A Research Roadmap for Bringing Continuous Quality Assurance and Optimization to Cloud Service Brokers

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Abstract: Cloud service intermediation is becoming increasingly recognized as a key component of the cloud computing value chain. Existing cloud service intermediaries already offer capabilities such as integration, customization or aggregation brokerage, but in the future, enterprises will require much more sophisticated capabilities going far beyond what is available today. The types of brokerage capabilities foreseen to be most valuable for service consumers, and at the same time most demanding for future enterprise service brokers to implement, are those addressing continuous quality assurance and optimization of cloud services. In this paper, we present a research roadmap for bringing continuous quality assurance and optimization capabilities closer to the reach of enterprise cloud service brokers. We present a scenario for motivating the need for such capabilities, as well as a discussion of the dominant views on cloud service brokerage.

1. Introduction

As enterprises increasingly adopt the model of cloud computing, their IT environments are transformed into a matrix of interwoven infrastructure, platform and application services delivered by multiple providers. In most cases, these services will span not only different technologies and geographies, but entirely different domains of ownership and control, making the strategic and operational management of the new, cloud-based IT landscape a rather challenging exercise.

To deal with the complexity of consuming large numbers of cloud services from diverse sources, future enterprises will increasingly rely on specialised cloud service delivery intermediaries. Existing cloud service intermediaries already offer related capabilities such as integration, customization or aggregation brokerage, but in the future, enterprises will require much more sophisticated brokerage services going far beyond what is available today. The types of brokerage capabilities foreseen to be most valuable for service consumers, and at the same time most demanding for future service brokers to implement, are those addressing continuous quality assurance and optimization of cloud services.

This paper presents a research roadmap for bringing continuous quality assurance and optimization capabilities closer to the reach of enterprise cloud service brokers. The objective of the research roadmap is to lead to the development of a software framework aimed at enabling cloud service intermediaries to equip their platforms with methods and mechanisms for continuous quality assurance and optimization of cloud services. Employing the capabilities provided by such a framework will assist future enterprise cloud service brokers in providing assurances towards consumers with respect to how reliable and how optimal the delivered services are.

The rest of the paper is structured as follows. Section 2 discusses the dominant views on cloud service brokerage. Section 3 presents a scenario for motivating the need for the aforementioned capabilities. Section 4 explains the capabilities required for continuous quality assurance and optimization. Section 5 presents a research roadmap for developing such capabilities. Before the paper concludes, related work is presented in Section 6.

2. Views on Cloud Service Brokerage

Technology market analysts at Gartner Inc. have defined service brokerage as "the purpose of a business that operates as an intermediary" in order to add value to the consumer's use of a service [1]. According to the same analysts, a business cannot be considered a Cloud Service Brokerage if it does not have a "direct contractual relationship with the consumer(s) of a cloud service" [2]. Gartner analysts draw a useful distinction between the terms "brokerage" and "broker". These terms are often used interchangeably, but actually refer to different concepts. In Gartner's view, a broker is "a person, company or piece of technology that delivers an instance of brokerage or, the specific application of a mechanism that performs the intermediation between consumers and providers".

According to Gartner, cloud service brokers deliver value via three primary roles (while additional roles are also possible). The first role is that of an Aggregation Broker, delivering two or more services to consumers and providers. This does not involve any integration or customization of services; its capabilities are to support large scale cloud provisioning, normalized discovery, access, billing, etc. The second role is the Integration Broker, whose value proposition is to make independent cloud services work together for customers. It can allow cloud to on-premises process integration or cloud to cloud integration (such as synchronizing between Gmail and salesforce.com. The third role is the Customization Broker, whose value proposition is to alter or add to the capabilities of a cloud service in order to improve it (e.g. by adding custom analytics to a cloud service).

By virtue of this broad definition, Gartner essentially considers any intermediation offering that adds some kind of value to a cloud service as a cloud service broker. Any provider of relevant services or technology, even with the most basic intermediation capabilities and a "simple" value proposition already qualifies as CSB. Some argue that this definition is too inclusive to be useful, and attribute Gartner's stance to the fact that it is a vendor-driven market research firm, rather than a vendor-independent assessor of best practice, and that the firm's views are forcibly shaped by the needs of constituencies that pay for its research: distributors, system integrators, and independent software vendors [3].

Forrester Research, on the other hand, defines a cloud service broker as the most complex of business models in the cloud computing space. Essentially, this model leverages skills and capabilities from all three of the traditional business models of software, consulting, and infrastructure. Forrester Research analysts argue that there are no brokers in the market yet, and that a cloud intermediary has to offer a certain complex "combined" value proposition in order to qualify as broker. Similarly to Gartner, Forrester also distinguishes between three types of Cloud Brokers, but according to the level of the cloud stack at which they operate: (i) Simple Cloud Broker, providing dynamic sourcing of public IaaS services; (ii) Full Infrastructure Broker, providing dynamic sourcing across public, virtual private, and private IaaS; and (iii) SaaS Broker, providing unified provisioning, billing, and contract management with multiple SaaS offerings, including integration [4].

