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The uncertain cloud: State of the art and research challenges ☆

Haithem Mezni [a], Sabeur Aridhi [b,*], Allel Hadjali [c]

[a] SMART Lab, University of Jendouba, Avenue de l'Union du Maghreb Arabe, Jendouba 8189, Tunisia
[b] University of Lorraine, LORIA, Campus Scientifique, BP 239, 54506 Vandoeuvre-lès-Nancy, France
[c] LIAS, 1 Avenue Clément Ader, BP 40109, 86961 Futuroscope Chasseneuil, France

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ABSTRACT

During the last decade, cloud computing became a natural choice to host and provide various computing resources as on-demand services. The correct characterization and management of cloud environment objects (clouds, data centers, providers, services, data, users, etc.) is the first step towards effective provisioning and integration of cloud services. However, cloud computing environment is often subject to uncertainty. This could be attributed to the incompleteness and imprecision of cloud available information, as well as the highly changing conditions. The purpose of this survey is to study, criticize and classify the already existing works that deal with uncertainty in the cloud. We present a taxonomy on the uncertainty in the cloud and we study how such concept was tackled by researchers in cloud environments. Finally, we identify the challenges and the requirements to deal with uncertain data in the cloud, as well as the future directions.

1. Introduction

During the last decade, cloud computing has attracted a lot of attention and was largely accepted as a powerful model for hosting and delivering services. This rapid rise and adoption have led to the publishing of a huge number of on-demand services including: storage, computation, networking, business processes, databases, etc. [1].

Even though cloud computing has attracted a lot of attention and is largely accepted as a powerful service provisioning model, organizations are still reluctant to use cloud services because of the uncertain nature of the cloud, especially in security and privacy levels, legal risks, resources elasticity and availability, etc.

Cloud services often are associated with some uncertainty in their information, including quality of service (QoS) levels, users ratings, available resources, workload and performance changes, dynamic elasticity, availability zones, service descriptions, etc. In addition, the highly dynamic cloud environment adds a new factor of uncertainty, as it may have a negative impact on the quality of cloud services and, consequently, on services provisioning and integration. This uncertainty regarding the cloud services context raises a question about how to trust the available cloud information and brings additional challenges to the cloud actors. Therefore, the need to model and handle uncertainty in the context of cloud environments is of paramount importance to maintain the sustainable use of such technology.

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* Corresponding author.
E-mail addresses: haithem.mezni@gmail.com (H. Mezni), sabeur.aridhi@loria.fr (S. Aridhi), allel.hadjali@ensma.fr (A. Hadjali).

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Extensive research has been conducted to address uncertainty issues in various fields including e-commerce [2], social networks [3], decision making [4], data integration [5], location-based services [6], and recently Internet of Things [7]. However, uncertainty issues in the context of cloud computing have not been solved yet. A main motivation behind addressing uncertainty in the cloud to satisfy user needs, is the growing reliance on such highly dynamic cross-platform also considered as a big distributed container of uncertain cloud services and their related data.

To deal with cloud computing uncertainty concerns, the few existing solutions mostly tried to adapt techniques inherited from Web domain and Web services, as they are considered the ancestors of cloud computing [8]. However, these approaches are not always adequate and, in many cases, are unrealistic due to many reasons such as the cloud architecture, the various service models, the large-scale cloud environment, etc. Consequently, the need to reconsider uncertainty issues in the context of cloud computing arises.

Several cloud computing issues should be revisited when talking about uncertainty in the cloud. In fact, this term is tightly coupled with various cloud management problems, including service deployment and resource provisioning, selection of optimal cloud availability zones for service deployment, data and service integration, data mining and knowledge discovery, trust management, security and privacy, etc. To address the above problems, existing approaches tried to define uncertainty models for the cloud computing context (e.g., clouds conditions, services, etc.) [9]. Other proposed methods deal with reasoning over uncertain cloud services [8]. Bayesian and probabilistic models were also studied to see their relevance to the uncertain cloud [10]. Few other researchers have adopted formal and fuzzy methods, as well as theoretical algorithms to solve some uncertainty issues [11].

In this survey, we study the uncertainty issues in the cloud and the existing models for uncertainty assessment and management. The main contributions of this work are as follows:

- We present a categorization and a taxonomy of uncertainty factors in cloud computing.
- We provide a literature review and a classification of uncertainty-aware cloud computing approaches.
- We point out the major research challenges related to the uncertainty problem in the context of cloud environments.
- We identify the future directions to handle uncertainty through the cloud services life-cycle management.

The rest of this paper is organized as follows. Section 2 presents the cloud computing paradigm. Section 3 introduces the concept of "uncertain cloud" and the major sources of uncertainty in the cloud. Section 4 discusses the existing works on uncertainty handling through the cloud services life-cycle. Section 5 provides a comparison and a summary on the presented approaches. In section 6, we identify the main uncertainty challenges and we provide the future directions in the field of uncertain cloud computing. The last section concludes the paper.

2. Cloud computing

According to the National Institute of Standards and Technology (NIST), Cloud computing is a new service delivery model that allows offering users an on-demand access via Internet to dynamic and scalable services including computation, storage, network, platform, software, etc. [12]. Those cost-effective and user-attractive features have led many IT giants like Microsoft, Amazon, Google to deploy their own cloud computing infrastructure and offer various types of services. Cloud computing has five major characteristics: on-demand self-service, broad network access, resource pooling, rapid elasticity, measured service. These characteristics distinguish cloud computing from other technologies and make this paradigm an attractive, highly useful business solution for enterprises that can observe a growth of benefits for a short period of time after adopting cloud computing.

Three main services are common in the literature, which are: Software-as-a-service (SaaS) such as online word processing and spreadsheet tools, CRM services and web content delivery services Salesforce CRM, Google Docs, etc.; Platform-as-a-service (PaaS) such as Microsoft Azure and Google App engine; Infrastructure as-a-service (IaaS) such as Amazon EC2 and S3, Terremark Enterprise Cloud, Windows Live Skydrive and Rackspace Cloud which provide cloud services to the user. These three services of a cloud can also be considered as services-by-layer, which refers to the layers of cloud computing service architecture [1]. This means that a service can be built on top of another service, as shown in the layered model of cloud computing (see Fig. 1).

Besides these three shapes of cloud services, other service models have emerged such as Hardware as a service (HaaS), Framework as a service (FaaS), Database as a service (DBaaS), Network as a service (NaaS), Business process as a service (BPaaS), etc. [13]. To cope with the heterogeneity of cloud users' profiles and requirements, cloud services are deployed and offered using different cloud deployment models, including public cloud, private cloud, hybrid cloud, and community cloud.

3. Uncertainty in cloud computing

There is a multitude of challenges to tackle with when speaking about cloud computing. We give as example the security, trust and uncertainty related problems. As it is a virtual environment that provides a virtualized service, the cloud should guarantee a certain degree of certainty that reassures its users about the products they consume. In fact, the cloud environment is characterized by an imprecision that is justified by its dynamic nature from one hand, and the lack of information

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