The Virtual Computing Lab (VCL):
An Open Source Cloud Computing Solution Designed Specifically for Education and Research

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ABSTRACT

In this paper, we describe the Virtual Computing Lab (VCL) with its main features and services. Also, we introduce the recent advances of the VCL system and its usage in research and education. The VCL is a cloud computing system that has been optimized for the educational services and research needs of the academic community. VCL is an open source cloud orchestration stack with a self-service portal that currently supports a large number of customers and commercial cloud, or cloud-related services and solutions. It was developed by NCSU with support from IBM Corporation. VCLs promise to support researchers and students in all academic levels to fulfill all their computing needs. In addition to supporting students and faculty members at NC State University and other UNC System universities, the NC VCL now also supports students at several NC community colleges. Also, we introduced cloud computing and service science related activities and achievements at Jordan University of Science and Technology.

Keywords: Virtual Computing Lab, Cloud Computing, Educational Services, Open Source Systems, SSME, TeachCloud

1. INTRODUCTION

Cloud computing is an emerging computing paradigm that is continuously evolving and spreading. Empowered by hardware virtualization technology, parallel computing, distributed computing, and web services, cloud computing presents a great revolution in the information and communication technology sector (Buuya et al., 2009). Cloud computing can be defined as “a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications and
services) that can be rapidly provisioned and released with minimal management effort or service provider interaction” (Mell et al., 2011). There are several examples of emerging cloud computing infrastructures and platforms such as Microsoft Azure (Mell et al., 2011), Amazon EC2, Google App Engine (Chappell, 2008) and VCL (Rindos et al., 2010). Furthermore, CC helps companies to improve their IT services, it also helps in the development of applications to achieve unlimited scalability, as well as in the automaticity of on-demand services of the IT infrastructure, and increasing their revenues (Joshi et al., 2011). Cloud Computing services include: Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS). Clients in CC might be users in other Clouds, organizations, enterprises, or might be a single user.

The Virtual Computing Lab (VCL) represents a true cloud computing solution that has been optimized for the educational and research needs of the academic community. Research began in 2002, with the first general production system launched in 2004 by North Carolina State University with support from the IBM Center for Advanced Studies (CAS), IBM corporate university relations, and IBM hardware development. It has been continuously improved upon for more than eight years, and is therefore extremely stable in production environments (Rindos et al., 2010). In 2012, the North Carolina VCL cloud (NC VCL) had delivered a quarter million user sessions to its students and faculty. Originally developed as the education and research cloud computing production system for NC State University, it now supports students at other universities within the University of North Carolina System, and many schools within the North Carolina Community College System. There are also several K-12 outreach pilots across the state. Similar education clouds based on VCL can be found in California, Virginia, Georgia and other states, as well as within the Historically Black Colleges and Universities (HBCU South) community as part of the HBCU Cloud initiative. VCL-based education clouds also can be found in Europe, the Middle East, India, China and Japan, with additional North American VCL efforts in Canada and Mexico. Its spread accelerated dramatically when VCL became an Apache open source project in 2009. On June 2, 2011, IBM announced the IBM SmartCloudTM for Education portfolio that included a set of solutions and services built upon VCL. VCL has been in reliable and secure operation in North Carolina since 2004. It has scaled today to more than 2,500 servers, supporting about 200,000 software images (services) in its library. It has easily scaled to this size over the years, becoming more efficient as the user population grows, allowing for judiciously alignment of peaks and valleys in resource demands of a large, heterogeneous user population while maximizing utilization and minimizing purchasing costs of hardware and software resources. Maintenance of the system requires about 2 full-time equivalents (FTEs). Given the energy efficiency of its chosen servers, discussed later, NC State is operating its cloud at just pennies per compute hour, with most universities that have adopted VCL experiencing annual total cost of ownership reductions in the range of 50 percent to 80 percent or more (Rindos et al., 2010).

