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Toward trustworthy cloud service selection: A time-aware approach using interval neutrosophic set

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HIGHLIGHTS

- Propose a time-aware service selection approach for uncertain cloud industry.
- Formulate a multi-criterion decision-making problem using interval neutrosophic set.
- Support tradeoffs between performance–costs and potential risks in time periods.
- Establish the CINS theory to calculate and compare the candidate cloud services.
- Develop a CINS ranking method to create a ranked list of trustworthy cloud services.

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ABSTRACT

Cloud services consumers face a critical challenge in selecting trustworthy services from abundant candidates, and facilitating these choices has become a critical issue in the uncertain cloud industry. This paper employs the time series analysis to address challenges resulting from fluctuating quality of service, flexible service pricing and complicated potential risks in order to propose a time-aware trustworthy service selection approach with tradeoffs between performance–costs and potential risks. The original evaluation data about the services is preprocessed using a cloud model, and interval neutrosophic set (INS) theory is utilized to describe and measure the performance–costs and potential risks of services. In order to calculate and compare the candidate services while supporting tradeoffs between performance–costs and potential risks in different time periods, we established a cloud service interval neutrosophic set (CINS) and designed its operators and calculation rules, with theoretical proofs provided. The problem of time-aware trustworthy service selection is formulated as a multi-criterion decision-making (MCDM) problem of creating a ranked services list using CINS, and it is solved by developing a CINS ranking method. Finally, experiments based on a real-world dataset illustrate the practicality and effectiveness of the proposed approach.

1. Introduction

1.1. Motivation

Recently, cloud computing has been gaining enormous momentum. Cloud service providers around the world have publicized many services [7]. Increasing numbers of cloud service consumers find the convenience and affordability of cloud services alluring; however, the rapid proliferation of cloud services draws consumers into the dilemma of service selection, especially when multiple services provide similar functionalities. This dilemma has created a critical issue in cloud computing field, that of facilitating cloud service consumers to select trustworthy services with tradeoffs between performance–costs and potential risks [29] among abundant candidates. This task includes the following challenges:

(1) The quality of service (QoS) of cloud services generally fluctuates within a certain range due to the dynamic cloud environment. The quality of experience [27] for consumers is often different from the QoS claimed by service providers. According to the evaluation reports [80] of cloud hosts in China, the performance of services varies widely. In some key

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indicators, such as network throughput and memory speed, the maximum measured value is ten times more than the minimum. The real QoS experienced by consumers can be influenced by factors such as client device type, network location and context [54,83,77]. In previous experiments [40] based on real-world WS-DREAM dataset #2 [88], we analyzed the response time for 5,825 services collected from 339 users, and found that the coefficients of variation for most of services exceed 1.0. As these data illustrate, how to accurately measure the uncertainty of QoS combining the feedback data [40] from consumers, continuous monitoring data [15] or auditing data [36] from service providers, and continuous evaluation data from third parties [80,12,10], has become a key problem in the cloud environment.

(2) Although the load-balancing strategies have been implemented in cloud platforms [34], the load conditions for cloud services may be quite different from one another based on different networks or geographical locations. Within a specified time period, some services are possible under a heavy load, while others might only be possibly under a light load, giving consumers different quality of experience. In order to balance loads, improve energy efficiency and maximize profits, service providers are likely to adopt flexible pricing over time for cloud services [78,48,53]. For example, a service might offer a considerable discount during its light load time period to attract more consumers, or charge additional fees during a time period that is highly volatile in user interaction. Moreover, consumers might in practice attach particular importance to specific time periods according to their application requirements, or purchase a service despite its poor performance during time periods that are less important to them. Therefore, identifying the different performance and cost of service in time periods is of great significance for consumers distinguishing among candidates.