The US National Institute of Standards and Technology (NIST) takes a different viewpoint, describing the cloud service broker as "an entity that manages the use, performance and delivery of cloud services, and negotiates relationships between Cloud Providers and Cloud Consumers". NIST categorizes brokers into another three categories according to their functions (with some differences compared to Gartner's definitions). The first is Service Intermediation, where a cloud broker enhances a given service by improving some specific capability and providing value-added services to consumers (e.g. by managing access to cloud services, identity management, performance reporting, etc.). The second is Service Aggregation, where a cloud broker combines and integrates multiple services into one or more new services, provides data integration and ensuring secure data movement between consumer and providers. The third is Service Arbitrage, which is similar to service aggregation except that the set of services being aggregated is determined dynamically based on multiple factors (e.g. based on external credit-scoring services).

It becomes apparent that there is an on-going debate on the definition of cloud (service) broker and the characteristics that a cloud service intermediary should have in order to be labelled as such. This is understandable, given that the field of cloud computing is still evolving and the technology and business models that are relevant to cloud service brokerage are not yet mature. Nevertheless, cloud service intermediation is becoming increasingly recognized as a key component of the cloud computing value chain. There are several cloud service intermediaries in the market who already offer capabilities such as integration, customization or aggregation brokerage, but in the future, enterprises will require much more sophisticated capabilities going far beyond what is available today.

To help enterprises deal with the complexity of consuming large numbers of cloud services from diverse providers, future brokers will need to implement a wide array of brokerage capabilities for continuous quality assurance and optimization of cloud services. Such capabilities will span across the cloud computing layers (IaaS, PaaS, SaaS), and will cover services ranging from simple programmatically-accessible web APIs to entire software applications accessed through a web browser.

3. Motivating Scenario

We argue that continuous quality assurance and optimization capabilities will assist future enterprise cloud service brokers to provide assurances towards consumers with respect to how reliable as well as how optimal the delivered services are. To motivate the need for such capabilities, let us consider the following fictional scenario.

CloudB is a state-of-the-art cloud platform allowing end-users to subscribe to a variety of on-demand enterprise applications from the platform's marketplace. The marketplace houses a large collection of various productivity and small office apps which are developed by CloudB's network of partners (ecosystem partners). The platform also allows advanced users to develop and deploy their own custom applications on the platform, as well as to create rich compositions of applications and processes offered by third-party cloud service providers (enterprise mash-ups). In addition, the CloudB platform has been enhanced with capabilities for continuous quality assurance and optimization.

At some point, one of the ecosystem partners decides to offer a new service on the CloudB platform, called "mindCloud", which supports collaborative creation of mind maps. In order for the new service to become available over the CloudB platform, a number of "onboarding" criteria should be checked for fulfilment. This is a task related to continuous quality assurance and is supported by the policy evaluation mechanisms of the platform, which guarantee that the new mindCloud service does not violate any of the CloudB platform provider's business policies, or the legal regulatory framework that CloudB needs to adhere to. Another type of quality control should be able to verify, through automated functional testing, that the programmatic interfaces of the mindCloud service adhere to the technical specifications created by the developers of the CloudB platform, so as to guarantee smooth integration with the execution environment and the service marketplace (certification testing). This is necessary not only during onboarding, but also whenever the developer of mindCloud wishes to update the service to a new version (regression testing).

As soon as mindCloud becomes available on the CloudB platform marketplace, the continuous optimization mechanism detects a new opportunity with respect to a particular user who is already subscribed to a similar but more expensive service. Switching to the mindCloud service would result to cost reduction by 15%. Based on the adaptation alternatives analyzed, the CloudB platform can recommend to the user to either renegotiate the terms of provision for the original service, or to replace it with mindCloud.

CloudB platform incorporates mechanisms that allow for continuously monitoring service performance against SLA agreements. In event of an SLA violation, the adaptation mechanism will reason about appropriate adaptation actions in order to recover from the failure, such as substituting a service. In addition, the failure prevention mechanism can indicate that there are risks for other consumers of the service that has just failed, and produce warnings or proactively generate an adaptation plan. This mechanism can also detect that the response time of some service is dropping rapidly, and predict a forthcoming failure, despite the lack of an immediate SLA violation.

