Research Report

QoS- and Security-Aware Optimization of Cloud Collaborations

WHILE CLOUD MARKETS PROMISE UNLIMITED RESOURCE SUPPLIES, INDIVIDUAL PROVIDERS MIGHT BE UNABLE TO OFFER SUFFICIENT PHYSICAL CAPACITY TO SERVE LARGE CUSTOMERS. A SOLUTION IS TO FORM CLOUD COLLABORATIONS, IN WHICH MULTIPLE CLOUD PROVIDERS UNITE FORCES IN ORDER TO CONJOINTLY OFFER CAPACITIES WITHIN CLOUD MARKETS. QUALITY OF SERVICE (QOS) AND SECURITY ASPECTS ARE THE PRIMARY CONSIDERATIONS IN BUILDING SUCH COLLABORATIONS. THIS RESEARCH REPORT PRESENTS A CORRESPONDING OPTIMIZATION APPROACH FOR THE SELECTION OF COLLABORATIVE CLOUD PROVIDERS UNDER CONSIDERATION OF FULFILLMENT OF CLOUD USERS' QOS AND SECURITY REQUIREMENTS.

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Introduction

In highly dynamic market environments, such as the financial industry, the corresponding business processes are also currently evolving. Reasons for business process evolution comprise new regulations adapting to competitive products and services as well as achieving maturity over time (Grivas et al., 2010). Since IT is a major enabler of most business processes in the financial industry (Berger, 2003), agility of the utilized IT is a crucial foundation in order to achieve business process evolution.

Cloud markets promise IT agility in terms of custom-tailored service provisioning on-demand in a scalable pay-as-you-go fashion with unlimited resource supplies (Buyya et al., 2009).

However, some cloud providers might be unable to serve large customers on their own, e.g., due to limited data center capacity and, consequently, limited range of services. A solution to this issue is to form cloud collaborations within cloud markets.

Besides capacity issues, cloud collaborations can also be formed in order to extend in-house cloud solutions by externally provided public cloud services. In this case, they constitute so-called hybrid clouds that utilize private and public cloud solutions.

Focusing on the financial industry, extending in-house cloud solutions can provide major benefits in order to meet new demands such as coping with big data and supporting the use of mobile devices. However, such cloud collaborations have both QoS and security impact.

Cloud collaborations represent the cooperation of multiple cloud providers that aggregate their resources and conjointly satisfy users' demands (Kretzschmar and Golling, 2011). Since a user may potentially be served by any provider within a collaboration, the aggregated non-functional service attributes (e.g., availability, security protection level, and data center location) will be determined by the "weakest link in the chain", in other words, by the provider with the lowest guarantees.

Take an example of two cloud providers: One provider guarantees 99.5% availability and another provider guarantees only 99%. If these providers aggregate their capacities, the availability guarantee will be determined by the worst one, i.e., 99%.

Considering country- and industry-specific data protection laws and regulations is another concern in building cloud collaborations since providers can act in different jurisdictions (the European Union, Canada, Singapore, or the United States), where data privacy laws and other related regulations differ (Goiri et al., 2010).

A selection of collaborative partners is an activity traditionally provided by a cloud broker, who acts as a mediator between cloud providers and cloud users (Grivas et al., 2010). In our research, we examine the *Cloud Collaboration Composition Problem* (CCCP) with a focus on a cloud broker and its objective to maximize profit, thereby examining the following research question: *How to compose cloud collaborations under consideration of QoS and security properties within a market scenario involving multiple cloud providers and cloud users in order to maximize profit for a cloud broker?*

In this research report, we present an optimal solution of the abovementioned problem as well as two heuristic optimization approaches that lead to improvements in computational time performance and solution quality.

Optimization Model for Cloud Collaboration Composition

Our solution approach to the Cloud Collaboration Composition Problem is based on the formulation of an optimization model. In our model, we define a cloud market that consists of a set of cloud providers P and a set of cloud users U. Each cloud provider offers a specified resource supply for a specified amount of monetary units. Likewise, each cloud user has a specified resource demand for which he/she is willing to pay a specified amount of monetary units. Our approach allows collaboration between cloud providers and cloud users only if the total resource demand of a potential collaboration does not exceed the total resource supply.

