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Complex Service Provisioning in Collaborative Cloud Markets

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Today's cloud consumers gain a high level of flexibility by using externally provided cloud-based services. However, they have no means for requesting combined services from different clouds or for enforcing an individual quality level. Laying the foundation for market-based cloud collaborations including the negotiation of individual quality parameters is an important aspect for future cloud computing. Cloud consumers, especially enterprises are then able to request complex services with consumer-driven quality guarantees according to their individual needs and are not concerned with the problem on how to make the different components work together. In this paper, we present an approach for collaborative complex service provisioning in cloud computing and an evaluation of selected mechanisms for the negotiation of quality parameters in such a collaborative market-based scenario.

1 Introduction

Cloud computing has recently attracted a lot of attention with respect to IT architectures and aims to provide computing resources in a highly dynamic and flexible manner. In 2010, the cloud computing market reached a large market volume and its size will grow further in the next years [11]. Nevertheless, cloud computing is still in a very early stage concerning open standards and interfaces [13], so that consumers cannot change selected cloud providers very easily. A vision aiming at these issues is a global cloud marketplace [1], which does not depend on the specifics of a certain vendor offering standardized interfaces. Such a cloud marketplace would also facilitate the combination of different services from various cloud providers and enable cloud federation scenarios [8]. Hence, it can be considered as a first step towards the Future Internet [7]. To realize the vision of a global cloud marketplace, several requirements have to be fulfilled. Quality parameters, such as reliability or availability, are especially crucial in a business environment. In order to retain control of the service quality, so-called Service Level Agreements (SLAs) can be negotiated between the service consumer and the cloud provider to ensure a level of quality consumers can rely on. Basically, an SLA represents a contract between two parties and defines the objectives (e.g., quality parameters) the cloud provider has to fulfill and the penalties in case the provider violates the agreement. At present, cloud providers offer no or only limited support for the negotiation of individual quality parameters [1]. Thus, consumers, especially enterprises are not able to obtain Quality of Service (QoS) guarantees according to their specific business constraints. But enabling consumer-driven QoS guarantees would increase the flexibility and efficiency when using cloud-based services. Furthermore, consumers wish to dynamically combine services from different cloud providers without further effort for the interconnection of the different components. This requires the collaboration between multiple cloud providers. Hence, an automated mechanism is required to negotiate individual QoS guarantees and to dynamically select collaboration partners from a set of multiple cloud providers.

In this paper, we present a collaborative cloud market model for complex service provisioning. The collaboration allows cloud providers to share their resources and to offer complex services on the cloud computing marketplace. Besides the selection of collaboration partners, negotiating individual QoS parameters is also a major issue that we address in the paper. The remainder of the paper is structured as follows. Section 2 describes the requirements for collaborative complex service provisioning, Section 3 introduces our collaborative market model and Section 4 presents initial experimental results of our approach. The paper closes with a discussion of related approaches in Section 5 and with a conclusion and future directions in Section 6.

2 Problem Statement

Our work focuses on a mechanism for collaborative complex service provisioning, in which services from different cloud providers can be combined to a bundle.

Definition 1 (Bundle) *A bundle B is a set S of m different functional services. Each component c in the bundle has communication relationships with a subset of $S \setminus \{c\}$, i.e., with some of the other components in the bundle.*

For example, an enterprise could request a set of services from multiple cloud providers to fulfill internal business activities, e.g., a Customer Relationship Management solution, data storage, virtual machines for data processing, and a database [8]. In this scenario, multiple providers offer heterogeneous services on the envisioned global cloud marketplace, where the following assumptions hold:

- **Specialization:** Each provider has specialized in providing specific service types. The providers participate in the market, because they are unable to provide all the required services on their own [9].
- **Comparability:** We assume that the services can be classified according to their functionality. Hence, all providers in a single category are competing with the other providers in the same category.
- **Standardized Interfaces:** There are no consumer switching costs due to specific service properties when changing cloud providers. The development of cloud standards is currently addressed by several activities[1].

