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A Cost Model for Hybrid Clouds

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A Cost Model for Hybrid Clouds

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Abstract: Cloud computing aims at allowing customers to utilize computational resources and software hosted by service providers. Thus, it shifts the complex and tedious resource and software management tasks typically done by customers to the service providers. Besides promising to eliminate these obstacles of resource management for consumers, Cloud computing also promises to reduce the cost of IT infrastructure. In particular, it promises to reduce the cost of IT through lower capital and operational expenses, stemming from a Cloud's economies of scale and from allowing organizations to purchase just as much computer and storage resources as needed whenever needed. A clear specification of savings however requires a detailed specification of the costs incurred. Although there are some efforts to define cost models for Clouds, the need for a comprehensive cost model, which covers all cost factors, is undeniable. In this paper, we cover this gap by suggesting a cost model for hybrid Clouds (i.e., the combinations of a private data center (private Cloud) and the public Cloud). This model is based on a comprehensive literature research on cost factors and the idea of combining cost of data centers and cost for using Clouds. Finally, we demonstrate the workings of the suggested cost model by applying it to a specific Cloud scenario.

Keywords: Cloud computing, hybrid Clouds, Infrastructure-as-a-Service, Cloud service migration, cost modeling, IT cost factors, Cloud economics, cost model comparison.

JEL Classification Numbers: C02, D24, D40, L24, L86, M15, M21.

1. Introduction

The Cloud computing paradigm has been established as a promising model for using computational resources and software resources on-demand [2, 15, 21]. It shifts the complex and tedious resource and software management tasks typically performed by the customers to the service providers. Therefore, it increases the flexibility to adapt to changes in demand [3] [19]. It also reduces the infrastructure investments and the cost of organizing the IT resources. The capital and operational expenses are lower, stemming from the Cloud's economies of scale. Consequently, Cloud computing has sparked a huge amount of interest in the IT industry. It is not only very attractive to business customers but also to small research groups in the computational science and engineering field [3]. Some statistics state that the market for Cloud computing services was $16billion in 2008 and will rise to $42billion/year by 2012 [17].

Despite these benefits and optimistic outlooks, there are also some researchers opposing those positive claims. A report by McKinsey argued that there would be only a few savings from a migration to the Cloud. They even state that moving to the Cloud would actually cost 144% more than current expenditures [12, 25]. The considerable uncertainty about cost savings and need for more details about actual expenditure were also discussed by Kondo et al. [3]. This still-ongoing discussion highlights the necessity for an overall cost model [11, 13].

Our research objective is to clarify whether and under which conditions Cloud computing can actually save money. In particular, we intend to construct an overall cost model that can be used by Cloud users to decide whether to use the Cloud for certain applications. This overall cost model comprises a comprehensive set of cost factors, necessary for making good cost estimation for running applications in a in-house data center or on a public Cloud.

In particular, we address the following three questions: (1) Which cost factors and what type of cost factors have been considered for Clouds? (2) How is a cost model for hybrid Clouds structured? (3) How can this cost model be applied?

To answer these questions, we conduct the following steps: First, we perform a systematic literature review of papers on cost factors and cost models in Cloud computing. Second, we identify the gaps in the current research on Cloud cost modeling. Based on the result, we perform a cost-benefit analysis to design a comprehensive overall cost model for hybrid Clouds. Finally, we apply this new cost model to demonstrate its workings.

The remainder of the paper is organized as follows. The next chapter gives an overview about cost factors and cost models, which have been proposed already in literature. Chapter 3 introduces our cost model for hybrid Clouds. The application of our cost model in a Cloud computing scenario is shown in chapter 4. The final chapter, chapter 5, concludes the paper.

2. Background

2.1. Cloud Computing

Although there are still many Internet forums and blog discussions on what Cloud computing is and is not, the NIST definition seems to have captured the commonly agreed Cloud computing aspects that are mentioned in most of the academic papers published in this area [19]. The NIST definition states that Cloud computing is *"A model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction."* As Cloud computing is still in its infancy, the definition of Cloud computing is likely to be improved later when new ideas, services, and developments in Cloud computing will be explored. Nonetheless, for the purpose of our paper, the definition given by NIST is fully sufficient.

2.2. The Need for Cost Models for Clouds

The majority of participants of a survey (which Rayport and Andrew conducted [18]) indicated that they used already public Clouds or discussed, planned, trialed, or implemented the use of a Cloud infrastructure. Their objective for using Cloud technology has been the potential reduction of data center costs. Even though there is a lot of mentioning about the benefits and even inevitability of migrating to a Cloud [14], the exact costs are still unknown. This lack of a cost model makes any decision on migration uncertain. This has been noticed in the academic and business world manifold [6, 7, 13, 15, 17].

