IaaS: from Private Cloud to Hybrid Cloud

Summary
In this document, we provide a perspective on IaaS cloud computing, and point out relevant developments and experiences in this area for the Dutch higher education and research institutions. We explore possible migration paths from a current local datacenter IT configuration to a private and hybrid IaaS cloud environment, and describe a number of relevant use cases. Furthermore, we discuss some of the best practices for using and deploying IaaS cloud services, with a focus on costs.
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Contents

1 Introduction .......................................................................................................................................................... 4

2 From private to hybrid ........................................................................................................................................ 9

3 Use cases .......................................................................................................................................................... 11
  3.1 Test and acceptance, and occasional usage ................................................................................................. 11
  3.2 Education ...................................................................................................................................................... 11
  3.3 Scalable applications with uncertain demand .............................................................................................. 12
  3.4 Backup in the cloud .................................................................................................................................... 12

4 Hybrid clouds in practice .................................................................................................................................. 13
  4.1 Costs models and procurement .................................................................................................................... 13
  4.2 Cloud costs versus datacenter costs ............................................................................................................ 14
  4.3 IaaS cloud cost effectiveness ....................................................................................................................... 16
  4.4 Cloud backup cost effectiveness .................................................................................................................. 16

Conclusions .......................................................................................................................................................... 17

References ............................................................................................................................................................ 18
1 Introduction

The last 5 years has seen tremendous growth in the utilization of cloud computing technology. Almost all IT departments were faced with questions concerning the consequences of this trend for their own institute or company. For many of them, the issue is no longer whether to jump on the bandwagon but rather how to integrate their existing (local) data center facilities with external cloud resources, to take advantage of the unique features of cloud computing.

Higher education organizations in the Netherlands want to benefit from cloud services. They collaborate to achieve this. Their collaborative IT organisation SURF, coordinates these joint efforts through the SURF-taskforce Cloud (http://www.surf.nl/cloud). This approach has enabled a considerable number of institutions to use cloud computing services. For most of them the starting point were collaboration and productivity suites such as Google Apps and Microsoft Office 365 (‘Software as a Service’, or ‘SaaS’). With this experience, institutions have a good overview of the pros and cons of cloud computing at this level. By moving these commodity service to the cloud, considerable cost savings could be accomplished.

![Cloud Computing Service Models](attachment:cloud-service-models.png)

**Figure 1: the cloud computing service models.**
When it comes to the other service models - **Platform as a Service (PaaS)** and **Infrastructure as a Service (IaaS)** - the uptake of cloud computing is much less significant in higher education. This has various reasons: the PaaS model, which typically offers a computing platform with a predefined set of basic services (operating system, runtime environment for a particular programming language, etc.), is not a natural fit with existing services in higher education. Examples of PaaS environments are Heroku, Mendix and the Google App Engine. For migration to this model, existing applications must be adapted or rewritten to run here.

For the IaaS model, similar considerations are valid. IaaS offers the most basic services such as virtual machines (VMs) and virtual local area networks (VLANs), often in combination with basic storage facilities. These resources can be managed and deployed in a dynamic manner and are typically billed on a utility computing basis, and, as such, costs scale linearly with the amount of resources used. To fully benefit from IaaS, applications must be able to adapt to growing and shrinking demand, and schedule tasks to run on a variable set of resources (e.g., a variable number of VMs). This dynamic configuration is currently not very dominant for services offered and managed by the IT departments of educational institutions.

Contrary to the adaptation of SaaS commodity services, cost benefits are not a driving factor, because, in various cases, the costs of running cloud machines are higher than running dedicated machines in a (local) data center. See also Section 4 for a discussion on costs for IaaS services.

Apart from costs considerations, other aspect play a role in the adaptation of the cloud computing service model. In general the benefits of cloud computing are:

- **On-demand deployment.** The cloud model supports rapid configuration of computing and storage resources, and allows for easy upsaling and downscaling given changes in demand. In traditional IT environments, the time spend on hardware specification and procurement usually takes considerable time - up to weeks and months - which results in over-dimensioning, or, in cases of peak loads, in overloaded systems. The time to provision resources in cloud platforms is often in the order of minutes, and is therefore much more suitable to follow demand. At the SaaS and PaaS level, resources are often automatically scaled, leveraging the size of the cloud computing provider (e.g., a GMail domain can easily grow from a few accounts to thousands of accounts). Cloud computing increases the efficiency and agility of the IT environment.

