Intelligent Decision-Making Service Framework Based on QoS Model in the Internet of Things

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***Abstract*—The Internet of Things (IOT) has recently become popular to emphasize the vision of a global infrastructure of networked physical objects. The service framework based on IOT global infrastructure can provide full context resources and transform everyday objects into smart objects that automatically understand and react to their environment. However, the framework is still lacking because of unclear structural standards in IOT. In this paper, we construct an intelligent decision-making service framework based on the general IOT global structure and explicitly define its components' function and which IOT layer it belongs to. As to key problem of the framework—how to make intelligent decision depended on the context, we propose a QoS model according to improved Analytical Hierarchy Process (AHP). We use hierarchical clustering algorithm, fuzzy comprehensive evaluation, scale-extending method, entropy weight method, etc. to overcome AHP's inherent defects such as subjectivity. In the end, we perform a simulation to verify our study results, which reflects that the service decision-making controller in our framework can promptly evaluate available services and select the best service for users with the model.**

Keywords-IOT;smart objects;service framework;QoS model; improved AHP

I. INTRODUCTION

The Internet of Things (IOT) is a vision in which the Internet extends into our everyday lives through a wireless network of uniquely identifiable objects [1]. And it is partly inspired by the success of Radio Frequency Identification (RFID) technology, which is now widely used to track objects, people, and animals [2-4].

The incredible amount of information captured by a trillion RFID tags has a tremendous impact on our lives. However, some issues remain such as how to build service infrastructure in order to support effective RFID service provision in the Internet of Things Computing (IOTComp) environment[5]. Its key challenge is to identify automatically whether the provided service is loadable for the mobile RFID reader with limited resource and whether the provided service can meet the users' needs.

IOT service infrastructure, also called IOT service framework, is expected to promptly evaluate the quality of services (QoS) and provide satisfying services for the users depending on the RFID context [6].The context represents the knowledge of IOTComp environment, which includes users' preference, device capability and current network status, etc. and can be used to provide intelligent service decision-making. The first contribution of this paper is to build an intelligent decision-making service framework based on IOT global structure. Another contribution is to propose a context-oriented QoS model by extending the Analytical Hierarchy Process (AHP) and address the critical problem in IOT service framework.

The rest of the paper is organized as follows. Section II is devoted to discussing related work, and provides a summary of various QoS modeling techniques in IOT. Section III is devoted to building an intelligent decision-making framework based on IOT. Section IV addresses the problem of constructing QoS model. In Section V, we perform a simulation to validate the result of our model. Then we state some conclusions and future working directions in the last section.

II. RELATED WORK

QoS model in IOT can analyze IOPComp context and provide methods to compute the value of QoS which acts as a metric for optimal service decision-making. Most previous studies focus on the RFID network protocols, middleware, RFID devices reliability, safety, and cost, etc.[7,8], while the research on QoS model for IOT global infrastructure is much less.

Reference [9] first proposed a QoS model of grey decision-making from the view of IOT global infrastructure and built an adaptive service framework. In [10], a quality evaluation technique of RFID middleware according to ISO/IEC 9126 standard and EPC global middleware quality factors was built by simple AHP. It really provided an idea of simplifying complicated evaluation factors in IOT. In [6], the author constructed another AHP QoS model based on IOT global infrastructure. Moreover, in most QoS models, many factors such as device performance, resource state, etc. were considered but users' feedback like user preferences was often ignored.

A good QoS model, on the one hand, should aim at IOT global infrastructure and don't rely on internal protocols. On the other hand, it must fully take users' feedback into consideration.

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III. INTELLIGENT DECISION-MAKING SERVICE FRAMEWORK IN IOT

There are different types of low-level RFID context which includes any information used to mark the characteristics of things in IOT. In service evaluation, the premise of intelligent decision-making is to transform these low-level contexts into meaningful, high-level information by classifying them and then to apply them. In this paper, context resources are divided into three categories: device performance context, resource state context, user feedback. This classification also constitutes three types of QoS evaluation indicator such as device performance indicator, resource state indicator, user feedback indicator.

Due to the computing complexity and mobility of IOT applications, more and more user requests need to be completed by the cooperation of more than one device. Therefore the service framework based on IOT global infrastructure is very important. It can use kinds of context to make an optimal service selection from all the usable services regardless of user's and thing's location.

We abstract an intelligent decision-making service framework from general IOT structure [11], it is shown in Fig.1.

