Public vs Private Cloud Usage Costs: The StratusLab Case

Ioannis Konstantinou
Computing Systems Lab,
National Technical University
of Athens, Greece
ikons@cslab.ece.ntua.gr

Evangelos Floros
Greek Research & Technology
Network
Athens, Greece
efloros@grnet.gr

Nectarios Koziris
Computing Systems Lab,
National Technical University
of Athens, Greece
nkoziris@cslab.ece.ntua.gr

ABSTRACT

Cloud computing claims to offer multiple advantages comparing to "traditional" computing infrastructures. These include among others: energy efficiency, reduction of the overall administration costs, better utilization of hardware resources by co-hosting multiple services environments, etc. This paper reports on the experience gained during the provision of an IaaS cloud service in the context of the StratusLab project and provides quantitative economic analysis of the total cost of ownership of such infrastructure by calculating the infrastructure, maintenance and operational cost. The analysis continues with the cost comparison of the private cloud against the popular Amazon's EC2 public cloud service by utilizing the collected StratusLab usage traces for a period of one year. It is shown that with an average utilization of 70%, a small cluster of 20 machines could amortize its total cost in a period of 2-3 years while offering the same rates compared to Amazon cloud if it were offered on a pay-as-you go basis.

1. INTRODUCTION

Cloud computing is revolutionizing the way IT resources are managed and provisioned. What started as a business model in order to capitalize on the spare computing resources owned by a single company (Amazon), has taken the Internet world by storm, becoming simultaneously one of the hottest topics and one of the most overloaded buzzwords in the IT business. Much has been written about the benefits of cloud computing including the abilities for optimal resource utilization, the reduction of operational costs through infrastructure consolidation and the overall flexibility cloud computing users experience from the ability to manage infrastructure as a network accessible commodity. Nevertheless, the actual economic benefits organizations can achieve through cloud computing are still vague. Organizations often face the question whether it is more beneficial to buy their own infrastructure instead of leasing resources from a cloud computing commercial provider. In other cases organizations consider the deployment and operation of private clouds in order to satisfy the computing requirements of various departments or even external parties (e.g. an e-Gov cloud offering resources to various public sector units).

This paper tries to answer this question by presenting an economic analysis of the private cloud infrastructure operated and managed in the context of the StratusLab project. This private cloud has been deployed by GRNET [13], one of the project's partners, in the organization's existing datacenter, using the StratusLab [18] IaaS (Infrastructure as a Service) cloud distribution developed by the project. One of the primary use cases for operating this service has been the hosting of virtualized grid computing sites. The paper analyses the cost for hosting this grid site in GRNET's private cloud and compares the result with the theoretical cost if the same site was hosted in Amazon's EC2 commercial cloud solution.

The paper is structured as follows: Section 2 provides a quick overview of StratusLab and the architecture of the project's cloud distribution. Section 3 presents related work carried in this area. Section 4 analyses the operational costs of the private cloud by calculating the Total Cost of Ownership (TCO) for running the cloud service for two years. Section 5 calculates and compares the cost for running a grid site on the private cloud and on Amazon EC2. Finally, Section 6 summarizes and comments on the results of the above analysis.

2. THE STRATUSLAB PROJECT

StratusLab is a European Commission funded project that started in June 2010 with the purpose to investigate the impact of the emerging cloud computing paradigm in the provision of grid computing services. StratusLab focuses on the Infrastructure-as-a-Service (IaaS) cloud paradigm, which implies the usage of virtualization technologies for the provision of computing resources. The project is integrating an open cloud software distribution that enables organizations to setup and provide their own private or public IaaS computing cloud. The StratusLab distribution builds on-top of popular infrastructure virtualization solutions like KVM (Kernel Virtual Machine) and the OpenNebula Virtual Machine Manager [16]. These tools are further integrated with additional components developed within the project, offering as a whole a turn-key solution for installing cloud computing services. The StratusLab distribution covers the core aspects of a cloud IaaS architecture, namely Computing (life-cycle management of virtual machines), Storage, Appliance management and Networking.

