"HySLAC" – A Conceptual Model for Service Level Agreement Compliance in Hybrid Cloud Architectures

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Abstract: Cloud computing provides IT infrastructures and services via networks, and it enables economic potentials for end users as well as a focus on core competencies. In addition to its extensive potentials, cloud computing in general, and hybrid cloud computing in particular, pose new challenges in the negotiation and formulation of Service Level Agreements, as well as in the monitoring of and compliance with contractual requirements. An understanding of cloud service and deployment models, perspectives, roles, and contractual terms is essential for a successful and compliant adoption of hybrid clouds. Consequently, this paper proposes the novel HySLAC model, focusing on service level agreement compliance in hybrid cloud architectures. Based on eight model requirements and a systematic literature review, the HySLAC model was conceptualized with UML 2.0. It comprises eight UML classes and five associated enumerations, and it is instantiated by means of a case study. The model offers scientific and practical application capabilities for the analysis of service components as well as hybrid cloud service compositions, and it opens up potentials for decision support.

Keywords: Cloud Computing; Service Level Agreement; Quality of Service; Compliance

1 Introduction

Enterprise Architectures (EA) are constantly faced with new issues in the digital age [BSC19]. A central challenge in this context results from the increasing spread of cloud computing, whose various forms directly impact organizational EA [KGN09]. Cloud computing is characterized as ubiquitous on-demand access to available computing resources via networks, and it has become very attractive for companies [PRS09] [MG11]. Cloud service providers today are offering highly available storage, complex services, development platforms, and massive parallel computing resources at relatively low cost and without any need for implementation on the customer side [Li15]. The possibility of paying for necessary services and resources depending on use, i.e., a so-called “pay-per-use"basis, offers companies substantial economic advantages [Ya16] [PRS09]. Therefore, it is not surprising to see a growing trend in practice to move formerly in-house service systems into the cloud [PRS09]. Such a shift also enables companies to concentrate on their core competencies while avoiding unnecessary back-office activities [PRS09]. However, in addition to the potentials that cloud computing opens up for companies, there are also new challenges for Enterprise Architects in general and Enterprise Cloud Architects in

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particular [BB18], such as the negotiation and formulation of contracts between cloud providers and cloud customers, so-called Service Level Agreements (SLAs), and the monitoring and verification of compliance with service quality requirements, so-called Qualities of Service (QoS) [JAB12]. These challenges become even more complex when cloud providers adopt the dual role of provider and customer, e.g., when their own cloud service offerings build on the services of external cloud providers. The resulting “hybrid cloud” (HC) architectures establish SLA hierarchies [Co09] and hamper both monitoring and compliance with contractual requirements and QoS [JAB12].
The understanding of different cloud deployment and cloud service models, different perspectives, dependencies, SLAs, QoS, and roles associated with the introduction and user acceptance of cloud computing in general and HC computing in particular is of fundamental importance for Enterprise Cloud Architects, as it provides the foundation for a successful and compliant (hybrid) cloud deployment. The current state of research already provides conceptual models addressing individual relevant aspects of SLA compliance in HC architectures, such as cloud service models [YBD08], cloud deployment models [LMB16], SLAs, and QoS [KPP16] [Gu11] [Co09] [Th10]. However, to the best of our knowledge and belief, a conceptual model holistically addressing all cloud service models, cloud delivery models, contractual aspects, associated roles, and existing dependencies in the context of SLA compliance of HC architectures is still missing. Consequently, the research objective (RO) of our study is as follows:

RO: *The goal of the study is to conceptualize a model for service level agreement compliance in hybrid cloud architectures, considering cloud service models, cloud deployment models, involved perspectives and roles, as well as related contractual aspects.*

In order to address this research goal, we first derive relevant model requirements (MRs) from the theory in Section 2. Using the rigorous method of vom Brocke et al. [vo09] described in Section 3, we subsequently analyze relevant theoretical domain knowledge with respect to the identified MRs (Section 4). Based on the insight that no existing conceptual model maps all aspects of SLA compliance in HC architectures, we present a novel conceptual model, called “HySLAC,” in Section 5. The HySLAC model maps cloud deployment models, cloud service models, business and IT perspectives, SLAs, SLA templates, QoS, as well as relevant roles and dependencies in the context of SLA compliance of HC architectures. Our model is instantiated by means of a case study in Section 6. The paper concludes with a summary and a discussion of limitations in Section 7.