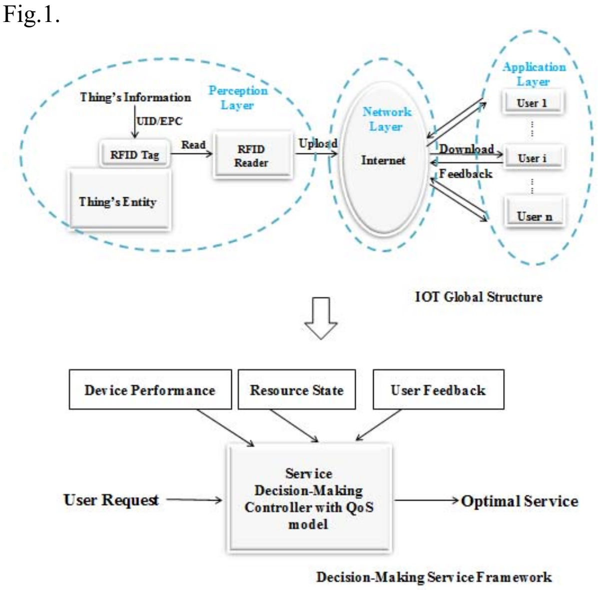

Figure.1 Abstraction process of decision-making service framework

The above decision-making service framework can be also defined as

$$
\begin{aligned}
&F(I,C,V,O)\\
&I=\{req_1,req_2,req_3\ldots req_k\}\\
&C=\{device-context, resource-context, feedback-context\}\\
&V=\{QoS_1,QoS_2,QoS_3\ldots QoS_m\}\\
&O=service_i, i\in\{1,2,3\ldots m\}
\end{aligned}
\tag{1}
$$

Where F represents service framework, it has four components of I, C, V, O. I includes the k users' requests from IOT application layer and is the input section of service framework. C means service framework's three types of RFID context in which device- and resource-context are all from IOT perception layer but feedback-context is from IOT application layer. V is the set of m services' QoS value, which is computed by service decision-making controller of IOT network layer. The final O is the selected optimal service which will output to application layer.

IV. THE QOS MODEL BASED ON IMPROVED AHP

In section III, we build the service framework based on IOT infrastructure. In this section, we will be devoted to studying the framework's key problem. That is namely the construction of QoS model in service decision-making controller, which provides calculation method of QoS and is particularly important for intelligent service decision-making.

AHP is a common method of evaluation and decision-making. Introducing it into QoS evaluation in the IOTComp environment simplifies the complicated IOTComp and can construct a QoS model based on IOT global infrastructure. However, the problem about AHP's strong subjectivity is still not resolved. In this paper, we further improve AHP and make it overcome subjectivity defects by the hierarchical clustering algorithm and fuzzy comprehensive evaluation method [12]. Our model's evaluation flow can be seen in Fig. 2.

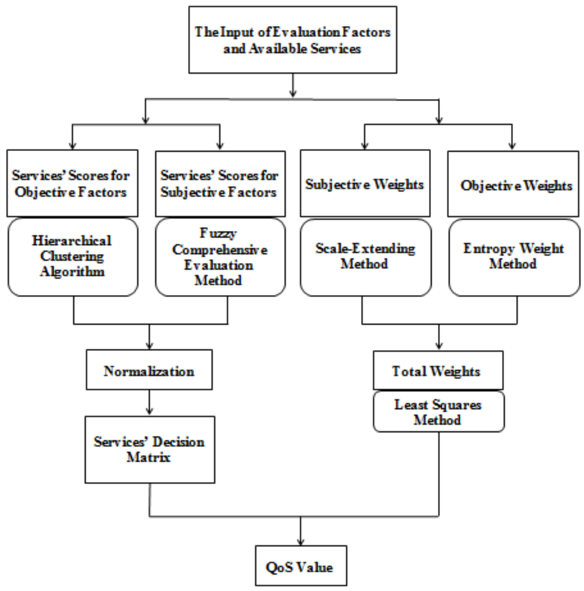

Figure.2 QoS model's evaluation flow chart

A. THE INPUT OF EVALUATION FACTORS AND AVAILABLE SERVICES

Evaluation indicators are equivalent to different types of RFID context, which are also divided into three types of device performance, resource state, user feedback. Every indicator has its several factors. In our service framework, evaluation factors and available services are generally input by service provider. Here, we consider n factors and m available services.

