Chapter 5
Cloud Computing for Education and Research in Developing Countries

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ABSTRACT

Recently cloud computing has offered attractive solutions for academic and research institutions due to several reasons. In this chapter, the authors present a study of how cloud computing can be used for research and teaching activities in higher educational and research institutions in developing countries. Instead of focusing on cloud computing offering for basic IT infrastructures used in daily work of these institutions, the authors concentrate on the use of cloud computing for satisfying ad hoc needs of computing resources in research and teaching activities. Thorough analyses of research and teaching activities, requirements for cloud computing, benefits of utilizing cloud computing, and adoption barriers for these activities are also included. The authors then present the selected challenges in tackling these barriers and discuss possible approaches for solving these challenges and report lessons learned and experiences in utilizing and developing cloud computing solutions for teaching and research activities in Vietnam.

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INTRODUCTION

Cloud computing promises a new way of provisioning elastic computational resources and software applications by enabling people to have timely access to resources and services, with reasonable costs, guaranteed SLA and reduced entry effort and investment (Hayes, 2008) (Creeger, 2009) (Armbrust, et al., 2010). This vision is attractive to research and educational groups in many developing countries where even big academic and research institutions are still lacking resources (and funding for acquiring resources) to sufficiently support their research and education activities. For research and educational groups without adequate computing resources in developing countries, cloud computing offerings could be a viable solution. However, for their research and teaching activities these groups face not only with common issues in accessing large computational resources and having short-time research plans, but also several other constraints in terms of technological infrastructure (e.g., network performance), educational objectives (e.g., mastering advanced technologies developed in developed countries) and economy (e.g., lack of money even for a short research plan).

While, from an economic perspective, it seems that cloud computing would be one of the best solutions for such groups, one of the important aspects needs to be considered is what technical and educational factors could impact on the selection of cloud solutions as well as how cloud computing features could be customized to support their adoption by existing groups in developing countries. In this chapter, we will analyze requirements and research issues. We will then present research approaches and our experiences in developing and adopting cloud computing technologies for research and educational groups in Vietnam. Our expectation is that this analysis will help to increase the awareness of cloud computing for education and research as well as to reduce barriers in adopting cloud technologies in the context of developing countries.

The rest of this chapter is structured as follows. We discuss background and related work in Section *Background and Related Work*. Then, we analyze characteristics and requirements for cloud computing from academic institutions in developing countries in Section *Characteristics and Requirements of Academic Institutions in Developing Countries*. In Section *Potential Benefits of Cloud Computing and Adoption Barriers,* we analyze in detail how cloud computing can address requirements of academic institutions and which adoption barriers exist. We then present research challenges and approaches in order to deal with identified adoption barriers in Section *Research Challenges and Approaches*. Section *Experiences* presents our lessons learned and experiences in developing cloud-based solutions to support research and teaching activities in Vietnam. We discuss and conclude our work in Section *Discussion and Conclusion*.

Background And Related Work

Cloud computing and its delivery forms, such as Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS), and Software-as-a-Service (SaaS), have been well explained in several works (Mell & Grance, 2009) (Creeger, 2009). Similarly, what constitute "developing countries" has been given in (Wikipedia, 2011). In this work, we examine *research and educational groups in higher educational and research institutions in developing countries*. The groups in our work are defined with the following characteristics:

- **Groups do not have access to adequate resources for research and teaching activities**: Not all groups in higher educational and research institutions in developing countries are lacking of computing resources and cutting-edge systems. For example, several groups in India and China have access to strong computing infrastructures and high-throughput networks. Here we do not focus on research and educational groups specially in developing countries that have access to the latest technologies (e.g., in China and Saudi Arabia, several groups have access to computing infrastructures in TOP 500 supercomputers).

- **Groups involve high teaching workloads:** Since teaching can be considered the most important responsibility of many groups in academic institutions in developing countries, we focus on groups in which teaching plays a major role. While teaching is usually managed at the institution level, the real courses, course materials and schedules are typically managed by teaching staff who are usually organized into small groups, responsible for a number of related courses. Therefore, by focusing on their teaching activities, we can examine better how they need on-demand resources for their teaching.
- **Groups have a small number of members and a low budget for resources:** In many cases, groups in our study are organized into small teams with a few members, without dedicated human resources for performing IT management tasks. Furthermore, their budget is low and hence they cannot invest a lot of money for owning adequate resources.

In the context of this chapter, research and teaching staff in these groups are responsible for specific courses in their institutions and conduct their research plans. In our work we analyze their requirements for computing resources. We concentrate on existing groups in academic institutions in Vietnam and elaborate our findings in a larger context of developing countries.