[1] An overview can be obtained from `http://cloud-standards.org/`

- **Scalability:** In our basic model, we further neglect resource constraints in the first instance. Thus, we assume that each provider has unlimited resource capacities concerning the provider's specific service types.
- **Collaboration:** After the determination of the collaboration partners, the providers are responsible for providing the bundle. Since the several components in the bundle must be able to directly communicate with each other according to their communication relationships, the providers must establish connections between the components coming from multiple clouds. Such a so-called sky computing scenario [5] typically requires to lay a virtual site over the distributed resources among the different administrative domains.
- **Adaptability:** Finally, we assume that the cloud providers can vary the QoS levels that they provide according to their cost functions. Since they have private information, e.g., concerning their cost factors, a negotiation of QoS parameters is necessary.
- **Relationships:** Although cloud providers are located worldwide, they cannot establish data centers everywhere. Thus, they may have difficulties in fulfilling all QoS requirements, e.g., due to network delays. Hence, the relationships between the different components must be taken into account since they have a direct impact on the QoS parameters.

Two major issues that have to be addressed arise in such a collaborative cloud market scenario: How to negotiate the QoS parameters of a bundle with multiple cloud providers and how to select the collaborating parties? Cloud consumers must specify their requirements (e.g., upper or lower bounds) for the whole bundle and for each service that is part of the bundle. A market model is required to maximize the consumer's utility and the cloud providers' utility (in terms of cost), while considering the boundaries for the different parameters.

3 Approach

3.1 System Model and Notation

Our model consists of three main actors: service consumers, cloud providers and a market platform. Service consumers SC can request a bundle of services at the market platform and specify their requirements concerning the non-functional properties of the bundle, i.e., QoS parameters and price. These requirements are used by the market platform to compose the bundle. The composition is structured into two phases: the negotiation between the market platform and the cloud providers and the selection of the collaboration partners for the provision of the bundle. The two phases are described in the following.

To perform a first analysis, we assume a sequential order of the m services within the bundle B. The consideration of more complex communication relationships will be part of our future work. Furthermore, the services can be grouped into functional categories Cat_i with $i \in (1, \ldots, m)$. Each category consists of a set of cloud providers CP with p elements, where each element represents a cloud provider offering a service with the same functionality. The cloud

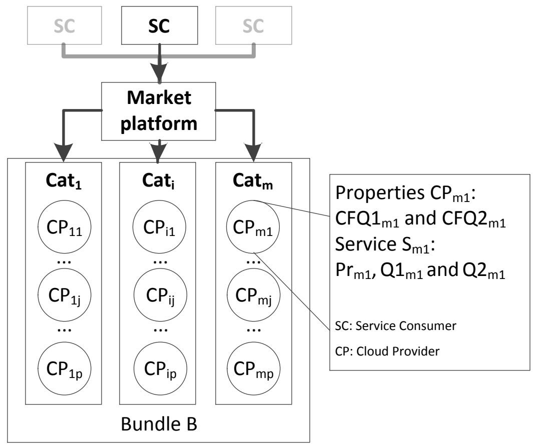


Fig. 1. Market system

providers are denoted with $CP_{i,j}$ and the service a cloud provider $CP_{i,j}$ delivers with $S_{i,j}$, where $i \in (1, \ldots, m)$ and $j \in (1, \ldots, p)$. We assume that a service $S_{i,j}$ is, besides its functionality, described with three properties: price $Pr_{i,j}$ and two QoS parameters $Q1_{i,j}$ and $Q2_{i,j}$, which are generic representations of possible QoS parameters (e.g., availability). From the service consumers' point of view, price is a negative attribute and QoS parameters are positive attributes. Service consumers specify their requirements with two elements: thresholds and utility functions. Both are provided for the functional category level as well as for the whole bundle. The thresholds on category level are $ThCatPr_i$, $ThCatQ2_i$ and $ThCatQ2_i$ for price and QoS parameters. In addition, the service consumer uses a utility function $UCat_i(S_{i,j})$, which shows the consumer's utility dependent on the non-functional properties of a service. The utility function is described in Section 3.2. During the negotiation, the goal of the market platform is to maximize the utility of the service consumer for each functional category while keeping the provided thresholds. Analogously, the cloud providers have a cost function, which specifies what effort is required to provide the QoS properties at a certain quality level for a given service. Therefore, each cloud provider $CP_{i,j}$ has two cost factors $CFQ1_{i,j}$ and $CFQ2_{i,j}$ for the two QoS parameters. The cost function $UCP_{i,j}(S_{i,j})$ reflecting the utility of a cloud provider is described further in Section 3.2. The overall model with its actors is shown in Figure 1.

