Consumer-Centered Cloud Services Selection Using AHP

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***Abstract*—With rapidly increasing number of cloud computing resources deployed over the Internet as on-demand services, more and more service-oriented solutions are available for selection to meet personalized requirements of consumers. However, how to choice a desired cloud service from the pools of candidate services is becoming an increasingly important research issue. The reason is that a group of functionally equivalent or overlapped alternatives are difficult to quantify in service decision making. A multi-criteria decision-making (MCMD) method based on AHP (Analytic Hierarchy Process) is proposed in the paper to transform consumer's qualitative and semi-quantitative personalized preference into quantitative numeric weights. The case study in medical cloud environment is used to validate the feasibility and effectively of our method.**

Keywords- cloud service selection, AHP, MCDM, consumer-centered, Quality of Service (QoS)

I. INTRODUCTION

Cloud computing is being changed into a paradigm composing of services that are commercialized and deployed over the Internet similar to public services and facilities, such as water, electricity, gas, and telecom. In such a model, consumer can select cloud service based on their need take no account of where services are deployed or how services are delivered [1]. Cloud computing provides varied services to the consumers such as big data computation, data retrieval and access. Based on the model of services provided, cloud computing can be classified into three categories, such as Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS) [2,3]. Based on the deployment models, the cloud has been classified into private, public, community and hybrid clouds [4-6]. Web services are broadly and commonly used in structuring service-oriented architecture (SOA) and distributed cloud services [7]. At runtime of service, a composited cloud service is selected and invoked by other relevant services. Quality of Service (QoS) parameters (i.e. response time, cost) play an important role in determining usability and reliability of multiplexed system [8].

Cloud computing is a paradigm for providing all sorts of cloud services, that can be rapidly deployed and delivered with minimal management cost and effort or reciprocity among service providers [9]. Many cloud providers intend to release cloud services in cloud platform. While this largely fueling growth of cloud services, the ever increasing number of cloud services may provide functionally identical or similar services in the cloud with different characteristics, which make it difficult for the potential consumers to judge and weigh which options balance their requirements best [10]. As multiple criterions are involved in decision-making process, it is a multi-criteria decision-making (MCDM) problem [11]. Selecting the best service based on consumer's preference is a complex problem due to the multiple consumer requirements [6]. Furthermore, users often discriminate these choices according to QoS property of services for selecting an ideal cloud service [12]. In view of these challenges, this paper proposes an efficient cloud service selection (CSS) method based on AHP theory for a shared service among multi-users who own different preferences and priorities imposing on the shared cloud service. Technically, it is feasible by introducing a multi-criteria decision-making method, called Analytic Hierarchy Process (AHP), into our work, which transform user's qualitative and semi-quantitative personal preference into quantitative numeric weights for forwarding cloud service selection.

The remaining part of this paper is organized as follows. Section II reviews related work. Section III describes consumer-centered cloud service selection method based on AHP theory. The case study in medical cloud environment is introduced in section IV. Finally, Section V concludes this paper and gives our future work.

II. RELATED WORK

For the past few years, many researchers have paid close attention on putting forward a kind of flexibility methodology to choose appropriate cloud service from cloud platform. In the view of selecting a qualified cloud service for some purpose, research works have been handled in cloud service selection and service composition in the area of cloud computing and service computing.

Silas et al [6] proposed an efficient service selection middleware using ELECTRE methodology in cloud computing environments. The service selection process has been modeled as multi-criteria decision-making problem. Numerous criterions influencing the process of service selection were considered, such as response time, service cost, responsiveness, trust, scalability, capability, flexibility, etc.

Chen et al [13] proposed a multi-criteria decision-making support for trading platform with choice of product service based on Fuzzy-AHP and TOPSIS aiding the customers' product selection and negotiation service on the e-shops.

Sundareswaran et al [10] proposed a extensive brokerage-based architecture called the CSP (Cloud Service Provider) index, which can efficiently regulate the potentially great number of service providers, to facilitate cloud service selection. A novel encoding technique is introduced to the

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CSP-index that acquiring similarity among various properties of service supplier. With the help of the CSP-index, cloud service selection algorithm further designed that considered convergence of services and provided rankings of possibility cloud service providers.