CloudCP 2012: 2nd International Workshop on Cloud Computing Platforms. Bern, Switzerland

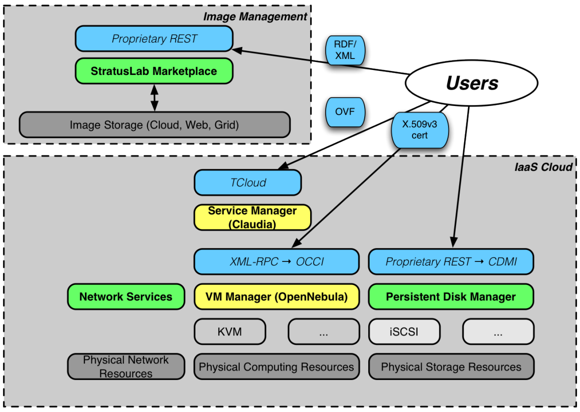

Figure 1: StratusLab Architecture

Figure 1 provides an abstract overview of the StratusLab cloud architecture. Virtual machine management is provided by OpenNebula which lies in the heart of this architecture. The Claudia Service Manager provides higher level Virtual Machine monitoring and management services like automatic elasticity based on user defined Key Performance Indicators (KPIs). Storage management is provided by the PDisk (Persistent Disk) service which is developed by the project. The Appliance Marketplace is a key component developed by the project. This service offers a registry of digitally signed Virtual Machine appliance metadata. The Marketplace is independent of a given IaaS cloud enabling users to securely publicize and share VM images.

3. RELATED WORK

In [11] the authors assume a datacenter of 50,000 servers and calculate its operational cost by breaking it down into different cost types. They provide hints and best practices for lowering the cost types. Nevertheless, their analysis is not based on measurements of actual running sites, in contrast to the StratusLab case. The Open Cirrus cloud testbed [6] also deals with the tradeoffs or owing a private cloud infrastructure vs a public cloud infrastructure. They conclude that if the service operates more than one year it is preferable to own the infrastructure. For the storage, this break-even point falls to six months. They also do not provide actual measurements. In the Montage example [8] the authors estimate the execution efficiency and cost of a data-intensive astronomy application if it was deployed in the Amazon cloud. Nevertheless, their analysis is also based solely in estimations. In [14] the authors present a case study of a potential migration of an IT system to the cloud. Nevertheless, the described IT system is a small two-tier web application consisting of one RDBMS and one application server and it cannot be directly compared to the StratusLab grid site of more than 16 VMs.

4. STRATUSLAB CLOUD COST ANALYSIS

The StratusLab distribution presented in Section 2 is used by the project to deploy and provide a public reference IaaS cloud service which is available to external users for testing and evaluation purposes. In this section we describe this infrastructure, we calculate the TCO for two years of operations and provide an estimated "break-even" cost for the provision of a "typical" VM such that if this cloud was offered commercially to third parties, the investment in the private cloud would be amortized within the project's lifetime.

4.1 Physical Infrastructure Description

The reference cloud services operated by the project are hosted in GRNET's datacenter in Athens, Greece. This datacenter was completed in 2010, a few months before the start of the project, with the purpose to support a wide range of computing requirements for the organization. The datacenter comprises of 4 racks, each hosting 32 compute servers and the required management servers. From these resources, a subset of roughly one quarter was allocated to satisfy the infrastructure requirements of StratusLab. This includes a complete rack and a few TBytes from the storage server. The reference cloud service which is the IaaS public cloud that the project provides is hosted in a subset of these servers. The size of the service has grown during the duration of the project in order to satisfy the service's increasing requirements.