While some authors have analyzed possible benefits of utilizing cloud computing in developing countries (Juster, 2009) (Greengard, 2010), such discussions cover generic topics for every possible cloud customers, rather than focus on education and research aspects. There are also several discussions of how cloud computing can be utilized for education purposes. Most of them consider cloud computing offerings as a basic IT infrastructure, such as email service, in academic institutions in developed countries. For example, Sultan (2010) discusses relationships between education and cloud computing and indicates that cloud computing adoption for educations has been widely employed in UK. The paper presents a case study at The University of Westminster (which utilizes Google systems for email and Google Apps) and discusses cost and flexibility concerns. A private cloud for The Hochschule Furtwangen University (HFU) has also been presented (Doelitzscher, Sulistio, Reich, Kuijs, & Wolf, 2011). This private cloud infrastructure offers virtual machines and applications for students and researchers. Similarly, North Carolina State University has also built a cloud-based Virtual Computing Laboratory to provide virtualized resources for faculties and students (Averitt, et al., 2007). However, the paper does not address concerns in developing countries. Different from the above-mentioned related work, we focus on cloud computing offerings for on-demand resources in research and teaching activities in developing countries. Truong and Dustdar (2011) have discussed open issues in supporting small research groups but not in the context of developing countries. Furthermore, this paper has not discussed the role of teaching activities, which are considered intensively in our chapter.

Characteristics and requirements OF ACADEMIC INSTITUTIONS in developing countries

Research and teaching activities have certain distinguishing characteristics. For example, unlike business services which have to run 24/7, several IT services, such as machines and educational software applications, in universities in developing countries are required intensively only in a short period, due to the structure of teaching semesters, while other IT services are required in a regular basis, such as email and storage services. Both types of the above-mentioned IT services can be offered by cloud computing, however, in quite different manners. Furthermore, as reported in many studies, in higher educational and research institutions in developing countries, research is very often not a main type of activity (The Task Force on Higher Education and Society, 2000) (Rena, 2009). Instead, groups in these institutions are overloaded with teaching activities.

In our approach, we characterize computing resource requirements for research and teaching activities in higher educational organizations and institutions in developing countries. In terms of resource, the focus is on irregular and on-demand IT services, instead of regular basic IT services. The research and educational groups under our consideration are those that have limited access to resource and budget. Therefore, different types of computing infrastructures and their usages are analyzed in order to understand where and why cloud computing could play an important role.

Teaching Activities

In developing countries, universities are the main source of highly trained and skilled work forces. Therefore, teaching is often considered as the main activity in most universities. Although there are research oriented universities or specialized research institutions, their numbers are much smaller than teaching oriented universities. In terms of teaching, computing facilities are necessary for student laboratories and libraries. Computing resources for teaching are commonly constrained by financial issues and characterized by the following properties:

- The student-resource ratio is very high, as, due to limitations in resources (finance and expertise), the number of universities is usually small, compared to the population. As a result, so many high school students have to compete with each other for places at universities, such as in the cases of China and Vietnam. Once they get into universities, they have to share the very limited resources, such as computer laboratories for practical courses.
- Typically student laboratories are only open at scheduled class hours. Out of the class hours access to laboratory facility is rather limited.
- Investment for dedicated, expensive resources is also limited. Access to these rarely expensive resources is very restricted, leading to low utilization of rarely expensive resources.
- Resource usage pattern is repeated and predictable

Due to these properties, academic institutions in developing countries need a lot of resources in short and fixed time periods. However, the institutions know in advance when and how much resource should be required. Furthermore, due to a large number of students, they would like to minimize computing laboratory facilities to reduce costs and but still to increase the access to laboratories.

Research Activities

Resources allocated to research activities are also constrained by financial issues. In teaching oriented universities, investment for research facilities is prioritized after that for teaching facilities. In addition, the facility usage and the ability to acquire research facilities are also limited by the capability of research staff of the universities. In many universities, teaching is considered as more important and is the basic duty of their staff. Thus, staff effort toward research is encouraged but not highly recognized. Consequently, research activities are patchy, driven mostly by staff personal interests. Many small research groups are formed but loosely coordinated. As a result, investment for research facilities is ad-hoc, on-demand, and very often, not very well coordinated. The research problems that these groups are trying to solve are usually small in size, are not cutting-edge, and require small computational power, partially because the lack of computing resources forces these groups to work on small problems. Some groups need high performance computing facilities for simulations and analyses of their computational models. However, due to budget constraints, the provided facilities are also limited in computational capability, heterogeneous and fragmented. These conditions have resulted in a number of issues:

- Resources are fragmented and not suitable for solving big scientific problems. There are so many chunks of small and disconnected resources for research groups. They are only suitable for small research problems. However, when the problems are scaled up, the available resources are no long useful. As researchers cannot break this issue, they tend to focus on solving small problems.
- Researchers tend to use resources in their own ways. They want to have total control and customize resources for their own problems. This way of using resources does not foster the resource sharing among groups.
- Constraints from financial conditions make investments for computational resources difficult. However, the fragmentation of invested resources together with the lack of coordinated efforts in sharing rarely invested resources result in low resource utilization.

In addition to research and teaching activities carried out by group members, the management also has a strong influence on how resources can be used. For example, specialized research disciplines, such as high performance computing, usually receive low priority, whereas, research on contemporary issues that are in immediate needs of the country and applications of new technologies coming from developed countries receive more attention and funding. Management also tends to look for and highly evaluate research work that can immediately generate benefits in the short term, but rarely invest on research that may have strong impact in the long term.

Overall, in both teaching and research, due to financial constraints in developing countries, resource investment is low. Addition to the financial issues, due to management priorities, resource investment is not well managed, leading to the lack of coordination in investment efforts and usage of rare resources. As a result, the resources are not well utilized, even though such resources are not enough.

IT Resource Requirements and Cloud Offerings

The above discussion shows that resource usage in developing countries is constrained by a number of factors such as financial investment, management strategy, the lack of coordination in investing resources for research groups and the lack/inefficiency of collaboration among small research groups.