(3) Over the past few years, security problems have increasingly emerged in cloud services, such as Salesforce services, EC2 services, BPOS services, SONY Playstation services and iCloud services. These events have proven that cloud computing is fraught with potential risks that must be carefully evaluated prior to engagement [19]. Recently the risk assessment in cloud services has attracted concern from some organizations, including Cloud Security Alliance (CSA) [13], China Cloud Computing Promotion and Policy Forum (3CPP) [10], and researchers [81,22]. Some primary potential risks to cloud services have been identified and analyzed [17,32]. Especially, recognized as the important risks inherent to the cloud, the availability [6,56] of cloud services and the disruption or failure of cloud computing network [49] are vulnerable to the heavy load and networks' susceptibility in specified time periods. In contrast to performance and costs of cloud services, these potential risks inherent to the cloud are more uncertain. The assessment of potential risks over multiple time periods adds extra complexity to trustworthy service selection problem.

In real-world applications, both the performance–costs and some potential risks of cloud services are dynamic and uncertain during different time periods. Naturally, consumers hope to select the most trustworthy cloud service among abundant candidates by considering the tradeoffs between performance–costs and potential risks over multiple time periods. Consumers may pay less attention to potential risks when performance–cost is more important to them, and may pay less attention to performance–cost during times of sensitivity to potential risks. In order to achieve higher performance–costs in cloud services, consumers can change the time periods of their usage, or they may pay more to enjoy better performance during specific time periods. This paper targets the research tasks of (1) accurately describing and measuring the performance–costs and potential risks of cloud services as a whole, with consideration of uncertainty, and (2) calculating and comparing candidate services with tradeoffs between performance–costs and potential risks, according to the requirements of different application scenarios during different time periods.

1.2. Our contributions

In this paper, to measure the uncertainty of cloud environment, we have adopted a new theory known as interval neutrosophic set (INS) [67,84], which is a generalization of classical, three-valued and fuzzy logic. The assessment data of cloud services and the user's application requirements are integrated and transformed into INS. Every service is measured from three aspects, namely performance–costs, potential risks and their uncertainty, which are equivalent to the truth-membership, falsity-membership and indeterminacy-membership, respectively, in INS. The services with high performance–costs, low risks and uncertainty may become the trustworthy candidates. Our strategy for selecting trustworthy services from an abundant field of candidates involves formulating the problem of time-aware service selection with tradeoffs between performance–costs and potential risk as a multi-criterion decision-making (MCDM) problem that creates a ranked services list using INS theory.

The main contributions of this paper are as follows:

(1) In order to measure the uncertainty of cloud services and compare candidate services with tradeoffs between performance–costs and potential risks, we propose the cloud service interval neutrosophic set (CINS), based on INS and combining the time period features of cloud services with the tradeoff coefficients from consumers. The aggregation operators and the entropy weight measure method for CINS are designed based on theoretical proofs.

(2) We describe and assess the performance–costs and potential risks of cloud services by utilizing the cloud model and INS theory from the new perspective of time series analysis. Based on this assessment, we formulate the time-aware trustworthy cloud service selection problem with tradeoffs between performance–costs and potential risks over multiple time periods as a MCDM problem employing CINS theory. We then develop a CINS ranking approach to solve the MCDM problem.

(3) We examine the proposed approach through experiments on a real-world dataset and an appropriate baseline for our comparative analysis. Results demonstrate that our approach can work effectively in the risk-sensitive service selection mode and the performance-cost-sensitive service selection mode, and also prevent malignant price competition launched by some low-quality services. This paper can provide decision support approach for time-aware trustworthy service selection problem.

The rest of this paper is organized as follows. Section 2 briefly introduces the related work. Section 3 defines neutrosophic set (NS), INS and CINS. Section 4 defines the problem. Section 5 presents the aggregation operators and the entropy weight measure method for CINS. Section 6 puts forward the time-aware trustworthy service selection approach. Section 7 analyzes the experiments and results. Finally, Section 8 presents conclusions.

2. Related works

2.1. Trustworthy cloud services selection

Facilitating users' selection of trustworthy candidates from a set of functionally equivalent cloud services represents an exciting