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An Autonomic Optimization Model of Multi-Layered Dependability for Intelligent Internet of things

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Abstract

Accompanying with the speeding up of Internet of things (IOT) construction, the dependability problems become the important factors constraining its all-round development. Based on the multi-level and multidimensional properties of IOT dependability elements, with the overall improving of the dependability index of IOT as the ultimate goal, the dependability elements of the local fine-tuning in each layer, this paper researches the change rule of internal dependability elements in perception layer, network layer and business layer, and adopts perception layer as the example, using the method of linear programming to seek the best proportion of all kinds of dependability elements and the optimal values of the elements, trying to construct a feasible autonomic optimization model for dependability elements of IOT system. Firstly, according to the function features and dependability properties of each layer, and change rules between the dependability index and dependability elements in each layer are analyzed. Secondly, based on the dynamic changes (up or down) of dependability elements in internal environment (that is, three layers in IOT), the ratio relations of dependability elements in each layer are dynamically controlled and adjusted to implement the local optimization, improving the overall autonomic configuration and autonomic adjusting ability of IOT system. At last, example analysis results show that the optimization model proposed in this paper can realize the substantial optimization in each layer of IOT.

Keywords: *IOT, Autonomic optimization, Liner programming, Fine-tuning*

1. Introduction

The Internet of things (IOT, for short) is seen as the third wave of information industry, following computer, Internet and mobile communication network. Due to its wide prospect of industrial application, IOT is brought to the attention of the governments. In the development of the IOT, because entities in the IOT scene have a certain perception, calculation and execution ability, these widespread perception equipments will cause new threat to national basis, social and personal information security. IOT is facing a lot of information security challenges. In view of the exposed or potential dependability threats in the perception layer, network layer and business layer of IOT, facing the system global and overall dependability and according to the multidimensional and multilayer architecture, how to build an operational optimization model to dependability elements in IOT that reflects global dependability characteristics, which becomes a key problem to be solved urgently in this field.

The establishment of such a model has important theoretical guidance and practical significance to the ascension of dependability in IOT. We know that the source of any network system dependability problem can be divided into two categories, external and internal factors. External attack, link or the device failure, users misoperation, virus and other factors, could eventually lead to system function decline or crash. What is important in an IOT system is that it needs the wisdom nature, that is, based on the dynamic changes (up or down) of system dependability elements in internal environment (that is, the system stratification), the system can dynamically control and adjust the ratio relations of the dependability elements to implement the optimization in a layer. On this basis, it needs to coordinate relations among each layer, reducing the mutual interference between the layers in the greatest degree. In current, many literatures devoted to analyzing the reasons to network interruption and abnormal information in IP backbone network, Internet services, BGP routing, and the results show that the configuration error is one of the most important causes [1]. The configuration errors have huge impact to the dependability of the system.

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As a result, autonomic configuration and management of complex and dynamic networks is a challenging problem for network researchers and designers. Such online optimization of systems can be performed in two ways: (i) using a separate model of the system for experimenting new configurations, (ii) using the system itself for experimentation without a separate system model [2]. At the same time, Self-organizing network, or SON, technology, which is able to minimize human intervention in networking processes, was proposed to reduce the operational costs for service providers in future wireless systems [3].

The research on the algorithm and model of autonomic configuration and optimization has achieved rapid development. Reference [4] proposed an approach for improving the enterprise fem to cell network's performance by automated optimizing the fem to cell base station's (FBS's) pilot power as well as antenna pattern, and the recently proposed multi-element antenna which is appropriate for fem to cell is also introduced.

