A User-Centric Decision Support Model for Cloud of Things Adoption Using Ellipsoidal Fuzzy Inference System

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Abstract. Cloud adoption for Internet of Things is gaining attention among researchers and organizations. The decision to choose a Cloud vendor is complicated and dynamic in nature. The majority of the existing Decision support systems designed to support migration to the Cloud have limitations. They mostly provide information to support evaluation and selection of vendors with cost being the main factor while some fundamental issues had been left unsupported. This work proposes a robust User-Centric Cloud of Things Decision Analytic Model using Ellipsoidal Fuzzy Inference System. The proposed model supports real time decision making process for the adoption of Cloud computing in Internet of Things by comparing User-defined Application demand and Cloud Decision attributes. The results of this work are expected to contribute to the acceptance of Cloud of Things services.

Keywords: Decision support · Cloud computing · Cloud of Things
Internet of Things · Ellipsoidal · Fuzzy

1 Introduction

The Internet of Things (IoT) permits communication between different sensors connected to the Internet and the use of their services towards relevant applications [1]. Cloud concepts are integrated with IoT so that storing and computation is done in the Cloud [2]. Essentially, the Cloud acts as intermediate layer between the things and the applications, where it hides all the complexity and the functionalities necessary for implemention [3]. The introduction of IoT to Cloud Computing gave birth to the concept called Cloud of Things (CoT).

As IT administrators take proactive measures to mesh IoT with their Cloud deployments, it becomes a great deal of concern which Cloud provider to adopt for IoT deployment [4]. The majority of the existing Decision Support Systems mostly provide information to support evaluation and selection of vendors with cost being the main factor [5]. This paper proposes a model that will evaluate CoT attribute parameters based on Cloud user experiences and IoT application security demands. The proposed model will help in choosing which Cloud vendor to adopt for any CoT deployment service.

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2 Related Works

Considering the availability of various Cloud providers, IoT users find it challenging to select the most appropriate secured Cloud for a Cloud IoT application. Several researchers have proposed several decision support systems for migrating to the Cloud. [6] proposed a solution based on user parameters for the migration of applications to the Cloud. [7] considered the characteristics of services provided by Cloud providers such as storage, intra-Cloud, cost, and so on. [8] developed the CloudGenius framework that provides a multi-criteria approach in decision support for selecting providers for IaaS in migrating a web server to the Cloud. [9] presented a Cloud adoption toolkit for Infrastructure as a Service (IaaS) that aids decisions on suitability of the technology. [10] considered various properties, security and availability to determine the best Cloud service provider for a particular application.

[11] proposed a model to support user decision-making by calculating the optimal amount of internal Cloud computing resources and expected cost reductions of strategic public Cloud deployment. [12] proposed a model that help decision makers consider whether and which forms of Cloud computing would operate best for their organization. It provides an estimate of the operational costs of adopting a Cloud system. [13] presented a system that can predict the costs for a Cloud deployment of an application. It provides expected trade-offs between cost and performance.

3 Methodology

The methodology to this research study entails classifying various Cloud of Things Attribute parameters (Decision Attributes) based on their characteristics and strength. This classification will be done under five (5) categories. These categories will be used as “decision criteria” for choosing the most appropriate Cloud resource for an IoT application deployment. From the features obtained from any category, a fuzzy based Cloud of Things decision system will be developed using user experiences of various Cloud resource providers while comparing it with “user defined” application demand by an IoT application.

[14] identified twenty security considerations for Cloud-supported Internet of Things. According to [15], Skyhigh network in conjunction with Cloud Security Alliance (CSA) also presented and evaluated 50 attributes that defines the rating of a Cloud service. These works formed a basis for identifying various CoT attributes across five categories defined thus; (1) Defense Capability Attributes (α), (2) Access Control and Device Attributes (β), (3) Data Attributes (γ), (4) Service, Business and/or Legal Attributes (δ), and (5) Primary Security Attributes (λ). Figure 1 below depicts an overall architecture for the proposed model.

