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Full Length Research Paper

Development and implementation of e-education model in a higher education institution

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This paper considers the problem of realization of e-learning infrastructure based on cloud computing at a university level. The primary goal is to develop a model of scalable and reliable infrastructure and services for e-learning. The proposed model is based on a private cloud realized within the existing infrastructure of a higher education institution. The model has been implemented at the Faculty of Organizational Sciences, University of Belgrade. The evaluation has been conducted within regular teaching and learning activities. The results of evaluation suggest that the introduction of cloud computing into e-education is feasible and it can greatly improve the efficiency of the system and achieve a win-win situation for both students and teachers.

Key words: Cloud computing, e-education, infrastructure for e-education.

INTRODUCTION

Modern information and communication technologies are used on a daily basis for communication, collaboration, retrieving information and other services. Development, availability and accessibility of these technologies lead to new paradigms in teaching and learning processes. Nowadays, many universities in the world organize courses and trainings via distance learning systems.

E-learning is a complex system that involves and includes the following elements (Despotovic and Radenkovic, 2005):

1. Distance learning and distance teaching are separated by time and distance.
2. Teaching materials can be in various forms.
3. The learning process can be individual and group processes.
4. Tutorial work with various forms of direct communication by using digital media.
5. Interacting and achieving synergy effects in groups of student.

The number of users and the quantity of content within these systems grows rapidly. Therefore, the design and implementation of these systems become more complex. With a huge growth in the number of users, services, education contents and resources, e-learning systems become more and more large-scale. One of the basic problems in developing a model of infrastructure for e-learning is how to provide scalability and reliability of educational applications and services.

The concept of cloud computing (in further text CC) is a completely new business model and technology platform, which is the result of evolution and convergence of many seemingly independent computing trends. Cloud computing is an area of computing that refers to providing customers with highly scalable IT capacities as a service via the Internet (Nabil, 2010). It is an abstract, scalable and controlled computer infrastructure that hosts applications for end-users. Services and data coexist in a shared and dynamically scaled set of resources (Srinivasa et al., 2009). Cloud computing is an infrastructure that can bring new value to an e-education

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Table 1. Cloud computing deployment models.

Deployment model	Management	Ownership	Location	Access right
Private	Organization	organization or cloud provider	within or outside the organization	authorized
Public	Cloud provider	cloud provider	outside the organization	Not authorized
Hybrid	Organization and cloud provider	organization and cloud provider	within or outside the organization	Both authorized and not authorized
Community	Cloud provider	organization or cloud provider	within or outside the organization	Authorized

system, because educational services can be delivered in a reliable and efficient way.

Virtualization is one of prerequisites for the realization of cloud computing (Dong et al., 2009). It enables resources to be used when they are necessary. The term virtualization refers to the environment or to a method of sharing hardware resources among several virtual systems or combining low scale resources into a more powerful computational environment. The most important technologies and concepts in virtualization are software sharing, time sharing, hardware simulation, emulation, etc. Physical resources are used efficiently, because many virtual machines (in further text VM) can operate on one physical machine (Jin et al., 2008). Educational institutions can also benefit by introducing the concept of virtualization. For example, same hardware resources can be used to deploy virtual machines for different courses. Peak periods when students have great demand in accessing the servers usually happen in different time for each course. Peak periods for each course are predictable, since they depend on time tables for classes and exams.

Therefore, it is possible to assign the same hardware resources to courses that need them most at the specific period of time. Another benefit is that the number of required software licences is decreased if students use software installed on one virtual machine.

Depending on the type of ownership of physical resources and infrastructure the following deployment models of cloud computing can be developed (Jin et al., 2010): a private cloud, a public cloud, a hybrid cloud and a community cloud. Table 1 shows characteristics of the deployment model from the standpoint of infrastructure (management, ownership and location) and users (access rights to cloud resources).