Dealing with financial problems in developing countries is hard: they cannot be changed in a short time. However, the other factors can be adjusted to improve the efficiency of investment efforts. A question posed here is how to maximize the utilization of resources, which are limitedly invested due to financial constraints. To answer this question, the following issues need to be resolved:

- Change in management strategy: both teaching and research need to be considered as the core activities of universities. Resources for teaching and research should also be well coordinated.

- Motivate the sharing of resources: we should not only concentrate on resource sharing between research groups for research activities, but also for teaching activities. This will require resource sharing far beyond computational resource sharing, such as sharing educational applications and educational data.
- Need efficient computing resource management and provisioning models: such models need to deal with a lot of specific constraints and characteristics of research and teaching activities in developing countries.

Coping with these issues, several solutions had been investigated, such as network of workstations, HPC (High Performance Computing) cluster, and Grid computing, in developing countries. In particular, Grid-based solutions had been investigated in the past (Pukdesree, Sukstrienwong, & Lacharoj, 2005) (Jin & Qi, 2005) (VNGrid, 2011), but they were not very successful for small groups due to the following reasons:

- Grid aims at supporting research activities; thus it does not support teaching activities well,
- Grid resources that belong to different institutions are still small and they are not well shared due to the ownership,
- Grid is hard to customize, users can only use, not able to customize resources, and
- Grid computing at the application level is for e-science and scientific computing, which are not in the main focus of research and teaching in many institutions where business and economic applications have higher priorities.

Cloud computing could potentially provide a strong solution for problems encountered by research and educational groups. However, we need to carefully examine how cloud computing offerings could support the above-mentioned teaching and research activities. Let us first analyze cloud computing requirements for teaching and research activities in these groups and the elastic properties of these requirements. Then we analyze the benefits of having cloud computing offerings for these requirements.

Table 1 summarizes on-demand cloud computing requirements for teaching and research activities. Here we do not include cloud offerings for basic IT operational services, such as emailing, enterprise resource planning (ERP), and data archival systems that are potentially offered by cloud computing. For such requirements, we need to consider which way to utilize existing technologies is the best and what should be developed. For example, a fundamental question is whether existing cloud technologies and services are strong enough to be deployed and bought, or new features must be developed in order to integrate different cloud service models or to customize existing cloud technologies. In answering this question, we need to examine elastic properties of these requirements.

Table 2 shows elastic properties of requirements. Overall, we see that the types of properties are similar for both teaching and research activities. However, the values of these properties are quite different. For example, in teaching activities, a fixed, large amount of resources is known in a short time but not in research activities. Given of these different requirements, we need to employ different approaches for supporting teaching and research activities.

POTENTIAL BENEFITS OF CLOUD COMPUTING AND ADOPTION BARRIER

General Cloud Computing Benefits

Many studies show that cloud computing has some distinct benefits such as cost reduction, efficient resource utilization and flexible and elastic provisioning (Armbrust, et al., 2010).

These benefits are applicable to a wide range of applications of cloud computing, including research and teaching activities. Several papers have analyzed how attractive cloud computing offerings are for developing countries. For example, Greengard (2010) has presented several benefits, such as easy access to computing infrastructure with low cost, improving collaboration efforts and access to the latest software and hardware. Such benefits are also perceived by general users in our studied groups. Overall, we think that accessing to the latest technologies and having maximum resources, while, at the same time, minimizing costs are considered the main benefits for research and educational groups in developing countries. However, minimizing costs is always a hard constraint, even if there is an urgency to get numerous resources to meet an important deadline. Given the priorities of teaching and research activities in developing countries, requirements can be ordered as follows: (i) first to have enough resources for teaching activities and, (ii) second, to have enough resources and have access to the latest technologies for research activities, both with minimum amount of money.

Table 1. Cloud computing requirements for research and educational groups in developing countries

Cloud Service Models	Teaching Activities	Research Activities
SaaS	• Need to run standardized/known educational applications (such as simulation, accounting, business process) • Need to share educational applications among institutions	• Need to perform research applications (such as computational simulations, scientific workflows, high performance data visualization)
PaaS	• Need PaaS for students to learn how to write applications. This is mostly for students in computer science, computational science and engineering, and economics.	• Need PaaS for developing research applications and algorithms.
IaaS	• Need to provide machines for basic courses, such as operating systems and basic IT skills.	• Machines provisioning based on application requirements.
DaaS (Data-as-a-Service)	• Need data services for storing lectures, papers, dataset for testing algorithm, presentations, etc. Most data is free and open.	• Data for research purposes. Information security concerns are important as many data are sensitive.