Bedi et al [14] proposed a framework which helped the user in finding the reliable cloud service providers in cloud environment using the recommendations in consideration of reliable acquaintances. The uncertainty feature present in the recommendations is conducted through Fuzzy Inference System (FIS). Fuzzy Inference System is responsible for inferring low outputs because of the inexact or changeable of inputs, simulation the reasoning of human thought.

Zhang et al [15] proposed a decentralized Web services selection algorithm based on multi-attribute group decision making (MAGDM) theory (DWSSA MAGDM) in pervasive computing environment. He presented a new user context ontology that mainly depicted the user's information. This algorithm is including standardization of the heterogeneous decision-making matrix, aggregation of the QoS evaluation and synthetically evaluation.

Wang et al [8] addressed the problem of web service selection and given evidence of the uncertainty effect of QoS in the service selection process. He proposed a novel concept, called QoS uncertainty computing, to construct the inherently uncertain of Web service QoS. Cloud model employed to compute the uncertainty of QoS for eliminating redundancy services while picking up reliable services. Then, mixed integer programming is used to choose optimal services.

Zeng et al [16] discussed the architecture and key algorithms of cloud service for cloud service selection with adaptive performances and minimum cost. Two cloud services selection algorithms also been presented with Available Service List Selection and Maximized Gain Minimized Cost Service Selection, which depend on an agency to estimate the service property and select the optimal service for user.

Generally speaking, the service selection methods presented in above works are often facilitated by explicit QoS properties. Technically speaking, QoS is a broadly concept that including a good deal of non-functional properties such as cost, response time, availability, reliability, and trust [17]. It is worth noting that these QoS properties may be divided into two types. For some QoS properties (i.e. cost), they are associated with an independent service completely determined by cloud service providers. As services are always spread all over the Internet, some of other QoS properties (i.e. availability and reliability) are influenced by the network communication, and from the user's point of view to evaluate rather than the perspective of cloud service provider [12, 17].

Essentially, a cloud service selection process among a set of QoS properties is a MCDM process. It could be similarly transformed into a single criteria decision-making process, by introducing a set of quantitative weight values into the process of multi-criteria decision-making analysis.

III. CONSUMER-CENTERED CLOUD SERVICE SELECTION BASED ON AHP THEORY

Cloud service selection exclusively based on user's judgment is a greatly cognition process which could be easily error-prone and quite time-consuming [11]. There are many solutions deal with this problem, such as Linear Programming, Fuzzy Analytic Hierarchy Process (F-AHP), Neural Network, Simulated Annealing Algorithm, Genetic Algorithm (GA), Grey Comprehensive Evaluation etc. If a problem is decomposed into clusters, and attributes are pair-wise compared within the cluster, then decision problems can be worked out readily by lessening cognition process. For cloud services are not very popularly used in actual systems at this stage for the public and there are many parameters difficult to quantify in service selection and service decision-making [18], AHP is more suitable introduced for user to select cloud services catering his preference.

A. *Preliminary Knowledge of AHP Theory*

AHP theory is initially presented by Saaty [19] [20]. AHP is a multi-criteria decision-making method which is established on the basis of statistics and extremely beneficial in facilitating multi-criteria decision-making problems transformed into hierarchical structure, consequently constructing the pair-wise comparison matrix to judge the weights. Originally it designed to ranking limited alternatives in according with limited attributes. In reality, it provides an effective way to eliminate error-prone for a certain decision-making criterion. A preponderance of hierarchy structure is eyeballing pair-wise comparison respectively on each of layer imposing on properties, which are aid in making a sound decision-making. Nowadays, AHP approach has been used in many areas for evaluating the relationship of candidate service [21,22]. Technically, AHP method is initiated by a 1-9 scale (see Figure 1) for pair-wise comparisons [23,24]. In this ratio scheme [12], value equal to 1 stands for the equally important; 3 stands for moderately important; 5 stands for strongly important; 7 stands for the demonstrably important, and 9 stands for extremely important. At the same time, an intermediary number is feasible (such as 2, 4, 6, 8), it means an middle number of its neighbors, and a reciprocal value is used for a reverse comparison.