Depending on how technology is provided and used, there are three approaches to deploying cloud computing services (Costanzo et al., 2009):

1. Infrastructure as a Service (IaaS) - the capability provided to the consumer is to ensure the provision of processing, storage, networks, and other fundamental computing resources.
2. Platform as a service (PaaS) - the capability provided to the consumer is to deploy onto the cloud infrastructure the consumer-created or acquired applications created using programming languages and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure, but has control over the deployed one.
3. Software as a service (SaaS) - the capability provided to the consumer is to use the provider's applications running on a cloud infrastructure. The applications are accessible from various client devices through a thin client interface such as the web browser.

The cloud computing infrastructure for educational institutions allows for an efficient usage of existing resources and gives a new perspective to scalability and reliability of educational applications, software and a system for e-learning. The cloud computing concept and its characteristics can help higher education institutions improve productivity and enhance hardware and software resources management that are necessary to provide e-education features, scientific and research activities and students projects (Caron et al., 2009).

Most resources are deployed and assigned for some specific tasks or applications, and physical machines are usually stacked simply and exclusively. When receiving high workloads, an e-learning system commonly deals with them by using new resources. With the growth of resources, the overhead of resource management becomes a key issue because of unacceptably increasing costs. Moreover, the utilization of those resources is another problem. E-learning systems often engage resources in as much the same way as when they are at their peak hours, even when some of them are idle. Meanwhile, educational contents are various and grow rapidly in amount, requiring scalable storage capacity. Specifically, the requests to education contents follow a highly dynamic rule.

These issues affect resource utilization to a great extent. During the learning process a large amount of teaching material is generated, which further aggravates the available resources. One of the biggest problems in the implementation of IT infrastructure is a competitive access to the shared resources in the higher education institution.

Talking about application of cloud computing infrastructure in higher education, three basic approaches can be noticed. First approach is complete outsourcing of e-education infrastructure (Nabil, 2010) that educational institutions provide to their users (teaching staff, administrative staff, researchers, students, etc.) with services such as e-mail, digital libraries, etc. through the leased infrastructure of a cloud provider. Second approach is cloud within the private infrastructure (Caron et al., 2009) that requires highly skilled cloud administrators and appropriate hardware and software resources within the educational institution. Third approach represents combination of previous two approaches (Costanzo et al., 2009). The educational institution can develop and deploy its own cloud infrastructure. If the infrastructure becomes overloaded, a third party cloud services can be leased in the periods of increased demand.

This paper discusses one possible approach for providing reliability and scalability of a system for e-learning in higher education institution, the Faculty of Organizational Sciences, University of Belgrade. The developed model for e-learning is based on private cloud. The model includes all services necessary for the implementation of activities in educational institutions and services for scientific research.

Literature review

In the previous years, there has been much research in the field of cloud computing. However, only a few dealt with the problem of developing and deploying models for e-learning infrastructure using cloud computing. Main research directions important for the problems considered in this paper include: identity management within cloud computing environment, modelling the cloud computing infrastructure, analyzing performances of the cloud computing, and resource management in e-learning systems.

The problem of identity has been present from the beginning of the mass use of the Internet. Nowadays, every user has multiple different digital identities, so that in the today's modern and quite scattered systems, the activity of authentication and authorization when accessing services is a problem for both users and system administrators. This problem also reflects in e-learning systems in higher education institutions, where different resources and services are often deployed through heterogeneous systems. Much research has proved that security, digital identity and access management are essential for successful deployment of infrastructure for e-learning (Zhang and Chen, 2010; Zhang and Chen, 2011).The aim of identity management systems is to establish a connection between identifiers of different services, so that information about the user associated with the identifier can be integrated. In this way, the system connects identity management business processes, security policies and technologies to help higher education institution in the management of identity and control to the access to resources. Specific problems arise in identity management in the cloud environment (Takabi et al., 2010; Subashini and Kavitha, 2011). The model presented in (Danfeng et al., 2011) uses dynamic control policies to support the multiple roles and flexible authority. However, most of these researches present theoretical models for identity management in the cloud that cannot easily be applied in e-education environments.