Many statements have also been made about the need for cost models for Clouds [3, 8, 11]. A cost model would allow determining the actual cost of using the Cloud. Using these cost values, one may investigate economic factors like Return-on-Investment (ROI), Net-Present-Value (NPV), Benefit-to-Cost-Ratio (BCR), and Discounted-Payback-Period (DPP). These measures are essential to decide when and under which conditions it is better to use Clouds [6, 7]. In other words, any company using Clouds has to execute a detailed cost-benefit analysis to determine whether running their services on the Cloud is more cost effective than purchasing in-house resources.

However, to perform this cost analysis, intimate knowledge about applications, hardware, and the load levels is required [1]. The difficulty in obtaining this knowledge makes it non-trivial to estimate short-term or long-term costs. As Ali et al. pointed out, it is difficult to know "the actual resources consumed by a system", "the deployment option used by a system, which can affect its costs as resources" and the "probable changes in the Cloud service provider's pricing scheme" [8].

2.3. Existing Research on Cost Factors

In order to find all major papers addressing our research objectives, we searched research databases with a combination of keywords from two groups. The first group comprises the keywords Cloud computing, elastic computing, utility computing, Infrastructure-as-a-Service, IaaS, Platform-as-a-Service, PaaS, Software-as-a-Service, SaaS, Everything-as-a-Service, and XaaS. The second group of keywords includes cost model, business model, cost estimation, cost parameters, and economics. The research databases used are IEEE Explore, ACM Digital Library, ISI Web of Knowledge, SpringerLink, ScienceDirect, and Google scholars.

In total, we have found 10 papers that discuss cost factors and cost models in the context of Clouds.

The first paper evaluates claims about the financial advantages that companies would gain from using a commercial Cloud [1]. The authors have calculated costs in four Cloud scenarios. For that, a comparison of the costs for a company, which purchases resources from Amazon EC2 or from a hardware vendor for its in-house data center, were pointed out.

Helping to decide when and under which situation it is recommended to move to the Cloud, a very good coverage of cost factors has been given by Tak et al. [2]. Moreover, the authors have also classified costs into quantifiable and less quantifiable cost factors. In particular, their classification also includes a grouping into direct or indirect cost.

Even though Kondo et al., the authors of [3], have not proposed any cost model, they conducted an economic comparison. For that, they covered all cost aspects of a Cloud project. In total, they considered 11 cost factors.

Besides identifying 6 cost factors, Armbrust et al. also compared Cloud and in-house cases, using a trade-off formula [4]. The authors did not focus on cost modeling but gave a general understanding of various aspects of Cloud computing. They have pointed to the cost-benefit tradeoff of migrating to the Cloud, and have proposed a simple formula to quantify decision makings [4].

The challenges, which enterprises face when applying hybrid Cloud models, were discussed by Hajjat [5]. Component placement is one of the challenges, addressing the decision of which of the components must be kept local and which components can be migrated. Another challenge is the specification of cost factors with respect to computing components, storage components, and wide-area communication. As the cost savings from migration depend on the placement of compute, storage-intensive, and communication intensive components, graph theory has been used to model the network of components and their data transfer relations.

Truong and Dustbar present a service for estimating and monitoring costs. The service distinguishes three situations: the complete use of on-premise resources, the partial use of Cloud resources, or the complete use of Cloud resources [6]. In particular, they discuss the composability of cost models and the migration of some application components to the Cloud. They have introduced seven cost models. The data used for the comparison of the models came from Cloud providers' pricing specifications [6].

Alford and Morton present an economic analysis to investigate the potential savings from a migration of services to the Cloud. They focus on IT data centers and use a proprietary cost model [7]. The study takes into consideration transition costs and life-cycle operations, as well as migration schedules. Although they did not specify the cost model, they emphasize the existence of the cost model that is owned by the Booz Allen Hamilton Inc. The cost model is used to compare the three scenarios: public Cloud, hybrid Cloud, and private Cloud.

Khajeh-Hosseini introduced the Cloud Adoption Toolkit. The toolkit provides a collection of tools that support decision making with respect to the adoption of Cloud computing in an enterprise. However, the cost model mentioned here has also not been described and presented. Only the cost factors have been described [8].

There is a very detailed analysis of costs in [9]. The authors conducted an analysis of different cost factors that have to be considered by a provider of a computational Grid. This analysis uses realistic values. In addition to this, the authors have shown an estimation of the total costs for resource providers in two real-world examples.

Although the main contribution of [10] is in the area of Software-as-a-Service only, some of the considered cost factors for the software selection process can be used in the overall Cloud environment. The authors have focused on the software license selection support. Their model helps users to select a SaaS Licensing (SaaSL) model or a Perpetual Software Licensing (PSL) model.

Among those 10 papers, which have been covered in this literature review, just three of them have proposed their own sophisticated quantitative model. These are the works in [4, 5, 6]. Although there are three other papers, which indicated to have their own cost models, they did not provide any details, making it impossible to evaluate or use them.