2 Theoretical Background and Model Requirements

In the following section, we address the theoretical background underlying this study as well as necessary concepts relevant to the problem context. The theoretical background serves to derive MRs with relevance for Enterprise Cloud Architects and provides us with a theoretical basis for a conceptual model of SLA compliance in HC architectures.

2.1 Cloud Theory

Our investigation is based on Cloud Theory (CT). Following the well-known treatise of the National Institute of Standards and Technology (NIST), three service models and four deployment models can be distinguished in the context of CT [MG11]. The service models are differentiated into Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS) [MG11]. IaaS addresses the operation of IT infrastructures by a provider who makes them available to end users "as a service" and provides the foundation for both PaaS and SaaS, since it is impossible to deliver platforms and/or software without infrastructure in terms of a service [MG11]. SaaS addresses the provision of software and related IT infrastructures for end users [MG11], and PaaS provides platforms and related IT infrastructures for application developers [Ya16] [MG11]. These service models give rise to MR1:

MR1: *Consideration of Software, Platform, and Infrastructure as a Service.*

In CT, the deployment models are divided into Private Clouds (PiC), Community Clouds (CC), Public Clouds (PuC), and Hybrid Clouds (HC) [MG11]. The PiC model is characterized by the fact that the cloud infrastructure is provided for exclusive use by a single organization [Go14]. However, PiC are often used by several customers, such as those of different business units [MG11] [Go14]. The PuC model includes cloud infrastructures for open use by the general public, and these can be owned by a business, academic, or governmental organization [Go14] [MG11]. The CC model combines the properties of the PuC and PiC models in line with requirements of one target user group [Go14]. The CC model is quite similar to the PiC model, but the infrastructures and computing resources are not exclusively available to one organization, but to two or more organizations [MG11] [Go14]. Thereby, CC aims to address common concerns of multiple organizations. The architecture of the HC model is far more complex than the others as it is composed of two or more different deployment models (PuC, CC, and/or PiC) that remain independent entities but are technologically combined [Go14] [MG11]. The second requirement for the conceptual model can be derived from the discussion of the deployment models as follows:

MR2: *Consideration of Private, Community, Public, and Hybrid Clouds.*

2.2 Involved Perspectives and Roles

The adoption of cloud services is associated with economic risks [PJW10], e.g., arising from downtime in business activities. These risks affect IT services (i.e., the IT perspective), business processes (i.e., the business perspective), and their intersections. Thus, the model-based connection between IT services and business processes represents MR3:

MR3: *Connection between IT services and business processes.*

The separation of involved roles into service providers and service customers is an essential feature for mapping cloud scenarios [MSY16]. In contrast to traditional, internal IT provisioning, the distinction between the interests of the roles involved must be taken into consideration [PM15]. However, in the context of HC architectures, the separation of roles into service providers and service customers reaches its limits. These limits result from the fact that the provider of a HC service is itself a user of a non-hybrid (ordinary) cloud service [PJW10]. In the given problem context, a total of four roles have to be distinguished: 1) the non-hybrid (ordinary) cloud service customer, 2) the non-hybrid (ordinary) cloud service provider, 3) the HC service customer, and 4) the HC service provider. Thus, we derive the fourth model requirement, which addresses the distinction of the four roles involved:

MR4: *Consideration of hybrid (4a) and non-hybrid (4b) cloud service customers, as well as hybrid (4c) and non-hybrid (4d) cloud service providers.*

2.3 Operational/Service Level Agreements and Qualities of Service

A SLA is a contract for an agreed IT service between a provider and a customer [PRS09]. The definition and formulation of SLAs is not trivial for either (hybrid) cloud service customers or (hybrid) cloud service providers. The reason for the non-triviality is that SLAs have to be negotiated individually in each case as uniform standards are largely lacking [Al15]. For example, the definitions and formulations of contractual penalties for non-compliance with promised performance levels of cloud services are generally diverse, which hampers a uniform risk assessment for service providers and customers [Al15]. A promising approach to address this challenge is the definition of SLA templates allowing for both providers and customers to use a consistent set of specifications [Br09]. On this basis, we define the consideration of SLA/SLA templates as the fifth model requirement:

MR5: *Consideration of Service Level Agreements/Service Level Agreement Templates.*