The reference service currently comprises 18 hosting nodes (where the VMs are actually instantiated), 1 frontend node (where OpenNebula is running and all the management of VMs lifecycle takes place), 4 nodes which host the testing infrastructure and one node operating as DNS/DHCP server resulting in a total of 24 nodes. Each physical node is equipped with Dual Quad-Core E5520 Intel Xeon® with Hyperthreading CPUs (for a total of 288 cores) running at 2.27GHz, 48GB of RAM and 2 SAS disks operating in RAID 1 (for temporarily storing virtual machine images). Each server is equipped with an IPMI interface (Intelligent Platform Management Interface), monitoring and storing the machine's daily average power usage consumption over one year. The storage of the infrastructure is served by an EMC Cellera NS-480 storage server which provides a total of 280TB.

The network infrastructure consists of 3×10 GbE (Gigabit Ethernet) switches. Each of the physical hosts has 3 GbE interfaces plus a management interface for access through IPMI. The relevant traffic (host/VM/IPMI management) is isolated using separate VLANs. The connectivity between the server rack and the storage server is provided by a fiber channel bridge which connects the 2×4 Gb FC storage link with the 10 Gb server link. The datacenter is connected through 2×10 GbE links with the GRNET network backbone. GRNET is the Greek NRN (National Research Network) offering data connections up to 10 GbE with the GEANT network.

4.2 Cloud Infrastructure Total Cost of Ownership

In this section, we are calculating the Total Cost of Ownership (TCO) for the Cloud services operated by GRNET in the context of StratusLab. For this analysis, we break down the cost for hardware and infrastructure, power consumption and manpower.

Hardware and Infrastructure costs: In order to provide a complete evaluation of the operational costs it is important to estimate the infrastructure cost. This cost covers a 7-year and 5-year guarantee for the datacenter and the servers, respectively. This means that all the necessary service and maintenance that took place during this period were offered free of charge. (Indeed there have been quite a few failed

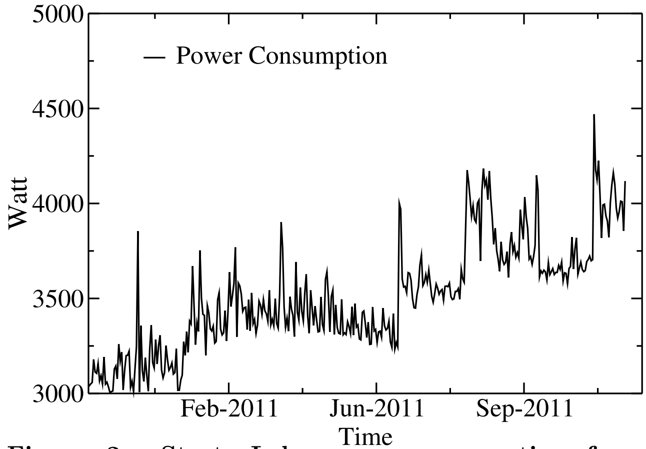

Figure 2: StratusLab power consumption from 11/2010 to 11/2011

hard disks, cooling funs and memory modules that required replacement).

We consider a 8 k€ cost per server, in which we include the network, storage and datacenter infrastructure cost, giving a total infrastructure cost of 24×€ 8 = 192 k€. Since this equipment will be re-allocated to different services once the project completes, it is fair to apply these charges only for the project's duration. By assuming a 5-year depreciation period (based on the server guarantee) and that the depreciation follows a non-linear reduction rate, we estimate that at the end of the second year the equipment will lose at least 60% of its initial value. Thus we presume that the total infrastructure cost is 192 k€× 60%=115.2 k€.

One additional operational cost is the expense for the network connectivity. The 2×10GbE lines have a flat 15-year leasing cost based on the distance from the backbone network provider, which in our case is the Hellenic Telecommunications Company (OTE). On top of this is a yearly maintenance cost calculated as 20% of the lease cost. For our datacenter, the overall cost for the network has been estimated to be 30 k€. Although the network is shared with the rest of the datacenter's hosted services, the network cost would be the same even if StratusLab were the only service. This holds since the cost is affected only by the lease time and not the bandwidth consumption. Therefore we keep this flat yearly rate for the rest of the paper. Notice that for the network expenses we have omitted the annual fees paid to GEÁNT by GRNET for accessing the network. Although this is related to an important expense of a cloud infrastructure, namely the inbound/outbound traffic generated by the VMs, the overall funding scheme of the network services makes this expense negligible for our cloud service.