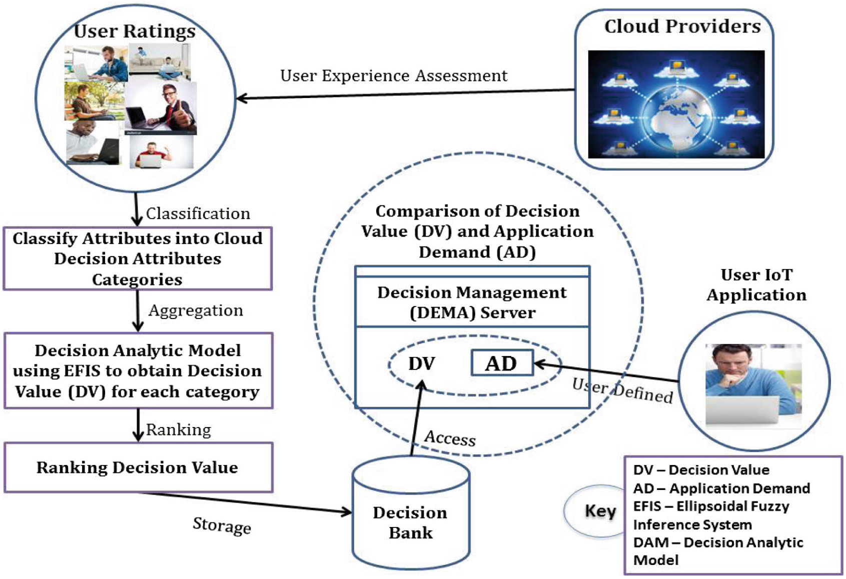

Fig. 1. Overall system architecture

The system architecture above depicts various stages of work to be carried out. The primary source of data for this work will be obtained from Cloud user ratings. A questionnaire will initially be designed and posted across various Cloud user and IoT forums to garner information about various Cloud providers as perceived by the users. Secondarily, CoT experts, Researchers and IoT developers will also be required to answer some questions about their Cloud resource usage experiences. The garnered information will then be categorized into five Decision Attribute categories (Defense Capability Attributes, Access Control and Device Attributes, Data Attributes, Service, Business and/or Legal Attributes, Primary Security Attributes).

The information for each category will then be used as input for developing the Decision Analytic Model Ellipsoidal Fuzzy Inference System (DAMEFIS). The result obtained for each category of decision criteria will be ranked in order of most suitable Cloud provider depending on the specified user-defined Application Demand.

3.1 Decision Analytic Model Ellipsoidal Fuzzy Inference System (DAMEFIS)

The proposed model is specifically designed for the evaluation of Decision attributes in Cloud of things. This model applies Ellipsoidal fuzzy inference system to evaluate the Decision value (DV) for any Cloud resource provider and compares it with the user-defined Application Demand for IoT applications. The aim is to aggregate each Decision attribute of Cloud resource sites into a single value output as illustrated in Fig. 2 below:

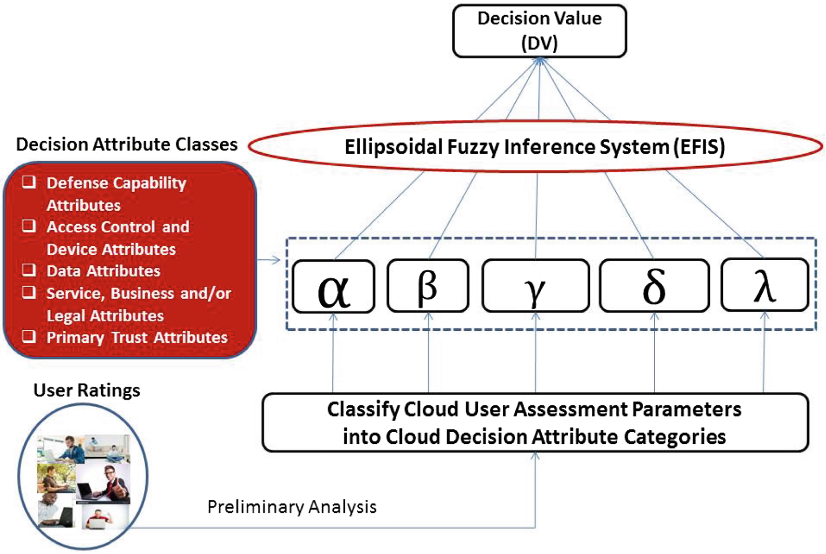

Fig. 2. Aggregation of decision criteria parameters into decision value

On the other hand, A CoT application issues an Application demand (AD) depending on the expected level of service for the application. The Application demand is based on important parameters as defined in the application. These include; authentication, access control, data integrity, data encryption and so on which has been categorized into five classes. These parameters are aggregated into a single value defined as the Application demand (AD) for the CoT application.

