote the efficiency is crucial. To solve this problem, a optimization idea was gave and a timeliness optimization model based on the information flow with the combination of C^4ISR system architecture OPDAR model and information flow model was proposed. In this paper, we proposed the whole optimization ideas that iterative optimize sub-structure bottleneck until effect of optimization convergence, and then analyse the timeliness optimization objectives and constraint condition, build the optimization mode of timeliness.

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Introduction

With the continuous development of information and network technology, C^4ISR system is facing the challenges about complex task, versatile function, uncertain environment, and many other challenges. These challenges have prompted widespread application of new technologies in C4ISR systems, breaking the existing geographical and resource constraints, and the constraints of institutional. The C^4ISR system have transformed from platform-centric system to a network-centric networked system[1].

Although there is no unified definition of the network C^4ISR systems, we think networked C^4ISR system is a complex system based on a grid network. The constituted elements distributed over a network system can be dynamically organized, formatting the system capacity to accommodate the dynamic changes of task and environment[2]. This build way of networked C4ISR system determines its structure, which is composed of a large number of different kind units distributed in different geographical and the complex relationship between the units. The build way also create the conditions for adjusting the system structure and optimizing the allocation of resources. The structure of networked C^4ISR system includes network communications layer, business logic layer and the information logic layer. In this paper, the structure of information logic layer is only study in timeliness optimization.

Because the number of the units constituted of networked C^4ISR system structure is large and the units distributed on grid network in different regions, the pros and cons of the system architecture would have a direct impact on timeliness of the system. Aim at the complexity of combat missions and the uncertainty of the external environment, how to re-organize the constituted elements of system effectively, and how to adjust system structure is critical to improve the system structure timeliness.

Situation Analysis

Currently, the study on timeliness optimization of C^4ISR system architecture mostly followed the method called FINC, which is proposed by Australian researchers Anthony Dekker and used for evaluating C4ISR system architecture[3]. Jincai H. and other researchers constructed a model based on FINC and eFINC model containing semantic content, combining with the timeliness evaluation index in FINC.Then they proposed design method of the adaptive system structural based on eFINC model and indicators, and proposed the principle about system optimization completeness and cohesiveness, which play a role in the system structure optimization [4]. Guoli Y. and others extends the FINC model from the combat system level, and propose the evaluation index and method about timeliness of the combat system [5], as well as the restructuring method and evolution method of the system.

These existing methods proposed system architecture timeliness targets and corresponding optimization principles and methods from different angles, which reflects the timeliness of the system architecture, and also provide a reference for the timeliness optimization in a certain extent. However, there are some points worth improving in those methods: on the one hand there method didn’t assess system architecture timeliness synthetically from the intelligence, command and control and collaborative three aspects, as a result, they don’t fully reflect the essential characteristics of the information relationship in C^4ISR systems. On the other hand, the optimization principles or methods mentioned do not have full operability so that there is no way to verify its validity.

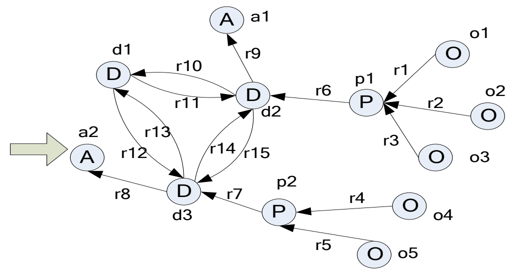
In response to these research status, this paper established the information flow model according to the different types of information relationship in the C^4ISR systems, and proposed the timeliness indicators of system architecture based on information flow, and then establish the optimization model containing of system architecture timeliness, performance risk and others. This paper also propose an iterative optimization idea based on feedback of optimization results.

Information flow model of system structure

System structure model

Because the information flow model is built on the system structure model, we first use OPDAR model[6] abstract system architecture model according to the function components and the general operation process of the networked C^4ISR system.

System structure can be formally defined as: system structure G = (N, R), where N represents the set of the system unit, R represents the set of information relationship, and N = OUPUDUA, wherein, O represents information acquisition unit, P represents information processing unit, D represents decision and control unit, A represents action unit, R represents the information relationship between the system unit. The network model of system structure is constructed by OPDAR as shown in Fig 1.



(a) sketch map of system structure (b) net model of system structure

Figure 1 A OPDAR model of system structure

Information flow model

The timeliness analysis of system structure is based on the concept of "information flow", the information flow is the flow process of information in channels, specifically containing the intelligence information, command information, feedback information flow processes in the system. In the system structure, an information flow is a path about information processing or a link formed by information relationship from end to end. According to OPDAR model of system structure and combined with the general mode operation of networked C^4ISR systems, the information flow can be divided into three categories containing intelligence information flow, information flow and coordination of information flow.