2.4. Cost Factors

All 20 cost factors, which have been identified within the papers listed in the previous section, are structured and categorized into six groups: electricity, hardware, software, labor, business premises, and service. This classification is shown in Table 1. In the column labeled ‘Papers’, the paper identifiers are listed. The paper identifiers are the same as the literature references. The meaning of the cost factors is as follows:

Electricity: The power usage for the consumption of in-house electronic devices like servers, gateways, routers, and other network devices is considered in this class [1, 2, 3, 4, 7, 9]. In some papers, the electricity consumed through cooling has been considered separately from other electronic devices [2, 4, 7, 9]. Additionally, for achieving accurate estimates, two kinds of values need to be considered for all devices: the power consumption, when the system is idle, and the power consumption, when the system is heavily used [9].

Hardware: Hardware cost refers to the acquisition of hardware resources. In particular, it distinguishes between the purchasing cost of computing hardware needed in-house [1, 2, 3, 7, 9, 10] and the purchasing cost of network devices (e.g., switches, routers) needed in-house [2, 7, 10]. In order to determine the actual annual costs of the resources, their economic lifetime has to be considered as well [9]. We consider a depreciation time of three years.

Software: The purchasing price of licenses of software, which is used in-house, is considered in this class. There are three types of software, which should be considered separately: basic server software, middleware software, and application software. Basic server software (e.g., operating system software, back-up software) refers to server licensing cost [2, 7, 10]. Middleware software refers to any commercial middleware software that is needed for running applications [7]. Application software refers to customer applications (e.g., Web server, enterprise resource planning software). Inevitably, depending on the application being used, the cost can vary in a very wide range [1, 2, 3, 6, 7, 9, 10].

Labor: This category comprises salaries for technicians, who work on maintaining software [2, 7], hardware [2, 7, 9], or on providing support [2, 3, 7, 9]. This cost factors are impacted by the region or country, in which the data center is located.

Business Premises: This category includes the basic costs, which are essential to establish an in-house data center. These basic costs are the cost for renting or purchasing the data center facility [4], the cost for racks and other non-electronic instruments, which are required for the safety and the reliability of the data center, as well as the cost of cabling the data center [7].

Service: The remaining cost factors, which are categorized as services, are mainly intangible items. Some of the service costs may incur independently to whether the customer uses in-house data center services or Cloud-based services. One cost factor is the charge for Internet connectivity (i.e., for Internet access for the enterprise) [3, 5]. Another cost factor is the usage cost for servers (CPU hours) [1, 2, 3, 5, 6, 8]. The cost for incoming data transfer (e.g., Cloud data transfer in) is another factor [1, 3, 4, 5, 6, 8, 9]. Similarly, there is the cost for the amount of outgoing data transfer (e.g., Cloud data transfer out) [1, 3, 4, 5, 6, 8, 9]. The Cloud storage factor describes the amount of storage, which is used in the Cloud [1, 3, 4, 5, 6, 8]. Finally, there is the cost for executing input requests (i.e., the cost of a write request to a database) as well as the cost for executing an output requests (i.e., the cost of a read request from a database) [3, 8].

Table 1. Comparison of contributions of papers with respect to cost factors.

Cost Type	Cost Factor		Literature									
			[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
		Number of Factors / Number of Papers	7	12	11	6	6	5	11	6	9	4
a) Electricity	a1) Cooling	4		1		1			1		1	
	a2) Electronic devices	6	1	1	1	1			1		1	
b) Hardware	b1) Server	6	1	1	1				1		1	1
	b2) Network device	3		1					1			1
c) Software	c1) Basic server software	3		1					1			1
	c2) Middleware	1									1	
	c3) Application software	7	1	1	1			1	1		1	1
d) Labor	d1) Software maintenance	2		1					1			
	d2) Hardware maintenance	3		1					1		1	
	d3) Other support	4		1	1				1		1	
e) Business Premises	e1) Air conditioner, rack	2		1					1			
	e2) Cabling	2		1					1			
	e3) Facility	1				1						
f) Cloud Service	f1) Internet connectivity	2			1		1					
	f2) Server usage	6	1	1	1		1	1		1		
	f3) Data transfer into Cloud	7	1		1	1	1	1		1	1	
	f4) Data transfer from Cloud	7	1		1	1	1	1		1	1	
	f5) Cloud storage	6	1		1	1	1	1		1		
	f6) Requests to input to Cloud	2			1					1		
	f7) Requests to output from Cloud	2			1					1		

2.5. Shortcomings of Existing Cost Models

Among those ten papers contributing to cost modeling of Cloud computing, just three of them proposed an explicit cost model [4, 5, 6]. However, even these three papers center only on either an analysis of certain scenarios or provide a very generic economic solution that has not been adapted well to the Cloud application area (e.g., Armbrust et al. has proposed a very broad economic formula [4]). This general formula needs much more efforts to be applicable in practice in the Cloud application area. Although the paper of Hajjat et al. provides details about optimization of application components, no cost formula has been specified [5]. But clearly, any kind of optimization should be based on the total cost. Finally, Truong et al. have suggested seven formulas, each one of them addressing a certain activity in Clouds [6]. But, in case of using hybrid Clouds, those formulas are incomplete. The formulas miss information about data center costs.