Based on the role model presented, we distinguish between SLAs and Operational Level Agreements (OLAs). An OLA is defined as an agreement between different service providers to ensure a SLA [KHB02]. Furthermore, an OLA is understood to be an agreement between different units within one service provider company [NK07]. The main difference between SLAs and OLAs is that OLAs are usually easier to negotiate and do not constitute a contract. We need to represent OLAs as a specialized form of SLA whenever two service components of the same service provider are used as part of a service composition. Thus, the sixth model requirement is as follows:

MR6: *Consideration of Operational Level Agreements.*

To measure and evaluate agreed performance levels of cloud services, QoS are commonly used [Su12]. Complex (hybrid) cloud architectures require an aggregation of QoS of individual service components that depend on the underlying service model and service architecture based on horizontal and vertical integration [BN13]. Common QoS aggregations are based, e.g., on multiplication and addition, the determination of local and global minima/maxima, and mean value calculations [Qi12]. Thus, the seventh model requirement addresses the representation of QoS as an offspring of the SLA and the consideration of horizontal and vertical aggregations of QoS across involved service components:

MR7: *Consideration of Qualities of Service and their horizontal/vertical aggregations.*

SLAs of PuC, especially for services that follow the SaaS model, are often non-negotiable due to the "one-to-many" relationship between a service provider and multiple service customers. According to [Co09], PuCs are usually defined as one-sided SLAs, i.e., as non-negotiable. Considering the different cloud deployment models which we already specified, different levels of negotiability can be derived: 1) full negotiability, 2) non-negotiability, and 3) partial negotiability. Partial negotiability occurs whenever at least one component of a service composition is non-negotiable. Consequently, the representation of the negotiability of an SLA and its levels represents our eighth and last model requirement:

MR8: *Consideration of the negotiability of Operational/Service Level Agreements and their levels.*

3 Research Method

The conceptual model for SLA compliance in HC architectures is to be constructed based on domain knowledge that we extract from the knowledge base of information systems research. Following the recommendations of Levy and Ellis [LJ06], we investigate this knowledge base by means of a systematic literature review (SLR). Moreover, to ensure scientific rigor in the procedure for carrying out our research, we rely on the well-known method used for SLRs proposed by vom Brocke et al. [vo09]. This method comprises a total of five steps: 1) definition of a review scope, 2) conceptualization of the topic, 3) literature search, 4) literature analysis, and 5) a summary and discussion of the research output.

3.1 Review Scope

For defining our review scope (step 1 according to [vo09]), we use Cooper's taxonomy of literature reviews [Co88]. As shown in Figure 1, the scope of our SLR is specified in terms of six characteristics.

Characteristics	**Categories**			
(1) Focus	**Research outcomes**	Research methods	Theories	Applications
(2) Goal	**Integration**	Criticism	**Central issues**	
(3) Organization	Historical	**Conceptual**	Methodological	
(4) Perspective	**Neutral representation**	Espousal of position		
(5) Audience	**Specialised scholars**	General scholars	**Practitioners**	General public
(6) Coverage	Exhaustive	**Exhaustive but selective**	Representative	Central or pivotal

Legend: **Selected category** | Unselected category

Fig. 1: Review scope of the systematic literature analysis

We investigate the literature base according to conceptual models, domain models, meta-models, and ontologies, hence our research focuses on the identification of corresponding research outcomes (1). In this context, the aim of our investigation is both to identify domain-specific concepts and to integrate related relevant issues (2). The organization of our review results is conceptual (3), as we aim to integrate the core concepts of the subject area as part of a comprehensive conceptual model. The research papers identified by the SLR and the conceptual model are presented and discussed neutrally (4). The research results will be particularly relevant for specialized scholars who deal with current problems of SLA compliance in the context of HC architectures, such as Enterprise Cloud Architects. Moreover, the conceptual model can be used as a starting point for practical reflections on dependencies, opportunities, and risks of cloud adoptions (5). Finally, the coverage of the SLR is comprehensive but selective (6). On the one hand, we selected well-known databases and specific search terms for our literature search. On the other hand, we conducted a comprehensive analysis of all search results based on this selective specification.