Power Consumption: We now present our calculations of the power consumption cost of running StratusLab private cloud on our infrastructure. Our monitoring period is between 4 November 2010 and 4 November 2011 (exactly one year). In Figure 2 we present our findings. The power is measured in Watts. The increase in consumption in June 2011 is due to an increase of allocated resources for the StratusLab grid site.

In order to calculate the total electricity cost for this period, we take into account that the data center's PUE (Power Usage Effectiveness) [4] is around 1.8 (a typical value according to Greenberg et al [12]).

In Table 1 we present the calculations to extract the total power consumption cost of the StratusLab cloud. According to the Public Power Corporation (PPC) of Greece, there are two types of charges: a charge for the power cost, which is a monthly rate based on the average measured consumption (different in summer months and in winter months) and a charge for the energy cost which is an hourly rate according to the amount of kWh used. The exact costs for 2011 were taken from the company's on-line price list [17]. Assuming a PUE of 1.8, we calculate the total cost.

The first column of Table 1 presents the cost type, the second column presents the measured unit used for charging, and the third column presents the unit cost measured in euros. In the forth column the unit amounts are presented: in the first two lines, we have a monthly power average of 8kW multiplied by six months in the summer and in the winter case respectively. The third line presents the total amount of kWh spent for the StratusLab's operations. Each line is multiplied by the respective cost in the last column, and by aggregating each cost we have a total yearly energy cost of € 3,738, or € 6.6K for a two year period.

Manpower costs: A relatively large team of people are involved with the datacenter administration and support. This team is part of GRNET's Network Operations Center (NOC) which has included the datacenter support activities as part of their daily tasks. A fair estimate is that the datacenter administration requires 1 FTE (Full Time Equivalent). By assuming an average salary of 40 k€/year and a 25% of the administrator's time dedicated to StratusLab, the total cost for two years is 2 × 40 × 25% = 20 k€ total administration costs.

In the project's context, two people are responsible for the site's administration and managing tasks like software upgrades, infrastructure maintenance, user management, user support for operational issues, etc. The budgeted effort for this task has been estimated to be 1FTE (80 k€ according to GRNET's rates) for two years.

TCO calculation: Based on the above calculations we can make an estimate of the Total Cost of Ownership (TCO) for the Cloud services operated by GRNET in the context of StratusLab. The cost breakdown for the cloud infrastructure is depicted in Table 2, giving an estimated TCO of 251.8 k€.

The above TCO value covers the cost of procurement, operation and provision of a typical small to medium IaaS cloud service for a total period of two years. It should be noted that the above infrastructure includes additional computing resources required for the provision of the service, as well as the resources provided through the service (≈60%). These include backup nodes for temporary VM deployments during service upgrades, pre-production testing nodes that are used to deploy and test the cloud middleware before upgrading the production services and a couple of additional services like DHCP and DNS.

Our calculations do not include license fees for the cloud software or for software support. The rationale for this is that StratusLab distribution is an open source software thus any potential cloud provider can download it, deploy it and extend it with no license costs. In a realistic production environment it is expected that some expenses should be forecast for support and maintenance. In our case this support cost is replaced by the cost required for the additional hardware

Table 1: Calculation of Electricity Costs

Cost type	Unit type	Unit cost (€) ×	Unit count	= Cost (€)
Power Costs Summer	€/kW/month	€6	× 6 months × 8kW	= 289 +
Power Costs Winter	€/kW/month	€2.65	× 6 months × 8kW	= 128 +
Energy Costs	€/kWh	€0.06 ×	55,321kWh	= 3,319 +
			Total Cost	**= €3,738**

Table 2: Cloud site estimated TCO

Hardware and Hosting Infrastructure including 5yr service	115.2k€	45.8%
Network line leases	30k€	11.9%
Power Consumption	6.6k€	2.6%
Datacenter administration	20k€	7.9%
Cloud site administration	80k€	31.8%
Total Cost of Ownership	**251.8k€**	**100%**

and administration effort used for testing and certifying the cloud middleware before deploying it in the production service.