Table 2. Elastic properties of requirements

Elastic Properties	Teaching Activities	Research Activities
Number of users	A large but known number of users	Small number of users
Usage time	Short usage time	Ad-hoc, long usage time
Burst time	Fixed burst time, during semester	Ad-hoc, dependent on research deadline
Types of machines (OS)	Fixed, limited, and known	Fixed, limited, known
Number of machines	Large but fixed numbers	Unknown, can be large
Data resource size	Known, predictable size	Unknown, can be large
Application types	Known, standardized, fixed	Unknown, research-dependent
Cost	Fixed cost	Limited but can be extended

Table 3. Cloud computing support for teaching and research activities

Cloud Service Models	Support for Teaching Activities	Support for Research Activities
SaaS	• Students can use standardized/well-known applications for laboratories. For example, in engineering, students can use simulation SaaSes to run experimental models. In business, ERP and accounting SaaSes can be used as application platforms for students to practice. Google Docs can help students with practicing work or spreadsheet processing. • Institutions can jointly establish educational application stores and SaaSes in order to reduce investment cost and to improve collaboration in teaching activities.	• Research applications and tools (e.g. computational simulations, scientific workflows, high performance data visualizations, etc.) can be provided and accessed via SaaSes.
PaaS	• Particularly useful for computing students who can use PaaS for learning and practicing programming tools and environment. For example, students can use Google App Engine, Amazon Hadoop or similar PaaSes to practicing web programming. • Students in economics, computational and scientific disciplines can also utilize PaaSes (e.g. MathLab/R computational platform) to build their custom simulation and analysis tools.	• Similar to teaching activities, PaaSes can be used as platforms for developing custom research tools to support research activities.
IaaS	• Provide on-demand machines for student laboratories and personal use. Students can acquire and design customized virtual machines that may include OS, laboratory exercises, communication and collaboration tools, IDEs, etc., for their course work. From universities' perspective, for exercises that require lots of machines in a short period, such as parallel processing, IaaSes can be used to save cost and management efforts.	• Computational requirements for research are usually ad hoc, particularly in computational and scientific disciplines. For some computational models, the resource required can be scaled up to a very large extent only for a short time. IaaSes are good solutions in these cases.
DaaS (Data-as-a-Service)	• For teaching, DaaSes can be used to store and provide teaching materials such as lecture slides, course contents, exam papers, etc.	• DaaSes can be used as the sources of research data and publications and also as means for sharing these resources.

Potential Benefits of Cloud Computing for Research and Educational Groups in Developing Countries

To satisfy these needs, typically, a private cloud computing model is used to virtualize teaching and research laboratories atop private cloud infrastructures, thus optimizing and saving money on IT infrastructures. For public cloud computing models, commonly, IaaS is used for executing applications while SaaS is for IT services within education and research institutions. Generally, the above-mentioned usage cloud models can be utilized by groups in our study. However, we need to examine the benefits of these models in detail, in the connection to teaching and research activities and cloud requirements mentioned in the previous section.

Table 3 shows a summary of how cloud service models could be used for teaching and research activities. In parallel with the use of cloud computing services, research and educational groups in academic institutions in developing countries can also provide and utilize different cloud deployment models. Such provisioning and deployment will help to address some issues discussed in the requirements of cloud computing. Table 4 summarized different cloud computing deployment models that can be used to address different issues of these institutions.

Adoption Barriers

However, there are also several adoption barriers in developing countries that have been discussed in general, for example, lack of connectivity, inadequate bandwidth, and instable power supplies (Greengard, 2010). Furthermore, Truong and Dustdar (2011) have discussed barriers for small groups to adopt cloud computing for computational science and engineering. In principle, groups in our study face these barriers as well. However, there are several other adoption barriers for groups in our study that are very specific to the characteristics of these groups in developing countries. In the following, we will present concrete barriers for research and educational groups given analyzed requirements in Table 1 and Table 2.

Cost and Payment

Cost analysis from existing clouds indicates that it is still quite expensive for research and educational groups in developing countries, compared with their income, in order to utilize clouds. Therefore, in order to convince these groups the costs of using cloud computing services need to be reduced. With respect to payment, popular payment methods accepted by many public cloud providers are done electronically. However, this could be a problem in developing countries, where the use of credit cards and online banking is still limited and banking systems are not well developed. In addition, in developing countries, there are also strict regulations on making overseas payments. Therefore, limitations of payment system also hinder the adoption of public cloud in academic institutions. We believe that the cost could partially be reduced and payment problems can be partially solved by localizing cloud deployments.

Service and Infrastructure Readiness

First, one of the main issues is that cloud infrastructure is not deployed locally in developing countries. This actually has several influences on both technical and managerial issues. With respect to technical issues, performance can be improved

Table 4. Requirements addressed by deployment models

Deployment Model	Requirements Addressed	Why
Private cloud	• Reduce cost • Deal with the lack/inefficiency of collaboration • Eliminate the habit of owning facilities	• Resources are centrally invested and managed. This method will eliminate the fragmentation and heterogeneity of investment and enable best resource utilization with limited finance. • Researchers can get access up to the maximum amount of invested resources when they need. Hence big resource problems can also partially be addressed. • Students can flexibly get access to virtual laboratories and materials from anywhere, e.g. their home PCs, laptop, etc. This will reduce the burden of universities in investing laboratory facilities and staff.
Public cloud	• Reduce cost • Access to latest technologies • Access to large pools of computational resources for research problems of almost any sizes	• Institutions do not need to invest and house large IT infrastructures for teaching activities, which are only needed for a short time. • New technologies from developed countries are quickly available in public clouds so students can access these technologies instantly. • For researchers, public clouds offer them to access any size of resources, enabling them to think and work beyond small research problems.
Hybrid cloud	• Balance between investment on private IT infrastructure and utilization of publicly available clouds	• In order to save money on investing resources public clouds are used as backup facilities and during peak computation period
Federated private and public clouds	• Motivate the sharing of computational resources and educational applications • Coordinate resource investment	• Federation of private cloud creates a larger pool of resources. It can be used to deal with big problems, and also to efficiently improve utilization of idle resources.

and data compliance concerns can be simplified. From the management point of view, because the management policy towards the utilization of cloud computing is under developed, local cloud service and infrastructure deployment would also simplify some management steps imposing on research and educational groups.

