Abstract

Virtual computing laboratories are widely implemented in universities, especially to support teaching and research in areas such as engineering, computer science, and information assurance. Most existing labs that support teaching or a combination of teaching and research are internally implemented and managed. Some universities are considering migrating their in-house labs into the cloud using solutions provided by multiple vendors. This paper explores the practical aspects of such a migration and describes costs, benefits, and challenges.

1. Introduction

Virtual computing laboratories (VLABs) in universities have evolved from experimental and home-grown solutions in the mid-2000s [2] [10] [15] to widely-implemented solutions with considerable vendor support at present [11] [16] [3]. Table 1 shows a sample of extant VLABs in 2012 and briefly summarizes their implementation specifics.

Current university VLABs are usually implemented using local computing resources. Though the supporting resources may be organized as or part of a cloud computing solution, that cloud is internally implemented. In contrast, there has been a trend toward moving other university-sponsored IT services to external cloud providers [8]. Examples include email, office (productivity) software suites, administrative applications, and some learning management system functions.

Since neither universities nor vendors are as far along the learning curve with VLABs as with other IT services it’s not surprising that most VLABs are implemented with local and internally-managed resources. Yet the same factors that have led universities to move other services to external cloud providers (e.g., cost, availability, resiliency, and scalability) make VLABs a service for which outsourcing should be considered.

This paper examines the current state of university VLAB implementations with a specific emphasis on issues most critical to cloud architecture in general and the outsourcing decision in particular. We focus primarily on labs that support instruction or a combination of instruction and research with large numbers of users since these are the most likely targets for commercial outsourcing. We examine existing external cloud environments in which such a VLAB might be hosted and provide a detailed case study of a specific VLAB and the decision to move or not move it to a specific external cloud environment. Our analysis exposes critical decision factors that underlie similar VLAB outsourcing decisions.

2. Virtual Computing Laboratories

University VLABs typically provide access to basic desktop virtualization services with software commonly used by students and faculty members. Software such as operating systems, office productivity suites, software developments, and statistical and mathematical modeling software can be packaged in a single virtual machine (VM) without the need to install it on physical workstations or on student-owned computing environments. In some environments, individual applications can be provided to user-controlled desktops rather than virtualizing an entire machine.

Though some university VLAB usage scenarios are very similar to desktop virtualization scenarios in business and governmental institutions, there are some important differences. For example, deployments in non-educational environments typically involve either a small set of applications or a single VM used by most or all members of the organization. In contrast, educational deployments typically offer a larger set of applications or use multiple VMs customized to specific types of users (e.g., students in engineering, chemistry, or digital media arts).
Table 1. Sample VLAB Installations

<table>
<thead>
<tr>
<th>University</th>
<th>Description</th>
<th>URL</th>
</tr>
</thead>
<tbody>
<tr>
<td>George Mason University</td>
<td>Apache VCL, general purpose computing laboratory, similar labs implemented at other Virginia state universities</td>
<td><a href="http://www.vcl.gmu.edu">http://www.vcl.gmu.edu</a></td>
</tr>
<tr>
<td>Georgia State University</td>
<td>Apache VCL, primarily supports students using SPSS and similar software</td>
<td><a href="http://www.gsu.edu/help/46646.html">http://www.gsu.edu/help/46646.html</a></td>
</tr>
<tr>
<td>GENI</td>
<td>Citrix Xen with significant extensions, supports advanced research into distributed applications</td>
<td><a href="http://www.geni.net">http://www.geni.net</a></td>
</tr>
<tr>
<td>SUNY - Buffalo</td>
<td>Citrix XenApp, general purpose computing lab, also provides access to common data storage</td>
<td><a href="http://ubit.buffalo.edu/software/virtual/index.php">http://ubit.buffalo.edu/software/virtual/index.php</a></td>
</tr>
<tr>
<td>University of Alaska - Fairbanks</td>
<td>VMware ESX and Lab Manager, provides specialized labs for information assurance courses.</td>
<td><a href="http://assert.uaf.edu/lab.html">http://assert.uaf.edu/lab.html</a></td>
</tr>
<tr>
<td>University of Maryland</td>
<td>Citrix XenApp, primarily supports engineering students</td>
<td><a href="http://eit.umd.edu/vcl">http://eit.umd.edu/vcl</a></td>
</tr>
<tr>
<td>University of New Mexico (UNM)</td>
<td>VMware ESX and Lab Manager, provides a general-purpose computing laboratory and specialized labs for information systems and information assurance</td>
<td><a href="http://vlab.mgt.unm.edu">http://vlab.mgt.unm.edu</a></td>
</tr>
<tr>
<td>University of North Carolina</td>
<td>Apache VCL, general purpose computing laboratory, similar labs used at other NC state universities</td>
<td><a href="http://vcl.unc.edu">http://vcl.unc.edu</a></td>
</tr>
<tr>
<td>University of West England</td>
<td>Citrix XenApp, general purpose computing lab, also provides access to a common data storage</td>
<td><a href="http://www.uwe.ac.uk/its/corporate/services/remotefiletransfer.shtml">http://www.uwe.ac.uk/its/corporate/services/remotefiletransfer.shtml</a></td>
</tr>
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</table>

