Cost Optimization of Cloud Computing Services in a Networked Environment

Eli WEINTRAUB
Department of Industrial Engineering and Management
Afeka Tel Aviv Academic College of Engineering
Tel Aviv, Israel

Yuval COHEN
Department of Industrial Engineering and Management
Afeka Tel Aviv Academic College of Engineering
Tel Aviv, Israel

***Abstract*—Cloud computing service providers' offer their customers' services maximizing their revenues, whereas customers wish to minimize their costs. In this paper we shall concentrate on consumers' point of view. Cloud computing services are composed of services organized according to a hierarchy of software application services, beneath them platform services which also use infrastructure services. Providers currently offer software services as bundles consisting of services which include the software, platform and infrastructure services. Providers also offer platform services bundled with infrastructure services. Bundling services prevent customers from splitting their service purchases between a provider of software and a different provider of the underlying platform or infrastructure. This bundling policy is likely to change in the long run since it contradicts economic competition theory, causing an unfair pricing model and locking-in consumers to specific service providers. In this paper we assume the existence of a free competitive market, in which consumers are free to switch their services among providers. We assume that free market competition will enforce vendors to adopt open standards, improve the quality of their services and suggest a large variety of cloud services in all layers. Our model is aimed at the potential customer who wishes to find the optimal combination of service providers which minimizes his costs. We propose three possible strategies for implementation of the model in organizations. We formulate the mathematical model and illustrate its advantages compared to existing pricing practices used by cloud computing consumers.**

Keywords—Cloud Computing; Pricing Model; Cost optimization; Software as a service; Platform as a service; Infrastructure as a service

I. Introduction

Traditionally, organizations base their computing facilities on server farms located inside the organization in geographical central sites. In the last years organizations began to shift parts of their computing infrastructures outside the geographic organizational borders to the cloud, where the facilities are owned and managed by other organizations. Reference [26] state that shifting computing infrastructure outside the geographic borders enforces performing changes in production processes and technological changes. Those organizations have to establish new processes of production control, service level monitoring, and resolve security and privacy issues.

Cloud Computing (CC) typically deals with organizations using computing services, communication and web applications. Most definitions state that CC technology enables on-demand services, scalability, and flexibility, in enlarging or downgrading computing consumption ([31] [29]). The National Institute of Standards and Technology (NIST) defines CC as a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (for example, networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service-provider interaction [23]. Reference [22] argues that occasionally cloud providers suffer outages, thus using a multi-cloud broker is a preferred solution to remove single point of failures. Reference [3] introduces an Inter-Cloud Computing additional layer on top of CC systems which enables shifting resources among the participating cloud systems in occasions of high load levels.

Cloud computing targets four main groups of organizational customers: private, public, community and hybrid [34]. For private customers, cloud model computing infrastructure services are typically located outside the organization's sites at a cloud service provider. A public customer typically chooses cloud service providers through a bidding process, issuing request for proposal, choosing the best proposal, and contracting for the best bidder having the best proposal. The cloud computing provider may use the same computing infrastructures for supplying the needs of other companies. In a community model, infrastructure services are shared by a group of customers. In a hybrid model, an organization can use infrastructure services supplied by public, private or as part of a community. Reference [11] who researched the emerging themes in financial services technologies found that cloud computing seems to be a cost-effective infrastructure affording capital efficiency for financial services providers.

We shall review the main motivations and obstacles to adopting the cloud technology by companies. Cutting cost has been found an important factor for CC adoption. Information security has been found as a barrier to CC adoption, and is an issue dealt intensively in CC research [7]. Reference [28] who researched CC trends, claims that security will not be a barrier for cloud adoption, since it will be implemented by centralized automated processes.

II. Cloud Computing Pricing Models

Economic issues concerning CC service pricing models are dealt by [10] who states that research need to be strengthened in the economic issues of CC pricing models.

Reference [37] claims that variance among providers' services put difficulties in comparing pricing models. Reference [37] utilizes a game theoretic model to analyze the pricing strategies for computing services and shows that price and revenue of computing services are significantly influenced by market structure and technological parameters**.** Reference [36] classified CC research publications. The researchers found that cost saving is the strongest incentive for organizations considering CC adoption. They also found that pricing is the least researched issue, but is an emerging topic in cloud computing research.

CC services are usually sorted to three groups: SaaS (Software as a service), PaaS (Platform as a Service) and IaaS (Infrastructure as a Service), each service belongs to a specified group, and is offered for specific prices.

There exist two main pricing models. Pay-per-use is the most used model [1], in which the consumer is charged a fee for a used unit in a specified duration. The unit used may be a certain computing unit of hardware, software or application, for example GB or CPU [5]. Fixed-price model, sometimes called subscription in which the user is charged for using a service unit for a fixed price, usually in periods of month or year. In the fix-price model consumers may consume an unlimited amount of unit resources, although in some contracts consumption is limited to a maximal amount which consumers do not intend to reach. In the fixed-price model consumers might be charged for resources they have not actually consumed. In certain cases their usage is stopped or degraded after reaching the maximal limit. Reference [1] surveyed pricing models and classifies them to three groups: fixed – in which the customer is charged the same amount all the time, dynamic – in which prices changes dynamically according to purchased volumes and market-dependant in which prices changes according to market conditions. Reference [1] found that the pricing approach are one of the following: fixed price with no volume limits, fixed price plus per-unit rate, assured purchase volume plus per-unit price rate, per-unit rate with a ceiling, and per-unit price. The authors found also several theoretical studies for cloud computing pricing which are not implemented in practice. Reference [18] performed an analytical and empirical examination of Cloud IaaS pricing models and found that pay-per-use pricing model is perceived as the dominant scheme by the scientific community.