VCL can deploy a wide range of solutions, from complex server clusters, to blocks of machines installed with all necessary software applications or middleware for a regularly scheduled class of students, to single physical machines and virtual desktops. As such, it has been used to support high performance computing (HPC) researchers, individual students and classroom instructors both in and out of class, university administrators supporting business applications, and even start-up businesses supported by university outreach programs and consultants, invaluable to regional economic development. It can support all this because VCL is a true cloud management stack with a self-service portal that currently supports a large number of custom and commercial cloud and cloud-related services and solutions. These include solutions delivering hardware-as-a-service (HaaS) and infrastructure-as-a-service.
(IaaS), platform-as-a-service (PaaS), software-as-a-service (SaaS), and even cloud-as-a-service capable of launching a complete VCL- or IBM-based cloud solution via a virtual image. It can support “bare-metal” server deployments using a solution like eXtreme Cloud Administration Toolkit (xCAT) that can, in turn, be used to create a large pool of HPC batch job processing servers (tightly- or loosely-coupled) with appropriate storage (managed by Load Sharing Facility (LSF) at NC State, though other solutions can and are being supported at other universities). It can also support a multitude of standard hypervisors for virtual machine deployment, including the free Kernel-based Virtual Machine (KVM) hypervisor, as well as many commercial Virtual Desktop Infrastructure (VDI) solutions. VCL can deploy various commercially available IaaS (including IBM SmartCloud Provisioning and Open Stack) or PaaS solutions. It can also easily access resources from existing commercially hosted clouds like Amazon EC2 or IBM SmartCloud, Enterprise, creating a public-private hybrid cloud solution. VCL was flexibly designed from the beginning to accommodate any and all new cloud computing paradigms and solutions that might arise, and modularly constructed to accept new software plug-ins that can orchestrate various solutions via the standard defined Application Programming Interfaces (API) typically defined for all (VCL 2014, Schaffer et al., 2009, Vouk et al., 2009). As a free and open-source cloud computing platform under apache license (Rindos et al., 2010), VCL’s primary goal of delivering dedicated custom compute environments to its users. VCL conceptual overview can be found in (Schaffer et al., 2009, Vouk et al., 2009).

Cloud computing in general and VCL in particular, help in boosting online computing services provided to the end users. The cloud services will be offered using a similar model of other service as described in (Pym & Sadler 2010, Cocca 2013, Géczy et al., 2012, Tinnila 2013). The rest of the paper is organized as the following: section 2 includes description of VCL features and functions key to education and research. Section 3 describes VCL Outreach to community colleges and K-12. Section 4 presents current advances of VCL system and achievements. TeachCloud Tool and VCL system at Jordan University of Science and Technology work are presented in section 5. Finally, the conclusion is presented in section 6.

2. VCL FEATURES AND FUNCTIONS KEY TO EDUCATION AND RESEARCH

VCL has many features and functions designed specifically for the education and research community. These include block reservations for regularly repeating classes; the ability of teachers, teaching and research assistants and others to build and permanently store classroom or research images, and “flick-of-a-bit” transitions from classroom to HPC pools. It supports both bare-metal and virtual machine deployments, including HPC clusters for the former and multiple hypervisors for the latter. It is also extremely stable, very inexpensive to maintain, and operational in production at many universities. Also, it is free as an Apache open source solution, though with support from various third party vendors. Any university’s identity management system can simply be plugged right in. VCL automatically manages licenses and provides a wealth of system statistics and metrics that can be used for detailed billing and metering, capacity planning (including license purchasing plans), and so on. Given that it is open source, VCL also can be used by educators to teach about cloud computing, since its inner workings and design are open to all. It also has a number of support communities that have grown around it that meet regularly to share best practices and resources such as image libraries, provide mutual support in problem solving, pursue joint funding opportunities, and other functions (Rindos et al., 2010, Schaffer et al., 2009, Vouk et al., 2009).