On the configuration and optimization of autonomous mode and framework, a Mid-level Network Services Configuration (MiNSC) framework was created to overcome the use of management translation mechanisms, to support the network's heterogeneity [5]. To guarantee the configuration management inter operability a data model definition language, named YANG [6], was created. However, the previous proposals cannot make the integrated management of heterogeneous elements while promoting their management automation. The Mid-level Network Services Configuration MiNSC framework was created to overcome the limitations of those translation mechanisms, providing a mid-level management abstraction based on the association of standard network management interfaces and standard network management information models [7]. Based on data modeling language, a configuration automatically generated model for semantic layer was designed by YANG, Elbadawi, etc, which defined as the CSM. The semantic layer can correctly, effectively and reasonably describe the network configuration [8]. Which makes that the configuration information automatically generated can be recognized and parsed by semantic layer, and then be distributed to a specific device. The main idea of feature selection is to choose a subset of input variables by eliminating features with little or no predictive information, [9] introduces two approaches in feature selection known as forward selection and backward selection.

So far as we know, there are a few convincing studies on the deployment and optimization of some certain networks, which can be fairly important in the future communication systems. But most researches focus on the configuration and optimization of local performance of a specific network application. Considering the multidimensional hierarchical system architecture of IOT system, from the global eyes, to drive global optimization by micro adjustment and establish an autonomic optimization model in accordance with layered architecture in IOT, has not been reported in literatures.

Autonomic computing improves the service performance by means of autonomic adjustment of software and hardware resources, which gives us important enlightenment. If we can apply it to construct the dependability optimization model, we maybe achieve a new train of thought to implement system autonomy and solve the problem of system safety performance. Many areas have carried out the application research of autonomic computing. Such as the FOCALE [10] project implements the autonomic network management. There ontologies are used to augment the facts represented in independent information and data models adding the adequate semantics that enables the mapping of their common vocabulary into the network elements heterogeneous management interfaces and data models. The reference [11] presents a virtualized solution by means of virtual machine live migration approach to enhance availability, resource management, power management, and fault-tolerance. At present, the method has been widely used in the research on system reliability and availability, and it has become hotspot in research and application with multidisciplinary cross characteristics. Based on autonomic computing principle, having overall dependability as the goal, from the local fine-tuning of the layers in dependability elements, this paper adopts the method of linear programming to implement the dependability optimization in the layers of IOT, building an autonomic optimization model of IOT system.

2. Modeling and analysis

2.1. Dependability Index Extraction

In each level, dependability factor is diverse. Such as information in perception layer will experience the process flow including perception, acquisition, gathering, fusion, transmission, storage, mining, decision-making and control, as a result, perception criterion affecting this layer dependability come from dependability of sensing node, resource restriction of sensing and gathering points, dependability of information collection, privacy of information transmission, to avoid the possible dependability problem, such as node camouflage, leakage of signals and interference, damage to sensing software and hardware, unauthorized use, perception data theft. As the core data transmission layer of IOT, Network criterion of network layer need consider dependability and dependability of Network, dependability of data and privacy, reliability of router protocol, to withstand transmission bandwidth occupied, rapid spread of dependability threat, message theft, message distorting, protocol damage, high energy consumption, etc. According to the difference of application domain and management mechanism, application criterion of application layer are restricted by Service industry, access control, information storage and management mode, which include service type, service object, heterogeneous network authentication, attack of virus/hacker/malware, illegal usage of 3G terminals, etc..

Extraction and abstract the critical elements of the system dependability from the multiple dependability elements and mapping them into the dependability index of system is the first step of the work. This paper selects the system dependability index and the key dependability elements as follows.

(1) Survivability describes the reliability of the system in the case of random failure of components. Survivability depends not only on the topological structure of the system, but also on the fault probability of system components, external fault and repair strategies. It is mainly affected by the topological connectivity, fault tolerance degree, network equilibrium degree, cohesion, end-to-end reliability, *K* terminal reliability, all terminal reliability, route coverage and business performance.

(2) Dependability includes physical dependability, data dependability, network dependability and application dependability, which includes the system ability to anti search, anti interception, anti directional analysis, anti cheating and anti external invasion.

(3) Completion refers to the system ability to accomplish the system service request by normal operation or degraded service at any moment of a specified task, when the task starts and the availability is certain. It is mainly reflected in the throughput, packet loss rate, delay, bandwidth utilization, response time and resource utilization.