It is not sufficient to specify only the requirements of single services of the bundle, but also the overall bundle must fulfill certain requirements. Therefore, the thresholds and an additional utility function for the service consumer are specified at bundle level. This information comprises the three thresholds $ThBuPr$, $ThBuQ1$ and $ThBuQ2$ and the utility function of the service consumer for the bundle $UBu(B)$. The goal of the market platform for the composition of the overall bundle is to fulfill the thresholds and to maximize the consumer's utility for the bundle. This problem is based on the previous negotiations in the functional categories and deals with the optimal selection among the resulting offers of the negotiation process.

3.2 Negotiation of Quality of Service

Negotiation takes place between the cloud providers and the market platform. The market platform uses the utility function of the service consumer and the provided thresholds for the negotiation. A service $S_{i,j}$ fulfills all thresholds if:

$$ThCatPr_i \geq Pr_{i,j} \text{ and } ThCatQ1_i \leq Q1_{i,j} \text{ and } ThCatQ2_i \leq Q2_{i,j} \quad (1)$$

The utility function is assumed to be additive and has a decreasing marginal utility (shown by the square roots) for both QoS parameters [2]. Each non-functional property of a service has an individual weight. The weight of the price is negative, whereas the weights of the QoS parameters are positive to express the utility for the service consumer. The weights are denoted with $wCatPr_i$, $wCatQ1_i$ and $wCatQ2_i$. The utility function of the service consumer is as follows:

$$UCat_i(S_{i,j}) = wCatPr_i * Pr_{i,j} + wCatQ1_i * \sqrt{Q1_{i,j}} + wCatQ2_i * \sqrt{Q2_{i,j}} \quad (2)$$

As already stated, each cloud provider has a cost function. In this function, every provider makes use of other cost factors to enforce certain QoS parameters, which are both negative, since the cloud providers have higher costs for providing better (higher) QoS values. Hence, the cost function represents the utility of the cloud providers. The utility function for the cloud provider $CP_{i,j}$ is as follows:

$$UCP_{i,j}(S_{i,j}) = Pr_{i,j} + CFQ1_{i,j} * Q1_{i,j} + CFQ2_{i,j} * Q2_{i,j} \quad (3)$$

The two parties fulfill the requirements for a negotiation, since they have different preferences for the given properties and want to maximize their utility. For the negotiation, a mechanism is required that specifies the protocol and the strategy of the parties on both sides. The given scenario with the market platform on the one side and p cloud providers in a functional category on the other side and three negotiation domains (price and QoS parameters) requires support for one-to-many negotiations and multiple attributes.

After an analysis of different negotiation protocols based on [12], which can be used in automated negotiations, we decided to use the contract net protocol [15] and the English auction [2] for an initial evaluation of the negotiation in the model. The contract net protocol is a simple protocol originally used for distributing tasks in computer systems. The tasks are specified by a central manager and sent to providers. The providers return an offer for the specification with the smallest price they can provide. After one round, the central manager assigns a task to the provider with the best offer. Using the contract net protocol, the price of the offer is calculated as follows:

$$Pr^{CNP}_{i,j} = -CFQ1_{i,j} * ThCatQ1_i - CFQ2_{i,j} * ThCatQ2_i \tag{4}$$

The cloud providers make a bid, if the QoS parameters they can provide meet the desired thresholds, i.e., an offer is valid, if $Pr^{CNP}_{i,j} \leq ThCatPr_i$. Since the utility function of the service consumer is private, the cloud providers only optimize the price of their offers according to the given thresholds. The assumption is that they are willing to make a bid until they gain no utility from the offer anymore. Hence, the value of the utility function is minimized in order to maximize the probability for a bid to get accepted.