3.2 Conceptualization of Topic and Search for Topic-Related Literature

The conceptualization of the topic (step 2 according to [vo09]) has already been discussed in Section 2, in which we analyzed the theoretical background of our study, including necessary concepts, and derived relevant MRs for our later concept-centered analysis.
The five well-known databases Springer Link, EBSCOhost, Science Direct, Association for Computing Machinery Digital Library (ACM DL), and Association for Information Systems electronic Library (AISeL) were used for the literature search (step 3 according to [vo09]; see Figure 2). Following our discussion of the theoretical background, the literature search was initially begun with the search terms «service level agreement*» and «hybrid cloud*». However, the search with these terms using truncation (*) and an OR operator in all search fields led to an exorbitant amount of results (>10,000). Consequently, the search string was adjusted. Following the definition of the service models of NIST [MG11], we limited the search scope by adding the subject-relevant search term «*as a service». An initial look at the search results showed that QoS play a major role in complying with SLAs. Therefore, the term «qualities of service» was integrated by an OR operator. Finally, the search string

for searching the five databases was «(service level agreement* OR (quality OR qualities) of service) AND hybrid AND *as a service».

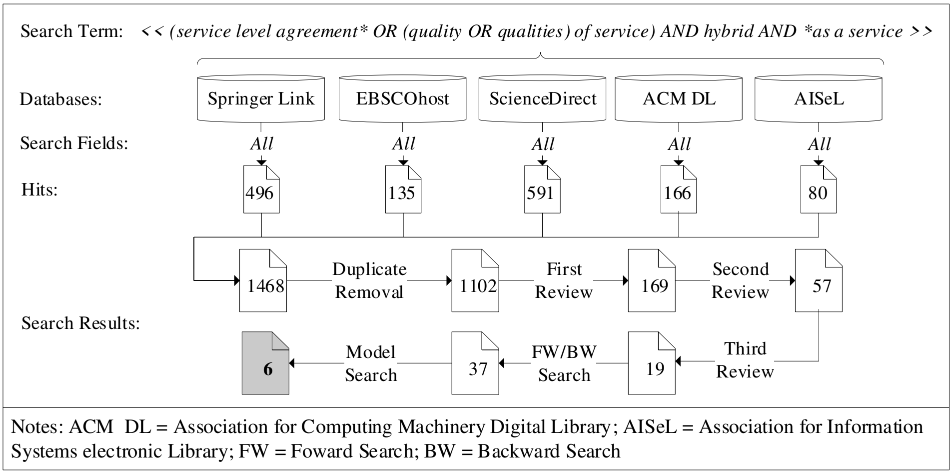

Fig. 2: Literature search process and search results

The literature management was done with Citavi 6. After implementing all search results in Citavi, we identified 366 duplicates. The remaining 1,102 hits were subjected to the first title-based selection, with 933 papers clearly sorted out due to irrelevance to the research problem. In the second evaluation phase, the abstracts of the remaining 169 publications were analyzed. The analysis of the abstracts was done by two independent researchers. Papers that were classified inconsistently were considered for further review. In the third review phase, the remaining 57 papers were subjected to a full text evaluation. As a result, 19 relevant papers were identified. Following the recommendations of Webster and Watson [WW02], we carried out an additional forward and backward search. This procedure enabled us to identify 18 additional relevant papers. The final 37 relevant papers were examined for conceptual models, domain models, meta-models, ontologies, frameworks, and further kinds of model-based conceptualizations which at least tackle the problem space of our study. The final search step led to a total of six relevant search results, which were subjected to a detailed model analysis. Brief summaries of the core contributions of the papers can be found in Appendix 1 (available at *https://bit.ly/3eKzp5h*).

4 Systematic Review of relevant Literature

The six relevant studies were analyzed by two independent researchers with regard to the fulfilment of the eight MRs (step 4 according to [vo09]). Due to consistent evaluation results, there was no need to discuss deviating evaluations. The results of the literature analysis can be found in Table 1, where a complete and partial representation of an MR by a source is represented by half (◐) and completely filled (●) circles.

	Model requirements (MR)										
Source	MR1	MR2	MR3	MR4a	MR4b	MR4c	MR4d	MR5	MR6	MR7	MR8
[Co09]	◐		●		●	◐	◐	●			◐
[KPP16]					●		●	●		●	●
[Gu11]										●	
[LMB16]	●	●			●	◐	●	●	◐	●	
[Th10]	◐		●	●	●	●	●	●			
[YBD08]	●										
Notes: ● = model requirement is completely represented; ◐ = model requirement is partially represented; empty cell = model requirement is not represented.											