(4) Availability is the ability of the system to maintain workable state at any time within the prescribed period and under specified conditions. The main basic parameters include information collection rate, error rate, blocking rate, transmission delay, throughput, the number of concurrent users, software fault tolerance, etc.

2.2. Optimization Model

The dependability factor of IOT has obvious multilayer and multidimensional characteristics, which make the ability to self configuration and self adjustment of IOT dependability is limited. Therefore, in this case, dependability regulation in one step is impossible. Based on the dependability index of IOT system, autonomic computing is fused into single-layer collaborative fine-tuning process of users that will directly decide the comprehensive dependability of system, to implement the single-layer configuration optimization. On this basis, multi-layer system dependability adjustment is implemented. From microscopic to global perspective, the autonomic configuration and adjustment, from single layer to multi layer, can achieve the self-renew and optimization of the whole system dependability configuration.

This paper researches the dependability insurance method from the perspective of the optimal resources configuration. By the key point or the weak link for the system composition structure, we use linear programming and multidimensional unconstrained optimization principle to consider single-layer and global dependability problem of the system; then we carry on the optimization of system configuration and achieve the final purpose to protect the system dependability through configuring the dependability factors of intra layer and inter layer. The system optimization model is shown in Figure 1.

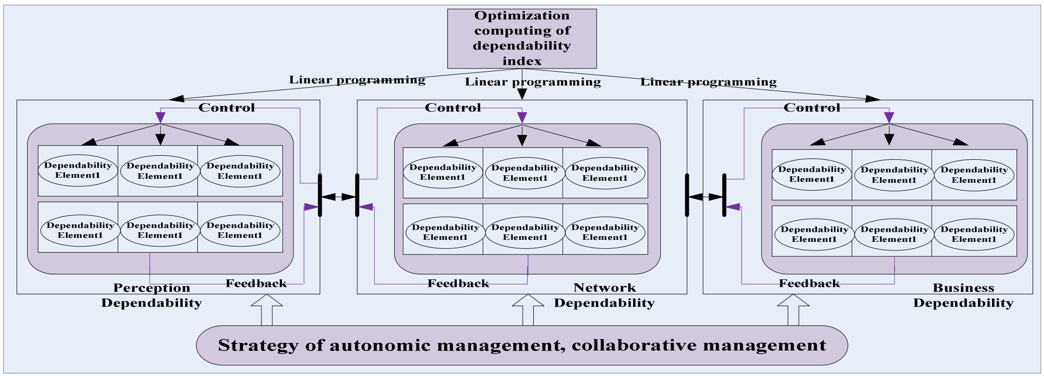


Figure 1. System Optimization Model

3. Optimal Configuration

3.1. Mapping between Dependability Index and Dependability Element

Among dependability element of perception layer(E_P),information collection rate(*Cr*), cohesiveness(*Ch*), terminal pair reliability(*Tr*) and resource utilization(*Ru*) will be the key elements affecting the survivability of perception (SV_p), safety of perception (SF_p), completion of perception(CP_p) and availability of perception(AB_p) of this layer. So, the survivability of perception SV_p is restricted by terminal pair reliability *Tr* and information collection rate *Cr*, and the calculation formula is as formula (1).

$$SV_p = \sum_i \varpi_{1i} E_{p1i} = \varpi_{11} \cdot Tr + \varpi_{12} \cdot Cr, \sum_i \varpi_{1i} = 1 \tag{1}$$

Safety of perception SF_p is restricted by terminal pair reliability *Tr*, resource utilization *Ru* and cohesiveness *Ch*, and the calculation formula is as formula (2).

$$SF_p = \sum_i \varpi_{2i} E_{p2i} = \varpi_{21} \cdot Tr + \varpi_{22} \cdot Ru + \varpi_{23} \cdot Ch, \sum_i \varpi_{2i} = 1 \tag{2}$$

Completion of perception CP_p is restricted by information collection rate *Cr* and resource utilization *Ru*, and the calculation formula is as formula (3).

$$CP_p = \sum_i \varpi_{3i} E_{p3i} = \varpi_{31} \cdot Cr + \varpi_{32} \cdot Ru, \sum_i \varpi_{3i} = 1 \tag{3}$$