Research aimed at understanding customers' motivations show that they are willing to control their payments, preferring to pay for services they had, and not being charged for fix prices which sometimes include services they have not consumed. Reference [16] claims that market competition powers using pay per use pricing model could bring efficient allocations of computing facilities. Reference [34] illustrates that current trends in CC show an ambition to base pricing models on dynamic pay-per-use pricing models. In certain cases consumers prefer to pay a fixed price, ignoring pay-per-use model advantages which fit their exact consumption and might minimize their costs [4], [26]. Reference [35] explored pricing models from both views: providers and consumers. The researchers found that some providers offer pay-per-use pricing and leave some consumer surplus to the customers, in order to be more attractive. Examining customers' point of view, usage-based pricing was also found more attractive because of higher consumer surplus. Reference [15] explored cloud provider pricing models using cluster analysis and found common business models; one cluster includes niche providers who use fix pricing, and another cluster includes mass players using pay-per-use pricing models. A possible explanation of using fix prices is lock-in situations prevalent among niche players' products. Reference [19] who researched costing schemes offers a decision model which calculates financial trade-off between private clouds and public clouds with respect to the workloads. The model takes in consideration cloud bursting as a third option of the two costing options. Cloud bursting is a deployment model which enables vendors to manage varying demands to resources, to supply stable quality of services according to pricing schemes.

Several researchers studied pricing models wishing to explain anomalies in consumer decisions. Reference [17] found that consumers wish to maximize their usage while minimizing their costs. The researchers also identified biased decisions of two kinds: cases of fixed-prices-bias in which consumers prefer a fixed price model although they would pay less on a pay-per-use tariff, and cases of pay-per-use bias, in which consumers prefer a pay-per-use tariff although they would pay less on fixed-price tariffs. Reference [17] states that possible cause for the fixed-price bias is an insurance effect leading consumers to pay more for their budget confidence. Reference [14] who surveyed pricing models, found that a fixed-price bias was found among half of consumers of the survey and among one quarter of consumers was found a pay-per-use bias. Those researchers state that the insurance effect has significant influence on the flat rate bias while the pay-per-use bias is influenced by the flexibility effects.

Providers' decisions concerning pricing models are influenced by strategic and marketing reasons. For example [14] states providers use to offer free of charge services using lock-in strategies, and [21] claims providers use to offer different prices for specific customers for marketing or cash-flow management reasons. They also state there may be cases in which providers offer different service quality at different prices, causing transparency difficulties in evaluating providers' prices. Providers are using bundling techniques which force consumers buy certain services which they would have not bought otherwise. Reference [34] found differences between private and organizational consumers. Most cloud services which are focused on private consumers are free of charge as Microsoft's Live Mesh [24]. In contrast, organizational consumers are usually charged, and only some add-on services on IaaS or SaaS are free of charge. PaaS providers often offer their development tools for free. Reference [30] claims providers' motivation in bundling extra services such as applications or infrastructures to the PaaS services which they are already committed to, thus locking-in their consumers. Reference [30] states that after a consumer had invested in customizing his applications to a specific platform, switching costs to other providers' services are high, due to necessary changes in programming language. Acting this way, providers are causing a monopoly situation.

Free competition enables maximization of consumers' benefits and minimizing consumers' costs. Existing pricing models may be characterized by several features which raise difficulties to economic competition. Reference [32] uses a multi-method approach for the evaluation of a pricing model raising the awareness of indirect and hidden costs in cloud computing pricing models. They found that some providers try to attract customers by a low price per storage while charging hidden costs for data transfer even for data transfer within the provider's infrastructure. Reference [7] states customers face difficulties in evaluating prices of cloud services, difficulties that are one of the main reasons preventing customers from adopting cloud services.

We found in literature three competition barriers' features: *bundling of services*, *lack of transparency*, and *varying tariff structures*.

- *Bundling of services*

Examining providers' pricing models as published in their websites (for example [2], [13], [24]) we can observe the phenomena of bundling services. We suggest introducing new definitions of two kinds of bundling: first is horizontal bundling, second is vertical bundling. In horizontal bundling a provider offers several services, all belong to one layer. For example Amazon EC2 offers several bundles each one is composed of the following components: CPU, ECU, memory, instance storage, and operating system. In such bundling situations consumers may not use their own operating system. In vertical bundling a provider offers services which belong to lower layers, in addition to the main needed service. For example Amazon offers SaaS services, in which the consumer is asked to choose the configuration of infrastructure he wants the software application to run. Existing Service Providers (SP) pricing models include two kinds of vertical bundles: SaaS bundles which include infrastructure and platform services offered by the SaaS provider, and PaaS bundles which include infrastructure services offered by the PaaS provider. A consumer may not use a PaaS service such as his own operating system or an operating system he bought from another cheaper service provider.

We argue consumers should be able to choose another infrastructure service provider instead of being forced to use the infrastructure services of the SaaS or PaaS main provider. Providers use to bundle services in ways that customers are unable to know the real prices of each service component. Such a situation contradicts economic competition principles, causing an unfair pricing model when examining customers' optimal alternatives. In the long run, market forces are bound to change this into a more competitive setting. Providers will have to improve their competitive advantages by adapting their infrastructures to improved interoperability, portability and standardization.

- *Lack of transparency*

Bundling masks the prices of services, in both situations: vertical and horizontal bundling. The provider offers a tariff for the whole bundle without breaking it to its components' services, in a package deal. In such situations customers do not know the price of a specific service which is part of the bundle. Feeling ignorance of the pricing structure, customers are reluctant of searching a competing service. Reference [32] found that public cloud customers receive no insight into the underlying IT infrastructure and have restrictive administrative rights. Transparency of service costs in cloud computing is a key factor to popular wide usage by organizations [8]. Reference [33] surveyed cloud monitoring tools and state that the design of monitoring tools is yet an under researched area. They state that lack of an appropriate strategy prohibits cost prediction, as well as other unwanted outcomes. Reference [6] proposes a pricing model which includes incentives to providers who are willing to present the pricing components of their services and also the configuration of the technological implementation such as the assets consumed for each service. Improving transparency will be feasible by breaking bundles to component services so that a consumer may choose each service by comparison to competing providers' prices.