Another difference is retention of application and VM state. State-less deployments are common in non-educational environments but some long-term projects require long-lived stateful deployments. Advanced instruction and research in fields such as computer science and information assurance often require a collection of VMs connected by specialized virtual networks [10] [11]. In advanced research scenarios such as those supported by GENI [9], VMs may be spread across multiple locations.

University VLABs address educationally-specific deployment scenarios by various means. For example, VM hardware and installed software can be customized to the needs of the user for specific instructional exercises, simulations, analyses, or research projects. VMs needed in longer-lived environments (e.g., to support a semester-long system development project or ongoing investigations) can be defined as a template, cloned for each user, and destroyed at the end of the course or project.

Table 2. Common university VLAB usage scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Details</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application virtualization</td>
<td>One or more applications (e.g., SPSS or Microsoft Office) hosted on server with presentation layer executing on user device</td>
<td>General-purpose computing</td>
</tr>
<tr>
<td>Stateless desktop virtualization</td>
<td>Complete VM with operating system and applications hosted on server with remote console on user device, VM initialized to default state each time it is used</td>
<td>General- and special-purpose computing</td>
</tr>
<tr>
<td>Stateful desktop virtualization</td>
<td>Complete VM with operating system and applications hosted on server with remote console on user device, per user VM state is stored between uses</td>
<td>Longer-term projects, configuration exercises</td>
</tr>
<tr>
<td>Multiple VMs with virtual network</td>
<td>Multiple VMs (e.g., servers and clients) interacting within a private isolated network (usually with state retention)</td>
<td>Advanced computer-related courses and projects</td>
</tr>
<tr>
<td>Distributed VMs with experimental network</td>
<td>Multiple VMs widely-distributed using I2/NLR and experimental protocols (with or without state retention)</td>
<td>Advanced research</td>
</tr>
</tbody>
</table>
3. VLAB Architecture

Figure 1 presents a generic model of key VLAB components to support the first four usage scenarios in Table 2. Users access the VLAB via a portal, typically implemented as a web site, and view the contents of a library of single VMs or configurations consisting of multiple VMs connected by a supporting virtual network. The deployment manager is a back-end software component that manages the library and interacts with a set of computing, storage, and network resources. When a user requests access to a VM or a multiple-VM configuration, the deployment manager accesses it from the library and creates a deployed instance by allocating appropriate computing resources.

Once initialized, the user interacts with the VM(s) through a Web browser plug-in functioning as a virtual console, remote desktop protocol (RDP) connection, or similar technology. When the user is finished with a VM or configuration, the deployment manager saves the VM state(s) back to the library or a user workspace (if appropriate), deletes the deployed VM(s), and returns their associated resources to the appropriate pools.

4. VLAB Vendor Support

Although there are variety of products and technologies that can host single VMs or configurations, there are relatively few product suites that integrate VM and configuration hosting with the other essential VLAB elements: the portal, library, and deployment manager. For example, Oracle VirtualBox, Microsoft Hyper-V, and Parallels for Apple Macs support desktop or server virtualization but there are no complete VLAB solutions built on those foundations.

As VLABs have matured, a set of supporting vendor products and services has evolved to provide an integrated set of VLAB services/tools.

Commonly-used commercial and open-source products for implementing locally-installed VLABs include:
- Apache Virtual Computing Lab (AVCL)
- Citrix XenApp and XenDesktop
- VMware ESX, Lab Manager and vCloud Director

4.1. Apache Virtual Computing Lab

AVCL is an open source software kit for deploying a VLAB. It arose out of a VLAB development project at the University of North Carolina that was donated to the Apache Software Foundation in 2008 [2]. AVCL provides a VLAB
portal, VM/configuration library, deployment manager, and VM console interface.