The VCL managed by NC State can be accessed by any user with a valid user account and password at http://vcl.ncsu.edu. All University of North Carolina system students...
with Shibboleth credentials (approximately 250,000) have access to it. A student or educator can access the site to request that one or more real (bare-metal load) or virtual machines be delivered immediately or at a later scheduled time. An image represents an operating system, typically Microsoft Windows or Linux, running one or more software applications or middleware, and can be selected to run on a chosen machine. The website can be accessed by any machine or device that can run a web browser, providing full use of all the resources requested. The interface is identical to what users would experience if the machines were under the desk, even allowing users to install additional software on the delivered machines. Once the user is finished, the resources can then be disassembled and returned to the general pool to be reallocated again for the next user. The resources are used only when they are needed, maximizing the utilization of the hardware and software licenses while minimizing energy costs and purchasing requirements. Access to those resources with the Internet means they are available around the clock from a classroom, a dorm room, or the home (Rindos et al., 2010).

When making a request at the NC VCL website, each educational institution can access its own “portlet” with a pull-down menu that is customized to appear as a web page for that specific school. Access control can be linked to a school’s LDAP, Shibboleth, or other sign-on system. The VCL appropriately manages the individual software license agreements, limiting the number of simultaneous licenses in use by authorized users if required. Group access to software can be managed by easy-to-program policies such as class enrollment lists. Relevant usage statistics are collected and can be used for metering and charge-back, future capacity planning, and so on (Schaffer et al., 2009; Vouk et al., 2009).

2.1. VCL in Support of Day-Today Educational Needs In and Out of the Classroom

The NC VCL supports a wide range of users, from HPC researchers to K-12 students. To support computationally intensive work, a researcher can access the VCL website and request a cluster of machines, possibly with a different software suite installed on each machine. Using the same infrastructure, a professor can select 20 or more machines for a class of 20 students. A special image can run on each machine with all the software needed for that class. The machines can be delivered on specific days in time for a class held from 2 p.m. to 4 p.m. Likewise, a middle school teacher can pre-schedule VCL machines each day to run “Project Lead the Way” software for a science, technology, engineering and math (STEM) course. At class time, the teacher can then roll out a cart with inexpensive thin clients that the students can use to access the course material (Rindos et al., 2010; Seay et al., 2010).

In support of the educator community, the VCL can provide:

- One or more machines, either as single physical or virtual machines, or as server clusters with any software required for in-class labs or educational demonstrations.
- Any number of machines for any number of students in a regularly scheduled class, with any software necessary for that class installed on each machine, all delivered automatically each time that class meets. VCL allows an educator to schedule such resource delivery in advance for the entire semester. For high-end applications like CAD/CAM, the software can be delivered on dedicated physical machines; for K-12 applications, the software can be delivered on virtual machines.
- Any number of virtual desktop or server applications, including existing vendor implementations, with existing VCL sites supporting VMware applications (ESX or GSX), KVM and Xen hypervisors.

VCL can also simultaneously provide high performance computing support for the research community on campus (see list in the following section). This capability allows a VCL-based cloud to support the needs of all communities on...
campus with the same single cloud infrastructure with tremendous cost savings.

In addition, in support of students, the VCL can provide:

- A suite of educational software on a physical or virtual machine at home, in the dorm, or in the classroom, that can be used for classroom instruction or out-of-class projects or homework.
- Tele-classroom and distance education applications, including continuing education, and education of military personnel stationed on bases.

2.2. VCL in Support of High Performance Computing

VCL development began in 2002, in part to address the information technology access needed by NC State students, and in part to compensate for the loss of the North Carolina Supercomputing Center that had supported its HPC research community. The result was one of the first true cloud computing infrastructures for university research and education, years before the term “cloud computing” became popular. Since support of the HPC and other university research communities was designed into it from the start, the VCL provides not only various HPC-specific services but also one or more servers or clusters of servers, either with or without the software applications pre-installed (Rindos et al., 2010, Schaffer et al., 2009, Vouk et al., 2009).

This can include:

- Either loosely or tightly coupled machine clusters such as a pair of tightly coupled, fully populated blade server classes, with or without the software pre-installed on the cluster machines. An example of the former is a high-availability web server cluster, with each machine appropriately installed with web server and database software, for internet-related research. An example of the latter is HaaS hardware-as-a-service.
- Any number of single machines, with a range of hardware specs such as computing, memory/storage, networking, and so on.
- Actual mini-clouds: for example, clouds-within-a-cloud, like the VCL sandbox or Hadoop clusters.
- Standard HPC (asynchronous) job queues and services managed by LSF LFS, running on (extensible) VCL hardware resources. At NC State, these services are available at http://hpc.ncsu.edu.