4.3 Cloud service provisioning break-even cost

An interesting question that arises from the above calculation is how much we should charge for the provision of cloud services to third parties? GRNET is a non-profit organization, thus it is not allowed to make revenue from the provisioning of its services. Therefore, in a scenario where this service is self-funded, the goal would be to break -even financially for the provision of the cloud services after two years. Based on the TCO we can calculate the hourly cost for hosting the service. For a two year period this would be:

$$251.8\,\text{k€}/(365\,\text{days}\cdot 2\,\text{yr})/24\text{h} \approx 14.37\,\text{€/h} \qquad (1)$$

As mentioned the cloud service offers 288 CPU cores, 864GB of total main memory and 3TBs of centralized storage. A "typical" VM instance in this case would consume 1 CPU core 3GB of main memory and 10GB local storage. This is actually very close to the average hardware profile of the VMs instantiated in our service during these months. Assuming that the service utilization is 70% (corresponding to 202 cores used at any moment on average, consistent with the StratusLab usage) in order to break even during the two years of service provisioning the estimated charge per hour for the "typical" VM would be:

$$14.37\,\text{€}/202\,\text{cores} = 0.0712\,\text{€/core} \qquad (2)$$

It is clear that if the service was offered on a pay-as-you go basis, after two years of operation the initial cost would be completely amortized and it would become profitable.

5. USE CASE: OPERATION OF VIRTUALIZED GRID SITE

In this section we provide a typical use case scenario pursued by StratusLab; the provision of virtualized grid computing sites on top of cloud infrastructures. Furthermore, we evaluate the cost for hosting this service in the StratusLab reference cloud and compare it with the cost if the same site was deployed in Amazon EC2.

5.1 Grid site structure

StratusLab operates a virtualized grid computing site running on top of the reference cloud service. The grid site is part of the EGI [9] grid infrastructure and officially running under the control of the Greek NGI being part of the Greek national grid infrastructure. The site provides the core grid services expected of a resource center [15]: a Computing Element (CE) together with a number of Worker Nodes (WN) that offer job execution -capabilities, a Storage Element (SE) that provides a large storage space (2TB) for Virtual Organization (VO) data and an APEL service [5] that collects and publishes accounting data to the relevant centralized EGI services. The site's computing power is provided by 16 virtualized WNs each with 2 CPU cores and a total of 4GB of main memory. The quality metrics of the site (availability and reliability) are monitored on monthly basis satisfying the relevant Operational Level Agreement ($\geq 75\%$ for both metrics) defined by EGI [7].

Since July 2011 the site offers support for 18 international VOs and is used daily for job submission and data storage. These include some of the most active and compute intensive VOs from the high energy physics (ALICE and ATLAS), biomedical sciences (Biomed), computational chemistry (CompChem) and Earth science (ESR) communities. During the period that this economic analysis was carried the site ran 31,781 jobs requiring 11,655 wall clock hours to complete. The Normalized CPU time consumed by the jobs was 28,321h.

The site is completely virtualized with all services running as VMs on the StratusLab reference cloud service. The project has prepared and maintains a set of VM appliances which provide the core grid services necessary for deploying a basic grid resource center. These appliances are publicly available from the StatusLab Marketplace.