For that, none of these three works has given us a comprehensive estimation of costs for hybrid Clouds. Most probably, using those models leads to inaccurate estimates.

Consequently, any optimization based on these estimates will be of little help. This uncertainty is an obstacle for applying these cost models in practice in hybrid Clouds.

3. The Proposed Hybrid Cloud Cost Model

3.1. Model Context

As shown in the following figure, the context of our model considers four stakeholders in the Cloud computing market: large enterprises, small and medium-sized enterprises (SMEs), Cloud providers, and Internet data centers (IDCs). Cloud providers offer consumers to buy resources on demand. The IDCs provide solutions for long-term outsourcing of IT infrastructures to consumers. Users in this market can be either SMEs or large enterprises.

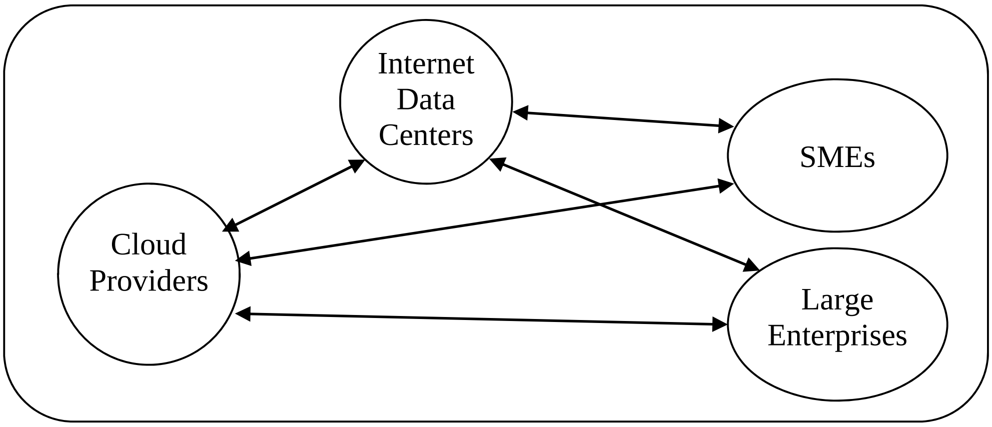

Figure 1. Stakeholders in the Cloud computing market.

The focus of this paper is on large enterprises and their relationship to Cloud providers. The reason for choosing this relationship is that large-sized enterprises have the option of migrating their tasks to the Cloud completely, keeping all tasks in-house (which is equivalent to using an IDC), or run a hybrid solution. This is the most challenging situation with respect to resource allocation decisions. For comparison, SMEs that have a few small IT jobs to complete the most fitting solutions will be to use Cloud providers.

3.2. Conceptual Model

The conceptual model assumes an organization, which comprises the execution of N applications and M services (across all applications). Applications usually consist of services, which are composed to run a business process. Services are assumed to be basic units, which can perform a set of functions. Users buy those services to construct their applications. Each service can communicate with all other services (if the other services allow) and transfer a specific amount of input data and output data (Figure 2).

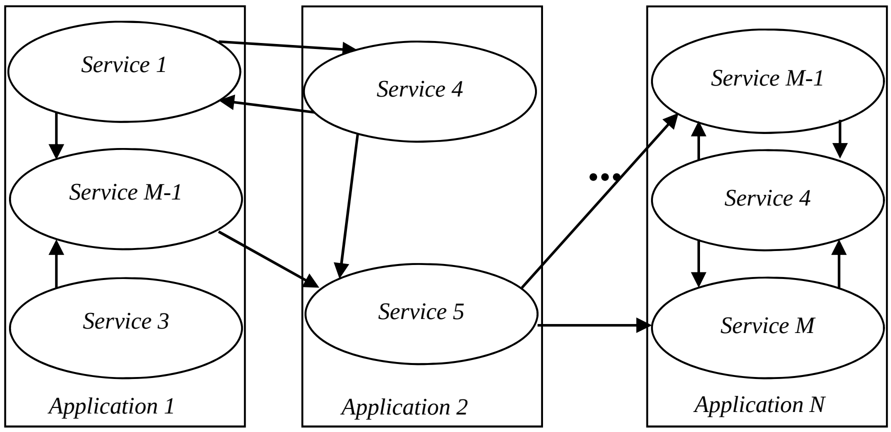

Figure 2. A schematic view of a set of N applications build on M different services with specific data transfer relations (black arrows) between services.