Cloud computing can be applied in educational institutions using different deployment and technology models. The problem of modelling infrastructure is specific in term of resource provisioning and how to deploy virtualized services (Sotomayor et al., 2009b). In (Ercan, 2010) author gives a review on how higher education institutions can benefit from CC infrastructure. Main areas of application include: students and administrative personnel have the opportunity to quickly and economically access various application platforms and resources through the web pages on-demand, cost of organizational expenses are reduced and more powerful functional capabilities can be offered. There have been several successful implementation of CC in higher education institutions (Khmelevsky and Voytenko, 2010; Bogdanovic et al., 2011). One of the most successful implementations has been developed at the Hochschule Furtwangen University, where a specific solution for private cloud has been developed (Doelitzscher et al., 2011).

Within the cloud computing infrastructure, resources are managed using specific set of tools (Nathani et al., 2012). Some authors focus on resource management frameworks for automatic runtime set-up (Gallard et al., 2012), while others focus on algorithms for resource scheduling (Chang and Tang, 2011).

For measuring the performance of deployed cloud computing infrastructure a specific set of measurements has to be used. Some authors evaluate CC infrastructure using performance indicators such as I/O performance, CPU performance and network transfer rate (Baun and Kunze, 2009). However, there are no standardized methods for CC performance analysis, and different authors use different metrics to evaluate their CC infrastructure (Iosup et al., 2011).

Within the private cloud infrastructure there are demands for centralised system that enables different services for his users. Digital identity management is defined as the process by which the existing technologies are used to manage digital identity information entities as well as to control access to resources (Takabi et al., 2010). The digital identities management objective is to improve the productivity and security while reducing costs associated with managing entities and their digital identities.

METHODOLOGY

Research context

The E-business Lab, University of Belgrade, organizes e-learning courses using a ubiquitous learning concept (Despotovic-Zrakic et al., 2012). More than 1000 students are engaged in over 20 undergraduate and postgraduate studies. The e-learning system is based on the Moodle learning management system (LMS).

Most e-learning resources are deployed and assigned for some specific assignment, and physical machines are usually stacked simply and exclusively. When receiving high workloads, an e-learning system commonly deals with them by using new resources. With the growth of resources, the overhead of resource management becomes a key issue. E-learning systems often engage resources in as much the same way as when they are at their peak hours, even when some of them are idle. Meanwhile, educational contents are various and grow rapidly in amount, requiring scalable storage capacity. Specifically, the requests to education contents follow a highly dynamic rule.

These issues affect resource utilization to a great extent. During the learning process a large amount of teaching material is generated, which further aggravates the available resources. One of the biggest problems in the implementation of IT infrastructure is a competitive access to the shared resources in the higher education institution.

In addition to scalability, the efficiency of the existing resources represents another problem. The E-business Lab owns a computer centre which was designed and built specifically for its own use. Its capacity has gradually become inadequate to meet the demands of scientific research and educational activities, while at the same time it has become expensive to maintain. In each semester students mostly require the most modern hardware with specific software requirements for their laboratory exercises and practical projects. Low utilization of available resources requires a different approach to the implementation of infrastructure systems for e-learning.

The three courses that enroll the highest number of students are E-business, Internet technologies and Simulation and simulation languages. The E-business course is organized at the third year, while Internet technologies and Simulation and simulation languages are at the fourth year of study.

E-business is a course that deals with key concepts in the designing and implementation of e-business projects. In the scope of their activities within the course, students create web presentations and e-commerce web sites, they learn how to use and customize customer relationship management solutions, and learn about social computing service in e-business. All these activities require appropriate platforms to be installed, as well as web hosting services. Students should be provided with virtual machines created in accordance with their needs.

The basic idea of the course Internet technologies is to learn key concepts in development of web applications. Students have to create advanced web applications enriched with JavaScript, JQuery, XML technologies. Further, students learn about service oriented architecture and develop their own web services in PHP, Java or Microsoft technologies. In order to implement their projects, it is necessary to provide different operating systems (Linux, Windows), development platforms (NetBeans, Eclipse, Dreamweaver, Aptana, Visual Studio), software tools, database management tools (SQL server, MySQL), web servers (Apache, IIS), applications servers (PHP, Biztalk, WebSphere), all modern browsers, etc. Therefore, various combinations of these technologies and platforms should be available to students on virtual machines.

