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Equilibrium in cloud computing market

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ABSTRACT

The emerging market of public and private cloud infrastructure benefits the end users, as it reduces their costs, introduces new efficient services and provides variety of products. End-users primary deal with private clouds or brokers, which serve all the users needs, and if needed, buy extra capacity from public cloud. In this paper we study such a three-level market structure. Our goal is to find Nash equilibrium of prices in this market as well as market influence on the end users. We observe that new resources at public clouds positively affect the market from the end-user perspective. Additionally our observation indicates that the switching cost plays an important role in achieving the optimal point in average market price value, and thus reduction of the switching costs will benefit end-users even more. Thus the results imply that standardization of the interfaces and interoperability between various clouds increases market efficiency.

1. Introduction

The increasingly perceived vision of cloud computing as utility like electricity or telephony creates great challenges to the development of the emerging market structures and related ecosystems. The history has shown that separation of network and service has increased competition in, former monopoly, energy and mobile-communications industries. When diverse new service companies entered into markets network companies had to cut their fees significantly. Additionally, the introduction of the number portability by the regulators of the telecommunications market has increased competition which resulted in declining customer loyalty and increased churn rates. The markets perform in these industries more efficiently because of increased interoperability and lower switching costs.

The public cloud computing market is still dominated by the services based on proprietary platforms and customer interfaces [1]. Under these kind of circumstances the customer expose switching costs and lock in to the cloud service provider [2]. Another significantly observed problem, which hinders the proliferation of cloud computing, is related to trust issues between service providers and their customers [3]. Software as a Service (*SaaS*) providers can easily lose their reputation, if the underlying Infrastructure as a Service (*IaaS*) infrastructure creates Quality of Service (*QoS*) or privacy related problems.

Hybrid or federated cloud is a promising architecture to the market oriented cloud ecosystems. In this context public cloud with unlimited capacity provides a solution to handle unexpected traffic peaks of variable Internet traffic and private cloud capacity for typical load. It has been discovered that optimal cost structure occurs in certain IaaS applications when

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40% computation is in private cloud and 60% in public cloud [4]. Additionally the hosting of private cloud can be outsourced to a broker, which is connected to the public clouds.

Currently there are significant efforts to standardize customer interfaces of public cloud in order to realize better interoperability between various clouds. In this paper we introduce a game-theoretical model, which describes the behavior of a hybrid cloud market. Additionally based on simulation we explore the effect of interoperability on the market efficiency. In particular we concentrate on the effect of the number of market players, switching cost and pricing.

The rest of the paper is organized as follows. In Section 2 we provide the related work in the field. Section 3 is dedicated to the three-layer market model. In Section 4 we analyze theoretically and study numerically the proposed model. In Section 5 we discuss the impact of switching cost on our model as well as the further development of the model. Finally, Section 6 concludes the paper.

2. Related work

Real workloads are very heterogeneous, and thus designing an optimal computing cluster is a difficult task. A hybrid cloud is a promising solution to meet the varying computing needs. In this approach the base load can be managed with a private cloud, while the excessive peaks can be redirected to a public cloud. However, the hybrid cloud architecture has a few major design challenges. First of all the load balancing algorithm must be fast, scalable, adaptive and robust [5]. Secondly, the solution should meet the performance [6–8,4], business [9–12] and greenness requirements [13].

One alternative to manage the cloud complexity is to utilize brokers [14]. The cloud broker market has already born and companies offer a unified view on different cloud resources. A broker paves the way towards utility computing, and furthermore it can also decrease prices and simultaneously make profit [15]. However, the broker will not fully remove the customer lock-in problem, because now customers are locked in to one broker instead of one individual cloud provider. This point can be solved by using parallel brokers, which create a fully competitive market.

Game theory has a long history in the research of economics [16]. Lately game theory has gathered popularity in the cloud computing context, too. In the basic case both cloud infrastructure providers want to maximize their profits and on the other hand, cloud SaaS users try to minimize their costs. This is a classical game theory setup, which can be mathematically formulated and the final output, so-called Nash Equilibrium (NE), can be calculated. In this status quo no player can improve the situation by changing own strategy if other players keep their old strategy [17].

In addition to cost, also SLA can be the other dimension in the game [18,19]. Several cloud providers can compete in performance and cost by offering single application [20]. The third dimension can be energy consumption which we want to minimize [21]. Also resource management problem can be formulated as NE game [22]. The Nuage mechanism provides an optimal deployment strategy [23].

3. Market model

First, we formulate market model which we consider in this work. For that let us introduce three main roles which are present in the cloud market today, namely, (i) *end-users*, (ii) *broker cloud service providers*, and (iii) *public cloud service providers* (see Fig. 1). Public cloud service providers (*CSPs*) are the big companies which sell their cloud capacity to individual clients or other CSPs. Conventionally, they are assumed to have large enough amount of resources which were provisioned for high demand peaks.

Broker CSPs are small or medium-sized cloud providers which have limited resources.[1] They do not provision high capacity and in case of higher demand peaks they buy resources from public CSPs. These broker CSPs may be pure virtual (without any internal resources), thus functioning as re-sellers, or they can provide some base of internal resource, thus, functioning as private clouds.

Finally, there are end-users. End-users may buy resources from both broker CSPs and public CSPs. The ones which buy resources from public CSPs are considered to be more advanced. We take them out of our consideration as they are normally adjusted to one public CSP and influence only load levels of that CSP. Other end-users are connected to broker CSPs (Fig. 1). They buy resources from a set of local[2] brokers.

Using the definition above we construct a hierarchical market structure (Fig. 1), where public CSPs are on the top. They are selling resources to everyone interested. Public CSPs have known pricing models which are defined in this work as the resource price per unit based on the current load of the public CSPs. Broker CSPs in the middle compete with each other and sell resources to end-users on the bottom. If the limited internal resources of the brokers are not sufficient enough to serve their clients, then the brokers buy resources from the public CSPs. Brokers can set the prices for own services directly. Although, if the price is too high, then the end-users start to prefer other brokers. On the other hand, if the price is too low, then brokers reduce their own profit, as well as have losses in case of excess of clients and insufficiency of own resources. Thus, the price that the brokers announce is defined by the competitiveness in the market and own resource availability.

1 See http://searchcloudprovider.techtarget.com/definition/cloud-broker, for a broader definition of broker CSPs.

2 Our game-theoretical model users logistic function for definition of locality. Logistic function defines locality through a corresponding parameter.