The representation of services and their data transfer relationships using graph theory allows the use of network analysis methods. Obviously, the resulting graph is a directed and weighted graph. Vertices represent services, while edges show data communications. If there is edge from vertex *i* to vertex *j* with a_{ij} as edge label, there is an average monthly data transfer from service *i* to *j*. An example of this representation is shown in Figure 3.

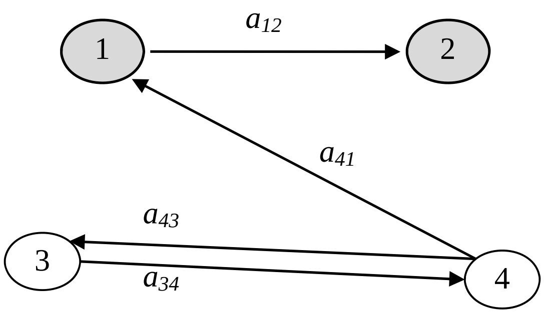

Figure. 3. Graph representation of services and their data transfers.

Using this representation of services, the distance matrix *D* can be used to represent the data-transfer related cost factors a_{ij} between service *i* and *j*. The matrix elements a_{ij} of the distance matrix that do not represent an arrow get infinity assigned. To calculate the total data transfer into the Cloud (i.e., Cloud data transfer inward T^{In}) and the total data transfer out of the Cloud (i.e., Cloud data transfer outward T^{Out}), we propose two formulas:

Cloud data transfer in: $$T_m^{In} = \sum_{i \in I, j \in C} a_{ij} \quad , a_{ij} \in D \qquad (1)$$

Cloud data transfer out: $$T_m^{Out} = \sum_{i \in I, j \in C} a_{ji} \quad , a_{ji} \in D \qquad (2)$$

Where *i* and *j* denote services. The set *I* represents the set of services that run in-house and the set *C* represents the set of services that run in the Cloud

3.3. Cost Formula

Based on the cost factors listed in section 2.4, we propose a comprehensive formula that covers all aspects of costs. The costs considered are the purchasing cost for all servers needed ($\sum_i^S C_i^{Se}$; b1 of Table 1), the purchasing cost for all network devices needed ($\sum_i^N C_i^{Ne}$; b2 of Table 1), the costs for all basic server software licenses ($\sum_i^B C_i^{BSS}$; c1 of Table 1), the costs for middleware licenses ($\sum_i^M C_i^{MS}$; c2 of Table 1), the costs for application software licenses ($\sum_i^A C_i^{AS}$; c3 of Table 1), the cost of facility space ($C_{Fa}F$; e3 of Table 1) that the company needs for its data center, the cost of the none-electronic equipment (C_{Nee}; e1 of Table 1) that is needed for a data center, and the cost for cabling (C_{Ca}; e2 of Table 1). These costs are fixed costs. The sum of these fixed costs FC is shown in equation 3.

$$FC(d) = \sum_i^S C_i^{Se} + \sum_i^N C_i^{Ne} + \sum_i^B C_i^{BSS} + \sum_i^M C_i^{MS} + \sum_i^A C_i^{AS} + C_{Fa}F + C_{Nee} + C_{Ca} \quad (3)$$

The parameters used in equation 3 are as follows: *d* denotes the depreciation period in units of months. S is the number of server devices, which are needed to run all services. C_i^{Se} is the cost of server i. N is the number of network devices that are needed. C_i^{Ne} is the cost of network device i. B denotes the number of basic server software. C_{Bss}^k is the cost of basic server software k. M denotes the number of middleware software which is needed. C_i^{MS} is the cost of middleware software i. A is the number of application software, which is used. C_i^{AS} is the cost of application software i. F denotes the size of the facility in square meters. C_{Fa} is the cost of facility space in square meters. Note, facility cost can be calculated based on rent contract conditions.

The following variable cost factors are calculated over time. They are summed up for each time period (e.g., monthly or annually). They comprise the cost of electricity usage from cooling and from other electric devices ($C_m^{Elec}(E_m^C + E_m^E)$; a1 and a2 of Table 1), the cost for Internet connectivity of the data center ($C_m^{Int}I_m$; f1 of Table 1), the cost of labor for maintaining software ($C_m^{LS}L_m^S$; d1 of Table 1), for hardware ($C_m^{LH}L_m^H$; d2 of Table 1), for other work ($C_m^{LO}L_m^O$; d3 of Table 1), the cost for data transfer that goes into the Cloud ($C_m^{TIn}T_m^{In}$; f3 of Table 1) and out of the Cloud ($C_m^{TOut}T_m^{Out}$; f4 of Table 1), the cost for Cloud storage ($C_m^{Sto}H_m$; f5 of Table 1), the Cloud server usage cost ($\sum_i^{SerType} C_{m,i}^{Se}S_m^i$; f2 of Table 1), and finally the cost of requests for input to the Cloud ($\sum_i^{RTypes} C_{m,i}^{InR}R_{m,i}^{In}$; f6 of Table 1) and the cost of requests for output from the Cloud ($\sum_i^{RTypes} C_{m,i}^{OutR}R_{m,i}^{Out}$; f7 of Table 1). Consequently, the total variable cost VC is calculated as the sum of all these costs as shown in the following equation:

$$VC(m) = C_m^{Elec}(E_m^C + E_m^E) + C_m^{Int}I_m + C_m^{LS}L_m^S + C_m^{LH}L_m^H + C_m^{LO}L_m^O + C_m^{TIn}T_m^{In} + C_m^{TOut}T_m^{Out} + C_m^{Sto}H_m + \sum_i^{SerType} C_{m,i}^{Ser}S_m^i + \sum_i^{RTypes} C_{m,i}^{InR}R_{m,i}^{In} + \sum_i^{RTypes} C_{m,i}^{OutR}R_{m,i}^{Out}. \quad (4)$$

The parameters used in equation 4 are as follows: C_m^{Elec} is the cost of electricity per unit in month m. E_m^C specifies the amount of electricity used for cooling in month m. Similarly, E_m^E specifies the amount of electricity used for all other devices in month m. C_m^{Int} is the cost for Internet usage per unit. I_m is the usage of the Internet in month m. (Note: the Internet cost calculation should be adjusted to the Internet contract, i.e., pricing scheme, used). C_m^{LS} is the cost of labor for maintaining software per unit and L_m^S is amount of labor in month m. C_m^{LH} is the cost of labor for maintaining the hardware per unit and L_m^H is the amount of labor for maintaining hardware in month m. C_m^{LO} is the cost of labor for other tasks per unit and L_m^O is the amount of this labor in month m. C_m^{TIn} is the cost of in-bound Cloud data transfer per unit in month m. T_m^{TIn} is the amount of data transferred into the Cloud in month m. C_m^{TOut} is the cost for out-bound data transfer per unit in month m. T_m^{TOut} is the amount of data transferred out of the Cloud in month m. C_m^{Sto} is the cost of Cloud storage per unit in month m. H_m is the usage of storage in month m. (Note: in some cases, different types of storage costs need to be considered). $C_{m,i}^{Ser}$ is the Cloud server usage cost for server type i per unit in month m. S_m^i is the amount of server usage of type i in month m. $C_{m,i}^{InR}$ is the cost per input requests to the Cloud for input request type i in month m. $R_{m,i}^{In}$ denotes the number of input requests to the Cloud for input request type i in month m. The meaning of $C_{m,i}^{OutR}$ and $R_{m,i}^{Out}$ is similar. $C_{m,i}^{OutR}$ is the cost per output requests to the Cloud for output request type i in month m. $R_{m,i}^{Out}$ denotes the number of output requests to the Cloud for output request type i in month m.

Therefore, the total cost of running a hybrid Cloud over d months (i.e., a depreciation period of d months) is the sum of the fixed cost and the variable cost over the period of d months:

$$TC = FC(d) + \sum_m^d VC(m). \tag{5}$$

3.4. Discussion and Open Issues

The first eight terms of the formula 3 (i.e., the fixed cost formula) can easily be populated, since it requires only capital expenditure (CAPEX) information. This information can be obtained from vendors or IT consultancy companies that design data centers for enterprises.

In making the decision about whether to move an existing service to the Cloud, one must additionally estimate the expected average and peak resource utilization. This is very difficult, since the applications deployed may have highly variable spikes in resource demand, the practical limits on real-world utilization of purchased equipment are not widely known, and the operational costs differ widely, depending on the type of Cloud environment considered [8]. In addition to this, finding the estimates for variable cost factors (e.g., cost factors on data transfer, Cloud storage usage, and server usage) requires further effort. In particular, a good estimate of the distance matrix for the in-bound and out-bound data transfer is difficult to get. For that, econometric methods need to be applied on past trends of data transfers between services.

Besides, the importance of each cost factor should be considered when estimating the overall cost. To be more precise, accurately focusing on major cost factors is suggested, since any error in their estimates has a large impact on the accuracy of the overall cost estimation. For instance, in many cases, 31% of cost of data centers comes from labor, 30% from servers, and 25% from cooling [20]. A low-quality estimate on those cost factors has a large impact on the result.

4. Analysis Example

For demonstrating the workings of the cost model, we assume a small scenario. The scenario comprises a large enterprise with a few software applications, which require 10 different services. Some services run on an in-house data center, which is owned by the enterprise, and some services run in the Cloud. All 10 services require the same amount of computational resources. As the enterprise has its own data center, the information about the fixed cost factors (equation 3) can easily be obtained from the accounting department of the enterprise. The fixed cost information includes the purchasing price of servers and network devices, the license costs for basic server software, middleware software, and application software, as well as the business premises costs (Table 2).