- *Varying tariff structures*

A consumer wishing to compare a service offered by several providers may find it difficult to perform, sometimes impossible at all. Reference [27] states that the large number of cloud providers' services based on varying pricing schemes has led to complexities in cloud service selection. This situation is due to the following reasons:

- *Services having different functionalities. For example operation systems and database management systems of different suppliers.*
- *Computing resources having different technological characteristics such as speed or volume, which relate to specific suppliers' technologies.*
- *Differences in service levels. For example differences in time limits for fixing software failures.*
- *Differences in contract duration. Providers use to offer better prices for long-term contracts.*
- *Differences in discounts. Different discounts due to high volume discounts offered for certain volumes; higher discounts for higher volumes.*

According to Reference [8] pricing models are not transparent thus making price comparisons difficult. Providers use different tariff structures; some providers such as Google charge separately for each service, and providers like Amazon and Microsoft offer predefined bundles of services.

The variability of charges between current SPs does not give sufficient common ground for a simple comparison. This variability is illustrated in the following table which shows the tariffs of Amazon, Microsoft and Google. As can be seen in the table, each service provider suggests different services with specific functionalities, for example different operating systems. Tariffs are based on different units such as storage capacity and time. We normalized the published tariff units to a standard scale based on Cents/Hour, but the process of normalization includes obstacles and barriers which are difficult to overcome, which is an outcome of the specific characteristics of suppliers' services, as illustrated in table I.

The differences in existing tariff structures illustrate the difficulties involved in making a comparison of the published cloud services pricing models, thus raising barriers to technological connectivity and free competition of cloud services.

TABLE I. VARIABILITY OF TARIFF COSTS OF AMAZON, MICROSOFT AND GOOGLE

SaaS	Amazon SP1	Tariff	Microsoft Azure SP2	Tarriff	Google cloud SP3	Tariff
	Email 1000 msg 10 cents. Assume 1000 msg / month	10	-	-	DropBox 10GB	1.4
	Cloud search Cent / hour	39			search 10k records	50
PaaS	**Amazon SP1**	**Tariff**	**Microsoft Azure SP2**	**Tarriff**	**Google cloud SP3**	**Tariff**
	Operating system Per hour	13.3	General purpose standard instance. Per hour.	18	Standard instance 2 vCores 3.75 GB. Per hour	7
	Support 49 $ per month (12-hour-response)	7	Developer support. 29$ Per month. 8 hour response	4	Silver tier support. 150$ per month. 4 hours -1 day response	21
IaaS	**Amazon SP1**	**Tariff**	**Microsoft Azure SP2**	**Tarriff**	**Google cloud SP3**	**Tariff**
	Relational Database services. Per hour	9	SQL DB (10-50GB). Per hour	6.25	Cloud SQL D2. 16B RAM Per hour	19
	Storage TB standard vol Per hour	7	Storage TB Per hour	1.5	Stored cloud DB for 1 TB 0.18$/month	2.5

In this paper we propose a pricing model in which the customer is free to choose service providers according to his own pricing preferences, composing the bundled services by his own, not according to constraints put by SP's. The proposed pricing model defines two fees: in cases a SP is requested by the consumer to interface to another underlying service provider, the consumer will have to pay two fees: a fixed sum of money for initiating the connection to the other SP, and a dynamic fee for each executed transaction. Those fees may be specific for each couple of two SP's, for a specific service (Saas, Paas or Iaas).

Cloud providers use two main pricing models: fix-rate pricing and pay per use pricing. Incorporating risk analysis and cash-flow management considerations consumers use sometimes fix-price pricing models. The model we propose handles both models. We do not deal with theoretical models cited by [1] and with schemes which limit volumes of consumed resources or models which lower prices when resources are not utilized by the consumer. Tariff tables are normalized to hourly time units. In cases a provider offers a fixed-price tariff we normalize it to a pay-per-use price transforming monthly rates to hourly rates. The pricing model we propose optimizes technological configuration of the costs of services a customer may choose, in a multi-providers network. The model simulates situations in which consumers may install software or hardware components on multi providers' sites, optimizing consumers' total CC expenses. The proposed model is aimed at solving the problems existing in pricing models: bundling of services, pricing transparency, and a common structure of pricing tariffs.

III. CLOUD COMPUTING ARCHITECTUE

Cloud computing architecture is described in literature as consisting of three layers: IaaS, PaaS and SaaS. Each layer performs certain functions, serving consumers' requests and also supporting functions requested by upper layers. This separation to layers also fits current services offered by Cloud providers. Reference [34] defines a framework of CC architecture composing three layers of functions supporting cloud computing services. Figure I describe architectures' components. White rectangles describe computing services, grey rectangles describe computing resources. Following the functions performed by each layer.

Infrastructure layer – This layer focuses on providing technologies as basic hardware components for software services. There are two kinds of infrastructures: storage capabilities and computing power.

Platform layer - includes services which are using cloud infrastructures needed for their functioning. There are two kinds of platform services: development and business platforms. Development platforms are aimed for usage by developers who write programs before transferring them to production and usage by organizations' users. Business platforms enable organizational developers make adaptations of software packages for deployment in their organizations.

Application layer - consists of the programs and human interfaces used by the organizations' end-users. Applications are running on cloud assets, making use of platform and infrastructure layers. There are two kinds of services in this layer: applications and on-demand services. Application services are software packages ready for end-users such as Microsoft Office, while on-demand services are software applications which are used by the organizations' customers. Those services are used according to on-demand needs, and used on a pay-per-use or fixed-price pricing model.