5.2 Grid site operational cost

The site is operated by two administrators. Their tasks include the preparation of the VM appliances that are used to deploy the virtualized site, the configuration of the site, the installation of periodic software updates, and the response to various security advisories. The preparation and maintenance of the grid VM appliances takes a significant amount of time since these appliances need to be kept up-to-date with the frequent releases of EMI grid software [10]. Since StratusLab is the first project that has focused on Grid-Cloud integration it has taken the responsibility to develop and maintain these appliances. Other teams can take advantage of these appliances and therefore reduce the time to deploy grid sites and the effort required to keep them up to date. Even with this additional task the total effort required for the administration of the site is rather limited since all the infrastructure maintenance (hardware service and upgrades, software backups etc) are provided by the cloud service. Based on the expenses related to the grid site administration for StratusLab, it is estimated that the total effort required for grid site administration is 0.3 FTEs (30% of a fulltime engineer) for site maintenance. Based on this calculation and GRNET salaries, the total cost for the grid

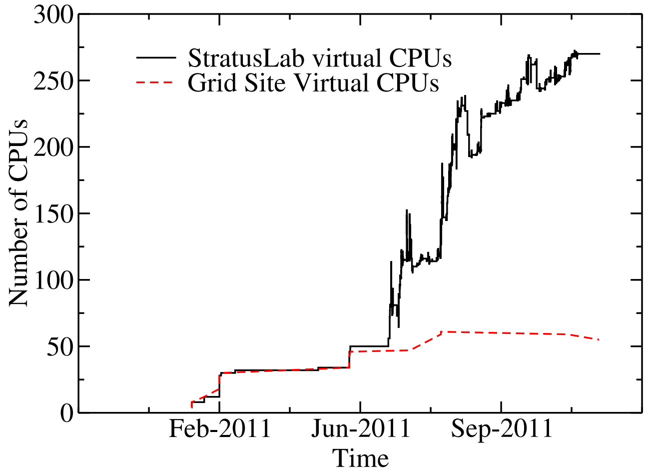

Figure 3: Virtual CPU usage over time for StratusLab and Grid site

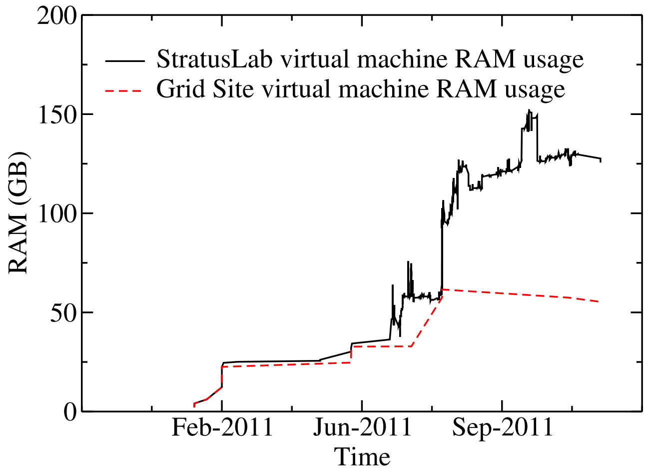

Figure 4: Virtual RAM usage over time for StratusLab and Grid site

site operation is 24 k€.

5.3 Cost Analysis on Commercial Cloud

In this section, we will calculate the theoretical cost in case we had deployed our StratusLab infrastructure in a public cloud. For this case, we consider the widely used Amazon EC2 cloud [3]. In order to make this estimation, we will apply the following methodology: First, we will extract the computing, storage and memory consumption statistics from the cloud's logfiles. Second, according to the extracted consumption statistics, we will calculate how much it would cost to utilize these resources in Amazon. We consider the same time frame, namely for a year starting from 4 November 2010.

Figures 3 and 4 present the CPU and RAM allocation of the total number of virtual machines running in the StratusLab infrastructure from information extracted from the cloud's logfiles. Black lines represent the total cloud's usage, whereas red lines represent only the resources reserved by the Grid site. We notice that both CPU number and RAM follow a similar pattern, with a sudden increase in June 2011. Recall that the same increase was observed in the cluster's power consumption graph in Figure 2: when more virtual resources were acquired and used, the power consumption increased accordingly.