In the English auction, bidders may bid for a particular good during several rounds, until no bids can be made anymore. A bid is valid, if it exceeds the currently highest ranked bid. Finally, the highest bid wins the auction. We use the English auction as a reversed auction (i.e., the cloud providers making offers which can be accepted by the marketplace) with a multi-attribute extension that enables the consideration of all requirements. In the original version of the English auction, cloud providers can be outbid during a single round. In our scenario, the market platform chooses the best offer after each single round and sets it as lowest bid for the next round. The dominant strategy for the cloud providers is to increase their offers in each round by a minimal difference $DiffOff$ between two offers. The increase does not refer to the price, but to the utility of the service consumer. This enables to consider not only the price, but all non-functional attributes for the auction. The calculation of the values for the increase and the prices is adapted from [2]. The QoS parameters are calculated as follows:

$$Q1^{EA}_{i,j} = \left(\frac{\frac{wCatQ1_i}{wCatPr_i}}{2 * CFQ1_{i,j}} \right)^2 \quad \text{and} \quad Q2^{EA}_{i,j} = \left(\frac{\frac{wCatQ2_i}{wCatPr_i}}{2 * CFQ2_{i,j}} \right)^2 \tag{5}$$

Based on these values and the utility of the current best offer $S_i^{BestOffer}$, the price is calculated as follows:

$$Pr^{EA}_{i,j} = \frac{\frac{\frac{wCatQ1_i^2}{|wCatPr_i|}}{2*|CFQ1_i|} + \frac{\frac{wCatQ2_i^2}{|wCatPr_i|}}{2*|CFQ2_i|} - UCat_i(S_i^{BestOffer}) - DiffOff}{-wCatPr_i} \tag{6}$$

However, there is a major difference between a standard English auction and the scenario in this work: the thresholds for the non-functional properties. These thresholds limit the properties and can lead to invalid solutions. Therefore, the approach used in this work adjusts the QoS parameters, if the calculated values are below the thresholds, and uses the new values for the calculation of the price.

Both negotiation protocols lead to a number of offers in each functional category. These offers must be composed to a bundle in the next step, which is described in the next section.

3.3 Partner Selection for Collaboration

The second part of the collaboration process is the selection of collaboration partners from the set of valid offers S_i^{Val} for each Cat_i after the negotiation. The size of S_i^{Val} is less or equal p, because not every cloud provider must make an offer. The selection of the collaboration partners is designed as optimization problem, which selects one service from each functional category. Each valid service $S_{i,j}$ has a binary decision variable $x_{i,j}$, which is 1 if the service is part of the optimal solution and 0 if not. The selection is based on the properties of the services as well as the connections between the services. Connections between services only exist if the services are neighbors in the sequential order of the bundle. A connection between services $S_{i,j}$ and $S_{i+1,k}$ is denoted with $Con_{i,j,i+1,k}$ and has the non-functional properties $CPr_{i,j,i+1,k}$, $CQ1_{i,j,i+1,k}$ and $CQ2_{i,j,i+1,k}$. The connections have an additional decision variable $y_{i,j,i+1,k}$, which is 1 if each variable $x_{i,j}$ and $x_{i+1,k}$ is 1. The aggregation operators of the non-functional properties are assumed to be summations. The second QoS parameter uses two additive functions to separate between services and connections. Other aggregation operators like multiplication or min-operators are also possible and can be considered in future research. The utility function of the service consumer for the bundle is as well additive and uses different weights to increase the flexibility just as the utility function of the service consumer for the functional categories. The weights $wBuPr(\leq 0)$, $wBuQ1(\geq 0)$ and $wBuQ2(\geq 0)$ are used for both, services and connections. The weighted utility and objective function and constraints are defined in Model 1, which is a linear optimization problem that can be solved optimally with a branch-and-bound approach [4].