- **Standardization and commoditization.** Since the beginning, IaaS cloud platform providers have offered standardized resources in the form of virtualized computing nodes and storage facilities. Software is targeted at these commoditized resources and no longer relies - as is sometimes the case in traditional data centers - on specialized hardware, e.g., to guarantee very low failure rates or support very short failover times. On cloud platforms, reliability and scaling go hand in hand: by running multiple instances of processing nodes – possibly in different data centers or availability zones - and having logic to automatically scale up and down, it is often straightforward to deal with failing nodes [1]. Handling those
resources also comes with standardized processes and compliance to security. In the end, this results in lower costs at various levels, including cost for training and staff.

- **Education, research and innovation.** The rise of cloud computing has resulted in many new innovations which is interesting from an educational and research point of view. Online courses are changing higher education [2] and enable universities to offer teaching to a new and wider audience - and spread the cost of courses over more students. It also allows them to work together differently and try out new services in a lightweight form, with limited costs. This is highly relevant for researchers working together in international, spread-out teams. Furthermore, for research projects with large amounts of data, a computing model in which the processing on the data is done close to the data – preventing in that way copying of the data – can be supported. From a technology perspective, it is interesting to offer students an environment which is also having traction in the market, and used by their future employers.

Cloud computing also has some limitations:

- **Performance.** Cloud environments are multi-tenant: physical resources in the cloud are shared between multiple users. Therefore, the available performance may fluctuate over time [3], which, in many cases may not pose a problem. However, when multiple applications experience high load while using the same physical server, network card or storage node, they are likely to influence each other. Cloud vendors do address some of these effects: Amazon, for instance, last year released ‘Provisioned IOPS’ for high performance cloud databases and other I/O intensive workloads, with a guaranteed number of input/output operations per second.

- **Security and privacy issues.** The party with physical control over a machine also, in the end, always has access to the data processed and stored on that machine. This has proven to be a major barrier for cloud computing: for some applications it is simply not acceptable to handover this control to an external (off-premises) cloud vendor. Additionally, this data is easier to intercept, lawfully or unlawfully, and therefore privacy sensitive information more easily leaks away to others.

- **Legal and compliance issues.** Several legal issues play a role when using the services of cloud providers. When offered in a certain jurisdiction, the laws in that country or region may apply to that service, even if the physical location of the cloud platform is elsewhere. For example, the EU Data Protection Directive may force, in certain cases, the storage of personal data to be at locations within the EU. In the ‘Megaupload Data Seizure’, the US government has acted by removing property rights of parties storing data within the Megaupload cloud environment [4], signaling in that way that property rights are limited for items stored in the cloud. The European Commission has determined that cloud providers complying with the US-EU Safe Harbor Principles offer an ‘adequate protection’ when there is data throughput. This does not guarantee that the actual storage and processing of such personal data in the U.S. also meets all requirements of the Dutch privacy legislation. CBP
(the Dutch Data Protection Authority) states that the Dutch companies and organization who use cloud services under the Safe Harbor arrangement, remain responsible for complying with privacy and data legislation. When cloud services are bought it must be ensured that applicable legal rules are covered\(^1\).

![Diagram of cloud computing deployment models](image)

**Figure 2: cloud computing deployment models (private, hybrid and public)**

Cloud resources are used in the context of different deployment models. The **public cloud** environment is made available, through the internet, by service providers such as Amazon and Rackspace. The public cloud is the initial (and dominant) cloud computing deployment model. More recently, a number of new deployment models have emerged: **community cloud**, **hybrid cloud** and **private cloud**.

A **private cloud** is operated for a single party and is usually physically located within the premises of that organization. It is essentially a data center facility, configured and operated in the same manner as a public cloud environment, with a single organization as the sole user. The resources are available in virtualized form (VMs, VLANs), much like the resources available in the public cloud.