Availability of perception AB_p is restricted by information collection rate *Cr* and cohesiveness *Ch*, and the calculation formula is as formula (4).

$$AB_p = \sum_i \varpi_{4i} E_{p4i} = \varpi_{41} \cdot Cr + \varpi_{42} \cdot Ch, \sum_i \varpi_{4i} = 1 \tag{4}$$

3.2. Local Optimization

Definition 1. Optimization cost (*OC*). On the premise of given the initial values to dependability factors, the local optimization in layers, values of dependability factors for dependability maximization will change, and the deviation of this change is called as the cost optimization. For example, the dependability factor set in business layer is $E_B = \{Ft, Ai, Nc, Ir\}$, if the initial values of dependability factors separately are Ft_0, Ai_0, Nc_0, Ir_0, and the optimal configuration values are $Ft_{OC}, Ai_{OC}, Nc_{OC}, Ir_{OC}$, then the optimization cost of this local optimization can be expressed as:

$$OC = \sum (|Ft_{OC} - Ft_0|, |Ai_{OC} - Ai_0|, |Nc_{OC} - Nc_0|, |Ir_{OC} - Ir_0|).$$

Definition 2. Local Optimization Objective (*LO*). Aiming at the goal to maximize the dependability in a layer, the maximum value of the difference between optimal configuration and optimization cost is the local optimization objective. To be clear, during the adjustment in a layer, 'implementing the optimal configuration with the minimum cost' is the ideal goal of this adjustment, while, because the optimal configuration and optimization cost are both constrained by the value of dependability factors, the maximum difference between the two is chosen as the optimization objective in the practical application.

Definition 3. Variable element $\alpha(0 \le \alpha \le 1)$.In addition to the value of a few key elements, the remaining variables values determining dependability index are called as variable elements $\alpha(0 \le \alpha \le 1)$.The value of the dependability index decided by the comprehensive value of key elements $\beta(0 \le \beta \le 1)$ and variable elements α is the ideal dependability value 1, that is $\alpha + \beta = 1$.

Definition 4. Quotas compensation. If when a key element is particularly outstanding, it can effectively compensate some aspects of the system dependability, then the quotas compensation of this key element can be used to make up for promoting the dependability of system. Such as $Tr + 3Ch = \beta$ or $2Cr + Ru = 1$.

Based on above definitions, the process of local optimization in perception layer can be calculated by the following formulas.

(1) Constructing the optimization objective function.

$$\begin{aligned} f(E_P) &= \sum \varpi_p (SV_p, SF_p, CP_p, AB_p) \\ &= \sum (\varpi_{SV_p} \cdot \sum_i \varpi_{1i} E_{p1i}, \varpi_{SF_p} \cdot \sum_j \varpi_{2j} E_{p2j}, \varpi_{CP_p} \cdot \sum_k \varpi_{3k} E_{p3k}, \varpi_{AB_p} \cdot \sum_l \varpi_{4l} E_{p4l}) \end{aligned} \quad (5)$$

So, the optimization objective in perception layer is:

$$\begin{aligned} \max f(E_P) &= (\varpi_{SV_p}\varpi_{11} + \varpi_{SF_p}\varpi_{21})Tr + (\varpi_{SV_p}\varpi_{12} + \varpi_{CP_p}\varpi_{31} + \varpi_{AB_p}\varpi_{41})Cr \\ &+ (\varpi_{SF_p}\varpi_{22} + \varpi_{CP_p}\varpi_{32})Ru + (\varpi_{SF_p}\varpi_{23} + \varpi_{AB_p}\varpi_{42})Ch \end{aligned} \quad (6)$$

$$S.\mathrm{T}.\begin{cases} Tr + Cr + Ru + Ch = \beta \\ \text{Quotas compensation} \\ Tr, Cr, Ru, Ch \le \beta \\ Tr, Cr, Ru, Ch \ge 0 \end{cases}$$