The NC VCL cloud servers are typically divided into two large pools: one supporting the HPC research community needs (accessed at http://hpc.ncsu.edu), and another supporting the educational, research, and other needs of the general university population (accessed at http://vcl.ncsu.edu). Services in each pool have slightly different networking and physical configurations along with different user policies, and different sets of available applications and services. However, with “flick of a bit” VCL allows a system administrator to move resources from one pool to the other. This provides tremendous flexibility, maximizes the effective usage of resources and yields significantly increased economy of operation.

For example, more than half of the resources are generally found in the HPC pool, but at the start of classes each semester, servers are transferred from the HPC side to the general purpose side, with the trend reversed during summer and vacation times. The HPC pool provides researchers with the servers and storage needed for large-scale computations. It also provides standard HPC (asynchronous) batch processing with most standard HPC applications, job queuing, and so on. The servers on the general purpose side (VCL 24x7) provide typical desktop or server application environments for in-class use, homework, class projects and so on, that are typically reserved for just hours at a time. However, the VCL 24x7 can also provide long-term reservations for servers and can provision research clouds -- for example, a Hadoop sub-cloud. Professors,
teaching assistants, or other students with permission have the authority to create and store their own special-purpose images. For example, a professor can select a licensed base Windows image running on a VCL server through http://vcl.ncsu.edu, install any software needed for a class and then place that image back in the campus image repository. Students in that class then can simultaneously access multiple copies of the image.

The NC VCL grew quite rapidly due to the policies put in place by the NC State Office of IT (OIT) and various campus departments and colleges. NC State HPC researchers in the field of engineering, life sciences, and other departments regularly received grants from the National Science Foundation (NSF), the U.S. Department of Defense (DoD), the National Institutes of Health (NIH), and others, that included funding for servers. However, the funding usually did not cover space, power, and cooling or personnel support, all typically predominant costs associated with operating a server over its lifetime. These costs had to be picked up by the departments or colleges. As a result, these groups enthusiastically supported the “deal” offered by OIT: free operational support for three years, with guaranteed delivery of the sole use of their server resources whenever the resources were requested by the funded researchers. In return, OIT defined the server specifications, thereby achieving a standardized homogeneous pool providing the best total cost of ownership (TCO). Additionally, they could “loan” the cycles on those research machines back to the general campus population when the cycles were not being used, which could be 50 percent or more of the time.

By judiciously combining HPC batch jobs and VCL 24x7 users, NC State has been able to operate the VCL research and education cloud at a cost of 3 to 20 cents per compute hour. This matches current subsidized rates provided by some other public cloud vendors without the corresponding reduction in guaranteed quality of service. As the owner of the cloud resources, NC State has better control over the satisfaction of user service level agreements (SLAs) or expectations. During the regular school semester, for its population of over 30,000 users, NC State consistently sees a daily peak plateau of nearly 500 simultaneous general-purpose (non-HPC) users between 10 a.m. and 10 p.m. This usage requires a minimum of 500 real or virtual servers allocated each day to support VCL 24x7 users. This requirement varies by school, depending upon the size and usage patterns. Without the flexibility provided by a VCL-based cloud, most of those real servers would be idle between 10 p.m. and 10 a.m. However, with VCL, during idle times, these resources can either be turned over to batch jobs or powered down to save energy. By using this approach, especially during vacation breaks, NC State is able to maximize resource utilizations, thereby driving down average cost per CPU (Rindos et al., 2010).

2.3. VCL in Support of University Administration and Business Applications

VCL does not distinguish between academic or business services or applications. Therefore, a number of efforts within the UNC System are under way to support the administrative side of its campuses. As these ongoing efforts demonstrate, a VCL-based cloud can readily deliver applications and services supporting typical Enterprise Resource Planning (ERP) systems, from student billing and payroll to class scheduling and grading. The CIO of Georgia State University (GSU) has embarked on a significant consolidation and virtualization of administrative computing, as well as building interest in a state cloud to address current budgetary challenges. Work is also under way in North Carolina on medical and public health-oriented projects in which the VCL will provide immediate, dynamically flexible applications and resources to respond to day-to-day needs and emergencies in the state.