Various software platforms support the creation and management of private clouds, e.g., Eucalyptus [6] and OpenStack [5]. An important reason for setting up a private cloud is to enable the easy migration to and cooperation with other cloud environments. For certain cloud applications, running in a private cloud and dynamically using cloud resources from a public cloud, e.g., in case of high load, is a viable mode of operation. This particular operation is called **cloud bursting**. As can be seen in the figure below, there has been a growing interest in private clouds in recent years.

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\(^1\) SURF is currently working on a Framework of Legal Standards for Cloud Services in Higher Education. This framework covers standard clauses concerning privacy, confidentiality, ownership of data and documents and availability thereof. It can be used for setting up contracts and SLAs between institutes of higher education and cloud service providers.
In a **hybrid cloud**, resources in a private cloud environment and resources in the public cloud are used in an intermixed configuration, not just for cloud bursting, but as a permanent setup. The main advantage of taking a hybrid approach is flexibility: it is easier to select the most appropriate environment for an IT service. The private cloud and the public cloud each have their own benefits and drawbacks - although more and more services are suitable to run in the public cloud, in many organizations there exists clear requirements to keep one or multiple services under tight control or in a specialized environment a local datacenter. The interest in hybrid clouds has also increased in the past few years.

When organizations work together to run and maintain cloud resources as a collaborative effort and share these resources to run their IT services, this is called a **community cloud** deployment. A possible configuration consists of connecting the private clouds of the individual organization together and manage them as a single cloud environment. This deployment model is mostly suited for organizations with a common requirements (e.g., for security, legal considerations, etc.). The participating parties can use each other's spare capacity, and therefore, in many cases, require less over capacity compared to running a private cloud by themselves.

When mapping the service models to the deployment models, it is clear that the greatest variety exists at the bottom of the stack. SaaS and PaaS services are offered almost exclusively as a public cloud service, while IaaS services can be offered in the context of a private cloud, public cloud, hybrid cloud, or community cloud deployments.

In this overview paper, we want to focus on the IaaS cloud computing perspective and point out the relevant experiences and developments for higher education and research institutions. We explore possible migration paths from a current local datacenter to a private and hybrid IaaS cloud and show a number of use cases. Furthermore, we discuss some of the best practices for using and deploying IaaS cloud services, with a focus on costs.

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2 http://www.google.com/trends/
2 From private to hybrid

The uptake of cloud computing in recent years is considerable, and one may conclude that all computing infrastructure is moving away from the traditional datacenter up to the point that all services are somewhere in the cloud. In reality, however, this is not likely to happen any time soon: from various perspectives, the traditional datacenter and dedicated hardware fit well with current and future use cases. Given the disadvantages of cloud computing described in the previous section, some uses will stay attached to computing resources which are fully under own (physical) control.

This does not mean, however, that the traditional datacenter setup and management processes will not change: the technologies deployed in the cloud influence the way the traditional datacenters are organized. These cloud technologies bring some of the benefits to IT solutions under own control.

Additionally, and perhaps more importantly, cloud technologies are applied to bring uniformity to the way services are run, irrespective of the deployment model. This allows IT departments to easily and more dynamically migrate services and resources between types of deployments. Even those organizations that are not going to the public cloud at this moment, benefit from this development: it allows them to start using public cloud facilities at a later stage with much less effort.

Also, for those organization that plan to take existing internal services gradually to the cloud, it is recommended to first organize the own services in a private cloud, applying all those technologies such as virtualization and dynamic resource management. After this is realized and IT processes are adapted, it is much easier to migrate some of these services to the public cloud. Given that many organizations will not migrate all their services to the public cloud, this effectively means running a hybrid cloud deployment.