The main goal of the course Simulation and simulation languages is to teach students the basic and advanced concepts of computer simulation. The course includes three areas: continuous simulation, discrete simulation and 3D modelling. According to this, students need different software solutions: CSMP, FONWebGPSS and 3ds Max. CSMP and 3ds Max are desktop applications running on Windows operating system. FONWebGPSS is a web application running on Windows Server 2003, and it requires a set of specific web services for building a simulation model, executing the simulation and visualizing the results of the simulation.

Participants and design

In order to evaluate developed infrastructure for e-learning based on CC, a research has been conducted. Main goal of the research was to gain answers to three questions:

1. To what extent e-learning based on implemented CC infrastructure influences the results that students achieve on final exams?
2. Are teachers satisfied with implemented CC infrastructure for e-learning?
3. Is performance of implemented CC infrastructure satisfactory?

In order to determine in what extent CC infrastructure for e-learning contributes to students' results, we have compared results of students who learned within the implemented CC infrastructure for e-learning and results of those who learned within previously used infrastructure for e-learning, where CC services were not available. For experimental group (EG), we have selected students who attended courses E-business, Internet technologies and Simulation and simulation languages in winter semester of the school year 2011/12. Students in EG attended the appropriate e-learning course, where some resources were provided in the form of VMs. In the end of the course, they took the final exam. For control group (CG), we have selected students who attended same courses in school year 2010/2011. These students have learned on e-learning infrastructure bases only on Moodle LMS, where neither resources nor services were provided through CC. In order to test equivalence of the EG and CG, we have used the average grades that students of both generations achieved in their previous course of study. Data was gathered within the business information system of Faculty of Organizational Sciences. Average grades for both EG and CG are shown in Table 2, for students of all three considered e-learning courses. Since Sig>0.05, we can conclude that there is no significant statistical difference of average grades for students in EG and CG.

For determining teachers' attitudes toward teaching in the implemented CC environment for e-learning, we have created a survey. Survey was distributed to all teachers who taught the three considered courses in the school year 2011/2012. Teachers completed the survey at the end of the semester. Total 26 teachers participated: 11 teaching E-business course, 8 teaching Internet technologies course and 7 teaching Simulation and simulation languages course.

In order to evaluate the performance of implemented infrastructure for e-learning based on CC, we have used a software tool Ganglia. Ganglia is a tool for collecting and displaying server performance metrics on pools of VMs (Massie et al., 2004). This software tool enabled analysis of the performance attributes such as stability of the system, availability, speed, and CPU performance.

Instruments

Experiment has been conducted using the following instruments:

Table 2. Statistical equivalence of average grades in EG and CG.

Course	EG (2011/12)		CG (2010/11)			
	N	Mean	N	Mean	F	Sig.
E-business	461	8.01	470	7.97	0.352	0.553
Internet technologies	256	8.07	228	8.03	0.283	0.595
Simulation and simulation languages	176	8.11	171	8.05	0.285	0.594

(a) a survey for examining teachers' attitudes toward e-learning infrastructure on CC, (b) Knowledge test for measuring students results in the course E-business, (c) Knowledge test for measuring students results in the course Internet technologies, (d) Knowledge test for measuring students results in the course Simulation and simulation languages.

The survey for examining teachers' attitudes toward e-learning infrastructure on CC included total 5 questions. The questionnaire has been validated using Cronbach's alpha coefficient, which is 0.814. Questions were formed in order to determine: productivity of teachers while preparing the course on CC infrastructure, productivity of teachers in realization of the course, satisfaction with technical support, satisfaction with e-learning analytics, and overall opinion on suitability of developed infrastructure for e-learning. All questions were assigned with a Likert five point scale. Questions can be seen in Table 5, further in the text.