In support of the administrative side of an educational institution, the VCL additionally can provide:
• Any business applications that can be delivered as physical or virtual servers or desktops, with multi-tenancy and long-term server “loans.”
• Dynamic scale-out capabilities of typically static server applications. It can dynamically increase the number of web server instances supporting a website that has become transiently popular.

2.4. Economies of Scale and Total Cost of Ownership Savings

An initial study of TCO was performed by Wake Tech Community College, a member of the NC Community College System that has a total of 60,000 full-time and continuing education students. The study determined that the annual TCO was reduced by nearly 50 percent when the college moved from a traditional IT infrastructure to a VCL-based cloud. The annual IT costs before the transition were $1.04 million annually; after the switch, those costs dropped to about $570,000 annually. Subsequent analyses performed by George Mason University (GMU), NC State, and others have shown even more dramatic cost savings, as high as 80 percent or more. For GMU, tremendous savings were obtained through the high degree of virtualization inherent in the Virginia VCL, a consortium of Virginia state institutions that adopted VCL. Georgia State University (GSU) conducted a detailed analysis of student tech fee funding (about $4 million per year) over 10 years that also validated the cost and return on investment benefits of adopting a VCL-based cloud computing model.

Some of the sources of such significant cost savings have already been discussed. These include maximized server and software license utilizations yielding decreased support and purchase costs, as well as virtualization. Currently, production VCL supports the popular VMware hypervisors, however, open source hypervisor provisioning modules (for example, for KVM) are available for those who wish to use them. VCL supports a wide range of computing hardware platforms. Currently, NC State uses the free provisioning engine xCAT, with its list of supported operating systems and hardware platforms at http://xcat.sourceforge.net/. However, other provisioning systems have been evaluated and can be implemented in a production setting. Cloud computing presents both challenges and opportunities for software vendors, especially concerning licensing issues and cost models, causing some to embrace the changes while others fear them. Tremendous opportunities for license sharing across the state present themselves, given a large number of state education or other users supported by a single cloud. State governments have the potential to negotiate large-scale software license purchases once, and not institution by institution or school district by school district, with implied bulk discounts. These opportunities are similar to what many state systems have negotiated in the past for licenses for their student or ERP systems. Likewise, because VCL collects all license usage statistics, metering of usage is possible, and purchases can be based on the actual number of simultaneously used licenses across a given group, as opposed to estimates. Finally, several universities that are deploying a cloud anticipate some interesting benefits associated with traditional labs or student workstation spaces. Some look forward to the increased personal safety of their students (and the associated reduced security costs) due to the ability to close those labs at night, or even permanently. Students can access VCL using their laptops or workstations from their dorms or from home. Some universities are redefining those spaces for student collaboration environments or for other purposes and activities, saving construction costs.

3. OUTREACH TO COMMUNITY COLLEGES AND K-12

In addition to supporting students and faculty at NC State University and other UNC System universities, the NC VCL now also supports students at several NC community colleges. NC State, through its Friday Institute and other K-12
outreach programs, as well as other universities, including North Carolina Central University (NCCU), Duke University, Morgan State University, and others, have been broadly exploring the use of VCL in support of K-12 education. Duke faculty members are studying the use of VCL to deliver the Alice programming environment and “Project Lead the Way” software to K-12 educators and students as part of statewide STEM programs. Instructors at Hillside New Technology High School in Durham are teaching with Alice software delivered by the NC VCL as part of an outreach project being led by faculty within the CIS Department at NCCU. A similar project for Baltimore inner-city students is being considered at Morgan State University, using its VCL installation. In all cases, VCL is able to address the Child Information Protection Act (CIPA) requirements defined by the local school districts.

With a cloud paradigm, technical support expertise must reside within the centers hosting the cloud computing resources. Since these centers can now be set up outside a K-12 school or school district, the local IT expertise required for the on-site IT infrastructure can be dramatically reduced. However, cloud computing still requires Internet connectivity and browser technology at the user site, so investment in statewide education network connectivity is strategic. The often-cited deployment model for VCL in the K-12 classroom is one in which a teacher rolls out a cart of cheap, thin clients that enable students to access the Internet and obtain advanced educational software and other resources and services, independent of the economic situation, technical infrastructure or geographical location of the school district.