One benefit of cloud computing is easy scaling in case of fluctuating demand. In a hybrid configuration, the scaling of services in the private deployment are - by definition - limited. In that case, it is possible to scale out to the public part of the deployment: something which is known as 'cloud bursting’. This type of scaling may be suitable in specific cases, e.g., when the service software is capable of dealing with dynamic resource allocation in a distributed environment, and it is cost-efficient to run in the private cloud as much as possible. Furthermore, this type of scaling also applies to community clouds, where community resources are used in case an institute's own resources do not suffice.
However, there are a number of arguments against cloud bursting. First and most important: your service must be capable of running in a dynamic cloud environment, i.e., must be able to dynamically allocate or de-allocate resources and (re)schedule tasks. Realizing these features for existing services is non-trivial. If your service supports this, it might as well run in the public cloud anyway. Second, it must be able to do so in a distributed environment, where cloud resources are geographically dispersed. This requirements adds an extra dimension to the dynamic operation of your service - and cannot be implemented for services where inter-task communication is latency sensitive. For instance database queries are very latency sensitive, so applications querying a database should preferably access it within the same geographical location. Finally, cloud bursting makes the cost model more complex, because it depends on two or more different deployments.
3 Use cases

In higher education and research, a number of cloud computing use cases are interesting to consider a bit further. The use cases below provide an indication of useful applications of cloud computing, from that perspective.

3.1 Test and acceptance, and occasional usage

The realization of new IT services, or the upgrade of current services, often requires testing out different kinds of products for evaluation or acceptance purposes - in an isolated environment, which mimics the environment in which these services will run in production. Public cloud resources are ideal for this situation: they can be quickly deployed and are only paid for the duration of the tests. Furthermore, it is not necessary to invest in hardware.

A public cloud environment also allows for trying out services in different circumstances. It is quite straightforward to run tests on different kinds of virtual machines and evaluate the most suitable configuration. Likewise, it is possible to investigate the behavior of services under load, by running load-generating clients on other cloud nodes.

3.2 Education

With the rise of cloud computing comes an increase in demand for skills that can work with cloud technologies and processes. These skills must be taught, so for higher education, cloud platforms and technologies must play a role in the specification of the curriculum - at least for those disciplines where cloud computing plays an important role. Obviously, this requires a cloud resource management mechanism with strict enforcement of permissions for delegated access to the cloud resources of an educational institution – to prevent abuse and high costs. An other important element is cloud monitoring. Monitoring is key in order to detect misconfigured VM’s that generate excessive data.

Additionally, electronics course material and services may be deployed in the cloud on demand. For example, if students require access to tools for numerical computing and mathematics (e.g., MATLAB or Mathematica), these tools can be installed on a variable number of cloud nodes, depending on the number of students taking a course.

In particularly for this usecase federated access to cloud services is beneficial. This enables educational organizations to offer fine grained cloud access and single-sign-on for their teachers, students and researchers. GreenQloud is so far the only known IaaS provider offering federated access.
3.3 Scalable applications with uncertain demand

Some specific cases exist within higher education that require occasional computing power, or computing power with uncertain upfront resource demands. Obvious examples are the high-performance computing jobs executed for scientific simulations and very high volume data processing, e.g., those coming from experimental physics or meteorological models. Computation for these jobs was mostly done by super computers in various sizes, but more recently, cloud platforms also started to be used.

An interesting development is the increasing availability of large amounts of data in scientific disciplines where this was earlier not the case, and the rise of new disciplines (e.g., bioinformatics). These disciplines do not all need supercomputing capacity and therefore can benefit from cloud computing.

3.4 Backup in the cloud

When storing data in the cloud, it may not be necessary to make separate backups of that data. Cloud storage facilities offer, in many cases, resilience by storing duplicates, which allows for recovery when one (or even multiple) copies of a data object are lost. Additionally, some cloud storage facilities offer versioning of the data, to support retrieval of the historical state of data objects. Obviously, data stored in the cloud is vulnerable in case the storage provider goes out of business. For that reason, it may be necessary to create a backup at another cloud storage provider.

When your data lives primarily in the (local) datacenter, cloud storage facilities may be used to create backups of that local data. The possibilities to backup to the cloud continue to expand, and currently there is a wide variety of services and features. Features such as scalability, availability and resilience determine the costs of the storage service. Some services are specifically targeted at data archiving and backup and are offered at an attractive price point (e.g., Amazon Glacier [7]).