Furthermore, we define QoS and security constraints as non-functional constraints. For maximum flexibility, we model these constraints using two sets of quantitative and qualitative non-functional attributes. Quantitative attributes represent numerical properties, e.g., availability, latency, and network throughput. Qualitative attributes refer to nominal properties, e.g., applied security policies, data center location, and compliance with related industry-specific regulations. Based on this observation, we define the values of quantitative attributes as real and the values of qualitative attributes as binary (i.e., whether an attribute is mandatory or not).

Each cloud provider is characterized by a set of guarantees: Qualitative and quantitative non-functional attributes that describe cloud provider's QoS and security properties. In contrast, each cloud user is characterized by a set of requirements: Qualitative and quantitative non-functional attributes that represent cloud user's demands for QoS as well as security properties and should be fulfilled by cloud providers. Furthermore, we calculate the cumulative non-functional values for quantitative and qualitative attributes of each collaboration. As explained before, the cumulative values of the quantitative properties are given by the "worst" value among all providers in a certain collaboration.

In our approach, we take the perspective of a cloud broker, whose task is to unite cloud providers to build cloud collaborations and to assign cloud users to these collaborations. Such assignments are provided under the constraints that all cloud users' demands are satisfied and that all non-functional requirements are fulfilled. The monetary objective of the proposed optimization approach consists in cloud broker's profit maximization – i.e., the difference between the revenue from the served cloud users and the spending on the used cloud providers should be maximized.

For further details, we refer the interested reader to our prior publication (Wenge et al., 2014).

Optimization Approaches

We have translated the proposed optimization model into an exact approach CCCP-EXA.KOM and solved it by an off-the-shelf optimization algorithm, namely branch-and-bound (Hillier and Lieberman, 2005). Furthermore, we have extended the introduced exact optimization solution approach with two heuristic approaches: CCCP-HEU.KOM and CCCP-INC.KOM.

The CCCP-HEU.KOM heuristic approach is based on the divide-and-conquer principle, i.e., the approach recursively breaks down the CCCP problem into sub-problems and combines the solutions of sub-problems to provide a solution to the original problem. Furthermore, it applies a greedy approach for the selection of solutions.

The CCCP-INC.KOM heuristic approach is based on the graph partition algorithm. Namely, this approach checks small subsets of users and providers for feasibility of non-functional attributes and potential profit, selects the best option, and adds it to a suitable collaboration or creates a new one.

Evaluation Results

In order to assess the required computation time and the solution quality of our approaches for different problem sizes, we have evaluated two test cases: One with a fixed number of cloud providers, and another one with a fixed number of cloud users. For each test case, we have created 100 problem instances. Each instance was solved using all proposed approaches with a time-out of 300 seconds being imposed. Based on the resulting sample of solved problem instances, we computed the absolute computation time, macro-averaged ratio of profit (solution quality), as well as the corresponding 95% confidence intervals.

Figure 1 provides the quantitative evaluation results of the computation time. These results indicate that the computation time of the pro-

Absolute Computation Time

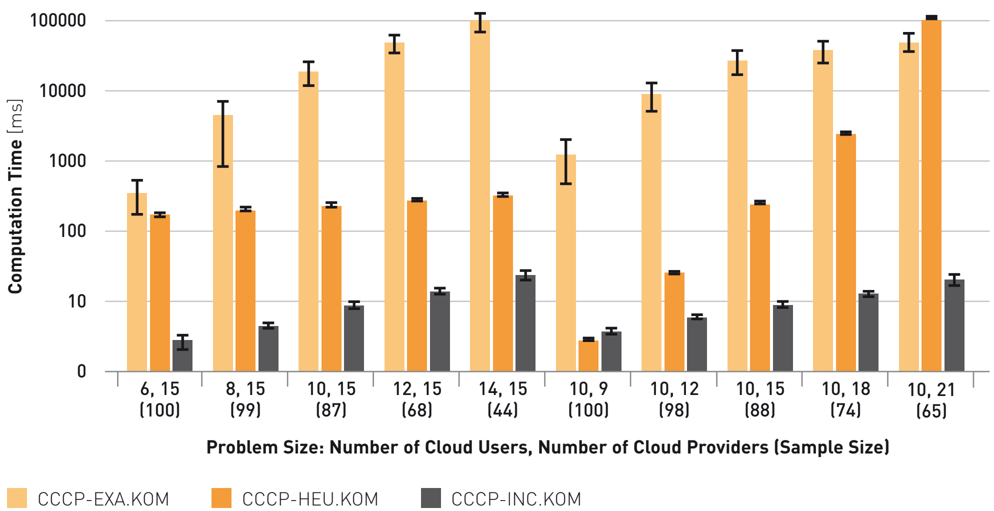

Figure 1: Absolute Computation Time (with 95% Confidence Intervals) for All Three Approaches by Test Case. Please Note the Logarithmic Scaling of the Ordinate.