Tab. 1: Evaluation of search results

The SLA management framework of Comuzzi et al. [Co09] and the architecture for multi-level SLAs by Theilmann et al. [Th10] partially address MR1, since they distinguish software and infrastructure layers but disregard the PaaS model. The unified cloud computing ontology of Youseff et al. [YBD08] completely addresses MR1 by describing the cloud service models as cloud layers. The ontology “CSLAOnto” of Labidi et al. [LMB16] contains specifications of deployment and service models completely addressing MR1 and MR2. The model of [Co09] completely addresses MR3 by linking software bundle SLAs and business SLAs. The model of [Th10] completely depicts MR3 as the role of the business manager agreeing with the SLA and the service provider being responsible to the customer. The model of [Co09] completely represents the non-hybrid service customer (MR4b), but cloud and HC service providers are only partially mapped (MR4c/d), as these roles are not clearly delineated. [KPP16] present a fine-grained depiction of SLA facets and related non-hybrid roles, thus completely addressing (MR4b/d). [LMB16] completely address MR4b/d by “SupportingParty” and “SignatoryParty” classes as well as corresponding cloud customers and cloud providers. Non-HC service providers (MR4c) are addressed, but they are not sufficiently differentiated from HC service providers. [Th10] completely distinguish ordinary and HC service providers (MR4c/d), i.e., so-called “Service Aggregators,” as well as customers of hybrid and non-HC services (MR4a/b). The consideration of SLAs (MR5) is completely represented by the SLA management framework of [Co09], the SLA facets of [KPP16], the SLA classes of [LMB16], and the SLA definitions of [Th10]. In [LMB16], OLAs (MR6) are only partially addressed (via “SupportingParty”), as the possibility of drawing conclusions on corresponding QoS is lacking. The capability to model QoS (MR7) is completely addressed by the QoS facet of [KPP16], the QoS level models of [Gu11], as well as the CSLAOnto of [LMB16]. The model of [Co09] partially depicts negotiability (MR8), but it lacks negotiation levels and implications. In contrast, [KPP16] completely represent negotiability through attributes that can be modeled at the finest QoS levels.

5 Conceptualization of the “HySLAC” Model

After analyzing the literature and determining that none of the existing models fully covers the identified MRs, we propose a novel conceptual model for SLA compliance in HC architectures called “HySLAC” (step 5 according to [vo09]). The model construction was carried out considering the methodology of March and Smith [MS95]. Hence, conceptual models can be built on the basis of domain knowledge and serve to represent new theories and/or phenomena by elements and their associations [MS95]. According to [MS95], such models are not primarily about truth but about utility.
The HySLAC model builds on the knowledge gained from our previous literature analysis, takes into account the eight MRs discussed in Section 2, and was created using the Unified Modeling Language 2.0 (UML). Since the UML allows the modeling of class diagrams on different levels of abstraction, it can also be used to create conceptual models that focus on domain concepts instead of software entities. Figure 3 shows HySLAC as a UML class diagram mapping core elements for SLA compliance in HC architectures as classes and their relationships as associations.