To summarize, SPs offer their customers' three kinds of services: IaaS, PaaS and SaaS. Each SP manages all underlying infrastructure for the offered service. For example a SP suggesting a SaaS product is also bundling into the product the PaaS and IaaS layers. Reference [38] state that according to cloud computing architecture a certain provider may run an application using another provider's infrastructure, but in practice both providers are parts of the same organization. Current practice is that when a provider suggests selling a PaaS service he also bundles the IaaS layer in the deal. Such bundling by service providers limit free market forces from entering the competition, forcing customers pay for components they may buy cheaper from other providers. For example a customer may buy a SaaS service from SP1, but buy the underlying PaaS service from SP2 which sells the appropriate platform service cheaper than SP1. Reference [25] claims that in the future, developers will plan their cloud applications which will enable migration of services among clouds of multiple clouds. According to [38] cloud computing architecture is more modular compared to traditional hosting architectures based in server farms, and programs running on different layers are loosely coupled, thus enabling the development of a wide range of applications. Reference [31] also claims that it is possible that applications belonging to different layers will be run on separate geographical locations even in different countries. Reference [27] claims that virtual machine migration allows transfer of a running application from one virtual machine to another, which may be provided by a different IaaS provider.

We propose a business model which enables implementing functionalities of a service provider interfacing the underlying platform or infrastructure service by other service providers according to consumers' preferences. Implementing this required functionality puts two requirements on cloud architecture. Firstly, the architecture should be based on open standards which will enable interfacing between many components among all providers in all three layers. Second, the architectures' building blocks should be loosely coupled. Implementation of those two functionalities should enable connectivity among vertical and horizontal services, thus elimination of the bundling phenomena. Figure II describes the new suggested cloud architecture. Arrows describe services supplied by underlying layers. Rectangles describe computing services.

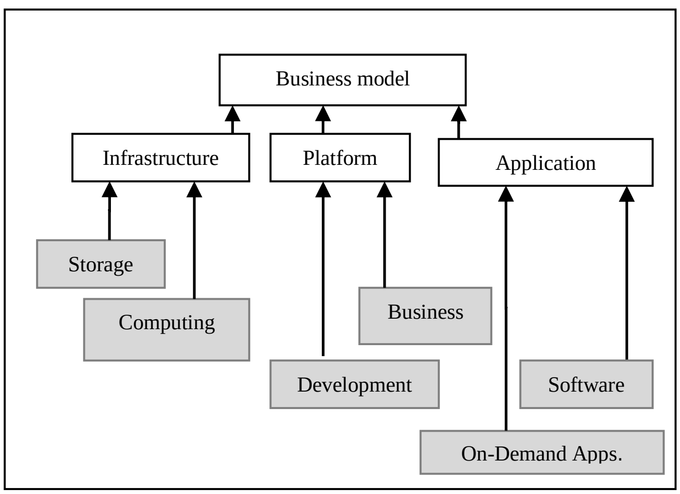

Fig. 1. Current Cloud business model Architecture

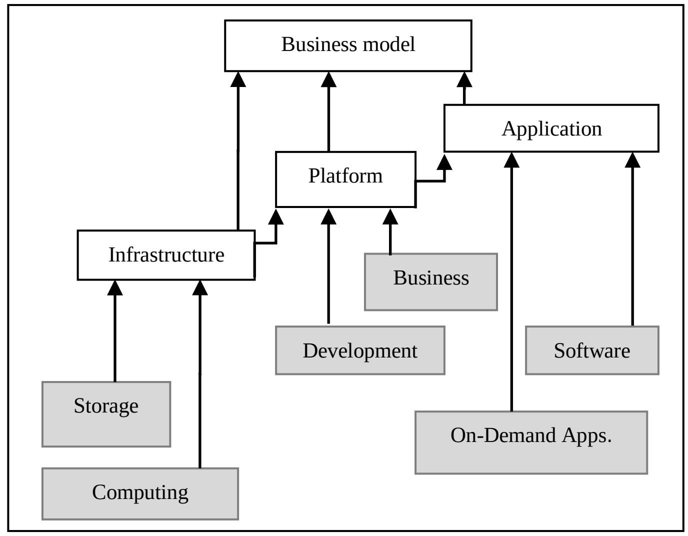

Fig. 2. A Dynamic Architecture for Cloud Computing

IV. Cloud Computing Pricing Model

In an efficient market, customers should be able to easily compare all their options, and choose the best. Thus, a simple common cost method should be used. Vendors will have to adapt their pricing models to standard schemes in order to improve their competitiveness and raise their quality of services. We suggest a simple pricing model with a common tariff base. The simplest basis is a single ratio of Cents/Hour of usage. A more advanced pricing model may include in addition to the usage payments, periodical fixed payments for various services. We shall start with the simple model first.

A. The Case Study Example

The inability to compare SP offerings is a competitive market failure which hinders not only SP competitiveness, but also the decisions of the customers. We claim that market forces are bound to drive cloud service tariffs to be more comparable than they are today. To enable simple comparison of SPs we suggest three competitive pricing models in which service providers are competing for giving the best offer to a customer having specific requirements. Each SP base its offer on its in-house offering with complimentary services bought from its business partners. Also, when a SP buys another underlying service from another SP, s/he must pay not only for the service, but also for the administrative work and the interfaces between suppliers involved in the purchase.

In this section we describe a theoretical example of three SPs and their tariffs, and an organizational customer that has to choose certain SP's based on its business and computing requirements. We introduce three pricing models which will make use of the data described in this section. Table II summarizes the estimated requirements of a hypothetic cloud services customer. All requirements are either in hours, volume or other specified unit. Table III lists the tariff of three SPs for the case study.

TABLE II. CUSTOMER ESTIMATED MONTHLY REQUIREMENTS

SaaS	Service name	Requirement in units	Units of service
	Data transfer	2,400	1 TB
	Email services	2,400	1000 messages
	Cloud search	600	1 search
	Documents Mgt.	200	1 hour
	ERP	2,400	1 hour
PaaS	Service name	Requirement in units	Units of service
	Operating system	600	1 hour
	Memory	1,000	1 hour, 1 GB
	Instance storage	1,000	1 hour, 1 GB
	Developer support	240	1 hour
IaaS	Service name	Requirement in units	Units of service
	Relational Database services	880	1 hour
	Storage standard vol.	240	1 TB, 1 hour
	Backup (GB)	1,000	1 GB, 1 hour

The customer contacts three candidate SPs to get a price quote. The published tariffs of these SPs appear in table III.