B. AVAILABLE SERVICES' SCORES FOR DIFFERENT FACTORS

According to types of indicators, we can know three kinds of evaluation factors. Among them, factors of device performance indicator and resource state indicator belong to objective factors and factors of user feedback indicator belong to the subjective factors. To facilitate description, we take n_d, n_r, n_u as the factors'number of device performance indicator, resource state indicator, user feedback indicator.

1) Service's scores of objective factors: The hierarchical clustering algorithm[13] first need provision classification levels, and then decide the clustering standard of service, finally cluster according to algorithm. We assume has 1~t levels and use the historical context resources as clustering standard, thus main steps of the algorithm are

```
Begin
    Initialize t, t' ← m, L_i ← {service_i}, i = 1,2,3...m
    Do t' ← t'-1
        D(L_i, L_j) = Min (Σ_{u=1}^{n_d+n_r} |f_iu - f_ju|)^φ under φ-th root, clustering
        L_i and L_j
    Until t = t'
    Return t service clusters
End
```

$$D(L_i,L_j)=Min\sqrt[\varphi]{\left(\sum_{u=1}^{n_d+n_r}\left|f_{iu}-f_{ju}\right|\right)^{\varphi}}$$

Where m is the number of available services, t' is the current number of service clusters, u is the number of objective factors which includes n_d factors of device performance indicator and n_r factors of resource state indicator, φ is an optional parameters (we take $\varphi = 2$). In the algorithm, we compute $D(L_i, L_j)$ with historical factors' value in context resource to find the minimum D and then merge L_i, L_j to a cluster.

Through the algorithm, we will eventually get t service clusters' respective level and determine service's scores of objective factors:

$$A_{obj}=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1(n_d+n_r)} \\ a_{21} & a_{22} & \cdots & a_{2(n_d+n_r)} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{m(n_d+n_r)} \end{bmatrix} \tag{2}$$

2) Service's scores of subjective factors: In this paper, fuzzy comprehensive evaluation method is introduced to get service's scores of subjective factors. The steps are as follows:

- Consider n_u evaluation factors, the set U includes them and is credited as $U = \{f_1, f_2, f_3 \dots f_{n_u}\}$.
- Determine the appropriate evaluation level and every level's score. When there are l levels, evaluation set $E = \{e_1, e_2, e_3 \dots e_l\}$.
- Define the evaluation matrix

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1l} \\ r_{21} & r_{22} & \cdots & r_{2l} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n_u 1} & r_{n_u 2} & \cdots & r_{n_u l} \end{bmatrix} \tag{3}$$

where r_{ij} represents the membership degree to evaluation level score e_j of evaluation factors f_i.

- Then the u service's scores of subjective factors are $a_{uv} = ER'$, where $v \in \{1, 2 \dots n_u\}$. Repeat the above steps for each service and we will get

$$A_{subj}=\begin{bmatrix} a_{1(n_d+n_r+1)} & a_{1(n_d+n_r+2)} & \cdots & a_{1n} \\ a_{2(n_d+n_r+1)} & a_{2(n_d+n_r+2)} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m(n_d+n_r+1)} & a_{m(n_d+n_r+2)} & \cdots & a_{mn} \end{bmatrix} \tag{4}$$

In our paper, we adopt 5 evaluation levels, so let $l = 5$ and $E = \{0.2, 0.4, 0.6, 0.75, 0.9\}$. Besides, we derive membership degree equation with statistical voting results of user feedback, thereby obtaining the evaluation matrix R. The membership degree equation is

$$r_{ij}=\frac{N_{ij}}{\sum_j N_{ij}} \tag{5}$$

where N_{ij} is the number of votes with which the users think factor i belong to the evaluation level j.

From *1)* and *2)*, we compute services' scores for all evaluation factors and normalize them, thus obtaining the final service decision matrix

$$A=\begin{bmatrix} A_{obj} & A_{subj} \end{bmatrix}=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \tag{6}$$

C. CALCULATE WEIGHTS

1) The Subjective Weights: We adopt scale-extending method to obtain the weights.