Additionally,

$$\sum \varpi_{1i} = 1, \sum \varpi_{2j} = 1, \sum \varpi_{3k} = 1, \sum \varpi_{4l} = 1, \sum (\varpi_{SV_p}, \varpi_{SF_p}, \varpi_{CP_p}, \varpi_{AB_p}) = 1, 0 \le \beta \le 1. \quad (7)$$

(2) Standardization

The optimization function is normalized as:

$$\begin{aligned} \min z &= -(\varpi_{SV_p}\varpi_{11} + \varpi_{SF_p}\varpi_{21})Tr - (\varpi_{SV_p}\varpi_{12} + \varpi_{CP_p}\varpi_{31} + \varpi_{AB_p}\varpi_{41})Cr \\ &- (\varpi_{SF_p}\varpi_{22} + \varpi_{CP_p}\varpi_{32})Ru - (\varpi_{SF_p}\varpi_{23} + \varpi_{AB_p}\varpi_{42})Ch \end{aligned} \quad (7)$$

$$z = -f(E_P) \quad (8)$$

4. Example Analysis in Perception Layer

Maintaining the normalized objective function unchanged, the quotas compensation in the optimal conditions can be specified as $(Tr + 3Ch = \beta) \wedge (2Cr + Ru = 1)$, then the optimization condition is:

$$S.T.\begin{cases} Tr + Cr + Ru + Ch = \beta \\ Tr + 3Ch = \beta \\ 2Cr + Ru = 1 \\ Tr, Cr, Ru, Ch \le \beta \\ Tr, Cr, Ru, Ch \ge 0 \end{cases}$$

In order to reflect the general, the weight $\varpi_{SV_p}, \varpi_{SF_p}, \varpi_{CP_p}, \varpi_{AB_p}, \varpi_{1i}, \varpi_{2j}, \varpi_{3k}, \varpi_{4l}$ and the value of key factors $\beta\,(0 \le \beta \le 1)$ in the objective function are random assigned. To be sure, the comprehensive value of key factors $\beta\,(0 \le \beta \le 1)$ is bigger than that of variable elements $\alpha\,(0 \le \alpha \le 1)$, so, in this example $\beta > 0.5$. Based on above conditions, the optimal solution of the objective function z in any conditions is calculated. And the calculation results are showed in Table 1.

Table 1. Calculation results of the example

ϖ_{SV_p}	ϖ_{SF_p}	ϖ_{CP_p}	ϖ_{AB_p}	ϖ_{11}	ϖ_{12}	ϖ_{21}	ϖ_{22}	ϖ_{23}	ϖ_{31}
0.532	0.167	0.221	0.08	0.674	0.326	0.846	0.1	0.054	0.579
0.315	0.256	0.12	0.309	0.258	0.742	0.289	0.543	0.168	0.426
0.567	0.023	0.125	0.285	0.563	0.437	0.659	0.232	0.109	0.349
0.257	0.367	0.313	0.063	0.736	0.264	0.159	0.101	0.74	0.601
0.359	0.063	0.213	0.365	0.144	0.856	0.265	0.507	0.228	0.389
0.467	0.174	0.222	0.137	0.289	0.711	0.164	0.058	0.778	0.689
0.356	0.251	0.066	0.327	0.678	0.322	0.013	0.165	0.822	0.156
0.369	0.222	0.101	0.308	0.103	0.897	0.749	0.111	0.14	0.365
0.746	0.116	0.105	0.033	0.819	0.181	0.722	0.022	0.256	0.356
0.458	0.259	0.036	0.247	0.568	0.432	0.322	0.368	0.31	0.643
0.583	0.211	0.046	0.16	0.458	0.542	0.268	0.253	0.479	0.364