Backup to the cloud, rather than a local tape unit, often introduces high latency between the local server environment and the cloud. It is key to examine if the proposed backup solution is capable of backing up your data within the required timeframe. A full backup takes more time than the daily incremental backup, so the full backup must be scheduled smartly. Modern backup solutions are capable of dealing with high latency by transferring data in parallel streams instead of sequential. Obviously restoring data from the cloud must meet business demands, as is generally defined in the recovery time objective (RTO).

Privacy and security concerns regarding moving backups to a cloud environment can be managed by using adequate crypto techniques. Make sure your crypto-key is not stored unencrypted in the same cloud. Advisable is to have the key stored locally and keep a copy in a safe off-site location.
4 Hybrid clouds in practice

There are several aspects to take into account when configuring your private and public cloud resources to form a hybrid cloud. A key thing to consider is whether services and workloads are bound to a deployment form (i.e., if constrained, whether it must run on the private or the public side). This division helps to model and predict the demand for resources on both sides.

With a demand model in place, it is possible to configure the amount and types of resources, and how those resources will scale up and down with fluctuations in demand. Now, another aspect is the amount of communication between the private and public sides: when the components of a service are spread out over the private and public side, and they need to interact frequently, the distance between the different cloud locations becomes important. A long physical distance between the private and the public side results in network delay that cannot be ignored. Applications running on top of the virtualized infrastructure cannot always cope with the additional delay.

When managing resources - either manually or automatically - it is beneficial to use similar management interfaces on the private and public side. The API offered by Amazon’s cloud are often also available for other environments and cloud frameworks. In this way it is easy to set up a cloud management framework on the private side - e.g., OpenStack [5], or Eucalyptus [6] - and manage the resources there in the same way as on the public side.

4.1 Costs models and procurement
The IaaS market is a moving market - new players appear regularly on the market and service offerings of older IaaS providers have matured by the addition of new features and techniques. The pricing strategy and the specific IaaS service offering varies considerably. This complicates a cost comparison between different IaaS providers.

Amazon is the market leader for IaaS services. They are the largest market player and the suite of products – offered under the Amazon Web Services (AWS) umbrella - is technologically most mature. Nowadays there are many third party tools than can interact with AWS components. The high availability of those third party tools indicate the broad support in the market for Amazon’s cloud.

There are new providers that focus on open source cloud standards like OpenStack and Cloudstack. An advantage of these clouds is the focus on open-standard, multiple hypervisors and flexible networks. Other new providers build up their platform using VMware technology. VMware is the nr 1 market player in server virtualization and is gradually moving into the IaaS area. Most higher educational institutes in the Netherlands use VMware for server virtualization in their datacenters. From a migration scenario point of view, or a cloud-bursting scenario, it makes sense to migrate a local VMware VM to a cloud bases VMware environment. Complicated or lengthy VM conversions are not needed in such a scenario. However, the VMware pricing strategy makes it hard for IaaS providers
that use the VMware platform to compete with other IaaS providers. Pricewise a VMware based public IaaS cloud is more expensive.

### 4.2 Cloud costs versus datacenter costs

IaaS providers offer calculation tools that indicate how much a running VM will cost. Those costs are based on variables like amount of CPUs, memory, disk size and network traffic. Often they sell additional services, like monitoring or enterprise support separately. The calculation tools are mainly based on specific IaaS provider offerings. That makes it difficult to compare the costs of having a VM running in your own datacenter versus the costs of running a comparable VM in the public IaaS cloud.

Another complicating factor is how organizations monitor the applications in their own datacenter. In order to compare costs of running a certain application in a public cloud environment metrics are needed that currently are unavailable. For instance the network traffic in datacenter is traditionally only measured on the overall utilization rate and not per application. Another example is the intensiveness rate of how the storage is used: such a metric is not always available per application.

In order to make a rough comparison we have asked a few higher educational institutes how much a running VM inside their datacenter would cost on a yearly base. All costs like electricity, housing, staff, and hardware have been taken in account. Obviously, VMs with many CPUs and large storage capacity are more expensive. In this case the institutes have roughly added all costs and divided by the amount of VMs they have deployed.