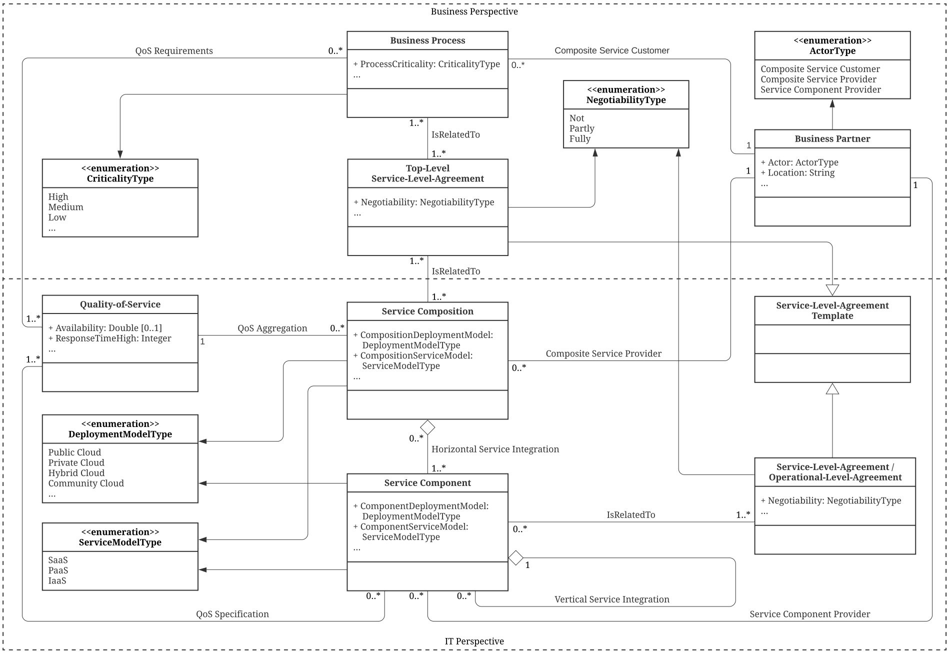

Fig. 3: The HySLAC model, represented as a UML 2.0 class diagram

The HySLAC model is divided into two thematic clusters. The first cluster represents the *Business Perspective*, which focuses both on *Business Partners* and *Top-Level-SLAs* of *Service Compositions*. This involves integrating the *Business Process* into the problem context. In contrast, the second cluster focuses on the *IT Perspective*. This cluster reflects the responsibilities of the IT department in the context of IT service management. It aims at ensuring the contractually agreed SLAs, taking into account *Qualities of Service* and Service Compositions. The central class of the conceptual model is the Top-Level SLA, which is an integral part of the negotiations between *Composite Service Customers* and *Composite Service Providers*. This class is used to compare the different *Requirements* from a business perspective with the technical possibilities, conditions, and prices of the Service Compositions.

In the Business Perspective, business criticality is evaluated based on the Business Process to be supported, and it is represented as an enumeration called *CriticalityType* with the attributes high, medium, or low. For example, core Business Processes can be specified with high criticality where the failure of an IT service would result in economic consequences (risks). The business-relevant evaluation of criticality is related to the *Negotiability* of (Top-Level) SLAs, which we modelled as an enumeration in line with the definition of negotiation levels as discussed in the context of MR8. By modeling the Business Perspective, it can be quickly determined whether changes in Service Compositions, such as the addition of non-negotiable PuC services, would jeopardize the compliant execution of business-critical processes. Another relevant aspect is the assignment of the Service Composition Provider to a Business Partner, which allows the business management to identify existing partnerships based on the enumeration *ActorType*, as well as resulting legal risks depending on the *Location* of the provider.

In the IT Perspective, the Service Composition is the key element resulting from the composition of Service Components. It always consists of at least one Service Component and represents the relationship to the Top-Level SLA. The Service Composition can consist of horizontally and/or vertically integrated components. *Vertical Service Integration* means that one service component serves as the technical basis for another Service Component, while *Horizontal Service Integration* means that services are combined and are not technically built upon one another. Service Components and Service Compositions are specified by the enumerations *ServiceModelType* and *DeploymentModelType*, whose characteristics are currently considered according to the NIST definitions [MG11], but which can easily be extended. If a Service Component or a Service Composition is provided by the same service provider, *Operational Level Agreements* are used instead of SLAs. However, if the service providers are different, SLAs are negotiated. QoS are modeled as measurable and predictable metrics for agreed OLAs/SLAs for the respective Service Components. The Service Composition aggregates (several) QoS of Service Components to a QoS of the Top-Level SLA. SLAs can also inherit from an *SLA Template* to achieve a consistent formalization of relevant QoS in tiered categories (e.g., gold, silver, or bronze). This allows service providers to specify established sets of characteristics of common QoS for service customers in order to simplify negotiations. SLA Templates have a high practical relevance, especially for PuC services, which are static due to their non-negotiability. Using public cloud SLA Templates, even Service Composition Providers can prepare service levels for HC services.

6 Instantiation of the HySLAC Model

We instantiated the HySLAC model based on a case study with a medium-sized company (see Figure 4). To conduct the case study, we 1) presented our HySLAC model and research project to the company, 2) discussed challenges of SLA compliance in the context of HC architectures, and 3) worked through a common application context.