ϖ_{32}	ϖ_{41}	ϖ_{42}	Tr	Cr	Ru	Ch	β	f	Quotas compensation
0.421	0.586	0.414	0.05	0.5	0	0.25	0.8	0.2097	$Tr + 3Ch = \beta$ $2Cr + Ru = 1$
0.574	0.268	0.732	0	0.6178	0	0.3089	0.612	0.3103	
0.651	0.458	0.542	0.005	0.5	0	0.25	0.755	0.2519	
0.399	0.364	0.636	0	0.5342	0	0.2671	0.71	0.2322	
0.611	0.458	0.542	0.147	0.5	0	0.25	0.897	0.3418	
0.311	0.514	0.486	0.194	0.5	0	0.25	0.944	0.3599	
0.844	0.898	0.102	0.245	0.5	0	0.25	0.995	0.3291	
0.635	0.566	0.434	0	0.5521	0	0.276	0.689	0.3448	
0.644	0.823	0.177	0.106	0.5	0	0.25	0.856	0.1823	
0.357	0.589	0.411	0.018	0.5	0	0.25	0.768	0.2349	
0.636	0.521	0.479	0.062	0.5	0	0.25	0.812	0.2725	

In Table 1, when the value of all weights and β are arbitrarily set in the range of effective value, the four key elements in perception layer can seek the optimal solution according to the needs of objective dependability. Meanwhile, because the selected quota compensation item is special, the value of dependability element Ru is always 0, which does not affect the calculation of local optimization objective on the basis of the optimal solution. Based on the results, and according to the conception of Optimization Cost in definition 1 and Local Optimization Objective in definition 2, we derive the calculation formula of the local optimization objective is as follows:

$$Lo_{ep} = \begin{cases} \sum_{i} ep_{i_0}, \forall ep_i \in Ep, \text{satisfies } ep_{i_0} \le ep_{i_{OC}}; \\ \sum_{j,k} (|2ep_{j_{OC}} - ep_{j_0}|, ep_{k_0}), \forall ep_j \in Ep, \text{satisfies } ep_{j_0} > ep_{j_{OC}}, \forall ep_k \in Ep, \text{satisfies } ep_{k_0} \le ep_{k_{OC}}; \\ \sum_{i} |2ep_{i_{OC}} - ep_{i_0}|, \forall ep_i \in Ep, \text{satisfies } ep_{i_0} > ep_{i_{OC}}. \end{cases} \quad (9)$$

Here, $Ep = [ep_1, ep_2, ..., ep_m, ep_{m+1}, ..., ep_n], i \in [1,...n], j \in [1,...m], k \in [m+1,...n]$.

The initial value $ep_{i_0} (i \in [1,...n])$ of optimization objective is assigned randomly. Because the optimal value of Ru is always zero, we choose the local optimal objective only considering the value changes of Tr, Cr and Ch. Values of the optimal objectives are showed in Table 2.

Accordingly, discrete point maps of the random initial values are shown in Figure 2. The initial values of discrete points are widely distributed.