In order to estimate the cost of running StratusLab on the Amazon Cloud, we have to "translate" the used resources into Amazon's resource types. Unfortunately, there is not an one-to-one match of StratusLab's virtual machine types with Amazon's instance types. The Amazon instance types that are most similar to the StratusLab VMs are the t1.small and the t1.micro instances [1]. By carefully observing the graphs of Figures 3 and 4 we notice that there is a quite constant ratio of RAM to number of CPUs, approimately 600MB. This means that on average each virtual CPU in the StratusLab cloud gets about 600MB of RAM. This profile is close to the t1.micro instance (1 CPU and 613MB of RAM). Nevertheless, the t1.micro instance has a low I/O performance and is suited for applications with low throughput requirements, something that does not hold in the StratusLab case. For this reason, in our analysis we will also consider t1.small instances (1 CPU and 1.7GB of RAM) even if its memory is larger then the one assigned to the grid VMs. The rate for using one linux t1.micro machine for one hour in Amazon's datacenter in Dublin is \$0.025, or around €0.019. The corresponding rate for the t1.small instance is \$0.095 or €0.07[1].

Apart from charges regarding the machine usage per time, Amazon also charges for the total data transferred in and out of the Amazon cloud. We consider this not to be significant, since Grid site jobs are more compute than data intensive. What is more, Amazon also charges for disk I/O when persistent EBS storage volumes are used. We do not consider this cost as we are assuming Amazon VMs with only local, volatile non-EBS volumes.

Using the results of Figure 3 and the break-even rate of €0.0712/h for amortizing the StratusLab datacenter TCO in two years with a 70% utilization as found in Section 4.3, we can also calculate the amount of the Grid site hosting in the StratusLab premises if we operated with a pay-as-you go business model. Under these assumptions, using the €0.019/h, the €0.07/h and the €0.0712/h rates and the data of Figure 3, we calculate the appropriate costs. In the case of the total StratusLab cluster, we would have to pay €15,832, €60,162 or €60,186 if StratusLab was hosted in t1.micro, t1.small or StratusLab VM instances respectively. In the case of the Grid site only, the amounts are €5,760, €21,888 and €21,896 for t1.micro, t1.small and StratusLab VM respectively. Table 3 shows this data in detail.

From the previous analysis, we notice that the grid site hosting in Amazon's premises is cheaper compared to the self-hosting in a private cloud when t1.micro instances are utilized. Nevertheless, t1.micro instances are unreliable and have a very low I/O due to over-commitment. Compared to the t1.small instance, the StratusLab achieves almost the same price. This is due to the grid cluster size: the cluster is big enough to justify its deployment in a private cloud. As the infrastructure keeps growing and is required to operate for longer time periods, private clouds are cheaper than public clouds. What is more, we notice that, by the end of the year, 53.4 k€ out of the StratusLab's 251.8 k€ TCO or 20% has been amortized by its use. Assuming an increasing trend in utilization, we can safely bet that after a couple of

[1]Euro/Dollar exchange rate and Amazon rates from November 2011 [2]

Table 3: Comparision of Costs in Amazon and StratusLab Clouds

# CPUs×	Time (h)	**t1.micro** ×€0.019/h	**t1.small** ×€0.07/h	**StratusLab VM** ×€0.0712/h
8	211	31.6	120.2	120
12	261	58.6	222.8	222.9
28	27	14.2	54.2	54.24
30	2,185	1,227	4,665	4,667
38	1.4	1	3.98	3.99
42	15	12	46.5	46.5
46	1,017	876	3,330	3,331
47	525	462	1,757	1,758
61	2,160	2,467	9,377	9,380
59	550	607	2,309	2,310
Total Cost		**€5,760**	**€21,888**	**€21,896**

years the StratusLab cost will be entirely amortized.

6. CONCLUSIONS

In this paper we presented an economic analysis of the private cloud infrastructure run by the StratusLab project. Taking into account the overall infrastructure cost and the operational and administrative expenses, we calculated the TCO of this private cloud for two years (the project's duration). In addition we presented a use case scenario, the hosting of a grid site on top of this cloud and compared the overall cost to deploy this service in our private cloud with the cost to run it in Amazon's EC2 commercial cloud.