TABLE III. TARIFFS OF THREE SERVICE PROVIDERS. TARIFFS ARE IN CENTS/HOUR. EXAMPLE PRICES. ASSUMING BASIC USAGE

SaaS	Service name	SP1 tariff	Sp2 tariff	SP3 tariff
	Data transfer	1	2	1
	Email services	2	3	1
	Cloud search	3	4	3
	Documents Mgt.	2	1	1
	ERP	50	47	60
PaaS	Service name	SP1 tariff	Sp2 tariff	SP3 tariff
	Operating system	13	18	7
	Memory	20	25	35
	Instance storage	12	10	15
	Developer support	3	4	2
IaaS	Service name	SP1 tariff	Sp2 tariff	SP3 tariff
	Relational Database services	9	6	19
	Storage standard vol.	17	15	25
	Backup	20	28	20

According to current practices each SP provides all the services using his/her tariff. So, based on current practices bundled services per SPs would give:

SP1 price per monthly usage: $ 2019.20
SP2 price per monthly usage: $ 2110.40
SP3 price per monthly usage: $ 2482.00

Therefore, SP1 is the least cost provider ($ 2019.20). However, our suggested model enables the consumer to set an efficient market price that further minimizes his/her expenses. This could take several forms depending on the main supplier of choice:

B. *Hierarchical Pricing Model*

Since fitting SaaS services to the customer is more sensitive to customer requirements (and usually more expensive) – this model assumes that each SP maximizes its SaaS capabilities and look for purchasing the best combination of platform and infrastructure services that best complements its own offerings in these levels. Since SPs seek simple management and control of sub-contracted services, only one SP could be chosen for complementing the platform or the infrastructure level. The Platform SPs can also purchase infrastructure services. Also, when a SP buys another underlying service he must pay two fees: a fixed monthly sum of money for initiating, controlling and maintaining the connection to the other SP, and a fee for each executed transaction.

While SaaS is the highest level in the hierarchy, the computations are started from the lowest level (IaaS) and progress through PaaS to the decision taken by the SP based on their SaaS and possibly sub-contracted PaaS and/or IaaS. In this example the IaaS total monthly costs (in $) per SP are as calculated in table IV, table V and table VI.

TABLE IV. IAAS MONTHLY PRICES PER SP FOR THE EXAMPLE

IaaS	Service	SP1 $/month	SP2 $/month	SP3 $/month
	Relational DB services	79.2	52.8	167.2
	Storage standard vol.	40.8	36	60
	Backup	200	280	200
Total		320	368.8	427.2

Thus SP1 is the IaaS provider of choice for the requirements of this customer.

TABLE V. PAAS TOTAL COSTS (IN $) PER SP FOR THE EXAMPLE

PaaS	Services	SP1 $/month	SP2 $/month	SP3 $/month
	Operating system	78	108	42
	Memory	200	250	350
	Instance storage	120	100	150
	Developer support	7.2	9.6	4.8
Total		405.2	467.6	546.8

Again SP1 is also the PaaS provider of choice for the requirements of this customer.

Finally, the SaaS total costs (in $) per SP per month are as follows:

TABLE VI. SAAS MONTHLY PRICE PER SP FOR THE EXAMPLE

SaaS	Service	SP1 $/month	SP2 $/month	SP3 $/month
	Data transfer	24	48	24
	Email service	48	72	24
	Cloud search	18	24	18
	Document mgt.	4	2	2
	ERP	1200	1128	1440
Total		1294	1274	1508

Here SP2 is the SaaS provider of choice for this customer.

The customer in this model would choose at each level the provider of choice for the requirements. If we ignore the fixed monthly sum of money for initiating, controlling and maintaining the connection between SP2 and SP1, SP2 is chosen for SaaS ($1274, Table VI) and SP1 for PaaS ($405.2, Table V) and IaaS ($320, Table IV).

The total cost per month would be the sum of minimum: 320+405.20+1274 = $ 1999.20

Assuming there is a fix monthly fee of $30 for initiating, controlling and maintaining the connection between two different SPs in each two consecutive levels. The monthly fee of 30$ is chosen as an example only, for model illustration, without limiting the generality of the model since comparing investment alternatives usually involve fix and variable costs, two components which our model includes. An additional $ 30 per month would be charged for the connection SP2(SaaS)-SP1(PaaS), and no charge for the same SP1 between PaaS and IaaS. In that case, the total cost would be: $ 1999.20+30 = $ 2029.20.

Let F be the fixed monthly fee for initiating, controlling and maintaining the connection between SP2 and SP1.

If F<1294-1274 the above policy would remain optimal with monthly cost of F+1999.20.

If F>1294-1274 than Choosing SP1 to supply the three levels of service would yield:
320+405.20+1294 =$ 2019.20

Of course supplier selection decisions require sensitivity analysis (finding the impact of small changes in requirements) but the example here is just for illustrating the required computations.

C. The simple pricing model

This model relaxes the assumptions about hierarchy and the need for simple management and control over sub-contracted services. Thus, in this model each SP offers the bundle of services that is composed of the minimal tariffs. The cost of sub-contracting management and control is assumed to be a fixed sum per service per period. Thus, each SP supplies his/her own services if their tariffs are minimal. Otherwise they sub-contract other suppliers (as shown in Table VII). For example SP1 offers the services included in SaaS PaaS and IaaS (Table II column SP1 tariff).