Knowledge test was taken by all students in both EG and CG. Knowledge tests contained questions on the matter studied within the attended course. Knowledge test was used to determine if there is statistically significant difference between results achieved by student in EG and CG. A specific knowledge test was created for each considered course (E-business, Internet technologies, Simulation and simulation languages). Cronbachs' alpha coefficients are 0.910, 0.875, and 0.890, respectively. The same tests are used during the previous five years in the considered courses.

Materials

Consolidation of computing resources for e-learning in the E-business Lab is realized using the model of of private clouds. This approach has been chosen beacuse it enables better usage of existing e-learning infrastrucure and the model can subsequently be expanded into a hybrid or public cloud (Sotomayor et al., 2009a). The aim of the implementation of the private cloud is to provide users run virtualized infrastructure, environment and service. The system for managing virtual infrastructure will automate, coordinate and integrate the existing solutions for: networking, storage,virtualization, monitoring and management of users. In this way, students and teachers are provided with tools for quick and easy access to the necessary educational and scientific services and resources. The implemented model allows for a better agility of IT systems at the higher education institution, since it is possible to move a virtual machine to another physical node without any downtime of service or a virtual machine all without any negative impact on users who are connected at that moment to the virtual machine (Sotomayor et al., 2009b). It solves many of the current problems in the management of server environments, and thus enhances the performance and responsiveness of the operating system and applications. Figure 1 shows logical model of the implemented infrastrucure. The model consists of Cloud Front End which enables users to use VMs, while administrators can manage the whole infrastructure. Image Catalog is a repository of VMs created for each e-learning course upon teachers' requests. User accounts are stored in centralized database implemented using Lightweight Directory Access Protocol (LDAP). LDAP also enables integration with Faculty Information System.

The key components of the implemented private cloud can be grouped into the following groups:

1. Services for resources and schedule management
2. Services for access to virtualized environment
3. Distributed system for files management
4. System for virtualized infrastructure management
5. Service for identity management

These components allow for an efficient work with VMs. VMs are stored in the image repository and could be restarted when needed or on users' demand. One of the core components of the model is the directory for identity management. It is a centralized repository for logical data and identities in the whole system. All components in the system communicate with the LDAP server when authenticating and authorizing users. All parts of the system communicate with the server for identity management during the authentication and authorization. Privileges are defined for the environment and for the available services. Each user in the model has a set of privileges for a specific environment and services within them. Users do not have the right of access to services that do not belong to an environment. LDAP hierarchy and roles in the cloud are shown in Figure 2.

Services that are available within the environment for students include: portal services, e-mail, file management system, services for database management, services for communication and collaboration. These services are referred to as educational resource pool, and provide students with the following:

1. Easy access to diversity of useful information and educational services;
2. Open lines of interaction among the community users;
3. Sharing information for common class activities;
4. Single consistent web-based front end to present information from a variety of resources
5. Integration with Moodle learning management system

Educational resource pool strategy has been defined upon needs of each course conducted within the E-business Lab. For each course (E-business, Internet technologies, Simulation and simulation languages) a set of VMs with specific hardware and software requirements has been defined. VMs for each of the three considered courses are shown in Table 3.

The implemented private cloud consists of the server that hosts all described software tools and physical computers (nodes) and their recourses. The server serves for the management of: cluster of physical machines, individual machines, nodes, i.e. virtual machines set up on the nodes, memory resources, and system and network users. A solution for the management and fine tuning of the virtual infrastructure has been implemented in order to achieve better scalability and stability. This solution enables the real time management of the complete system infrastructure.

For deploying the private cloud infrastructure, the following software tools were used: Operating system - Centos 5.6 64bit, Xen