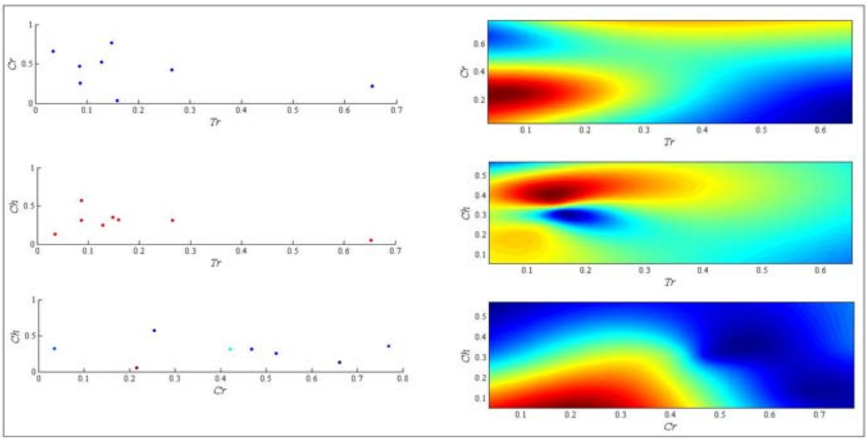


Figure 2. Discrete point of Tr_0, Cr_0 and Ch_0

Table 2. Corresponding local optimal objective of $ep_{i_0} (i \in [1,...n])$

Tr_0	Cr_0	Ch_0	f_0	Tr	Cr	Ch	Lo
0.0346	0.6608	0.1265	0.282924	0	0.6178	0.3089	0.7359
0.2646	0.4218	0.3149	0.405561	0	0.6178	0.3089	0.9893
0.1285	0.5216	0.2516	0.388233	0	0.6178	0.3089	0.9017
0.1483	0.7683	0.3516	0.429906	0	0.6178	0.3089	0.8818
0.0869	0.2549	0.5726	0.296562	0.147	0.5	0.25	0.4144
0.1586	0.0346	0.3186	0.158572	0	0.6178	0.3089	0.4924
0.6526	0.2156	0.0542	0.433038	0	0.5342	0.2671	0.9224
0.0864	0.4682	0.3107	0.392218	0	0.6178	0.3089	0.8617

Before optimization, the value distribution of Tr_0, Cr_0 and Ch_0 is with representative significance, and the values of Tr, Cr and Ch after optimization should converge the discrete situation of the initial value to a certain extent. The comparing between Tr_0, Cr_0, Ch_0 and Tr, Cr, Ch is showed in Figure 3. Here, the values of Tr, Cr and Ch converge the initial value.

In 11 cases of Table 1, to each set of assigned values $ep_{i_0} (i \in [1,...n])$, the optimal objective corresponding to the optimal solution can be calculated. For example, when Tr_0 =0.2646, Cr_0 =0.4218 and Ch_0 =0.3149, the optimal objective Lo =0.9893, then the optimal solution Tr =0, Cr =0.6178, Ch =0.3089. So, the optimization effect in the conditions of assigned initial value is shown in Figure 4.

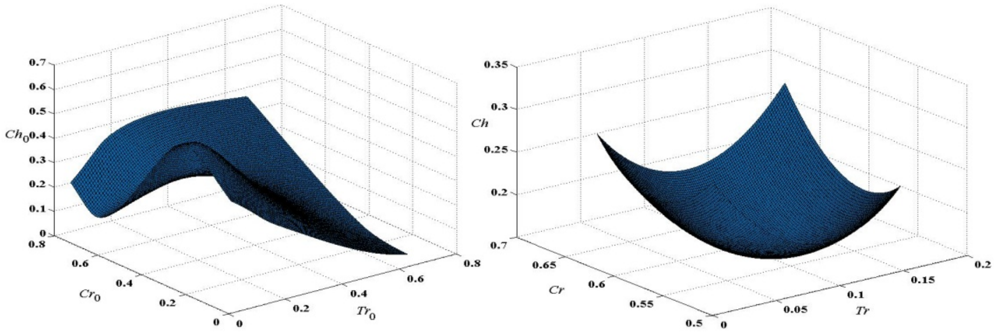
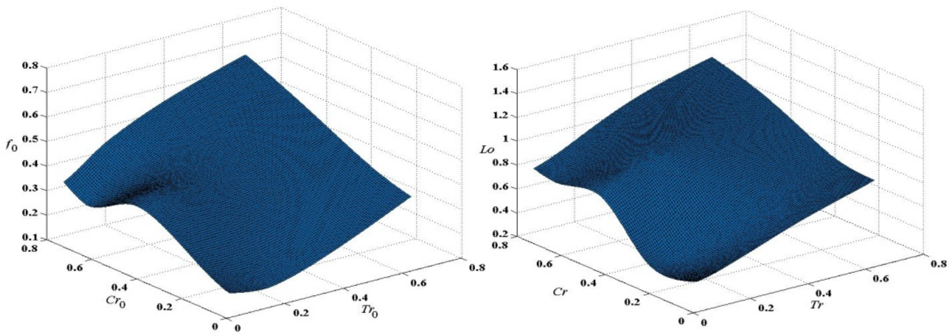
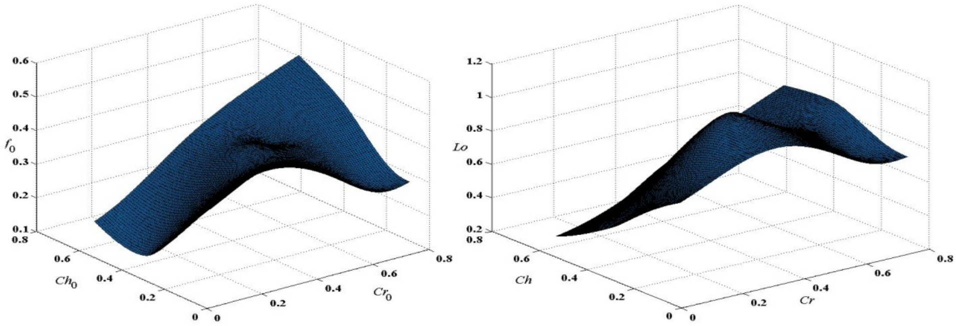