4. Capabilities Required for Continuous Quality Assurance and Optimization

To support the brokerage scenario outlined above, a set of continuous quality assurance and optimization capabilities are required. We can identify four groups of such capabilities to be addressed within a unified software framework:

1. Capabilities for cloud service governance and quality control: managing the lifecycle of cloud services as they evolve; evaluating services for compliance to policies addressing technical, business and legal aspects of service delivery; continuously monitoring services for conformance to SLAs; repetitively testing services to certify conformance to specifications or regulations and compatibility with expected behaviour.
2. Capabilities for cloud service failure prevention and recovery: reactive and proactive detection of cloud service failures; selection of suitable adaptation strategies to prevent or to recover from problematic situations as these surface; recommendation or (where possible) automated enactment of adaptation actions such as service substitution or renegotiation of service terms.
3. Capabilities for continuous optimization of cloud services: continuously identifying opportunities to optimize the set of services consumed by an enterprise with respect to different goals such as cost, quality, or functionality; ranking of optimization alternatives through multi-criteria decision making, based on quantitative and qualitative characteristics of services and their providers and exploiting a large number of QoS attributes, such as agility, assurance of service, cost, performance, usability.
4. Brokerage framework interfaces and methods for platform-neutral description of enterprise cloud services: a precondition for delivering the continuous quality assurance and optimization capabilities outlined above, is the ability of the brokerage framework mechanisms to interact with the cloud service delivery platform in which they are to be integrated, using appropriate platform-independent interfaces, as well as the availability of platform-neutral methods for description of cloud services.

5. Research Roadmap

The proposed research roadmap comprises seven milestones addressing the development of a platform-independent software framework intended to equip cloud service intermediaries with advanced methods and mechanisms for continuous quality assurance and optimization of software-based cloud services. The milestones are as follows:

1. Understanding the implications of introducing continuous quality assurance and optimization in enterprise cloud service brokers: the first milestone is to develop a thorough understanding of the requirements that the brokerage framework should address, and the implications that arise with respect to integrating such a framework in enterprise cloud service delivery platforms.
2. Creating specifications for the framework architecture and its interfaces to enterprise cloud service delivery platforms: the milestone that follows from the analysis of functional and non-functional requirements is the development of a conceptual architecture for the brokerage framework that identifies its core components and their functions, and the specification of the interfaces through which the framework could interact with the enterprise cloud service delivery platforms.
3. Developing methods and tools for creating platform-neutral descriptions of enterprise cloud services to facilitate continuous quality assurance and optimization: this milestone concerns the development of platform-neutral methods by which enterprise cloud services can be described to provide for all the necessary information upon which the mechanisms for continuous quality assurance and optimization can reason. It addresses the fourth group of capabilities of the framework and it includes methods for describing technical, business, and operational characteristics of cloud services.
4. Developing methods and mechanisms for enabling continuous cloud service governance and quality control: this milestone addresses the first group of capabilities of the brokerage framework, the development of mechanisms to help enterprise cloud service brokers perform governance and continuous quality control over the software-based services they deliver. It encompasses mechanisms for policy compliance checking, lifecycle management, dependency management, as well as methods for ensuring functional conformance of services to requirements through testing and certification.
5. Developing methods and mechanisms for enabling continuous cloud service failure prevention and recovery: this milestone addresses the second group of capabilities, the development of mechanisms to help brokers of software-based enterprise cloud services provide continuous failure prevention and recovery through reactive but also proactive failure detection and adaptation. This encompasses event-based methods and mechanisms for cross-layer monitoring and proactive monitoring for detecting and predicting failures, as well as mechanisms for reactive and preventing adaptation for recovering or preventing failures of cloud services.
6. Developing methods and mechanisms for enabling continuous optimization of cloud service delivery: this milestone concerns the development of mechanisms to enable enterprise cloud service brokers to continuously identify opportunities for optimizing the set of services consumed by an enterprise with respect to different goals like cost, quality, and functionality. These goals correspond to a number of precise (i.e. measurable) and imprecise (i.e. fuzzy) criteria that should be managed in a unified way through fuzzy and linguistic multi-criteria decision making.
7. Validating the framework: the last milestone in the research roadmap is validation of the framework through case studies on introducing brokerage capabilities to enterprise cloud service delivery platforms. Evaluation should be done with respect to the completeness and effectiveness of the framework, through diverse usage scenarios.

6. Related work

An extensive survey of the state-of-the-art in relation to cloud service governance and quality control can be found in [5]. Cloud service governance refers to policy-based management of the complete service lifecycle, which includes quality assurance of the cloud services themselves, and all their related artefacts [6]. Current practice in the related field of SOA governance [7,8] focuses on the use of registry and repository systems, with purpose-built software to check centrally whether service-related artefacts conform to the desired policies [6,7]. The identical approach has recently been applied to SaaS [9,10]. A major weakness in today's governance tools is failure to achieve appropriate separation of concerns between defining governance policies and evaluating data against these policies [11]. In the future, we envisage the development of methods leveraging Linked Data principles and Semantic Web technologies to effectively decouple the two concerns [6].