These three types of information flow is established primarily for the needs of intelligence support capabilities, command and control capabilities and interoperability of network C^4SIR system. It can reflect the information intelligence capabilities of the system by analyzing intelligence information flow. Similarly, it can reflect the decision-making command and control capabilities of the system with analysis about command and control information flow. And it can reflect sensors, weapons platform synchronization capabilities by analyzing the coordination of information flow.

timeliness optimization model of system structure

optimization ideal

Due to the large number of unit and the unit complexity of relationship's connections in networked C^4SIR system structures, it is neither reasonable nor feasible to optimize the entire structure directly once. Therefore, we can adopt the optimization strategy that continuously optimize the bottleneck substructure affecting the timeliness of the system structure to gradually improve the timeliness of the overall structure, which namely optimize sub-structure iteratively and analyze the convergence of the optimization effect until the predetermined threshold value designed by system designer. Here, we define the bottleneck substructure that is the substructure restricting timeliness of the whole system structure, constituted of the units and the relationship from the all information flows between the two units. Synchronously, we take timeliness indicators subtracting value of the whole structure after two adjacent optimization as the definition of the optimization effect. Therefore, the timeliness optimization problem of entire system structure is transformed into the iterative optimization problems about a plurality of bottleneck sub-structure.

The entire optimization ideas is:

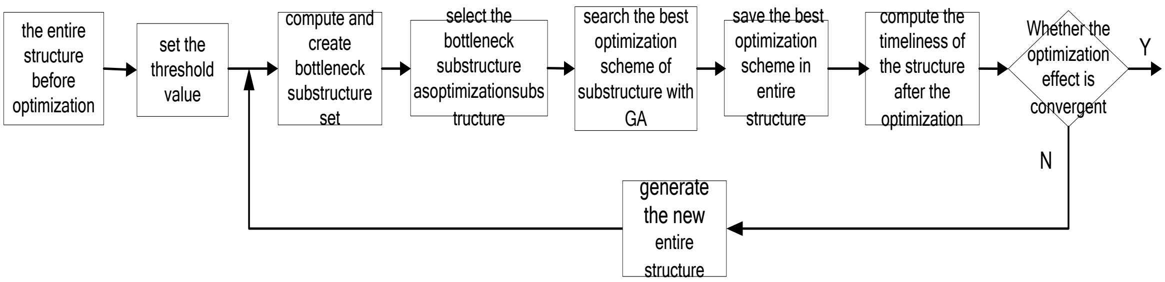


Figure 2 the overall optimization process of the structural timeliness

As shown in Figure 2, the step " compute and build a bottleneck structure set " and the step " search the best optimization scheme of substructure with GA " are the two key areas in the whole process. Where the former calculate the structural characteristics indicators of the all sub-structure in the global structure, and order in descending, and then selected some bottleneck sub-structure at the forefront of the bottleneck sub-structure set for design, the latter is a search method to obtain the best optimizing scheme in each bottleneck sub-structure optimization process. It is necessary to indicate that the latter will be implemented in future.

Optimization goal

System structure timeliness is the efficiency of the system structure, the timeliness indicators can be measured through the average delay supported by the system architecture to complete the task [7]. The networked C^4ISR system structure essentially organizes the information, command and control, state and other content information, and completes the task through the grid network support. This shows that different average delay of system information flow reflects different aspects of system structure timeliness: the average delay $Delay_{ID}(G)$ of information flow in the system structure G reflects timeliness of information guarantee about system structure, and the average delay $Delay_{AA}(G)$ of coordination information flow in system structure G reflects synergy timeliness between actor units in the systems structure, and the average delay of command and control information flow $Delay_{IDA}(G)$ in system architecture G reflects the timeliness about the higher unit command and control subordinate unit. The definition and calculation method of $Delay_{ID}(G)$、$Delay_{AA}(G)$ and $Delay_{IDA}(G)$ can be find in Ref. [6].

Therefore, in order to analyze the different information flow of system structure and fully reflect the different levels of the system structure timeliness, we give the system structure timeliness calculation method based on the on information flow, adopting a balanced strategy to build timeliness indicators:

$$Delay(G) = \beta_1 Delay_{ID}(G) + \beta_2 Delay_{AA}(G) + \beta_3 Delay_{IDA}(G) \tag{1}$$

Where $\beta_1, \beta_2, \beta_3$ indicates the relative importance of each information flow of system structure, which related to the task type undertaken by the system and conducting phase, that means, it can reflect the importance of the task at each stage through setting these three parameters. And $\beta_1 + \beta_2 + \beta_3 = 1, \beta_1, \beta_2, \beta_3 \in (0,1)$ .The smaller the average delay of system structure information flow is, the better the system structure timeliness is.

Constraints

System performance risk

System performance risk is the risk of completing the task, brought by the failure of system unit and relationship. When measure the performance risk indicators, risk event probability and consequences that are the two properties of system unit and relationship are taken as parameters. Base on the risk model of information flow, a risk assessment model of system performance is proposed.