Macro-Averaged Ratio of Profit (Solution Quality)

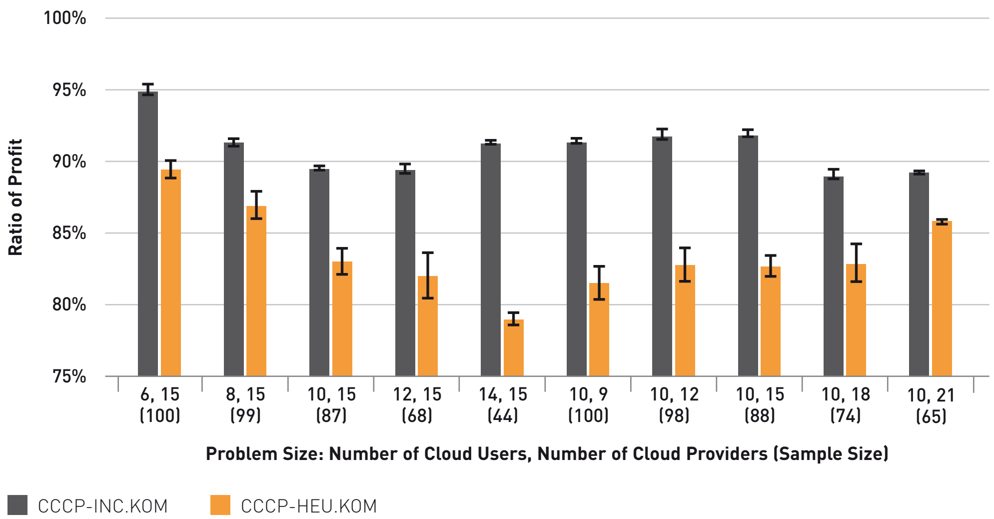

Figure 2: Macro-Averaged Ratio of Profit (Solution Quality) Compared to the Optimal Profit.

posed CCCP-EXA.KOM exact solution grows roughly exponentially with the number of market participants, which indicates its limited practical applicability to large-scale problem instances.

The CCCP-HEU.KOM approach exhibits polynomial time behaviour and shows improvements in computation time, emphasizing its applicability in current cloud markets, where the number of cloud providers is rather fixed. In the case with a fixed number of cloud users, the computational time of the CCCP-HEU.KOM grows with an increasing number of cloud users and demands further improvement.

In contrast, the CCCP-INC.KOM approach exhibits significant reduction of computation time (over 95%), even for the largest test cases (14, 15) and (10, 21), therefore confirming its superior scalability and proving the model's applicability in real market scenarios.

The evaluation of the solution quality with the comparison to an optimal, i.e., 100%, solution quality is provided in Figure 2. As can be seen, the CCCP-HEU.KOM approach exhibits significant profit reduction, which points out its limited practical interest. In contrast, the CCCP-INC.KOM approach consistently achieves over 90% of the optimal profit, proving its excellent applicability in practice again.

Conclusions and Outlook

While cloud markets promise virtually unlimited resources, the physical infrastructure of cloud providers is actually limited and they may not be able to serve the demands of large customers. Therefore, cloud providers can cooperate with each other building cloud collaborations. In this research report, we introduced the corresponding Cloud Collaboration Composition Problem along with exact and heuristic solution approaches. Our evaluation results indicated drastic improvements in computation time and solution quality, and also showed that the proposed algorithms are applicable in real cloud market scenarios.

In our future work, we will aim at extending the model with additional monetary attributes, more complex non-functional constraints, and dynamic structures. Furthermore, we plan a development of metaheuristics, e.g., best-of-breed, in order to support dynamic changes in our model.

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