TABLE VII. MINIMAL COST SUPPLIER FOR EACH SERVICE

SaaS	Service name	SaaS Minimal tariff	SP1 Sub contract (**Bald**)	SP2 Sub contract (**Bald**)	SP3 Sub contract (**Bald**)
	Data transfer	1	SP1	**SP3**	SP3
	Email services	1	**SP3**	**SP3**	SP3
	Cloud search	3	SP1	**SP3**	SP3
	Documents Mgt.	1	**SP3**	SP2	SP3
	ERP	47	**SP2**	SP2	SP2
PaaS	Service name	PaaS min. tariff	SP1 Sub contract	SP2 Sub contract	SP3 Sub contract
	Operating system	7	**SP3**	**SP3**	SP3
	Memory (GB)	20	SP1	**SP1**	**SP1**
	Instance storage GB	10	**SP2**	SP2	**SP2**
	Developer support	2	**SP3**	**SP3**	SP3
IaaS	Service name	IaaS min tariff	SP1 Sub contract	SP2 Sub contract	SP3 Sub contract
	Relational Database services	6	**SP2**	SP2	**SP2**
	Storage TB standard volume.	15	**SP2**	SP2	**SP2**
	Backup (GB)	20	SP1	**SP1**	SP3

The minimal tariff of each item yields total monthly price for the customer's requirements of: $ 1831.60.

In addition, the customer must contact the other two SPs to establish the purchases and track the transactions. Assuming a monthly cost per SP per service of $ 30.00 for the administrative work of ordering, tracking and payment management yields:

Main SP1: 1831.60+8*30 = 2071.60
Main SP2: 1831.60+7*30 = 2041.60
Main SP3: 1831.60+5*30 = 1981.60

Thus, Main SP3 is chosen with monthly expenses of: 1981.60, compared with the minimal cost SP, this is annual savings of $ 451.20).

D. The Complete Mathematical Model

While the hierarchical pricing model and the simple pricing model reduce costs significantly, they do not find the absolute minimal cost solution. To complete the modeling of cloud pricing, this section presents a solution that finds the optimal cost solution. This section defines a complete mathematical optimization formulation that could be applied by prevalent optimization software packages. We use the following definitions.

Definitions

i – index of infrastructure providers
k – index of platform service provider
m – index of software service providers

j – index of infrastructure service type
l – index of platform service type
n – index of software service type
X_j - usage of infrastructure service j.
Y_l - usage of platform service l.
Z_n.- usage of software service n.
IC_{ij} - infrastructure fixed cost of provider i and service type j
I_{ij} - infrastructure variable cost of provider i and service type j.
PC_{kl} - platform fixed cost of provider k and service type l
P_{kl} - platform variable cost of provider k and service type l
SC_{mn} - software fixed cost of provider m and service type n
S_{mn} - software variable cost of provider m and service type n
PI_{ki} - a fixed sum of money for initiation the connection between platform SP k and infrastructure SP i
SP_{mk} - a fixed sum of money for initiation the connection between software SP m and platform SP k

The computations start at the Infrastructure stage:

At that stage there are i infrastructure service providers (SPs) and j service types. The usage of infrastructure service type j is the variable X_j. Thus, the infrastructure price corresponding to the i^{th} service provider and j^{th} service type is $IC_{ij}+I_{ij}X_j$. These are also the published infrastructure tariffs.

The next stage is the Platform services.

At that stage there are k platform service providers (SPs) and l platform service types. The usage of infrastructure service type l is the variable Y_l. Thus, the infrastructure price corresponding to the k^{th} service provider and l^{th} service type is $PC_{kl}+P_{kl}Y_l$. These are also the published platform tariffs.

The connection cost between Infrastructure SP and Platform SP is: C_{ki} and the purchased infrastructure price for a given k (SP) is $\sum_j IC_{ij}+I_{ij}X_j$

So, the cost for a given platform SP k the prices s/he offers for a given Y_l is the optimal combination of:

$$MIN\{\sum_k \sum_{l:Y_l>0} (PC_{kl}+P_{kl}Y_l + \sum_i C_{ki} \sum_{j:X_j>0} IC_{ij}+I_{ij}X_j)\}$$

Last stage is performed on software service provider.

At that stage there are m software service providers (SPs) and n software service types. The usage of software service type n is the variable Z_n. Thus, the infrastructure price corresponding to the m^{th} service provider and n^{th} service type is $SC_{mn}+S_{mn}Z_{mn}$. These are also the published software tariffs. The connection cost between software SP and Platform SP is: C_{mk}.

So, the cost for a given software SP (m) the prices s/he offers for a given Z_n is the optimal combination of:

$$MIN\{\sum_m \sum_{n:Z_n>0} (SC_{mn}+S_{mn}Z_n \sum_k C_{mk} \sum_{l:Y_l>0} (PC_{kl}+P_{kl}Y_l + \sum_i C_{ki} \sum_{j:X_j>0} IC_{ij}+I_{ij}X_j))\}$$

S.T.

Software types and requirements:

Values of $Z_n\ \forall n$

Values of $Y_l\ \forall l$

Values of $X_j\ \forall j$

The constraints are the software type and usage requirements: Z_n and its derivative requirements: Y_l and X_j

Overall, this is a quadratic optimization formulation that could be solved by the prevalent solvers (software packages) including [9], [20], and [12].

When adding a fix monthly cost of $30 per service of another SP, the optimization yields the minimal cost solution: $ 1866.40 which is better than the corresponding solution of the simple model ($ 1981.60) or the hierarchical model ($ 2019.20).

To understand the optimization results it is useful to understand that minimizing cost drives one main SP that subcontract services (from the other SPs) in cases that contribute to the main SP competitiveness. Thus, in our case there are only three possible main SPs: SP1, or SP2, or SP3.

We shall use table VI here again for the rest of the explanations.

If SP1 is chosen, the minimization yields:

SP1 supplies data transfer – SP1 rate is minimal ($24)

SP1 supplies Email services – SP1 rate is less than $30 higher than the minimum ($48).

SP1 supplies Cloud search - SP1 rate is minimal ($18)

SP1 supplies Document Mgt. - SP1 rate is less than $30 higher than the minimum ($4)

SP2 supplies ERP service – with cost of ($1128+$30 = $1158).