Though AVCL is based on open-source software and thus vendor neutral in theory, many current VLAB implementations are based on software and hardware provided by IBM. IBM add-ons and related services have helped AVCL-based VLABs evolve from home-grown experimental projects to something much closer to commercial off-the-shelf software [12].

4.2. Citrix Virtualization Products

Xen was originally developed at the University of Cambridge and spun off commercially through a private company that was later acquired by Citrix. [4] In its original form, Xen was a hypervisor targeted primarily to Linux hosts and clients. After the Citrix acquisition, Xen was systematically expanded to support additional client operating systems and hardware and was integrated with other Citrix products. Xen was released by Citrix under the GNU public license in 2010 though, as with AVCL and IBM, most university VLAB implementations based on Xen rely on additional Citrix-supplied software and services.

Two Citrix Xen-related products are used in university VLAB environments:

- **XenApp** [5] delivers individual or groups of applications to client devices running various OSs. A client-installed application enables servers to deliver applications to the client desktop via graphics-drawing functions similar to an X11 window manager.

- **XenDesktop** [6] delivers a desktop environment (hosted OS and installed applications) to a client. It provides similar functionality to AVCL and VMware desktop virtualization products.

4.3. VMware VLAB Products

VMware offers multiple virtualization products in both workstation- and server-oriented versions. VMware has 80% market share in the server consolidation arena [14] and has actively sought additional markets and application areas including university VLABs.

VMware VirtualCenter provides core services for managing VM libraries and deploying them to servers running the VMware ESX operating system. VMs executing within an ESX host support console interfaces using a protocol similar to Microsoft's RDP. If the VM is accessible via a public network, users can also login remotely to the VM's DNS name or IP address.

VMware's Lab Manager product is an add-on that provides the VLAB portal component via a Web site hosted on a Microsoft Windows 2003 or 2008 Server. Lab Manager also supports browser-based VM consoles via browser plug-ins.

4.4. Cloud-Based Products

Vendors of VLAB products are following the trend of enabling their products to work in internal (private), external, and hybrid cloud environments. For example, IBM has packaged AVCL and other educational software with its SmartCloud services [13]. Universities can implement hybrid or fully external cloud-based VLABs using large-scale IBM-owned computing facilities located throughout the world.

VMware is migrating Lab Manager users to a newer product suite named vCloud [17], which provides similar services to users but expands back-end capabilities to enable VLAN infrastructure to be replicated across multiple internal and external sites. Vendors such as Dell have adopted vCloud as the basis for a suite of services providing hybrid and outsourced cloud services to a variety of clients including universities and their VLABs.

The remainder of this paper will one particular university’s VLAB based on current VMware products and the decision whether to move it partly or completely into compatible Dell vCloud-based services.

5. Cloud Benefits, Costs, and Risks

Moving applications and services into the cloud provides significant benefits to users and owning organizations though it raises some challenges that must be addressed when deciding which applications and services are suitable targets for migration. Chief among the benefits are flexibility and reduced cost. Three specific use cases that favor cloud computing due to these factors are [1]:

- Demand for a service varies with time
- Demand is unknown in advance
- Massive parallelism shortens execution time to needed levels

Typical university VLAB usage scenarios overlap the first two use cases. Demand fluctuates from minute to minute depending the number of users, often peaking in the evening. Demand varies during a semester or quarter as a function of resources needed to learn to use tools and to complete related assignments. Most university computer labs see a steady rise in demand from the start of a semester or
quarter to the end. In addition, though numbers of students users can be reasonably anticipated in a typical university, their demand for computer resources is less certain, especially over a period of years. Thus, university VLABs are well-positioned to realize the same economic benefits as many other cloud computing adopters.

Common challenges to cloud computing adoption applicable to VLABs include [1]
- Data confidentiality/auditability (security)
- Data transfer bottlenecks
- Performance unpredictability

Data transfer bottlenecks are discussed in more detail later in this paper. Data confidentiality might be easily breached in the virtual environment since security models for cloud computing are not yet well-developed. Data integrity can be potentially impacted by the unforeseeable security threats over the Internet. Furthermore, data availability is threatened by the unknown physical location of hardware and software that warrants site inspections and audits.