4 Experimental Results

For the evaluation, the previously described model has been implemented. The implementation is agent-based and describes the behavior of the market platform and the cloud providers during the negotiation and solution of the optimization problem. The evaluation is a proof-of-concept for the developed model and, at the same time, analyzes the influence of the amount of cloud providers on the negotiation. The tests have been performed on a laptop with a 64bit dual core 2.53 GHz processor with 4 GB RAM and Windows 7 as operating system. For the simulation of the agents, Repast Simphony[2] has been used and the optimization problem has been modeled and solved with LPSolve[3]. The number of cloud providers within a category is varied between 2, 4, 6, 8, and 10 cloud providers. For each variation, 20 test cases have been generated. The scenario has been tested exemplary for 5 functional categories. The values for the parameters of the following evaluation are shown in Table 1. The table shows the ranges of the random numbers or if no range is given the fixed values of the parameters. Besides these parameters, the English auction uses a minimal difference between offers of 0.5 utility units.

[2] `http://repast.sourceforge.net/`
[3] `http://lpsolve.sourceforge.net/5.5/`

Model 1 Collaboration Partner Selection Problem

Objective Function (Maximize):

$$\sum_{i=1}^{m} \sum_{j \in S_i^{Val}} x_{i,j}(wBuPr * Pr_{i,j} + wBuQ1 * Q1_{i,j} + wBuQ2 * Q2_{i,j}) + \sum_{i=1}^{m-1} \sum_{j \in S_i^{Val}} \sum_{k \in S_{i+1}^{Val}} y_{i,j,i+1,k}(wBuPr * CPr_{i,j,i+1,k} + wBuQ1 * CQ1_{i,j,i+1,k} + wBuQ2 * CQ2_{i,j,i+1,k}) \quad (7)$$

Constraints:

$$ThBuPr \geq \sum_{i=1}^{m} \sum_{j \in S_i^{Val}} x_{i,j} * Pr_{i,j} + \sum_{i=1}^{m-1} \sum_{j \in S_i^{Val}} \sum_{k \in S_{i+1}^{Val}} y_{i,j,i+1,k} * CPr_{i,j,i+1,k} \quad (8)$$

$$ThBuQ1 \leq \sum_{i=1}^{m} \sum_{j \in S_i^{Val}} x_{i,j} * Q1_{i,j} + \sum_{i=1}^{m-1} \sum_{j \in S_i^{Val}} \sum_{k \in S_{i+1}^{Val}} y_{i,j,i+1,k} * CQ1_{i,j,i+1,k} \quad (9)$$

$$ThBuQ2 \leq \sum_{i=1}^{m} \sum_{j \in S_i^{Val}} x_{i,j} * Q2_{i,j} \quad (10)$$

$$ThBuQ2 \leq \sum_{i=1}^{m-1} \sum_{j \in S_i^{Val}} \sum_{k \in S_{i+1}^{Val}} y_{i,j,i+1,k} * CQ2_{i,j,i+1,k} \quad (11)$$

$$\sum_{j \in S_i^{Val}} x_{i,j} = 1 \forall i \in (1, \ldots, m) \quad (12)$$

$$\sum_{j \in S_i^{Val}} \sum_{k \in S_{i+1}^{Val}} y_{i,j,i+1,k} = 1 \forall i \in (1, \ldots, m-1) \quad (13)$$

$$x_{i,j} + x_{i+1,k} - y_{i,j,i+1,k} \leq 1 \forall i \in (1, \ldots, m-1) \wedge \forall j \in S_i^{Val} \wedge \forall k \in S_{i+1}^{Val} \quad (14)$$

The median run times of the two negotiation protocols are shown in Figure 2. They are distributed from 1.9 to 13.6 ms. For both protocols, the run time increases with a growing number of cloud providers. The contract net protocol shows slightly higher run times than the English auction. The reason for this is that the contract net protocol produces a larger set of valid services than the English auction, which increases the time to solve the optimization problem.