The aggregated values are then used for Decision Support in determining the most suitable Cloud resource provider for any CoT application.

3.2 Vector Spaces and Ellipsoidal Fuzzy Rules

This work proposes that Cloud attributes can be defined as a vector space hence every Cloud resource maintains a Decision vector (DVEC) defined as:

$$\mathbf{V_i} = (\mathbf{A_1}, \mathbf{A_2}\ldots\ldots\ldots\ldots\mathbf{A_n})^{\mathbf{T}} \text{ for } \mathbf{1} \leq \mathbf{i} \leq \mathbf{n} \quad (1)$$

Where V_i = Decision Vectors for the Cloud and A_i = Decision Attributes for CoT.

It should be noted that the Decision Vector is an aggregate of all related Decision Attributes in the Cloud. It is made up of each of the five (5) attributes classes. Each Cloud attribute parameters are the Decision attributes.

The whole Cloud can thus be defined by a Decision Matrix (DM) defined as an aggregate of all Decision vectors (V_i) in a Cloud as an $n \times m$ matrix.

$$\mathbf{DM} = \left(\mathbf{V_{1,}V_{2,}\ldots\ldots\ldots V_m}\right)^{\mathbf{T}} \tag{2}$$

$$\mathbf{DM} = \begin{matrix} \mathbf{A_{11}} & \mathbf{A_{12}}\ldots\ldots & \mathbf{A_{1j}} \\ \mathbf{A_{21}} & \mathbf{A_{22}}\ldots\ldots & \mathbf{A_{2j}} \\ \cdots & \cdots & \cdots \\ \mathbf{A_{n1}} & \mathbf{A_{n1}}\ldots\ldots & \mathbf{A_{nm}} \end{matrix} \tag{3}$$

Regarding EFIS, the covariance of the Matrix identifies ellipsoidal rules. In particular, each rule is represented by an ellipsoid covering a portion of inputs-outputs space and they overlap. Geometrically, an ellipsoid z can be represented by Eigenvectors and Eigenvalues of a definite matrix DM: If n and p are the number of inputs and outputs respectively, q = n + p represent the dimension of the ellipsoid. Its columns are the unitary eigenvectors.

Let R = Diagonal matrix of Eigen values of DM

S = Orthogonal matrix that orient the ellipsoid

Then

$$\begin{aligned} \boldsymbol{\mu}^{\mathbf{2}} &= (\mathbf{z} - \mathbf{c})^{\mathbf{T}}\, \mathbf{R}(\mathbf{z} - \mathbf{c}) \\ &= (\mathbf{z} - \mathbf{c})^{\mathbf{T}}\, \mathbf{S} \wedge \mathbf{S}^{\mathbf{T}}(\mathbf{z} - \mathbf{c}) \end{aligned} \tag{4}$$

Where:

$$\mu \; = \in \mathrm{R}^{+}$$

c = Centre of ellipsoid

Each ellipsoid represents a fuzzy rule and then, its projection on each possible values axis represents the support of membership function.

3.3 Evaluation and Ranking

Finally, the result obtained for each category of decision attribute will be aggregated into a single Decision Value (DV) for any Cloud provider. The DV is normalized as a single real number with 0 representing the Cloud with a condition of low acceptance and 1 representing the condition high acceptance.

The normalized DV will be used to rank Cloud providers based on users Application Demand (AD) in order to recommend the most suitable Cloud provider. The DV is then compared with the Application demand (AD) such that DV > AD. This will in turn be used for decision making. For example, if a user defines the Application Demand for an IoT based application to be 0.7, it is assumed that this value is obtained from the normalized weighted average of the priority score given to various critical decision attributes by the user.

4 Conclusion

Cloud adoption for Internet of things is gaining attention among researchers and organizations. The decision to choose a Cloud vendor is complicated and dynamic in nature. This paper proposed a model to support the decision making process for the adoption of Cloud computing in IoT. This system mainly provides an efficient method for decision making purposes using soft computing methodology and is aimed to be highly beneficial to any individual or organization. As a future work, extended efforts are being made to enhance the model by integrating service level agreements (SLA) from Cloud providers into the decision making process. Works can also be done to ensure that metrics to measure the Quality of Service (QoS) for CoT by Cloud Providers is integrated.

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