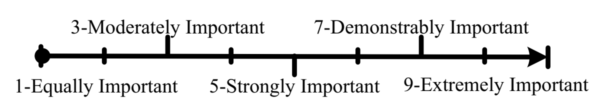

Figure 1. Saaty's pair-wise comparison scale, where 2, 4, 6, 8 is respectively intermediary number of its left and right

For a set of alternative services and a group of selection criterions, a complicated comparison matrix is used for each pair-wise comparison between two candidates or alternatives. Theoretically, a pair-wise comparison matrix $A_n = (a_{ij})_{n\times n}$ has the following definitions and attributes [19, 20]:

Definition 1: Set matrix $A=(a_{ij})_{n\times n}$, element a_{ij} satisfies following properties: (1) $a_{ij}>0$, where $i, j=1, 2, \dots, n$; (2) $a_{ij}=1$, where $i=j$, and $i, j=1, 2, \dots, n$; (3) $a_{ij}=1/a_{ji}$, where $i\neq j$, and $i, j=1, 2, \dots, n$. We call matrix $A=(a_{ij})_{n\times n}$ is reciprocal matrix.

Definition 2: Suppose that matrix $A=(a_{ij})_{n\times n}$ is a reciprocal matrix, and satisfies the transitivity property $a_{ij}\cdot a_{jk}=a_{ik}, (i, j, k=1, 2, \cdots, n)$, then we call matrix $A=(a_{ij})_{n\times n}$ is consistent matrix. Otherwise $A=(a_{ij})_{n\times n}$ is inconsistent matrix.

When a pair-wise comparison matrix A is consistent, its eigenvector equals to a group of normalized weights associated with limited alternatives referential by matrix A. Otherwise, an approximate value of matrix A by a consistent matrix is needed. In real life decision-making problems, pair-wise comparison matrixes are rarely or never consistent. Saaty [19] proposed the following method for calculating the inconsistency of a pair-wise comparison matrix A. Computing the largest eigenvalue λ_{max} of matrix A, he has shown that $\lambda_{max}\geq n$, and established condition of equal sign is if and only if matrix A is consistent matrix.

Definition 3: Suppose that matrix $A=(a_{ij})_{n\times n}$ is a reciprocal matrix, λ_{max} is the largest eigenvalue of A, then consistency index (CI) is defined by $CI=(\lambda_{max}-n)/(n-1)$. Matrix $A=(a_{ij})_{n\times n}$ is consistent matrix if and only if $CI=0$. Here, since $\lambda_{max}\geq n$, CI is always greater than or equal to zero. The less the value of CI, the better the consistent of matrix A.

In order to make sure the permissible scope of the degree of inconsistency in matrix A, Saaty introduced the concept of random index (RI) as a criterion to leveraging the degree of consistent of matrix A. The process of computing RI as follows: For a fixed number n, randomly construct reciprocal matrix $A'=(a'_{ij})_{n\times n}$ (each element a'_{ij} randomly chosen from scale 1, 2… 9 and 1, 1/2… 1/9). Take a sufficiently large sample random pair-wise comparison matrices of size $n\times n$, computing the mean value of the largest eigenvalue as λ'_{max}, and defined $RI=(\lambda'_{max}-n)/(n-1)$. For different number of n, Saaty recommended referred values of RI (see Table 1).

TABLE 1. The value of random index RI

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The consistency ratio (CR) of a given pair-wise comparison matrix A is defined by $CR=CI/RI$. Saaty concluded that an consistency ratio less than or equal to 0.1 may be considered acceptable [19].

AHP theory as a practical method for transforming cloud services parameters appointed in a qualitative way into a set of quantitative weight values in view of statistics.

B. *Cloud Services Selection Criteria Model*

It is obvious from the literatures that many demands such as cost, time, availability, reliability etc effect the selection of service requester in the cloud. In fact, different service providers in a cloud can provide similar services with overlap functionality but be equipped with different criteria. Consequently, the needs and the predilections of the consumers will be varying. In this section, criterions that effect the selection of the cloud consumer in a cloud have been provided. Consumers are supposed to be very good at one to one comparison according to QoS criteria provided by cloud service.