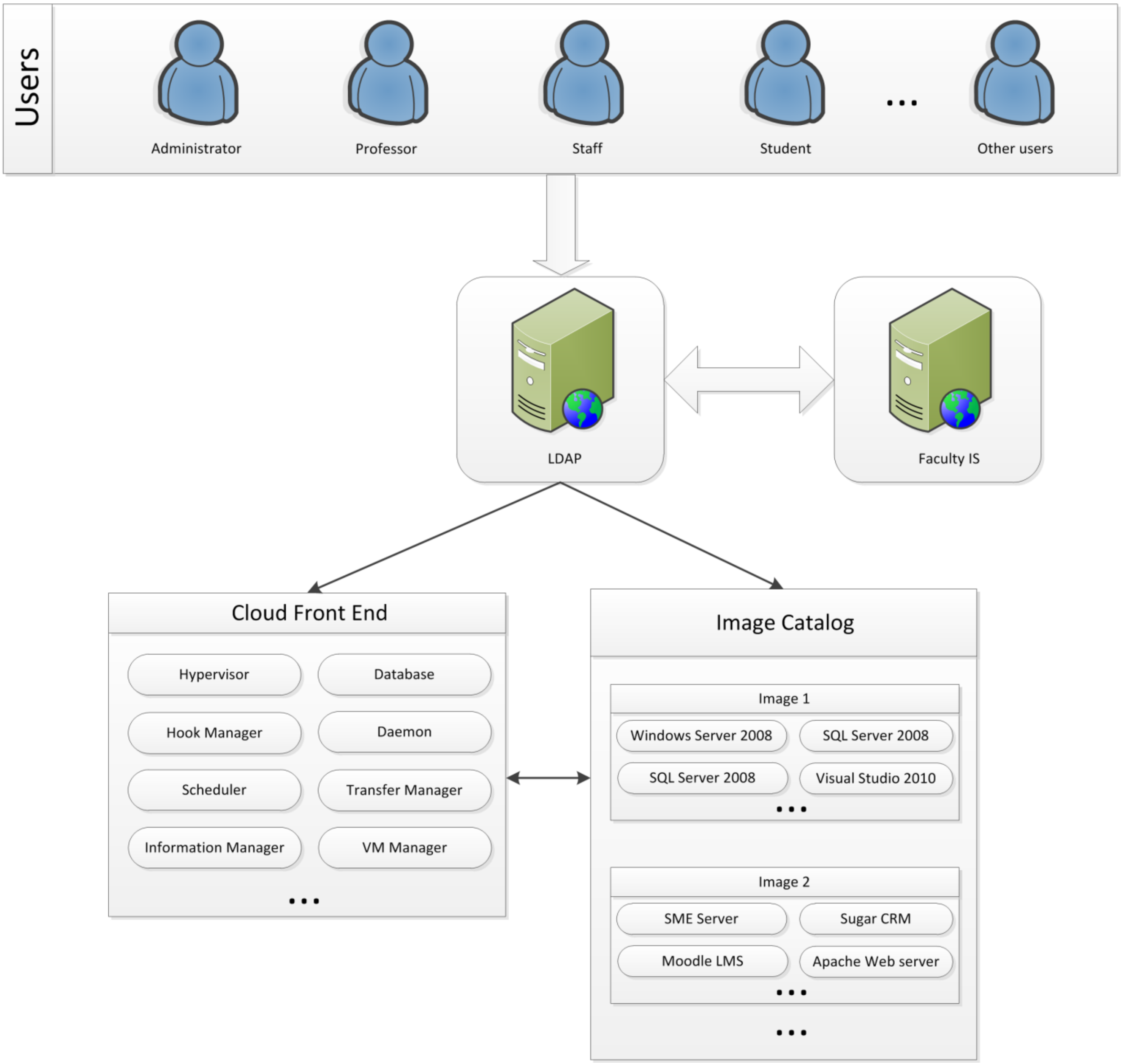

Figure 1. Logical structure of the e-education model within a private cloud infrastructure in a higher education institution.

– hypervisor, OpenNebula – virtual infrastructure management system, MooseFS – distributed file system, Ganglia – automated monitoring system, Haizea – an open source lease management architecture (Sotomayor et al., 2009a) which enables the provision of resources required for teaching and laboratory exercises.

OpenNebula provides a flexible, extensible management layer which allows for the automation of the processes of resource virtualization in a higher education institution. This tool offers users a flexible and scalable platform for a rapid delivery of service. Services are in the private cloud implemented as virtual machines that run, monitor and control the OpenNebula interface. The OpenNebula and the MooseFS meet the requirements for the construction of a private cloud within a higher education institution by using the existing hardware and the open source software, with the aim of reducing costs and increasing scalability and efficiency of a higher education institution resource.