Second, for research and teaching activities, most cloud providers at the moment in developing countries do not focus on educational purposes. IaaS, DaaS and PaaS are the most crucial services due to the fact that teaching and research activities are varying from institutions to institutions and the user is not the end-user but students, developers and researchers.

Third, to efficiently utilize invested hardware infrastructures, many institutions in developing countries opt for virtualizing their computing resources using private cloud models. These private clouds are usually small in size. This virtualization approach is useful in cases where the demands for computing resources are relatively small and stable. It is still inefficient when the demand scales up unexpectedly at some time to solve big problems. In the interest of groups in our study, hybrid deployment models – private cloud combined with public cloud – are on high demand. Most public cloud providers at the moment support only virtual private network as a means to establish hybrid cloud models. There are still many open research questions on hybrid cloud models with respect to scaling up and down in hybrid clouds with low network bandwidth and unreliable connectivity and with respect to joining and leaving public parts in hybrid cloud models to minimize the cost.

Cloud Computing Expertise

Not only lacking of computational resources, research and educational groups in developing countries also lack cloud computing expertise. While cloud computing aims at reducing administrative efforts from non-IT people, expertise in cloud computing is required for both technology (such as virtualization, cloud APIs, web services) and regulatory compliance (laws, data compliance, tax & payment, etc.). This lack of expertise cannot be filled in a short time and is a strong barrier in utilizing public cloud offerings for developing countries.

Information Security Concerns and Compliance

Similar to other users of cloud computing, research and educational groups in developing countries have several common security questions when adopting cloud computing. Examples of common, widely discussed, security concerns are data protection, user lock-in, and lack of control (Chow, et al., 2009) (Kaufman, 2009). However, there are also different specific questions that prevent these groups to utilize cloud computing for their teaching and research activities. First of all, existing cloud solutions are developed in developed countries and targeted to developed countries. With respect to security concerns and compliances, these cloud technologies support law and regulations in well developed countries but they neglect local law and regulations in developing countries. In fact, this is a general issue not only for teaching and research activities but also for any business in developing countries when they select public cloud offerings. The main issue is that when information about cloud offerings is not clear, it is hard for groups in our study to convince their institutions to adopt cloud computing technologies. Furthermore, groups in public institutions need to ensure that the pay-per-use services follow local government regulations in terms of warranty, liability, and indemnity. This issue is also not well described in cloud services.

RESEARCH CHALLENGES AND APPROACHES

Given the list of adoption barriers, we identify the following research challenges that should be addressed in order to support research and educational groups in developing countries.

Cost and Payment: Integrated Billing Systems

Cost and payment involve both technical and policy issues. Here we just discuss technical challenges required for billing support for teaching and research activities. In current ways of billing and accessing cloud resources, typically an individual pays the money and gets the individual's access credential. However, it is not suitable for teaching and research activities in developing countries. On the one hand, not everyone can perform payment methods in contemporary cloud systems. One the other hand, each individual's usage of cloud computing resources is strictly based on a limited quota, due to the lack of funding and resources. Therefore, we need billing systems for cloud resources that support group registration and payment but individual usage must be recorded and controlled by the group.

Service and Infrastructure Readiness: Application Discovery and Store

Service and infrastructure readiness needs to deal with several questions about application discovery and storage for teaching and research activities, software licenses, and cross cloud systems. Application stores for teaching activities must be able to grow and support search and frequent updates. Educational applications might be simple, but written in different languages, and have a lot of users and developers. Their relevant information has to be linked together to show sources, binary, data input, etc., to support students to learn courses. Application stores for research are quite different because research applications are often complex, but have a few users and developers. Such application stores have not yet been developed.

With respect to software license, research and educational groups in our study rely on free software. Even many institutions can utilize free software/cheap software provided by big companies under academic licensing (e.g., Microsoft Academic Program). However, in cloud computing, this software license model has not been well supported (e.g., Amazon mentions that if Microsoft increases the software license, the cost for resources could be increased). Using public cloud computing machines, it would be good if these groups can utilize resources with built-in academic software licenses so that the cost could be reduced.

In terms of cross cloud systems, researchers have been discussing cross cloud systems recently. Such systems are particularly important to groups in our study due to the "cost" aspect: they would like to use free and private clouds for small scale experiments and testing, and pay the fee for public cloud only when they need more resources. They also want to switch easily from one public cloud to another one if they could save costs. Therefore, the following challenges should be addressed to satisfy their needs: (i) quickly moving applications from one cloud to another, (ii) capable of running applications on multiple clouds concurrently, and (iii) combining seamlessly local and cloud resources in hybrid clouds. In order to address these challenges, the limitations of network connectivity in developing countries should be carefully considered in cross cloud systems. Solutions based on virtual private networks or moving virtual images among private and public clouds might not work.