Table 2. Cost factor values for running an in-house data center, based on market research [16].

Cost Category	Cost Factor	Usage	Cost (€/year) Assuming a Three Year Depreciation Period
Electricity	Cooling		6000
	Elect. devices		
Hardware	Server		6000 (for 6 servers)
	Network device		15000
Software	Basic server software		10000
	Middleware software		5000
	Application software		40000
Labor	Software maintenance		90000
	Hardware maintenance		
	Other support		
Business Premises	Air conditioner, Rack		25000
	Cabling		5000
	Facility		70000 (in case of purchasing).
Cloud Service	Internet usage		1920
	Server usage	12*2.5 KH	21000 (0.07 €/CPU-hr[1])
	Storage usage	12*200 GB	192 (0.08 €/GB-month[2])
	Requests to input	12*18 M I/O	17,28 (0.08 €/million I/O requests)
	Requests to output	12*120 M I/O	115,2 (0.08 €/million I/O requests)

The variable cost, which comprises the usage-based cost for electricity, Internet, and storage, the labor costs in terms of maintaining the software, hardware, and other tasks, need to be estimated using the past consumption and the price development in the market.

1 based on Amazon EC2
2 based on Amazon S3

For our scenario, we assume the following cost factor values, which are based on market research for data center (Table 2).

The cost for the in-house data center covers sufficient computational resources to run 6 services, of which are five security critical services (i.e., they have to run on the in-house data center). Services numbered 1-4 run currently in the Cloud (e.g., Amazon EC2). Since all services require the same computational resources, the cost of running in the Cloud would incur the same cost for all 10 services (i.e., the cost for Cloud server usage would be the same). The only missing values are the data transfer into the Cloud and out of the Cloud.

For calculating the data transfer cost into and out of the Cloud, we analyze the data transfer. Figure 4 shows the ten services and their data transfers. The average monthly data traffic between these services has been illustrated as weights of the edges (in units of 100 GB). Services labeled 5 to 10 run on the in-house data center. Services 6 to 10 are the security critical services.

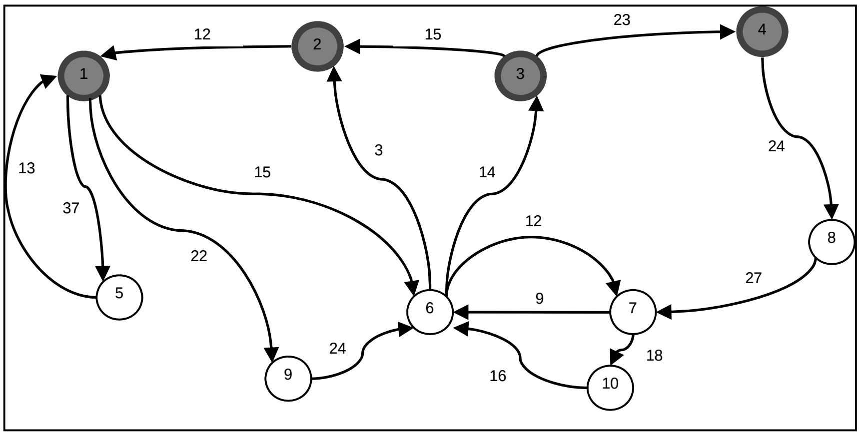

Figure 4. Scenario services that run in the Cloud (dark vertices) and on the local data center (white vertices) and the data transfer between these services.

Based on the data shown in Figure 4, the distance matrix *D* can be constructed, as described in section 3.2:

$$D = \begin{bmatrix} 0 & \infty & \infty & \infty & 37 & 15 & \infty & \infty & 22 & \infty \\ 12 & 0 & \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty \\ \infty & 15 & 0 & 23 & \infty & \infty & \infty & \infty & \infty & \infty \\ \infty & \infty & \infty & 0 & \infty & \infty & \infty & \infty & 24 & \infty \\ 13 & \infty & \infty & \infty & 0 & \infty & \infty & \infty & \infty & \infty \\ \infty & 3 & 14 & \infty & \infty & 0 & 12 & \infty & \infty & \infty \\ \infty & \infty & \infty & \infty & \infty & 9 & 0 & \infty & \infty & 18 \\ \infty & \infty & \infty & \infty & \infty & \infty & 27 & 0 & \infty & \infty \\ \infty & \infty & \infty & \infty & \infty & 24 & \infty & \infty & 0 & \infty \\ \infty & \infty & \infty & \infty & \infty & 16 & \infty & \infty & \infty & 0 \end{bmatrix} \quad (6)$$

Applying equation 1 and equation 2 on the distance matrix *D* (equation 6), the in-bound and out-bound traffic for the current situation (i.e., service 1 to 4 run in the Cloud) can be calculated. In order to figure out which of the 5 services (service 1 to 5) should run in-house, we calculate equation 1 and equation 2 also for the other 4 cases (e.g., services 1, 2, 3, 5 run in the Cloud and service 4 in-house). The results for these five cases are shown in Table 3.