The extent to which typical concerns over data security and privacy apply to university VLABs is unclear. VMs used for learning and research rarely contain confidential data in the same sense as a student records or financial database. But VMs are intellectual property assets. They are valuable in terms of their cost to create and their potential to generate revenue (e.g., tuition) for their owner.

As with many outsourcing decisions, cloud-based VLABs are a threat to in-house IT culture in terms of data security, IT management, and IT policies. Universities are often places where local control, distributed decision-making, and significant autonomy are highly valued. Moving a VLAB into the cloud can be viewed by faculty and IT staff as a threat on all of these dimensions.

6. Sample VLAB In Detail

6.1. UNM VLAB Development

The University of New Mexico (UNM) VLAB has evolved through several generations of software and hardware. In its first version, the VLAB was a collection of repurposed desktop PCs remotely accessible through the Windows RDP protocol built into the Windows XP client operating system. Users accessed the machines via a web portal that included internally developed code that displayed icons for currently available machines. This version of the VLAB was soon upgraded with more powerful network switches for better throughput, a SAN where each student could store VMs, and limits on session duration.

Though it served its small target population well, this initial VLAB design suffered from one major design flaw, lack of scalability. Increasing demand for VLAB services couldn’t be cost-effectively addressed by adding more desktop PCs to the pool of available resources due to space and power requirements, physical network limitations, and required web portal redesign.

6.2. Current UNM VLAB

In 2009, through a grant from Dell, the UNM VLAB design was migrated from a locally distributed model of multiple desktop PCs to a cluster of rack-mounted servers running VMware ESX. [3] Additionally the web portal and library were replaced by a VMware commercial product, Lab Manager (LM). LM provided greater flexibility in creating and managing configurations with the required virtual machines to support specific courses or individual lab exercises. Also, LM was customizable as a web product to maintain the previous VLAB and UNM branding. Scalability concerns were addressed by tight integration between LM and ESX. ESX enables servers to optimize their physical resources to match demand in real time. In addition, long-term demand increases could be addressed by adding additional hardware to the cluster. The most time-consuming aspect of the VLAB reimplementation was the migration and creation of VMs and configurations to support specific courses.

The current UNM VLAB is architecturally similar to the one deployed in 2009 though server, storage, and networking hardware have been upgraded to increase capacity. The lab currently supports up to 250 hundred simultaneous users from a student base of approximately 1500. Virtual environments include a “standard” desktop image that supports many classes, a handful of specialized environments that support specific courses in information systems and information assurance, and a library of dozens of multiple-VM configurations that support advanced classes and research in information assurance and system administration.

6.3. Current VLAB Limitations

In its present form, the UNM VLAB has a number of limitations, some of which may be addressed by moving the supporting infrastructure to an internal cloud architecture or by outsourcing the VLAB infrastructure to an external cloud.
### 6.3.1 Scalability and Resiliency

The current architecture provides limited scalability through its use of VirtualCenter, ESX, and rack-mounted server and storage nodes. Storage and computing capacity can be increased by adding new nodes or upgrading existing nodes. However, the range of capacity increase is limited by available power, physical space, and existing network connections to the rack.

Because the current VLAB is hosted on a single server cluster, service availability faces risks common to any single site installation including network and power outages, physical threats, and environmental malfunctions. These have been present to different degrees since the VLABs earliest days. However, increasing dependence on the VLAB for teaching, learning, and research have made these limitations more pressing these past few years.

In addition, the department that owns and manages the VLAB service does not manage any of the threat elements listed above. While collaboration with other entities at the university like central IT, physical plant and the police department are essential, the ability of the partners to maintain their services and speed of response can be limited by shrinking budgets and diverse operational priorities.

### 6.3.2 Network Bandwidth

Application and desktop virtualization are bandwidth-intensive. Part of the bandwidth requirements are internal—comprising the connections among servers and storage devices within the VLAB infrastructure. The current UNM VLAB uses gigabit and 10 gigabit connections among infrastructure components which are sufficient to meet current performance requirements. Connections between servers and storage devices are occasional performance bottlenecks, particularly when large numbers of users deploy stateful VMs (e.g., at the start of an exam).