Performance and safety properties means that the provided cloud service is how performance is prominent and services is reliable. Cost property means the service price that can be cooperated with each cloud services no less than a whole system [25]. From the cloud service properties, the criteria are important making-decision elements, we just consider performance, safety, and cost in this paper (see Table 2)

TABLE 2. Cloud service selection criteria [25]

Characteristic	Sub-Characteristic	Definition
Performance	Response Time	Time form sending request to receiving response
	Throughput	Ratio of service request completed in unit time
Safety	Availability	Whether a service exists and is available instantly
	Reliability	Reliability degree for service
Cost	Cost	The price involved in using a service

C. *Relation between Consumer and Cloud Services*

The primary object of cloud service is to provide users with inexpensive and convenient service. The relationship of cloud services and consumers are apparent. Users can access cloud services through a cloud platform with many available services. The Figure 2 means users can access service clouds by the cloud platform to select cloud service from candidates to cater his preference. The Figure 3 means that multi-users can access cloud services by the cloud platform collaboratively select cloud service from candidates to meet their common needs, which is a group decision-making problem. For a service selection process promoted by a group of users, optional services are often assessed by a group of end users who may have different experience and professional skills. On this occasion, it is often a challenging endeavor to make a tradeoff among various preferences or priorities of multi-users.

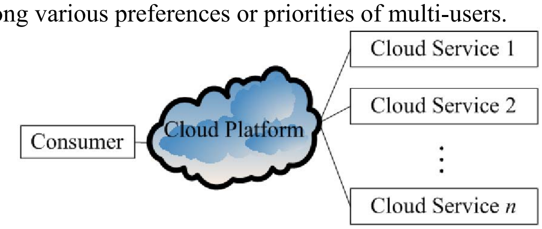

Figure 2 Single user context of cloud service selection

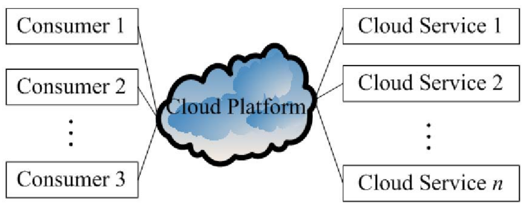

Figure 3 Multi-user context of cloud service selection

D. Hierarchical Analysis Model of Consumer-Centered Cloud Service Selection

Our work is based on the AHP model as show in Figure 4. In the model of cloud service selection, the top layer is the object layer of cloud service selection. It defines the scheduled goal of the problem. The intermediate layer is the criterion layer. It defines five secondary indexes, including response time, throughput, availability, reliability, and cost, for the evaluation of cloud services selection. The bottom layer contains a lot of available alternative services.

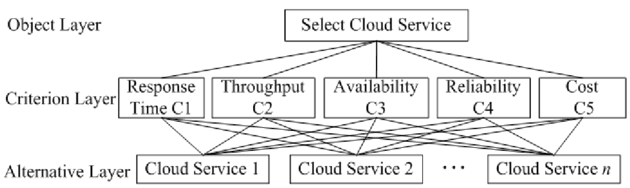

Figure 4 AHP model of cloud service selection

IV. CASE STUDY

A. Single Consumer Context of Cloud Service Selection

For single user context of cloud service selection, we take Figure 2 as an example. Suppose that user is a stroke patient, who wants to select a cloud service from cloud platform for health medical rehabilitation. There are three kinds of cloud service (CS) providing stroke rehabilitation therapy in cloud platform. User can access cloud platform to select desired medical cloud service according to his personal preference and the demand of treatment. The modeling process using by AHP theory and computation results as follows, see Table 3-Table 5.