We suppose that the information flow $f = v_0 e_1 v_1 e_2 v_2 \cdots e_n v_n$ is a simple path from the system unit v_0 to the system unit v_n (the unit of the path will not be repeated); the occurrence probability of risk event Ai in the node v_i is p_i, and the risk consequences is $c_i, 0 \le i \le n$. The occurrence probability of the event Bi in relationship e_i is q_i, and the risk consequences is d_i, $1 \le i \le n$.And then the risk model of information flow $f = v_0 e_1 v_1 e_2 v_2 \cdots e_n v_n$ is

$$Risk(f) = p_0 c_0 + \sum_{i=1}^{n} (q_i d_i + (1-q_i) p_i c_i) \prod_{j=0}^{i-1} (1-p_j) \prod_{j=1}^{i-1} (1-q_j) \tag{2}$$

With those, the risk model of system structure is established based on three types of information flow. According to this mode, the system performance risk can be measured, as follows:

$$Risk(G) = \frac{\beta^{IS}}{N_f^{IS}} \sum_{i=1}^{N_f^{IS}} Risk(f_i^{IS}) + \frac{\beta^{CC}}{N_f^{CC}} \sum_{i=1}^{N_f^{CC}} Risk(f_i^{CC}) + \frac{\beta^{CO}}{N_f^{CO}} \sum_{i=1}^{N_f^{CO}} Risk(f_i^{CO}) \tag{3}$$

Where β^{IS}、β^{CC}、β^{CO} represents the relative importance of each information flow of system structure, related to the tasks type, and $\beta^{IS} + \beta^{CC} + \beta^{CO} = 1$, $0 \le \beta^{IS}, \beta^{CC}, \beta^{CO} \le 1$, N_f^{IS}、N_f^{CC}、N_f^{CO} respectively is the number of three kind information flow.

Optimization Model

According to the overall optimization ideal described above, we establish the performance timeliness optimization mathematical model, in which timeliness is the optimization goal, and the performance risk and cost of system is the constraints:

$$\min_{G_{\Delta_i}\in\Omega} Delay(G_{\Delta_i}) = \beta_1 Delay_{ID}(G_{\Delta_i}) + \beta_2 Delay_{AA}(G_{\Delta_i}) + \beta_3 Delay_{IDA}(G_{\Delta_i})$$

$$s.t.\begin{cases} \Omega = (G_{\Delta_1}, G_{\Delta_2}, \cdots, G_{\Delta_i}, \cdots, G_{\Delta_h}) \quad h < \infty \\ \Delta = (\Delta_1, \Delta_2, \cdots, \Delta_i, \cdots, \Delta_h) \\ R_{space} = \{r_1, r_2, r_3, ..., r_n\} \\ \Delta_i \in R_{space} \\ \beta_1 + \beta_2 + \beta_3 = 1, \quad 0 \le \beta_1, \beta_2, \beta_3 \le 1 \\ Risk(G_\Delta) \le r \end{cases} \tag{4}$$

Where, $Delay(G_{\Delta_i})$ is the timeliness of new sub-structure G_{Δ_i} after bottleneck sub-structure add the optimization program Δ_i, Ω is the sub-structure set after bottleneck sub-structure add the various optimization program, Δ is the optimization scheme space composed by each optimization scheme, and each optimization scheme Δ_i is a combination of random pieces relationship of R_{space}. R_{space} is the relationship set constituted of the addible relationship in the sub-structure bottleneck, denoted as $R_{space} = \{r_1, r_2, r_3, ..., r_n\}$. $\beta_1, \beta_2, \beta_3$ indicates the relative importance of the intelligence information flow, coordination information flow, command and control information flow of system structure, and r is the maximum thresholds of system performance risk.

Conclusion

Combined with architecture OPDAR model and information flow model ,and based on the analysis of networked C4ISR systems structural features and the existing timeliness optimization method, the iterative optimization ideas was proposed based on the optimization effect feedback in this paper. And the optimization model was constructed with the goal of timeliness, and the constraints of risk and cost. In future studies, we will use the GA to solve the best optimization scheme of local structure for each optimization of bottlenecks sub-structure, and demonstrate the effectiveness and feasibility of the method through simulation experiment. Besides that, it is possible to further expand the optimization idea and deepen the optimization model, and perfect the solution method. Consequently, the timeliness optimization method of system structure is more scientific and reasonable.

References:

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

[2] Mao Shaojie, Deng Kebo, Wang Heng, etc. Complexity of Net-Centric and Service-Oriented C4ISR System[J]. Command Information System and Technology, 2012, 3(4): 1-6.

[3] Anthony Dekker. Applying Social Network Analysis Concepts to Military C4ISR Architectures, CONNECTIONS, 2002, 24(3): 99-103.

[4] Jincai H. Liu Z.，Performance-oriented Adaptive Design for Complex Military Organizations，PESARO 2011，2011

[5] Yang Guoli, Huang Jincai, Zhang Weiming,etc. Aquantitative assessment method of combat system based on FINC model, computer engineering，2011，37(10): 287-290.

[6] Lan Yushi, Yi Kan, Wang Heng, etc. Timeliness analysis of C4SIR network system structure[J], Systems Engineering and Electronics, 2013, 35(9):1908-1914

[7] Weiming Z. Jincai H., etc. The modeling and efficiency analysis method of C2 System Of Systems based on FINC model, IEEE International Conference on MLC 2010,2010: 2026-2030.