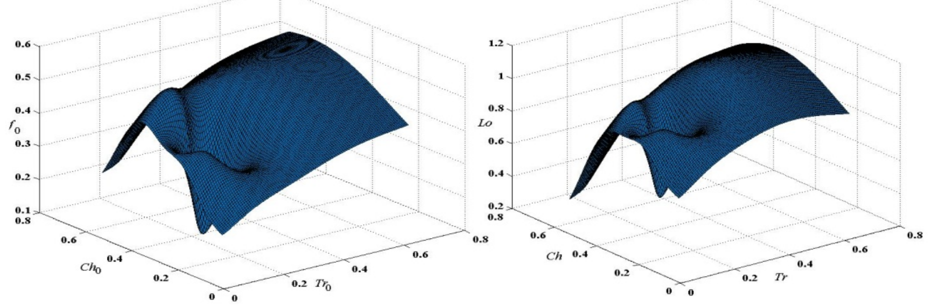
Figure 3. Comparing between Tr_0 , Cr_0 , Ch_0 and Tr , Cr , Ch



(a) Comparing of optimization effect between Tr_0 , Cr_0 ,f_0 and Tr , Cr , Lo



(b) Comparing of optimization effect between Cr_0 , Ch_0 , f_0 and Cr , Ch , Lo



(c) Comparing of optimization effect between Tr_0 , Ch_0 , f_0 and Tr , Ch , Lo

Figure 4. Comparing between optimization effect in perception layer

In Figure 4(a), (b), (c) separately express the comparing of optimization effect between Tr_0 , Cr_0 ,f_0 and Tr , Cr , Lo , the comparing of optimization effect between Cr_0 , Ch_0 ,f_0 and Cr , Ch , Lo ,the comparing of optimization effect between Tr_0 , Ch_0 , f_0 and Tr , Ch , Lo . We can see that, when Tr_0=0.1483, Cr_0=0.7683, Ch_0=0.3516, the initial dependability is f_0=0.429906, and the optimized performance reaches 0.8818, that is to say, the dependability in perception layer is optimized by 1.08 times; when Tr_0= 0.1586, Cr_0= 0.0346, Ch_0= 0.3186, the initial dependability is f_0= 0.158572, and the optimized performance is 0.4924, which is increased by 2.1 times.

5. Conclusion

Based on layered thought in IOT, this paper has integrated autonomic computing concept to the autonomic optimization process of the system. Having perception layer as the example and using linear programming method to research and set up an autonomic optimization model oriented to intelligent IOT system. Having the change of dependability elements directly affecting the dependability of system as the internal cause, based on the fusion results of dependability elements, the complex multi-source dependability parameters variables, configuration variables of IOT and dependability environment variables have been abstracted. Using the linear programming method to derive the mapping relationship between the dependability elements and the dependability in perception layer, the optimization model of intelligent IOT has been obtained. At the same time of local configuration optimization in perception layer, the complete system configuration coordination has been performed to promote the overall system dependability. The last analysis results of examples show that, in the condition of random assignment to key elements, the average optimization range of proposed model is bigger than 39%. Perception layer has improved the dependability, and the optimization effect is significant. In the future work, we will focus on the global coordination and optimization.

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