Firstly, we obtain factors' order of importance based on feedback: $p_1 \ge p_2 \ge p_3 \cdots \ge p_n$;

Secondly, according to the order we establish a scale matrix

$$C = \begin{bmatrix} 1 & c_1 & c_1c_2 & \cdots & c_1c_2\cdots c_{n-1} \\ 1/c_1 & 1 & c_2 & \cdots & c_2c_3\cdots c_{n-1} \\ 1/c_1c_2 & 1/c_2 & 1 & \cdots & c_3c_4\cdots c_{n-1} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1/c_1c_2\cdots c_{n-1} & 1/c_2c_3\cdots c_{n-1} & 1/c_3c_4\cdots c_{n-1} & \cdots & 1 \end{bmatrix} \quad (7)$$

Where the scale value

$$c_i = \frac{p_i}{p_{i+1}} \in \{1.2, 1.4, 1.6, 1.8, 1/1.2, 1/1.4, 1/1.6, 1/1.8\}.$$

Therefore, subjective weights are

$$w_j^1 = \frac{\sqrt[n]{\sum_{k=1}^{n} c_{jk}}}{\sum_{k=1}^{n} \sqrt[n]{\sum_{l=1}^{n} c_{kl}}}, j = 1, 2 \cdots n \quad (8)$$

2) The Objective Weights: We use entropy weight method to caculate the weights[4].

In accordance with decision matrix A and information theory, the entropy H_j of the factor j is

$$h_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}}$$

$$H_j = -(\ln m)^{-1} \sum_{i=1}^{m} h_{ij} \ln h_{ij} \quad (9)$$

when $h_{ij} = 0$, the $h_{ij} \ln h_{ij}$ is set to 0. Then we can get the objective weights

$$w_j^2 = \frac{1 - H_j}{n - \sum_{k=1}^{n} H_k}, j = 1, 2 \cdots n \quad (10)$$

Finally, by least squares method we calculate the total weight vector $W = \{w_1, w_2, w_3 \cdots w_n\}$ with (8) and (10):

$$\sum_{j=1}^{n} w_j = 1$$

$$Min\{\sum_{i=1}^{m} \sum_{j=1}^{n} \left[((w_j - w_j^1) a_{ij})^2 + ((w_j - w_j^2) a_{ij})^2 \right]\} \quad (11)$$

D. Compute the QoS value

Each service's QoS can be computed as

$$QoS_i = \sum_{j=1}^{n} w_j a_{ij}, i = 1, 2 \cdots m \quad (12)$$

Obviously, the higher QoS value is , the better.

V. Application Simulation

To verify the QoS model, we perform a simulation. The users' request faces IOTCommunication, which has four available services. They are

- Objective-to-Internet-Human (OIH),
- Human-to-Internet-Objective(HIO),
- Objective-to- Internet-Objective (OTO),
- Objective-to-IOT Objective (OIOTO)[7].

We provide all the evaluation factors, which are shown in Table.1.

Table.1 Evaluation factors in the simulation

Factor Types	Factor Description		
Objective Factors	Device Performance	D_R	reliability
		D_S	memory storage
		D_T	fault tolerance
	Resource State	R_C	CPU cost
		R_E	battery energy
		R_B	bandwidth usage
Subjective Factors	User Feedback	U_F	user friendly

- Using the hierarchical clustering algorithm and fuzzy comprehensive evaluation method to establish the decision matrix, then normalize it.

$$A = \begin{bmatrix} 0 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0.25 & 0.25 & 0.25 & 1 & 0.875 & 0.625 & 1 \\ 1 & 0.33 & 1 & 0.33 & 0.33 & 1 & 0.33 \\ 0.33 & 1 & 0 & 0 & 0 & 0.33 & 1 \end{bmatrix}$$

- Through scale-extending method and entropy method, we get the subjective and objective weights, then deriving the total weights.

$$W = \{0.2988, 0.1026, 0.0901, 0.1234, 0.0295, 0.1607, 0.1949\}$$

- From the above results, the final QoS values are

$$QoS=\begin{bmatrix} 0.3146 \\ 0.5674 \\ 0.6982 \\ 0.2542 \end{bmatrix}\begin{matrix} OIH \\ HIO \\ OIO \\ OIOTO \end{matrix}$$

From these QoS values, we can know the optimal service based on the assumed RFID context is OIO and the rank of their QoS is OIO > HIO > OIH >OIOTO. With the model's evaluation results, service decision-making controller in service framework evaluates instantly all the usable services and provides the best service for users.

VI. CONCLUSIONS

In this paper, we abstract an intelligent decision-making service framework based on the IOT global infrastructure, at the same time analyzing its several components' functions and layers. Then, for the key problem of framework, we propose a context-oriented QoS model. It's based on the improved AHP which overcomes inherent subjectivity by introducing hierarchical clustering and fuzzy comprehensive evaluation. Moreover, the model aimed at IOT global infrastructure, don't rely on internal protocols and take users' feedback into consideration fully.

As future work, we plan to design new IOT service framework because the structure standard of IOT is not clear at present and is still improving. We will correct and optimize our study according to the latest scientific research.

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