External bandwidth requirements support interactions between users and the VLAB infrastructure. In most VLAB usage scenarios, the user experience should mimic the experience of interacting with local resources. However, that requires high-bandwidth and low-latency network connections to transmit keystrokes, mouse clicks/movements, and other user inputs from user devices to the VLAB infrastructure and screen and other updates from the infrastructure to the user device.

Data transfer between the VLAB infrastructure and external clients uses campus networking connections which include redundant gigabit and 10 gigabit connections within the campus and multiple T3 connections between the campus and the Internet. Both on-campus and Internet connections are shared with all other campus users and no traffic prioritization is implemented. Thus, VLAB I/O performance is subject to slowdowns when the campus network or its external Internet connections are saturated.

### 6.3.3 Virtual Environment Support

The emulation requirements for early VLAB implementations were quite simple—Windows XP and a portfolio of applications used in information systems and security courses had to be accessible over the Internet from laptop and desktop computers. Over the last decade, the expanding variety of computing device types from smartphones to tablets has complicated access to and provision of VLAB services. Users demand access from any/all devices, operating systems, and browsers. Courses in information systems and security can benefit from the ability to virtualize all device and network types.

VMware Lab Manager has relatively limited support for both console access and device emulation. Operating systems that can be installed within a VM are limited to Linux and Windows with no support for OS X or Android. Also, Lab Manager cannot support virtualization of Apple desktop or laptop computers, iPads, or mobile devices running Android. Thus, emulating a typical network of heterogeneous devices is not possible.

Finally the VLAB service can only emulate wired network connections leaving an unmet need for wireless and cellular network emulation capabilities.

### 6.3.4 Costs

Current UNM VLAB costs fall into the following categories:
- Infrastructure hardware
- Infrastructure software
- Networking, power, etc.
- System administration and technical support

Hardware and software infrastructure includes server nodes, storage devices and supporting storage-area networking hardware, and software licenses for VMware ESX servers, Virtual Center and Lab Manager. Hardware and software costs are amortized over a three year cycle given the expected life of the hardware and rate of software upgrades.

VLAB configuration and administration requires human resources with a significant skill set. While there is a sizeable startup requirement to configure the service, continuing VLAB administration requires only a few hours a week. The VLAB also relies on infrastructure resources including the campus data...
network and power grid. For the current VLAB these are considered “free” resources though a full costing analysis should account for these hidden costs.

Perhaps the most significant cost that’s been observed is the opportunity cost incurred by faculty and staff who administer, support, and use the VLAB. Faculty members spend a considerable amount of time managing VMs and configurations used in their classes and dealing with other administrative activities. Faculty members would like to engage in fewer time-consuming administrative activities and devote more time to using the VLAB in support of their pedagogical and research efforts. This issue is a significant motivation to consider outsourcing all or part of the VLAB to an external service provider.

7. Migrating the VLAB to a Hybrid or External Cloud

Previously noted limitations of the current VLAB have led current lab administrators to consider alternative VLAB architectures. A cloud-based architecture that distributes VLAB infrastructure across multiple internal or external locations is a logical choice for improving resiliency. Distributing the VLAB infrastructure could also address network-related performance issues by placing some resources outside the campus network or by better distributing I/O load across internal locations.

A cloud-based architecture using internal resources wouldn’t eliminate risks associated with supporting services such as network, power, security and environment. But physical redundancy would lower the risk of service loss or disruption if properly designed. However, hardware and software costs will quickly rise as each location would require a similar financial investment. Synergies may be available in the cost involved in configuring and managing the multiple sites.

Outsourcing to an external cloud provider presents some clear advantages in terms of overcoming the limitations and risks previously listed as they are now transferred to (and addressed by) the vendor. Cost savings may also be realized to the extent an external vendor can provide supporting infrastructure at lower cost than internal resources. However it remains unclear in these early stages of cloud-based VLABs and VLAB outsourcing whether an outsourced environment can meet the unique needs of a multi-purpose university VLAB. It’s also unclear whether up-front costs of setup, migration, and the learning curve for administrators, faculty, and users can be fully recovered.

The following sections discuss the details of some unique challenges for migrating an existing VLAB to a cloud-based architecture. These details are largely based on our own evaluation of the Dell Cloud service (based on VMware products) during late 2011 and early 2012, though many details can be generalized to other vendor products and other university VLABs.