3.1. Suggested Rollout for a Campus as a Possible First Step towards a State Education Cloud

VCL support at NC State was rolled out incrementally over several years, starting with select classes and departments in the College of Engineering. It gradually was extended to the other colleges, ultimately providing VCL access to all faculty and students. More recent explorations include extending VCL services in support of the administrative personnel of several campuses. Not surprisingly, the biggest challenges to its deployment were not technological, but cultural and political. Many resource owners were not ready to give up ownership of their servers or were worried about server availability and quality of service. Job insecurity and “not-invented-here” thinking created opposition to widespread deployment in some departments and colleges that had their own IT shops. However, intensive education, thorough testing of VCL services before deployment that helped guarantee positive first impressions and executive policy helped to overcome these social and political challenges. Ensuring that initial users had a positive experience created champions within a given department or college and helped accelerate adoption.

This same incremental process, assisted by the creation of campus champions, allowed for the more rapid expansion of VCL to many state universities and NC community colleges. Smaller state universities and community colleges “subscribe” for services by providing additional servers to the state education cloud, based on their anticipated usage patterns and needs. Because it collects the necessary statistics from its daily operations, the NC VCL can meter, and if need be, charge for usage, an option that other state education clouds could choose to implement. Some campuses, like ECU and Western Carolina University (WCU), have established significant on-campus VCL infrastructures. The resources of these campuses can be readily linked to the larger NC education cloud maintained by NC State, with additional hosting at a remote facility called MCNC (formerly known as the Microelectronics Center of North Carolina), an independent, non-profit institution supporting NC educational networking and other IT needs. Some private universities, such as Duke University, also have their own VCL installations. The existence of a successfully operating production cloud at NC State for many years, with its very real demonstration of enhanced services and reduced costs, convinced
many CIOs, executives and key decision makers to adopt this cloud-computing paradigm (Rindos et al., 2010).

The current NC VCL servers are spread across a number of data centers several miles apart. The cloud paradigm allows servers and other resources from disparate locations to be managed as a seamless, common pool that can be accessed by all. A state education cloud can comprise resources from data centers located at several places across the state, providing, among other things, disaster recovery and contingency support, as well as addressing political and connectivity realities. It allows universities, community colleges, and school districts with existing large data center facilities to provide at least partial support of such a cloud. In a recent proof-of-concept demonstrated to the NC governor, servers running VCL in the IBM Innovation Center in RTP Research Triangle Park, NC, were seamlessly added to the larger NC State University education cloud, with users unaware that they were running on servers in an IBM data center. This provides the option for part, or all of a state education cloud to be hosted in a third-party data center; an important option if state-owned facilities are exhausted as more and more educational institutions joins the cloud (Rindos et al., 2010).

The bigger challenges are policies, politics, and culture, with a strong need for “teach-the-teacher” and student education programs. To date, university outreach programs, with their existing ties to the K-12 community, have been extremely important in the previously cited examples. Similar VCL-based education clouds have appeared in other states. GMU George Mason University has led the effort to establish the VA VCL, which includes Virginia Polytechnic Institute and State University (Virginia Tech) and others. In Georgia, the VCL effort is led by GSU Georgia State University. The California State University System, the largest university system in the US, has begun to build a VCL-based education cloud. Also, within the Historically Black Colleges and Universities (HBCU) community, the HBCU Cloud initiative is being led by the TTP that includes, among others, Southern University (LA), Morgan State University (MD), Norfolk State University (VA) and Tennessee State University (TSU) (Rindos et al., 2010).