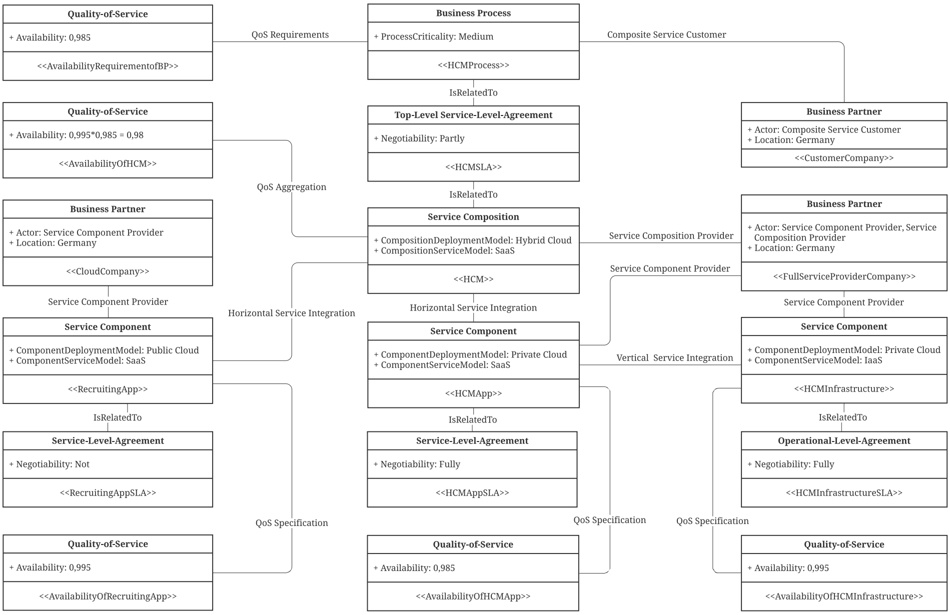

Fig. 4: Instantiation of the HySLAC model, represented as a UML 2.0 class diagram

The starting point of phase 3) was an ongoing Human Capital Management (HCM) service of the company under review which was previously provided as a PiC service for one of its customers. This service was to be extended by functionalities of a new PuC service (RecruitingApp) for the business process of recruiting. The new application was intended to replace the existing recruiting functionality within the company's IT system, while all other functionalities required for the HCM process would continue to be provided from the PiC service. Some data between the new application and the existing HCM system (e.g., applicant data in case of hiring) had to be synchronized systematically. This required the integration of the two service components into a HC service and the aggregation of the respective QoS. The original PiC service was provided through vertical integration of an underlying IaaS HCM infrastructure with a fully negotiable OLA. To illustrate our use case, service availability is shown as a QoS example in Figure 4. The instantiation shows a SLA adjustment after non-negotiable availability constraints are added to the aggregated QoS.

7 Conclusion

Cloud computing provides IT infrastructures and services via computer networks in order to achieve economic potentials for end customers and to enable companies to concentrate on core competencies. However, besides its extensive potentials, cloud computing in general, and HC computing in particular, pose challenges in the negotiation and formulation of SLAs, as well as in monitoring and complying with contractual requirements. An understanding of cloud deployment models, cloud service models, perspectives, roles, and contractual conditions (i.e., SLA and QoS) is of fundamental importance for Enterprise Cloud Architects as it provides the foundation for a successful and compliant (hybrid) cloud deployment. Therefore, this paper aimed to provide a conceptual model focusing on SLA compliance in HC architectures – the so-called HySLAC model.

Based on the derivation of eight MRs and a systematic analysis of domain knowledge according to the rigorous method of [vo09], we conceptualized the novel HySLAC model in UML 2.0, which comprises eight UML classes and five associated enumerations. In general, the model opens up practical application potentials for the analysis of service components and service compositions with regard to connected roles, as well as dependencies on SLAs, SLA templates, and QoS. The model specifically opens up practical application potentials for Enterprise Cloud Architects to analyze HC service compositions with regard to SLA hierarchies and QoS aggregations. Thus, the HySLAC model can be used as a tool for analyzing dependencies and restrictions before HC adoptions, and it opens up potentials for decision support. Scientists can specify the model for different cloud scenarios and new application contexts. Furthermore, the model provides a starting point for deriving context-specific SLA hierarchies and, based on this, opens up the potential for deriving new QoS aggregation algorithms across different hierarchical levels.

In order to adequately assess the explanatory power and scope of the model, the limitations of our investigation have to be considered. The derivation of MRs for the HySLAC model is founded purely in theory. Although the construction of a conceptual model based on domain knowledge is considered legitimate according to [MS95], we cannot fully ensure that all relevant model requirements have been considered. An additional empirical analysis, e.g., by means of a survey with experts, would address this limitation and represents a research desideratum. Moreover, our systematic literature review cannot guarantee that all relevant literature has been identified. However, the rigorous documentation of our literature review according to the method of [vo09] ensures traceability and reproducibility. Although our model was instantiated on the basis of a use case, a well-founded empirical evaluation is still pending. As a consequent next step of research, it is planned to extensively test the HySLAC model with partners from practice for further development.

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