Per institute we received one average price. The price range for the majority of institutes is between €60-€95 / month.

A cost comparison between different public IaaS vendors is depicted in Table 1. In this table the on-demand pricing of small VMs, including 50 Gb outbound data transfer, are shown. The initial setup costs are omitted. GreenQloud is currently most affordable due to their zero outbound traffic costs for Dutch educational institutes. Another advantage is the fact that GreenQloud is the only sustainable public cloud that is 100% carbon neutral.

**Table 1: On-demand pricing per small VM (including costs for outgoing data)**

<table>
<thead>
<tr>
<th>Leverancier</th>
<th>Instance</th>
<th>CPU Cores</th>
<th>RAM</th>
<th>Storage</th>
<th>Total Windows / month (€)</th>
<th>Total Linux / month (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microsoft</td>
<td>Small</td>
<td>1 vCPU</td>
<td>1.75 GB</td>
<td>100 GB</td>
<td>66.33</td>
<td>45.90</td>
</tr>
<tr>
<td>Amazon EC2</td>
<td>Small</td>
<td>1 vCPU</td>
<td>1.7 GB</td>
<td>160 GB</td>
<td>67.57</td>
<td>49.86</td>
</tr>
<tr>
<td>GreenQloud(^3)</td>
<td>Small</td>
<td>2 vCPU</td>
<td>2 GB</td>
<td>80 GB</td>
<td>53.64</td>
<td>44.39</td>
</tr>
<tr>
<td>Rackspace</td>
<td>Small</td>
<td>2 vCPU</td>
<td>2 GB</td>
<td>80 GB</td>
<td>114.56</td>
<td>87.32</td>
</tr>
</tbody>
</table>

\(^3\) Data-transfer outbound via SURFconext is free.
Table 1 only shows a simple cost comparison, based on the cloud provider’s online calculation tools and does not involve costs like:

- Security changes, like architectural (redesign) costs because of segregation of intern/external resources. This may also involve the procurement of security management software.
- Integration costs, like network-level integration and costs of replicating a Windows domain server into the cloud.
- Training of IT-staff in order to procure, provision and support the cloud services.
- Backup. When an application is running in the cloud an adequate backup solution needs to be implemented, which may need to be different than the standard own-datacenter backup facility.
- Monitoring. In a cloudbursting scenario both clouds, local and public, need to be monitored integrally. The monitoring provides input for deciding if a certain application cost-wise should run internally or in the public cloud.
- Disaster Recovery. When moving applications to the public cloud, the prevalent Disaster Recovery approach should be adapted.
- Application adaption. Cloud providers offer highly standardized services and some legacy applications have specific demands not catered in a public cloud. Moving such applications to the public cloud will involve application adaptation/development costs.

When taking these aspects into account, the costs per instance as indicate in Table 1 become higher. Furthermore, Table 1 shows the prices for small VMs, while for many situations larger instances are necessary, and therefore result in higher costs. More elaborate costs comparisons can be found online, such as the one on the TechRepublic website⁴.

In order to make a useful overall comparison between running a VM in your own datacenter versus running it in the IaaS cloud, we have scheduled calls with several analysts of a known information technology research and advisory company. According to these analysts a VM running all-day, including network traffic costs, would have a break-even point about € 165,- / month. So when the average costs of a VM running in your own datacenter is lower than this amount, it is cheaper to host there than in the public cloud.

The numbers above indicate that the costs of continuously running a VM in the public IaaS cloud is likely to be more expensive than running a similar instance in your own datacenter. Obviously, for a thorough analysis of the costs involved in a specific case, it is necessary to look at the specific details of that case.

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4.3 IaaS cloud cost effectiveness

SURFnet has run multiple IaaS pilots in 2012. In the pilot phase, educational institutes were able to use IaaS resources for free. Afterwards, those institutes were interviewed about their willingness to pay for IaaS cloud offerings. All institutes that have participated consider the current IaaS pricing as expensive for VMs that run 365 days/year. However, public IaaS pricing is dropping every year so in a couple of years it may be different.