Total SaaS cost: 24+48+18+4+1158= $1254

If SP2 is chosen, the minimization yields:

SP1 supplies data transfer – SP2 rate is less than $30 higher than the minimum ($48)

SP3 supplies Email services – SP2 rate is more than $30 higher than the minimum

($24+$30= $54)

SP2 supplies Cloud search - SP2 rate is less than $30 higher than the minimum ($24)

SP2 supplies Document Mgt. – SP2 rate is minimal ($2)

SP2 supplies ERP service – SP2 rate is minimal ($1128).

Total SaaS cost: 48+54+24+2+1128= $1256

If SP3 is chosen, the minimization yields:

SP3 supplies data transfer – SP3 rate is minimal ($24)

SP3 supplies Email services – SP3 rate is minimal ($24)

SP3 supplies Cloud search – SP3 rate is minimal ($18)

SP3 supplies Document Mgt. – SP3 rate is minimal ($2)

SP2 supplies ERP service – SP2 rate is minimal with cost of ($1128+$30 = $ 1158).

Total SaaS cost: 24+24+18+2+1158= $1228

These are only SaaS computations. The minimization computations continue in the same manner for the PaaS and IaaS (using tables IV and V). While the above calculations show that main SP3 is the least cost SaaS provider, the overall computations (with the addition of PaaS and IaaS) show that main SP1 is the minimal cost $ 1866.40.

V. Discussion

In this paper we presented three possible pricing models that could serve as free market tools to form competition. To ensure the free market competition, we eliminated few of the competition barriers in each of our pricing models: bundling of services, lack of transparency and varying tariff structures.

Table VIII evaluates the level of optimization yielded by each model and ease of technological implementation in cloud computing architecture. The evaluation criteria are discussed below.

TABLE VIII. Summary of Pricing Models' Evaluation

Evaluation criteria	Hierarchical pricing model	Simple pricing model	Complete mathematical pricing model
Vertical unbundling	Partial	High	High
Horizontal unbundling	No	High	High
Pricing transparency	Limited	High	High
Tariff structure	Limited	High	High
Cost optimization	Low	Medium	High
Ease of technological implementation	High	Low	Low

Evaluation criteria:

Vertical integration is partial (but still existing due to the possibility to choose providers) in the hierarchical model since all services of one layer are bundled to one provider whereas in the two other models vertical unbundling is high since services of one layer may be supplied by different providers.

Horizontal unbundling does not exist in the hierarchical model since consumers select a providers' bundle of services, but cannot select services from other providers. In the other models consumers select services independently from any provider.

Pricing transparency and tariff structure are limited in the hierarchical model since selection in based on providers' bundle price, but are not based on prices of services. This is in contrary to the two other models.

Cost optimization is optimized in the complete mathematical model. In the simple model the optimization is not maximal since selection of services is performed on a subgroup of all providers' services. In the hierarchical model optimization is low due to selection on the basis of providers' bundle's price, but not based on services' prices.

Ease of technological implementation is high in the hierarchical model since the number of interfaces among suppliers is minimal, thus minimum resources needed to build and maintain. In the other models the number of interfaces is high since all services interfacing with different providers need to be built.

Each organization has to calculate the above parameters, assess the impacts on the level of optimization and ease of implementation and then make his cost optimization decisions.

VI. Conclusions

This paper proposes three cost minimization models for cloud computing consumers, (while keeping the published tariffs). Choosing one of the models is performed by taking into account organizational considerations. The first model is hierarchical; one supplier is chosen for each of the three layers (SaaS, PaaS, IaaS). The hierarchical model is easy to implement and also reduces customers' costs compared to the current situation. This model produces only a limited amount of services unbundling and only limited transparency of prices. The second model, we call the simple pricing model, enables high transparency and unbundling of services and further cost reduction. Implementing this model is more difficult since the control of various providers and services is more complicated. The third, called the complete pricing model is similar to the simple pricing model but goes one step further enabling full cost optimization.

Three preconditions are required for effective competition, and for our pricing models to be effective. We claim market forces are bound to cause these conditions to materialize in the long run. First, suppliers have to offer standard features of their services. This will be the ground for a comparison of different supplier services. Secondly, having standard features will enable standardizing tariff tables for cloud computing market, and make service cost structure transparent. Thirdly, software suppliers should build their services according to open standards, (which nowadays are not the case), thus enabling connectivity among different services offered by suppliers.

In this paper we dealt with cost minimization of cloud services. Further research is needed for incorporating additional consumers' considerations such as preference of a fix-price model on a pay-per-use model due to risk aversion, and providers' impacts on consumers' biases in buying decisions. Further research is needed for better understanding the providers' considerations in the cloud computing market.

References

[1] Al-Roomi, M., Al-Ebrahim, S., Buqrais, S., Ahmad, I., (2013), Cloud Computing Pricing Models: A Survey. International Journal of Grid and Distributed Computing: Vol 6. No 5.

[2] Amazon Web Services – How AWS Pricing Works, https://d36cz9buwru1tt.cloudfront.net/AWS_Pricing_Overview.pdf, accessed 02 June 2014.

[3] Aoyama, T., Sakai, H., (2013). Inter-Cloud Computing, Business Information Systems Engineering 3/2013.

[4] Anandasivam, A., Premm, M., (2009). Bid Price Control and Dynamic Pricing in Clouds. ECIS – European Conference on Information Systems 17.

[5] Bitran, G., Caldentey, R., (2003). An overview of pricing models for revenue management. Manufacturing & Service Operations Management 5(3):203–229.

[6] Blau, B., Neumann, D., Weinhardt, C., Michalk, W., (2008). Provisioning of service mashup topologies. In: Proceedings of the 16th European conference on information systems, Galway.

[7] Chen, Z., Han, F., Cao, J., Jiang, X., Chen, S., (2013). Cloud Computing-Based Forensic Analysis for Collaborative Network Security Management System. Tsinghua science and technology, Vol 18/1, 2/ 2013.