TABLE 3 Object layer compare with criterion layer

***CR*=0.0944<0.1; Global Weight=1.0000; λ_{max} =5.4227**						
Select Cloud Services	Response Time	Throughput	Availability	Reliability	Cost	w_i
Response Time	1	1	0.1667	0.125	0.3333	0.045
Throughput	1	1	0.1429	0.1111	0.1667	0.0371
Availability	6	7	1	1	7	0.3791
Reliability	8	9	1	1	9	0.444
Cost	3	6	0.1429	0.1111	1	0.0947

TABLE 4 Criterion layer compare with alternative layer

***CR*=0.0036<0.1; Global Weight=0.0450; λ_{max} =3.0037**				
Response Time	CS 1	CS 2	CS 3	w_i
CS 1	1	5	3	0.6483
CS 2	0.2	1	0.5	0.122
CS 3	0.3333	2	1	0.2297
***CR*=0.0904<0.1; Global Weight=0.0371; λ_{max} =3.0940**				
Throughput	CS 1	CS 2	CS 3	w_i
CS 1	1	0.2	4	0.1991
CS 2	5	1	8	0.7334
CS 3	0.25	0.125	1	0.0675
***CR*=0.0053<0.1; Global Weight=0.3791; λ_{max} =3.0055**				
Availability	CS 1	CS 2	CS 3	w_i
CS 1	1	5	4	0.6908
CS 2	0.2	1	1	0.1488
CS 3	0.25	1	1	0.1603
***CR*=0.0707<0.1; Global Weight=0.4440; λ_{max} =3.0735**				
Reliability	CS 1	CS 2	CS 3	w_i
CS 1	1	3	0.1667	0.1662
CS 2	0.3333	1	0.125	0.0726
CS 3	6	8	1	0.7612
***CR*=0.0000<0.1; Global Weight=0.0947; λ_{max} =3.0000**				
Cost	CS 1	CS 2	CS 3	w_i
CS 1	1	3	1	0.4286
CS 2	0.3333	1	0.3333	0.1429
CS 3	1	3	1	0.4286

TABLE 5 Final result

Alternatives	**Weight**
Cloud Service 1	0.4129
Cloud Service 2	0.1349
Cloud Service 3	0.4522

As Value (CS3) >Value (CS1) >Value (CS2) (i.e. 0.4522>0.4129>0.1349), it is obviously see that cloud service 3 is the most qualified cloud service that would be selected as the final candidate providing stroke rehabilitation therapy for the stroke patient.

B. Multi-Consumer Context of Cloud Service Selection

For multi-user context of cloud service selection, we take Figure 3 as an example. Suppose that there are three medical service experts (Stroke Expert, Healthcare Expert, Neurology Expert) in client side for group decision, and give stroke patient the evaluation advices of medical cloud service for health medical rehabilitation and diagnosis. There are also three kinds of cloud services (CS) providing stroke rehabilitation therapy in cloud platform. Experts can access cloud platform to evaluate medical cloud service according to his personal experience and professional skills. In consideration of difference existing in personal experience and professional skills of three medical experts, we set different priorities and numeric weights for three experts. The weight of neurology expert and healthcare expert are both 0.3, the remaining weight 0.4 is set to stroke expert. The computing process and result as follows, see Table 6-Table 8.

TABLE 6 Object layer compare with criterion layer by experts

Select Cloud Service	Stroke Expert	Healthcare Expert	Neurology Expert
Response Time	0.0949	0.0859	0.1744
Throughput	0.1665	0.1797	0.0958
Availability	0.3288	0.3272	0.3571
Reliability	0.3698	0.3548	0.3224
Cost	0.04	0.0523	0.0503
Global Weight	1	1	1
CR	0.0914	0.049	0.095