Approaches

In dealing with these challenges, we suggest the following approaches. First, *cloud solutions for teaching activities and research activities should be considered separately*. The main reason is that teaching activities and research activities have different workload, usage time and payment policy. Furthermore, separating them also allows us to provide different capabilities, e.g., we cannot simply allow students to use public cloud and charge them. While such a separation seems contradiction with what high quality, research intensive institutions do (e.g., embedding research activities into teaching activities), this solution is quite suitable for most universities in which teaching activities have very different properties. Second, *billing policies and frameworks should be based on developing countries' needs*. Developing countries have specific conditions in billing and payment that should support the registration at the group level but fine-grained monitoring and billing for group's individual usage. An example that we can learn is the Enterprise Account Management model in RightScale (RightScale, 2011). Such specific conditions should be the core features of cloud services, rather than cloud-vendor specific features. Furthermore, it should allow the specification and enforcement of specific policies. Third, *solutions for hybrid clouds for developing countries need to be simple but efficient*. One way to achieve this is to focus on developing dynamic discovery methods to spot cloud resources with minimum costs. Another way is to deal with programming models that work atop multiple clouds, instead of bridging clouds using virtual networks.

EXPERIENCES

In this section, we discuss our experiments in adopting and developing cloud-based solutions for teaching and research activities in Ho Chi Minh City University of Technology (HCMUT - www.hcmut.edu.vn). As one of the largest universities in Vietnam, HCMUT needs to provide various solutions for teaching and research activities. Such solutions are developed by the faculty of Computer Science and Engineering. We will discuss our lessons learned from Grid computing and how we employ cloud computing to support teaching and research activities. In particular, we show two different solutions, having something in common, that clearly explain why we believe we should separate cloud platforms for teaching activities from those for research activities.

Grid Computing Lessons Learned and Implications for Cloud-Based Solutions

The VN-Grid project was carried out from 2007 to 2010 at HCMUT, aimed at setting up a Grid computing infrastructure for several universities in the Ho Chi Minh City. The primary focus was on solving technical challenges, such as resource discovery, execution, information and monitoring services. However, at the end of the project, it turned out that getting users to use the Grid computing infrastructure was a much more challenging problem. By the end of the project, a couple of new challenges arose:

- The heterogeneity of resources, especially network and computational resources, made the application deployment and running processes very difficult. In theory, the Grid had a lot of available resources. However, an application usually required some specific configurations of platform such as compatible operating systems, libraries and network bandwidth. In reality, because of the heterogeneity, very few resources were able to meeting the application's specific requirements.
- A much more challenging issue was to get the users to use the system. We had two groups of users: the current users who

were using our high performance computing cluster in the traditional way, and the potential users who might have benefited from using the system. The current users kept using the system in the way that they used to, whereas, it was very difficult to attract the potential users to use the system. We realized that this problem was not technically solvable. Social approaches were needed in these situations.

As cloud computing technologies become popular and mature, we found that in order to address the above challenges, several cloud computing techniques could be employed. First of all, for the resource heterogeneity issue, virtualization techniques commonly used in cloud computing is adopted. Instead of providing the users with the preconfigured resources, with virtualization, the users may specify the type of resources together with required configuration. The system will provide the resources as requested. Second, to attract the potential users to the system, motivated by the current social computing on the cloud, such as Facebook, we develop a web-based collaborative environment, in which the users can exchange scientific information in a sociable way. The environment also acts as a PaaS, allowing the users to submit and run their applications on resources aggregated using underlying Grid technologies. Third, for high performance computing in general, for better utilization of available computational resources, both technical and social issues need to be addressed. Without the users a system becomes meaningless, regardless of how beautiful the technical solution is. We develop solutions for the user issue by employing social computing concepts.