7.1. Migration, Operation, and Bandwidth

Moving the existing VLAB to a cloud architecture requires moving existing configurations, virtual machines and networks, into the new infrastructure. Although vendors provide tools to accomplish this step there are some issues to consider. Current operating systems used by VMs, such as Windows 7 and Windows 2008 R2 require large virtual disk drives—at least 16GB for Windows 7 and 40GB for Windows 2008 R2. Moving a single large VM or ISO file from a campus VLAB to an externally hosted infrastructure can take minutes or hours and be subject to time-outs and other problems. Table 3 shows computed transfer times for a range of ISO/VM sizes and available bandwidth assuming 10% overhead. Moving multiple VMs or ISO files proportionally multiplies the transfer times.

### Table 3. Transfer times in minutes

<table>
<thead>
<tr>
<th>Size (GB)</th>
<th>Available bandwidth (Mbits/sec)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>15.02</td>
</tr>
<tr>
<td>5</td>
<td>75.08</td>
</tr>
<tr>
<td>10</td>
<td>150.18</td>
</tr>
<tr>
<td>20</td>
<td>300.37</td>
</tr>
</tbody>
</table>

Once a cloud-based VLAB is operational, faculty, staff, and users need to be able to create new VMs and configurations. In the current VLAB there is considerable flexibility in how this is accomplished and related performance issues are minor concerns. Currently-used methods include:

- Creating or modifying VMs and configurations entirely within the VLAB
- Creating VMs within the VLAB but using resources such as software installation CDs hosted outside the VLAB
- Creating VMs offline and later importing them into the VLAB

When the VLAB infrastructure, other servers, and user workstations are located on the same high-capacity network any of these methods are possible and there is little performance difference among
them. However, as some or all VLAB infrastructure is moved into the cloud, bandwidth limitations between local servers, local workstations, and cloud-based VLAB components become a potential performance bottleneck. Adequate bandwidth must be provided or methods for creating and modifying VMs and configurations must be restricted to those that minimize bandwidth consumption.

This is a significant issue for the UNM VLAB given the large number of existing VMs and configurations, their rapid pace of change, and the need for students, faculty, and staff to create and modify VMs and configurations in many advanced courses and for research.

Providing sufficient operational bandwidth to support user access VMs to from on- or off-campus locations to a cloud-based VLAB is considerably less problematic than migrating entire VMs or ISO files. Based on estimates from VMware [18] and Citrix [7], a client system will require between 50 to 150 kbps when using a moderate resolution and non-graphic intensive applications. Increasing the screen resolution of the VM or the refresh requirements through the use of a graphics intensive application will require additional bandwidth on the client side. At the cloud service provider end a gigabit link with a 10% overhead could support I/O for approximately 9500 clients at 100 Kbps per clients, assuming administrators were not uploading ISOs or VM files at the same time.

7.2. Migrating Groups of VMs and Associated Networks

To support advanced VLAB usage scenarios typical of computer science and information assurance courses, the cloud architecture must support creating and modifying internal private networks as well as enable routed (NAT) internet access for multiple-VM configurations. For example, consider complex configurations to support behavioral analysis, detection of network malware, or examining incident responses after a simulated intrusion. Such scenarios require multiple virtual machines connected by isolated non-routable networks.

In a local VLAB with maximal management access and infrastructure flexibility, designing and enabling these additional components is a feasible task. When migrating to a cloud architecture consideration must be given to whether or not the vendor will support these types of networks and at what level. A cloud vendor may be reluctant to provide virtual network creation capabilities to a customer to prevent that customer from accidentally or intentionally interfering with other custom network configurations running on the vendor’s infrastructure.

Even if support is provided, an isolated network with the needed specifications may not be available (e.g., a needed IP range may already be assigned to another customer). Or, the user may not have direct access to the administrative capabilities needed to create and deploy private internal networks (e.g., a security measure for the cloud infrastructure).

As an example let’s use a simple routing configuration with two clients and one server. Client A has an interface (192.168.0.10) on private network 192.168.0.0. Server A, tasked with routing between network 192.168.0.0 and network 192.168.5.0 will have two network interfaces, one on each network and IP addresses of 192.168.0.1 and 192.168.5.1 respectively. Client B is configured with an interface on network 192.168.5.0 and an IP address of 192.168.5.1.