4. CURRENT ADVANCES OF VCL SYSTEM AND ACHIEVED AWARDS

In the last two years, VCL usage in both research and education fields’ shows an increasing momentum, many research groups and education usage scenarios were reported. Joshi et al., introduces the case of USM Community Cloud that is based on VCL-based Academic Cloud (Joshi et al., 2011). Seay et al., present their experience with using VCL based cloud computing at two Historically Black Colleges (Seay et al., 2011). Curtis Collicutt et al., introduce the integration of both VCL and OpenStack to provide a virtual computing lab (Collicutt et al., 2010). In Kocsis et al. (2014) the authors provide their approach to achieve a Cyber-Physical system technology over the VCL system. An automating approach for the Installation of Apache VCL on OpenStack is presented in Wolfe et al. (2014). In Burton (2014), an automated creation of a custom VCL cloud infrastructure is presented.

The NC State VCL was twice named a Computer Worlds Honors Program Laureate (in 2007 and 2009) for benefits to society through the application of IT. George Mason University was awarded the highly coveted 2009 Virginia Governor’s Award for the Innovative Use of Technology in Higher Education for its leadership in the Virginia VCL project, the commonwealth’s education cloud. California State University East Bay was awarded the 2011 Innovations in Networking Award for Educational Applications by the Corporation for Education Network Initiatives in California (CENIC) for its system-wide VCL Initiative (Figure 1).
5. CLOUD COMPUTING, SERVICE SCIENCE, AND VCL SYSTEM AT JORDAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

Jordan University of Science and Technology (JUST) was one of the first universities in the Middle East to introduce cloud computing concepts in its courses for both graduate and undergraduate students. Moreover, and with a close collaboration with IBM, JUST built a state of the art cloud infrastructure that is used today for both teaching and research. JUST is also working now to utilize a large scale VCL system in collaboration with IBM and NCSU, and the system is anticipated to be in production phase by the end of 2014. Currently, VCL is in deployment phase using a small data center with one rack of 24 servers and a storage system in collaboration of NC state and IBM. On the research side, there is TeachCloud (Jararweh et al., 2012), a comprehensive, easy-to-use, and efficient cloud computing modeling and simulation toolkit. TeachCloud tool is developed by a team in JUST. TeachCloud fills a large gap in teaching cloud computing caused by the lack of such a comprehensive and easy-to-use tool, in addition to the high-risks and costs of allowing students to experiment using a real cloud system. TeachCloud provides a rich, yet simple GUI to build cloud infrastructures, and present results and charts. TeachCloud allows a user to customize all aspects in a cloud infrastructure from the host processing nodes to the network topology. In addition, MapReduce model is integrated in TeachCloud to allow the processing of large datasets (Althebyan et al., 2014, Althebyan et al., 2013, Quwaider & Jararweh, 2013). It also allows users to integrate the SLA and other business aspects into the tool. Furthermore, it includes an extensive workload generator capable of representing real world cloud applications accurately. Moreover, the modularity in TeachCloud’s design allows users to integrate new components or extend existing ones easily and effectively. TeachCloud makes it easy for users to comprehend the different cloud system components and their roles in the whole system. Users can modify the different components and their parameters, run simulations, and analyze results. As future work, our

Figure 1. VCL Conceptual overview
goal is to formulate practical exercises using TeachCloud, where instructors can use them as guidelines in the teaching process. TeachCloud was used in many research projects and provides an excellent opportunity for researchers to complete their research objectives and to achieve their goals as presented in Al-Ayyoub et al. (2014), and Quwaider and Jararweh (2013). A comprehensive curriculum for the undergraduate program is designed in Service Science Management and Engineering (SSME) by number of researcher at JUST and presented in Al-Badarneh et al. (2013).

6. CONCLUSION

Cloud computing is showing an increased pace of advancement, with more communities working currently to adopt cloud computing into their day to day work and business. VCL provides a state of the art cloud solution that can support a large number of users with minimal cost. This paper presents a comprehensive discussion for different aspect of the VCL system form the technical point of view. It also provides different showcases of using VCL in both academia and research. The showcases indicate that many academic institutions are collaborating to realize cloud computing services based on the VCL system. Moreover, this paper presents the recent efforts in enhancing the capabilities of the VCL system and the possible integration with other cloud systems such as OpenStack. The paper also presents the current ongoing activities related to cloud computing, SSME and cloud educational tools at Jordan University of Science and Technology.

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