Our analysis suggests that even for a small scale private cloud installation, like the one in StratusLab, the economic benefits can be experienced in a relatively small period of 2-3 years. In our case, the theoretical cost for compute resources provisioning is almost the same compared to large-scale cloud providers like Amazon. These benefits can become even more evident in larger cloud installations in which case the economies of scale will significantly improve the hardware efficiency and consequently the investment on a private cloud will be amortized in a shorter period of time (less than a year). Another important factor is the level of utilization. Indeed, the larger the utilization (more VMs running and thus less CPU cycles wasted) the higher the return of investment will become. Finally, the applications that the cloud service targets also play an important role in the overall economic assessment. Indeed compute demanding applications (as those in e-science or grid computing environments) can run in a more cost effective way if an organization has full control over the underlying virtualization infrastructure than using commercial clouds in which such resources are typically charged with higher hourly fees.

Acknowledgements

StratusLab is co-funded by the European Commission through the 7th Framework Programme (Capacities), contract number INFSO-RI-261552. The authors also acknowledge the support provided by other members of the StratusLab collaboration and by the institutes involved in the project.

7. REFERENCES

[1] Amazon. EC2 Instance Types. `http://aws.amazon.com/ec2/instance-types/`, 2011.

[2] Amazon. EC2 Pricing. `http://aws.amazon.com/ec2/pricing/`, 2011.

[3] Amazon. Elastic Compute Cloud (EC2). `http://aws.amazon.com/ec2`, 2011.

[4] C. Belady, A. Rawson, D. Pfleuger, and S. Cader. Green Grid Data Center Power Efficiency Metrics: PUE and DCiE. *Consortium Green Grid*, 2008.

[5] R. Byrom et al. APEL: An implementation of Grid accounting using R-GMA. In *UK e-Science All Hands Conference*, 2005.

[6] R. Campbell et al. Open CirrusTM Cloud Computing Testbed: Federated Data Centers for Open Source Systems and Services Research. In *Proceedings of the USENIX Workshop on Hot Topics in Cloud Computing (HotCloud)*, 2009.

[7] A. Candiello et al. A Business Model for the Establishment of the European Grid Infrastructure. In *Journal of Physics: Conference Series*, volume 219, page 062011. IOP Publishing, 2010.

[8] E. Deelman, G. Singh, M. Livny, B. Berriman, and J. Good. The Cost of Doing Science on the Cloud: the Montage Example. In *High Performance Computing, Networking, Storage and Analysis, 2008. SC 2008. International Conference for*, pages 1–12. Ieee, 2008.

[9] EGI. European Grid Initiative. `http://www.egi.eu`.

[10] EMI. European Middleware Initiative. `http://www.eu-emi.eu`.

[11] A. Greenberg, J. Hamilton, D. Maltz, and P. Patel. The Cost of a Cloud: Research Problems in Data Center Networks. *ACM SIGCOMM Computer Communication Review*, 39(1):68–73, 2008.

[12] S. Greenberg, E. Mills, B. Tschudi, P. Rumsey, and B. Myatt. Best practices for data centers: Lessons learned from benchmarking 22 data centers. *Proceedings of the ACEEE Summer Study on Energy Efficiency in Buildings in Asilomar, CA. ACEEE, August*, 3:76–87, 2006.

[13] GRNET. Greek Research and Technology Network. `http://www.grnet.gr`, 2011.

[14] A. Khajeh-Hosseini, D. Greenwood, and I. Sommerville. Cloud migration: A Case Study of Migrating an Enterprise it System to IaaS. In *IEEE CLOUD*, pages 450–457. Ieee, 2010.

[15] E. Laure et al. Programming the Grid with gLite. *Computational Methods in Science and Technology*, 12(1):33–45, 2006.

[16] OpenNebula Project. OpenNebula. `http://opennebula.org/`.

[17] Public Power Corporation of Greece. Power Usage Price List. `http://bit.ly/tH7vMn`, 2011.

[18] StratusLab. Enhancing Grid Infrastructures with Virtualization and Cloud Technologies. `http://www.stratuslab.eu/`, 2011.