[8] El Kihal, S., Schlereth, C., Skiera, B., (2012). Price comparison for Infrastructure-as-a-Service. In: ECIS 2012 Proceedings.

[9] GAMS homepage (2014). http://www.gams.com/, accessed 02 Jul 2014.

[10] Gens, F., (2009). Clouds and Beyond: Positioning for the next 20 Years in Enterprise IT, IDC presentation on innoforum09, 25-03-2009, http://www.slideshare.net/innoforum09/gens.

[11] Gill, A., Banker, D., Seltsika, P., (2015). Moving Forward: Emerging Themes in Financial Services Technologies Adoption, *Communications of the Association for Information Systems*: Vol. 36, Article 12.

[12] Gino optimization software (2014). http://www.mat.univie.ac.at/~neum/glopt/software_l.html, accessed 02 Jun 2014.

[13] Google Cloud platform (2014). https://cloud.google.com/?gclid=Cj0KEQjwmPKeBRCj4bOro6nBitABEiQABa2FJJiC0E3d61rVTIdBElecEgzYWDTaf_EyAckJ_nOykH4aAsnH8P8HAQ, accessed 02 Jun 2014.

[14] Koehler, P., Anandasivam, A., Dan, M., Weinhardt, C., (2010). Customer heterogeneity and tariff biases in cloud computing. Thirty First International Conference on Information Systems, St. Louis 2010 1, ICIS 2010 proceedings.

[15] Labes, S., Erek, K., Zarnekow, R., (2013). Common Patterns of Cloud Business Models. In Proceedings of the Nineteenth Americas Conference on Information Systems, Chicago, Illinois, August 15-17, 2013.

[16] Lai, K., (2005). Markets are dead long live markets. In: SIGecom Exchanges 5(4): pp 1–10.

[17] Lambrecht, A., Skiera, B., (2006). Paying Too Much and Being Happy about It: Existence, Causes and Consequences of Tariff-Choice Biases. Marketing Research 43, number 2 (2006): 212-223.

[18] Lampe, U., Hans, R., Selieger, M., Pauly, M., Schiefer, M., (2014). Pricing in Infrastructure Clouds – An Analytical and Empirical Examination. In: Proceedings of the 20th Americas conference on Information systems.

[19] Lilienthal, M., (2013). A Decision Support Model for Cloud Bursting, Business & Information Systems Engineering 2|2013.

[20] Lindo systems (2014). **www.lindo.com**, accessed 02 Aug 2014.

[21] MacKie-Mason, J. K., Varian, H. R., (1995). Pricing Congestible Network Resources. IEEE Journal on Selected Areas in Communications 13, number 7 (1995): pp 1141-1149.

[22] Mansouri, Y., Toosi, A., N., Buyya, R., (2013). Brokering Algorithms for Optimizing the Availability and Cost of Cloud Storage Services, 2013 IEEE International Conference on Cloud Computing Technology and Science.

[23] Mell, P., Grance, T., (2009). “The NIST definition of cloud computing”, National Institute of Standards and Technology, NIST, Vol. 53 No. 6, p. 50.

[24] Microsoft cloud services pricing details (2014). .https://azure.microsoft.com/en-us/pricing/details/cloud-services/, accessed 02 Aug 2014.

[25] Paraiso, F., Haderer, N., Merle, P., Rouvoy, R., Seinturier, L., (2012). A Federated Multi-Cloud PaaS Infrastructure, 2012 IEEE Fifth International Conference on Cloud Computing.

[26] Pueschel, T., Anandasivam, A., Buschek, S., Neumann, D., (2009). Making money with clouds: Revenue optimization through automated policy decisions. ECIS - European Conference on Information Systems 17.

[27] Rehman, U. Z., Hussain, F. K., Hussain, O. K., (2011). Towards Multi-Criteria Cloud Service Selection, 2011 Fifth International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing.

[28] Staten, J., (2014). Forrester, Cloud predictions for 2014: Cloud joins the IT portfolio, http://blogs.forrester.com/james_staten/13-12-04-cloud_computing_predictions_for_2014_cloud_joins_the_formal_it_portfolio, accessed 02 March 2014.

[29] Vaquero, L., Rodero-Merino, L., Caceres, J., Lindner, M., (2009). A Break in the Clouds: Towards a Cloud Definition. Editorial note. ACM SIGCOMM (2009). Computer Communication Review 50 Volume 39, Number 1, January 2009.

[30] Varian, H. R., (2003). Economics of Information Technology. Working Paper.

[31] Velte, A., Elsenpeter, R**.,** Velte, T. J., (2009). Cloud Computing: A practical approach. Tata McGraw-Hill Education Pvt. Ltd.

[32] Walterbusch, M., Martens, B., Teuteberg, F., (2013). Evaluating cloud computing services from a total cost of ownership perspective. Management Research Review Vol. 36 No. 6, pp. 613-638.

[33] Ward, S. J., Barker, A., (2014). Observing the clouds: a survey and taxonomy of cloud monitoring. *Journal of Cloud Computing* 2014, **3**:24.

[34] Weinhardt, C., Blau, B., Stößer, J., (2009). Cloud Computing – A Classification, Business Models, and Research Directions. Business & Information Systems Engineering 05/2009.

[35] Wu, S., Banker, R., (2010). Best Pricing Strategy for Information Services. Journal of association for information systems.

[36] Yang, H., Tale, M., (2012). A Descriptive Literature Review and Classification of Cloud Computing Research. *Communications of the Association for Information Systems*: Vol. 31, Article 2.

[37] Yung-Ming, L., Chia-Ling, C., (2012). Analyzing The Pricing Models For Outsourcing Computing Services. *PACIS 2012 Proceedings.*

[38] Zhang, Q., Cheng, L., Bautaba, R., (2010). Cloud computing: State-of-the-art and Research challenges. J Internet Serv Appl (2010) 1:7-18.