The service consumer's utility considered in the problem is measured on two levels: for each category and for the overall bundle. For the former, the absolute and the relative utility of the consumer is measured and for the latter, we only measure the absolute utility, since the relative utility is 100% for all the offers. The relative utility is calculated by using the Lagrange method [4] to evaluate the maximal possible utility a cloud provider can provide without given boundaries and without achieving an own utility. The result is set as maximum and the achieved utility is set in relation to it. The results for the relative utility are shown in Figure 3(a). They show that the contract net protocol reaches a relative

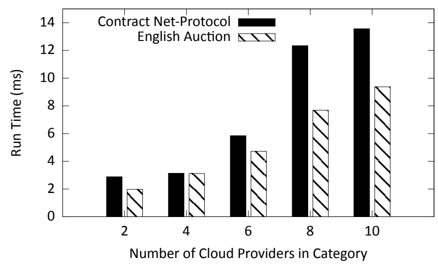


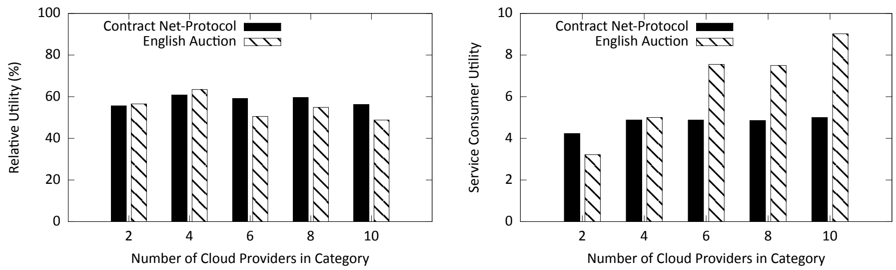
Fig. 2. Run time of negotiation protocols

utility of 60% and remains on the same level for all scenarios. The English auction achieves a similar level, but the relative utility decreases for a higher number of cloud providers within the categories. The reason for this decrease is that more providers lead to a higher probability that one provider cannot reach the optimal values for the non-functional properties. Thus, this provider increases the utility faster, which leads to earlier discards of other providers and lowers the value. Another result, the best absolute utility within a category, is shown in Figure 3(b). Concerning the utility, the contract net protocol does not depend on the number of cloud providers and remains on the same level. In contrast, the English auction shows a positive correlation between the number of cloud providers and the best achieved utility. The reason for this is, that more providers lead to a higher competition and, therefore, a higher utility value. The probability that the two best providers have similar cost factors and increase their offers to the maximum is higher in scenarios with many providers.

The evaluation of the service consumer's utility for the bundle is shown in figure 4. The median utility achieved with the English auction is much higher for the chosen weights than the utility achieved with the contract net protocol. This can be explained with the low values for the two QoS parameters resulting from the contract net protocol in contrast to the high values resulting from the English auction. Low values lead to a low utility, since the achieved price cannot compensate them.

Table 1. Values of the parameters for the evaluation

Category		**Bundle**	
Parameter	Values	Parameter	Values
$CFQ1_{i,j}$ and $CFQ2_{i,j}$	$[0;1]$		
$wCatPr_i$	-1	$wBuPr$	-1
$wCatQ1_i$ and $wCatQ2_i$	2	$wBuQ1$ and $wBuQ2$	0.5
$ThCatPr_i$	$[15;20]$	$ThBuPr$	$[15;20]*m$
$ThCatQ1_i$	$[0;5]$	$ThBuQ1$	$[0;3]*m$
$ThCatQ2_i$	$[0;5]$	$ThBuQ2$	$[0;1]$