When is it considered to be cost effective to use public IaaS resources today?
  • In use cases where temporarily extra resources are needed, like controllable bursting scenarios. For example when a specific web service in a certain timeframe will be heavily used, like an online exam server, this server including the backend services can be replicated to a public cloud in order to distribute the load between local setup and the cloud.
  • Virtual organizations or researchers collaborating in a dynamic structure that lack internal IT support.
  • DTA environment (Development, Test, Acceptation) in which specific VMs are temporarily needed. Being able to deploy a specific VM fast is essential. Most institutes currently have an extensive DTA environment and can save money by moving it (partly) to the public IaaS cloud.
  • Temporarily need of clustered computers in order to perform scientific calculations. Many institutes have local running small-scale clusters that are used ineffectively.
  • In an education scenario, when during a specific course cloud resources or software licenses deployed on IaaS VMs are temporarily needed.
  • In offsite tape backup scenarios, an IaaS cloud offering can be price effective (like Amazon Glacier)

4.4 Cloud backup cost effectiveness

There are a numbering of cloud vendors offering a very competitive price for remote storage. Amazon Glacier has a $0.01 per Gb/month offering which is positioned as a long-term archive facility. Retrieval of the stored data is not real-time and additional costs are involved to access it. Amazon’s offering is relatively cheap, but plug and play storage solutions capable of using the Glacier benefits are not yet mature. It is expected that this will change soon.

GreenQloud is a promising cloud startup company that currently offers an object storage service StorageQloud, suitable for remote backup applications. GreenQloud has a no-data-transfer-cost offering for educational institutes in the Netherlands and bills $0.07 per GB/month.

Managing local tape backup is more troublesome than disk backup and when examining the current costs of cloud storage, institutes can save money by deploying a smart backup strategy. This does not mean that all backups should be moved directly into the cloud. It is advisable to retain most recent backups locally, for quick recovery and in order to have a staging environment before it will be moved to the cloud.
Conclusions

In higher education, the transition from a traditional datacenter based IT environment to a cloud-based IT environment has several benefits. Although many organization already are using SaaS cloud facilities, they do not yet take full advantage of the possibilities of IaaS services. We have argued that a transition, when appropriate, is in many cases best done from the datacenter, to a private IaaS cloud, followed by a transition to a hybrid IaaS cloud.

The perception of public cloud services is that they tend to be very cost effective. The massive scale, the large datacenters and the highly standardized approach combined with cloud providers offering multiple free SaaS services gives an impression that IaaS cloud services should be much more cost effective than running IaaS services in a private datacenter. In practice, however, it seems that, contrary to the adaptation of SaaS commodity services, cost benefits by moving all private cloud IaaS services into a public IaaS cloud are not a driving factor. In various cases, the costs of running cloud machines are higher than running dedicated machines in a private data center. So far public IaaS prices tend to cut down every year so maybe in a couple of years a generic cost comparison will be different. This makes it worthwhile to reconsider these findings after some time.

Several use cases benefit from the deployment of an IaaS cloud. These comprise activities for test and acceptance, education, applications with scalability needs, backup, and occasional usage. More specifically, the following use cases can be identified:

- Situations where temporarily extra resources are needed, like controllable bursting scenarios. For example when a specific web service in a certain timeframe will be heavily used, like an online exam server, this server including the backend services can be replicated to a public cloud in order to distribute the load between local setup and the cloud.
- Virtual organizations or researchers collaborating in a dynamic structure that lack internal IT support.
- DTA environment (Development, Test, Acceptation) in which specific VMs are temporarily needed. Being able to deploy a specific VM fast is essential. Most institutes currently have an extensive DTA environment and can save money by moving it (partly) to the public IaaS cloud.
- Temporarily need of clustered computers in order to perform scientific calculations. Many institutes have local running small-scale clusters that are used ineffectively.
- In an education scenario, when during a specific course cloud resources or software licenses deployed on IaaS VMs are temporarily needed.
- In offsite tape backup scenarios, an IaaS cloud offering can be price effective (like Amazon Glacier)
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