Virtualizing Student Laboratories

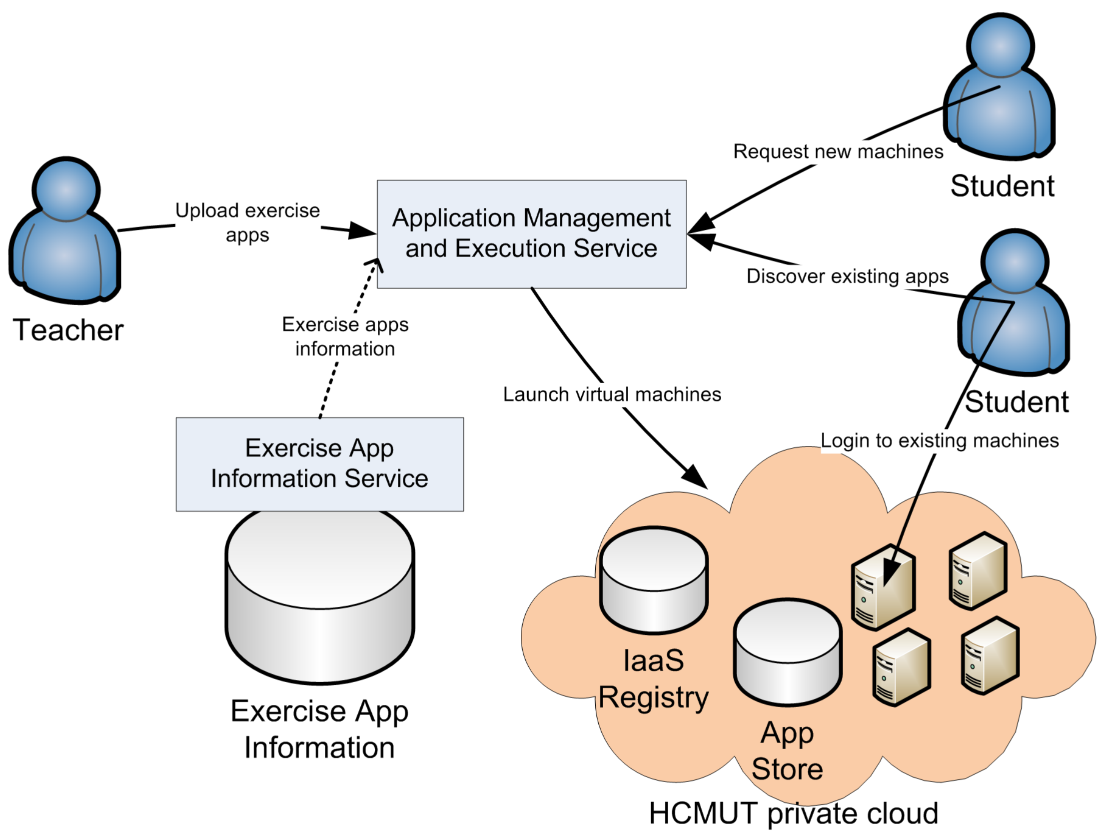
At the time of writing, student laboratory management at HCMUT has several issues. Operating systems and software applications are installed and configured manually on each computer in laboratories. Each course requires different environments (operating systems, libraries and software applications). Sometimes, they are incompatible and conflicting with each other. Thus, each course requires its own machine image, which contains an operating system together with software applications and libraries. This approach requires large disk space to store machine images on each computer, whereas, the number of courses that a computer can serve is very limited. In the worse cases, this situation leads to the overloading of laboratories. Furthermore, laboratory managers have to install software and configure them for each computer. When a computer is crashed, laboratory managers have to manually reinstall that computer. This manual installation process takes a lot of time, and students cannot use the laboratory during that period. As a result, laboratory classes will be delayed. Whenever there is a change in software configuration for each course, all related machine images and consequently computers in related laboratories have to be reinstalled. This manual laboratory management process takes a lot of time and effort.

To solve this problem, a private cloud computing model is adopted to provide computing resources, storage and software in form of virtual resource services for students to practice. Instead of providing students with access to physical machines in laboratories, students will access laboratory exercises through virtual machines. With this method, only a single virtual machine image for each course is stored on the server. Furthermore, such virtual machine images can be prepared by teaching staff. As a student needs to practice, he/she gets to the server and selects the desired course. The server loads the image of the course from the image repository to a virtual machine on the server and runs that virtual machine for the student to practice. When a computer is crashed, the student neither has to wait for the laboratory manager to reinstall that computer nor move to another computer. He/she just restarts the virtual machine, reloads the image to this virtual machine and runs it to continue practicing. This approach requires less disk space as only a single virtual machine image for each course is stored on the server, whereas, the number of courses that a computer can serve is not limited. Furthermore, laboratory managers do not have to install and configure software applications for every individual computer. Every time the software applications and their configurations for a course need to be changed, laboratory managers only need to modify or reconfigure the master virtual machine image (in some cases, this is performed by teaching staff). With this approach, we reduce management complexity and storage.

Besides the management of virtual machine images, in order to support students to perform course exercises, we provide and pack exercises as cloud applications. Such applications are diverse, as students have free choice to select suitable programming languages in many cases, for example, in our fundamental programming language course we allow student to use Java, C, C++, Prolog, Python, etc. While different exercises written in different languages are packed under applications, several applications are also linked to course materials, testing data sets, application documents, and even source code of the applications for certain courses in computer science, computational science and engineering and economics. Therefore, we decide using ontology to develop a model for specifying exercise applications.

Figure 1 shows our execution platform for virtual laboratory that enables students to access exercise applications on our private cloud. The *Exercise App Information Service* is developed as

Figure 1. Machines and course exercise execution platform with private cloud in virtual laboratories