Table 3. Calculated monthly in-bound and out-bound data traffic (in GB) for the five different cases of the scenario.

		Services that Run in the Cloud				
		Case 1	Case 2	Case 3	Case 4	Case 5
		1, 2, 3, 4	1, 2, 3, 5	1, 2, 4, 5	1, 3, 4, 5	2, 3, 4, 5
Data Traffic	T_m^{In}	3000	1700	4100	2600	5400
	T_m^{Out}	9800	3700	6100	7600	4900

The data transfer cost is set to 0.14 €/GB. By using these values, we can apply the fixed cost function (equation 3) and the variable cost function. The result shows that the fixed cost equals to €388,000. The monthly variable cost for each of the five cases is depicted in Table 4.

Table 4. Total variable cost per month (€) for each case.

	Services that run in the Cloud				
	Case 1	Case 2	Case 3	Case 4	Case 5
	1, 2, 3, 4	1, 2, 3, 5	1, 2, 4, 5	1, 3, 4, 5	2, 3, 4, 5
Total Variable Cost	21012	13612	18412	18412	18512

Table 4 shows that case 1 (i.e., service 1 to 4 run in the Cloud and service 5 runs in in-house data center) incurs the highest cost. Therefore, the current allocation needs and can be improved. Case 2 (i.e., services 1, 2, 3, 5 run in the Cloud and service 4 runs in the in-house data center) incurs the lowest variable cost. Therefore, case 2 is the best option to lower the cost. This result is also depicted in Figure 5.

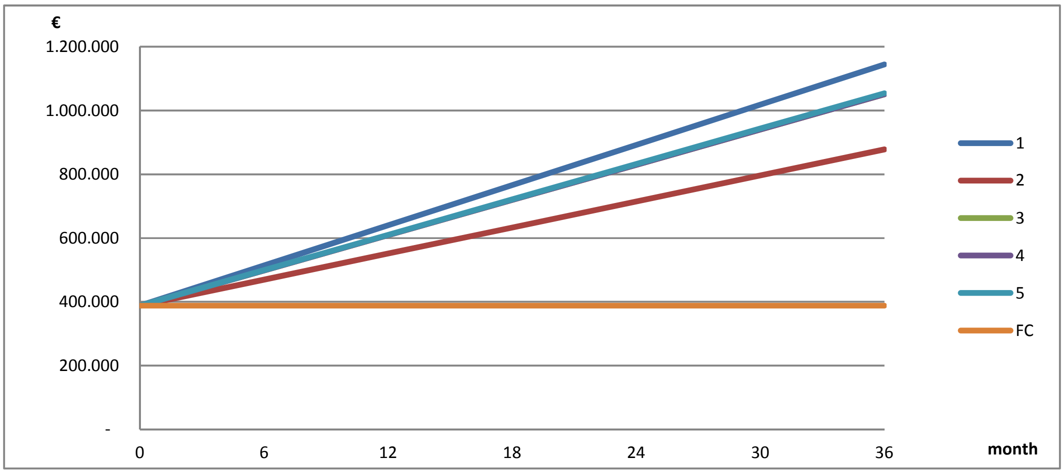

Figure 5. Comparison between the overall costs for five scenarios and the fixed cost (FC).

Figure 5 also shows that there is a large cost difference between the current alloation (i.e., case 1) and the low cost option (i.e., case 2). The savings over a period of 3 years (i.e., the depriciation period for fixed costs) are significant. Case 1 incurs cost of 1,144,429 Euro while case 2 incurs cost of 878,029 Euro only.

5. Conclusion and Future Work

In this paper, we have reviewed cost factors of Cloud computing, which have been considered in the research community, and have represented them in a categorized form. Our contribution is the presentation of these cost factors in a comprehensive cost model for hybrid Clouds (i.e., some of the enterprise services run on an in-house data center and some run in the Cloud). This cost model is useful for enterprises that own a data center.

For the calculation of the data transfer cost factor within the cost model, we suggest to use a graph representation for the data transfer between services. This allows performing service placement optimization, considering data transfers in and out of the Cloud. In order to show the workings of the cost model, we apply it to a specific scenario. The analysis example focuses on the application of the cost model and demonstrates the service placement optimization.

The main objective of our present work has been to cover all costs for hybrid Clouds. However, to be more useful in practice, enterprises need decision making support for running hybrid Clouds. Therefore, a future step of our research work is to propose a resource allocation model that considers the cost model presented in this paper. The resource allocation model will help finding the optimum set of services to run in the Cloud. The resource allocation model can also be extended to consider hybrid Clouds with more than one Cloud provider.

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