TABLE 7 Criterion layer compare with alternative layer by experts

Response Time	Stroke Expert	Healthcare Expert	Neurology Expert
CS 1	0.6483	0.2851	0.2872
CS 2	0.122	0.0623	0.078
CS 3	0.2297	0.6527	0.6348
Global Weight	0.0949	0.0859	0.1744
CR	0.0036	0.0707	0.0904
Throughput	**Stroke Expert**	**Healthcare Expert**	**Neurology Expert**
CS 1	0.309	0.3234	0.4444
CS 2	0.5816	0.089	0.1111
CS 3	0.1095	0.5876	0.4444
Global Weight	0.1665	0.1797	0.0958
CR	0.0036	0.0088	0
Availability	**Stroke Expert**	**Healthcare Expert**	**Neurology Expert**
CS 1	0.6833	0.2926	0.183
CS 2	0.1998	0.0668	0.0752
CS 3	0.1168	0.6406	0.7418
Global Weight	0.3288	0.3272	0.3571
CR	0.0236	0.0961	0.0424
Reliability	**Stroke Expert**	**Healthcare Expert**	**Neurology Expert**
CS 1	0.1744	0.6491	0.6833
CS 2	0.6337	0.0719	0.1998
CS 3	0.1919	0.279	0.1168
Global Weight	0.3698	0.3548	0.3224
CR	0.0088	0.0624	0.0236
Cost	**Stroke Expert**	**Healthcare Expert**	**Neurology Expert**
CS 1	0.2797	0.5396	0.1998
CS 2	0.6267	0.1634	0.1168
CS 3	0.0936	0.297	0.6833
Global Weight	0.04	0.0523	0.0503
CR	0.0825	0.0088	0.0236

Table 8 Final result

Alternatives	Weight
Cloud Service 1	0.4604
Cloud Service 2	0.1969
Cloud Service 3	0.3427

As Value (CS1) >Value (CS3) >Value (CS2) (i.e. 0.4604>0.3427>0.1969), we conclude that cloud service 1 is the expert group opinions from three medical service experts. This cloud service as a reference is suitable for stroke patient to select as the final candidate for providing stroke rehabilitation therapy.

C. *Sensitivity Analysis*

For the context of single-user multi-object, user also can carry through cloud service selection according to personal preference for single target. If solely consider the availability of cloud service, cloud services 1 is undoubtedly the most suitable option, see Figure 5. For the context of multi-user multi-object, group judgment suggestions have been given by three experts according to their personal experiences and professional skills. The user can precede a cloud service selection decision-making on the basis of the advices from experts combined with their own preferences. Take availability into consideration, cloud service 1 also be the most suitable choice, see Figure 6.

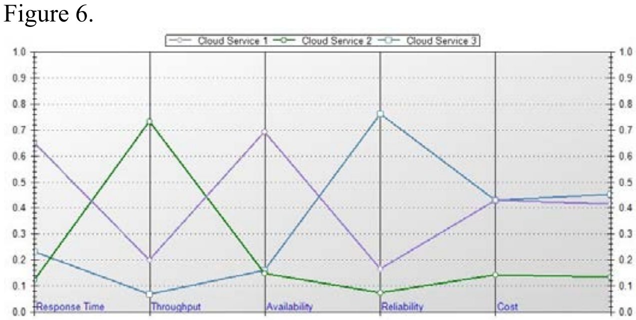

Figure 5. Sensitivity analysis for single user

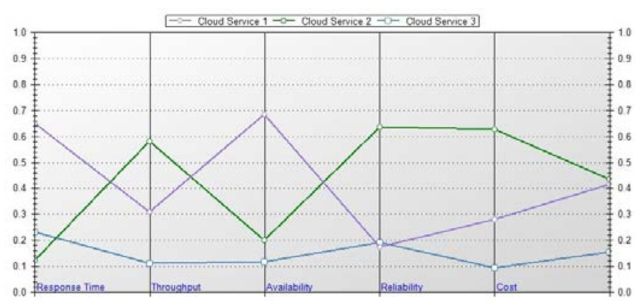

Figure 6. Sensitivity analysis for a group of users

V. CONCLUSIONS AND FUTURE WORK

In this paper, we investigated a novel consumer-centered cloud service selection method based on AHP theory. Our method and application are two-fold: First of all, there are rarely literary concerns about cloud service selection based on AHP theory, especially used in medical service cloud environment. Moreover, we present consumer-centered service selection mainly consider user's preference in multiple context (single user and multiple user). We finally give a novel thought of cloud service decision-making (CSDM) for making a reasonable cloud service selection, which is readily applicable to other areas for which a similar information model is available.

In the future, we will mainly concern about dynamic change of cloud service criteria for cloud service selection. We also research the effect of relationship among multiple layer criteria and group decision-making. The research area can also include evaluation and prediction for cloud service using AHP theory.

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