Quality control for SaaS has to date been assured through provider-based code-inspection and functional testing. Explicit methods for service testing have largely been interface-based [12,13], although some attempts to specify complete behaviour have been suggested using graph transformation rules [14], WSDL augmented with UML state machines or OCL [15,16] or SAWSDL augmented with pre- and postconditions [17-19]. The latter showed how a complete service EFSM could be generated from interfaces descriptions specifying inputs, outputs, preconditions and effects (IOPE). The state machine specification was then amenable to the Stream X-Machine complete test generation method, which tests exhaustively for all positive and negative transitions [20,21]. This suggests a way ahead involving standard state-based specifications for services in XML, from which complete abstract test-sets may be synthesized automatically, before being grounded for particular service applications that use REST, SOAP or rich-client communications.

The field of adaptive service-based systems (SBS) [22] is concerned with the development of techniques for monitoring and adapting SBS, which share similar characteristics and problems with cloud services. Therefore, techniques from this domain can be adapted for the context of cloud service brokerage, which requires the intermediary to monitor data from heterogeneous sources for detecting symptoms and correlating those symptoms with additional knowledge to identify or predict failures. An extensive state of the art analysis can be found in [5], which describes techniques for monitoring or adaptation of SBS, approaches for multi- and cross-layer monitoring and adaptation, as well as relevant work on failure prevention in SBS. The survey identifies several challenges relevant to cloud service failure prevention and recovery that are not addressed in the literature, including (i) the metrics that can be used for identifying failures of cloud services and a broker should collect data for, (ii) the method that the broker should use for avoiding being overwhelmed during monitoring of the different metrics concerning a large number of cloud services, which are provisioned by many cloud service providers and (iii) the appropriate prediction technique that the cloud service broker should use for identifying an impending failure, based on a metric. In addition, several other architectural issues related to flexibility, extensibility and dynamicity should be considered [23].

Up to now, cloud services optimization has been primarily investigated from a cloud provider's perspective as a multi-objective decision problem [24,25] that considers user satisfaction as a constraint rather than as the actual optimization goal. From the perspective of the cloud consumer, Han et al. [26] proposed a service recommender framework using network QoS and Virtual Machine (VM) platform factors for assisting user's decisions when it comes to cloud service optimization, addressing only IaaS issues. Furthermore, in [27] the use of a so-called service optimizer (SO) has been proposed that manages dynamic SLAs. It is evident that existing work has mainly focused up to now on the optimization methodologies rather than on the optimization process as a whole. Existing work (e.g.

[27,28]) mainly focuses on IaaS layer and does not consider the variety of changing conditions that may occur in a cloud service ecosystem. Moreover existing optimization methodologies consider only quantitative/measurable metrics in service characteristic evaluation [29]. Real world examples show that quantitative and precise models cannot always reflect the ranking among the services accurately [30].

The brokerage framework has to offer a set of interfaces enabling interactions between the involved actors and access to the quality assurance and optimization mechanisms in an interoperable way, i.e., as services. Furthermore, the service descriptions have to be exchanged in a platform-neutral way among the different actors involved in a brokerage scenario. The service descriptions have to reflect different aspects of a brokered service at the business, operational, and technical level.

To the best of our knowledge, there is no existing brokerage framework providing interface specifications for quality assurance and optimization. However, at least at the technical level, there is a range of fragmented state-of-the-art results that are relevant. There are several different strands of service description languages, techniques, reference frameworks and standardization efforts that are relevant for the conceptualization of service descriptions. The different approaches can be grouped together with respect to their scope (strand), namely those concerning the purely technical considerations, functional semantics, more comprehensive descriptions factoring in business-level, non-functional properties, and dedicated service conceptions in wider systems or networks. The service description efforts consolidating business, operational and technical aspects culminated in the development of the Unified Service Description Language (USDL). A comprehensive overview of the state-of-the art in the field of service description and the positioning of USDL is provided in [31]. Linked USDL, the successor of USDL, employs Linked Data principles to offer better extensibility than USDL, and can be used as an anchor for extensions addressing the specific needs of quality assurance and optimization brokerage [32].

7. Conclusions

Cloud service brokerage represents a new service model in the area of cloud computing, aimed at helping enterprises to deal with the complexity of consuming large numbers of cloud services from diverse sources. We are already witnessing a growing number of cloud service intermediaries that offer integration, customization or aggregation brokerage capabilities, but in the future, enterprises will require much more sophisticated brokerage services.

Brokerage capabilities for continuous quality assurance and optimization of cloud services are of high value to service consumers, and at the same time, of high complexity for enterprise cloud service brokers to implement. This paper has presented a research roadmap for bringing continuous quality assurance and optimization capabilities closer to the reach of enterprise cloud service brokers. The roadmap consists of seven milestones which lead to the development of a platform-independent software framework supporting continuous quality assurance and optimization for future enterprise cloud service brokers.

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