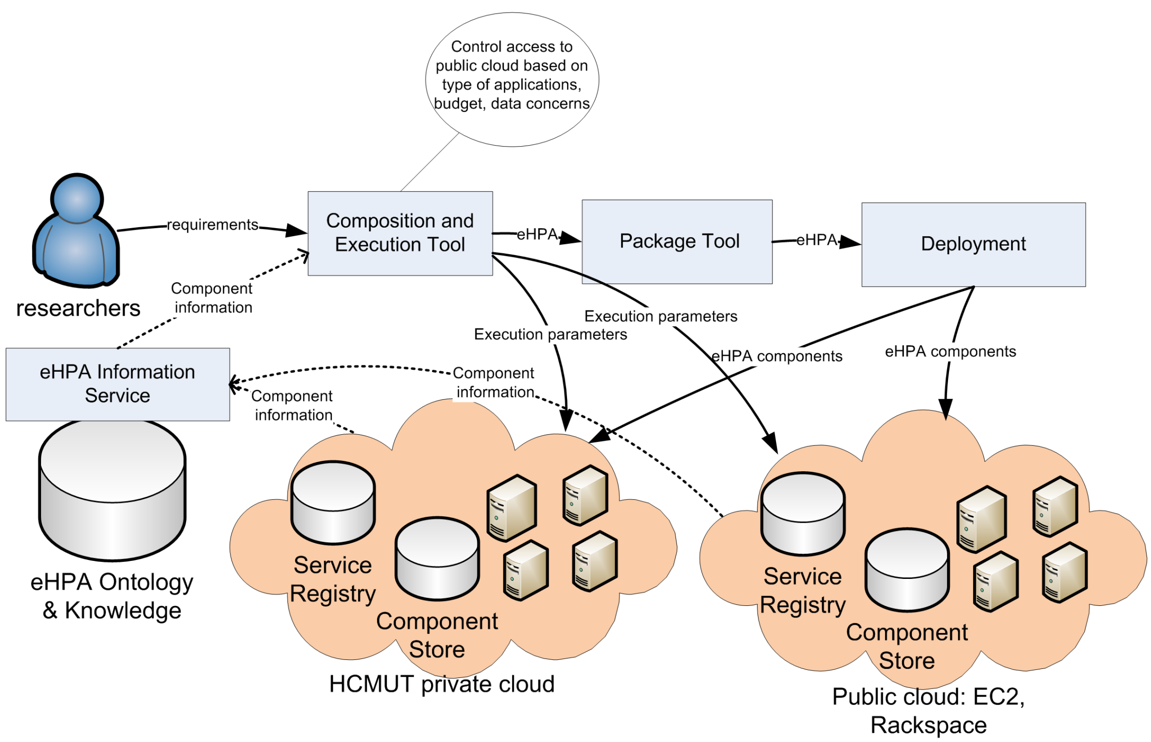


an ontology to store information about applications and their dependent components. The HCMUT private cloud is built based on Open Nebula (OpenNebula, 2011). Virtual machine images for different courses will include corresponding operating systems and exercise applications. Via *Application Management and Execution Service,* students can find the right virtual images with exercise applications they need or find virtual machine images and install exercise applications during their practice. Due to the lack of storages and complex management of personal virtual images in teaching, we do not support saving virtual images by students and, due to the lack of policy and billing mechanism, we cannot allow students to perform experiments on machines outside our private cloud. These management strategies are clearly different from that for research staff that we will discuss in the next section.

Application Management for Research Activities

In order to support researchers to build complex applications, we also design an application store and execution platform for research applications. One of the main features is that research applications can be executed on different cloud platforms, including private as well as public clouds. At the starting point, we focus on elastic high performance applications (eHPAs). Each eHPA has several properties characterizing resources, costs, quality, usage rights and time. Based on these properties and user needs (e.g. budget and time), we control the execution of the applications in our private cloud or public clouds. Unlike the cloud model for teaching, in this case, we have a different deployment and integration model. Figure 2 illustrates our application execution platform for

Figure 2. Research application execution platform in research activities



research activities. We develop an *eHPA Information Service* to store information about eHPAs. This information service has similar objectives to that for the *Exercise App Information Service*, such as based on similar techniques and support application description. However, this service provides richer information about applications due to the complexity of eHPAs, compared with course exercise applications. Furthermore, two different management strategies are introduced for research activities: the researcher can connect to public clouds and the researcher can store their machine images and data into our private cloud system. This requires us to develop billing systems for research activities.

DISCUSSION AND CONCLUSION

In this chapter, we have analyzed requirements from groups in higher educational and research institutions in developing countries. In particular, we focus on the case of Vietnam. We have identified several requirements and possible cloud adoption for these requirements that are very specific to the context of research and educational groups in developing countries. Our analysis has presented some research challenges and possible solutions in order to support these requirements. In particular, we believe that cost and payment, application store, software license, cross cloud platforms are important issues that need to be solved. Furthermore, unlike existing work in developed countries for research and educational activities, we suggest to separate cloud adoption for teaching and for research in the context of developing countries, due to several different elastic properties in their requirements.

Our analysis is mainly based on existing groups in academic institutions in Vietnam with some elaboration for other institutions in developing countries, but we lack comparative studies and detailed information from other developing countries. However, we believe that our study in Vietnam is also applicable to other developing countries due to several similar characteristics among small groups in academic institutions with respect to research and teaching activities, funding and management policies, and computing infrastructures. Another reason why our approaches and solutions may be suited well for other developing countries is that we are focused on technical solutions, which are generally applicable, rather than on management and policies which are specific from countries to countries.

In our future work, we plan to examine this topic in other developing countries and to develop a roadmap for the development of cloud adoption for higher educational and research institutions in Vietnam. We are also proceeding with the development and improvement of our approach in this chapter. In particular, we are working on an elastic high performance application composition and execution framework that can work across cloud platforms and includes billing systems suitable our context.

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KEY TERMS AND DEFINITIONS

Data-as-a-Service: A particular type of service in the cloud that offers features for storing, managing and accessing data.

Elastic high performance application: A high performance application of which available usage time, offered quality, offered cost, consumed resources, and offered usage rights can be elastic.

Exercise application: An application which is designed for students to practice concepts studied in courses.

On-demand cloud computing requirements: Requirements for computing resources in the cloud needed for research and teaching activities.

Research and educational group: A group of people who perform research and/or teaching activities in higher academic institutions.