(a) Median relative utility (b) Median best utility

Fig. 3. Service consumer median utility of negotiation protocols for categories

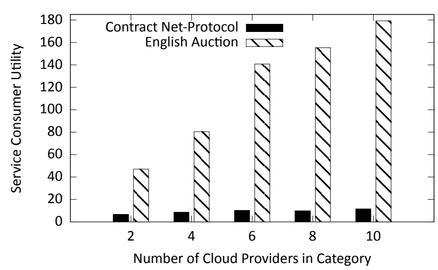


Fig. 4. Service consumer median utility of negotiation protocols for bundle

It can be observed from the evaluation that both negotiation protocols show small median run times and thus, are applicable in a dynamic collaborative environment. Concerning the utility of the bundle, the English auction achieves higher median utility values than the contract net protocol. However, the English auction depends on the amount of the providers. In summary, the contract net protocol is preferable in scenarios, where the services must only satisfy minimal requirements and the price is considered as the most important criteria. In contrast, the English auction should be applied in case of a large number of providers in order to achieve a high utility. Nevertheless, no negotiation mechanism outperforms the other in all settings.

5 Related Work

A lot of research has been done in cloud computing. Yet, only a few approaches focus on market-based scenarios. To the best of our knowledge, this is the first work that combines the negotiation of individual consumer-driven QoS guarantees and the selection of collaboration partners from sets of competing cloud providers in a market-based cloud computing scenario. In contrast, Buyya et al. [1] present a vision of a cloud market for trading resources in order to establish a balance between supply and demand. The authors also consider the negotiation of QoS parameters between a consumer and a provider. However, collaborations are not considered in their work. Based on the market model of Buyya et al., Sim [14] focuses on QoS negotiations to allow for flexible pricing. He divides his scenario into two disjunct markets for cloud services and cloud infrastructure resources interconnected via brokers. Again, collaborations are not part of his work. Concerning the selection of collaboration partners, Hassan et al. [3] propose a multi-objective optimization model with multiple target functions that depend on each other. The authors' goal is to minimize the price and to maximize the service quality and the performance of collaborative past relationships. The collaborations are initiated by primary cloud providers, who identify a specific business opportunity and search for appropriate partners. In the second step, the resulting groups of collaborating cloud providers use the market to offer a set of services to consumers, who can bid a price for the set of services. Negotiating individual consumer-driven QoS guarantees is not considered in their approach. In their work in [6], Briscoe and Marinos describe a community cloud market model, where community members provide and manage the resources. The authors also discuss the enforcement of certain QoS levels with the help of a community currency serving as a means for admission control. However, collaborative resource provisioning is in the focus of their work, disregarding the negotiation of individual QoS guarantees.

6 Conclusion

In this paper, we have presented an approach for collaborative complex service provisioning in cloud computing and introduced a corresponding market model. The model provides a good solution for market-based collaborations in cloud computing and considers individual consumer-driven QoS guarantees. Furthermore, the model can be adapted to different negotiation mechanisms and consumer and/or provider requirements. Hence, it serves as a foundation for future investigations concerning collaborative cloud markets. In addition, we have explored the applicability of different QoS negotiation mechanisms in the designed market model. The results revealed that both investigated negotiation mechanisms are applicable in a dynamic collaborative setting. Although each strategy offers advantages in some situations, no single negotiation mechanism outperforms the other in all settings. Thus, further negotiation mechanisms (e.g., Vickrey auction[4]) will be explored in future work. Also, smaller cloud providers will not be able to offer an unlimited amount of resources. Hence, a small amount of resources could also be considered as an incentive for collaborations. Therefore, further directions for future work are the consideration of restricted resource capacities of the providers as well as time constraints, which evolve through parallel consumer requests for the same resources and the temporary allocation of the resources.

[4] The Vickrey auction is a sealed-price sealed-bid auction, where the best strategy is to bid the best estimate value of a good [10].

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