In an ideal scenario, the cloud architecture will enable the user to create and configure two internal networks, 192.168.0.0 and 192.168.5.0 in support of this configuration. In a cloud service not as flexible a vendor may offer to create the internal networks for the customer and may require an additional administrative process for creating and modifying these resources, with an additional challenge that the exact network numbers may not match or be available. In the worst case, internal networks may not be available or may be limited to one in which case the desired configuration can’t be supported or may need significant redesign.

7.3. Authentication and Authorization

Ideally any cloud vendor will provide a mechanism to interact with a customer’s LDAP infrastructure and avoid duplicate user management systems. Generally this configuration setting can easily be supported if the client controls its own LDAP infrastructure. However, it is common within universities for central IT to manage the campus wide LDAP system, including student accounts, and it may not be feasible, either for lack of resources or technical capabilities, to request access for the cloud vendor interface. This limitation can create a significant burden in the management of user access to the cloud VLAB given that user accounts will have to be duplicated, maintained and the end user will be asked to remember yet another set of credentials.
7.4. Customization and Control

Attractive features of local VLAB installations include the ability to customize the web portal interface and the infrastructure configuration at a very granular level. For example in LM, and administrator or faculty member can customize available lease times for the storage and deployment of configurations by modifying values in the local configuration database. This is a critical feature when optimizing limited resources and ensuring that memory, storage and CPU cycles are not being consumed by unused configurations and their VMs.

External cloud vendors typically limit the ways in which a customer can configure the cloud infrastructure as a security measure and to prevent one customer from making changes that might negatively affect other customers. However, the result may be suboptimal performance for one specific customer, excess resource utilization and associated charges, or a combination. Configuration changes can be negotiated between a customer and the vendor but the process is much less direct and timely than when the customer directly controls his own cloud infrastructure.

7.5. Supporting Information Assurance Education and Research

In addition to issues raised in previous sections, information assurance courses, projects, and research present special problems related to malware, hacking, penetration testing, and other “nefarious” activities. Coursework in information assurance courses typically includes many exercises and projects in which students and faculty intentionally introduce malware and other rogue software into a simulated network. Capture-the-flag and similar exercises test students’ abilities to launch attacks and defend against those attacks.

When such activities take place in an internally implemented VLAB, administrators and faculty members can exercise significant control over the testbed environments and isolate them from other VLAB users. In a hybrid or external cloud the degree of control is generally lower and the risks for other users are generally higher since the infrastructure underlying the VLAB is shared with many other users and uses. As such, campus infrastructure administrators and external vendors are understandably reluctant to permit many “normal” activities by information assurance students and faculty.

The inherent risks in such class-related and research activities raises the question of whether it is even feasible support IA courses and exercises with VLAB resources located in an internal or external cloud. Some vendors have balked at our queries on this issue. However, in an initial pilot with Dell cloud services the vendor indicated confidence in their ability to isolate environments, such as VMs and networks, and prevent any leakage of malware or otherwise unwanted activities to other tenants. It remains to be seen whether other vendors will step up to this challenge.

7.6. Costs and Service Levels

While a cloud solution provides a significant improvement in terms of reliability, performance and availability it is difficult to measure what the recurring cost of such a move will be. At this time it appears that vendors are providing tiered services, where they can lease the entire infrastructure or provide a solution shared with other customers. The difficulty lies in that charges/costs appear to be tied to utilization of resources within each tier. Given this utilization cost approach a tool capturing existing loads by semester for a given course or the entire local infrastructure would be beneficial to provide a valuable analysis in identifying whether cost savings can be realized in the long run. This cost model also increases the value of having customization capabilities on the cloud vendor service, such as the lease values mentioned previously, to minimize the use of resources needed and eventually billed.

8. Summary and Conclusions

For VMware-based VLABs, a move to a hybrid or external cloud-based architecture entails significant short term risk and uncertainty. Pricing and network bandwidth requirements are uncertain and the robustness and ease of remote administration (or lack thereof) are unknown. As such, migration of an entire VLAB with a mixed group of users and faculty should probably not be attempted. Rather, administrators should consider migrating only a small portion of VLAB content and users—preferably, those that require basic desktop services via single or small number of single VMs. Once migration is completed, administrators can perform a detailed evaluation/comparison of costs, performance, ease of use, and suitability to need and purpose. Based on that evaluation/comparison, administrators can determine whether further or complete migration is warranted.

Migration of VLAB content that involves rapidly changing VM images, stateful VMs, or multiple-VM configurations with virtual networks should be
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10. References