Procedure

The procedure of integration of e-learning services with the cloud computing and conducting e-learning courses is shown in the figure 3. The courses are created in Moodle LMS by a professor or a course creator. Then, teaching materials are prepared, as well as the activities and the assignments for each e-course. Also, specific software tools necessary for learning are chosen. The student accounts in Moodle LMS are created and stored on LDAP server integrated with the user directory of the educational institution where the student accounts are located. After that, the virtual machines with necessary operating systems and software are

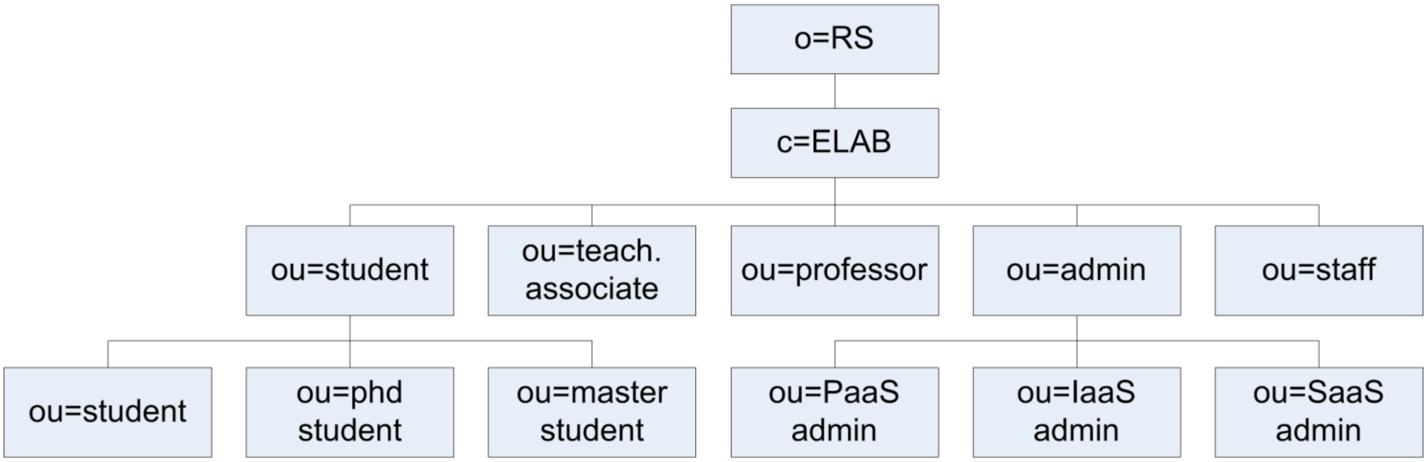

Figure 2. Roles and identities in the cloud.

Table 3. Virtual machines for e-learning courses.

Course	VM name	VM description	Role of VM in teaching	Delivery type
E-business	VM-ecomm	Windows XP Apache PHP MySQL	Students install open source solutions (Joomla, VirtueMart, osCommerce, ZendCart, or similar) and develop their e-commerce projects	PaaS
E-business	VM-crm	Ubuntu Server Apache PHP MySQL SugarCRM	Students learn about customer relationship management concept through using the appropriate software	SaaS
Internet technologies	VM-php	Windows XP Apache PHP MySQL	Students develop their own web applications	PaaS
Internet technologies	VM-voip	Ubuntu Server Asterisk	Students develop their voice over IP solutions	PaaS
Internet technologies	VM-android	Android OS	Student test their Android applications	PaaS
Simulation and simulation languages	VM-webgpss	Windows Server 2003 IIS ASP.NET SQL Server Express FONWebGPSS	Students learn on discrete simulation by creating and executing models of discrete systems	SaaS
Simulation and simulation languages	VM-csmp	Windows XP CSMP/FON	Students learn on continuous simulation by creating and executing models of continuous systems	PaaS

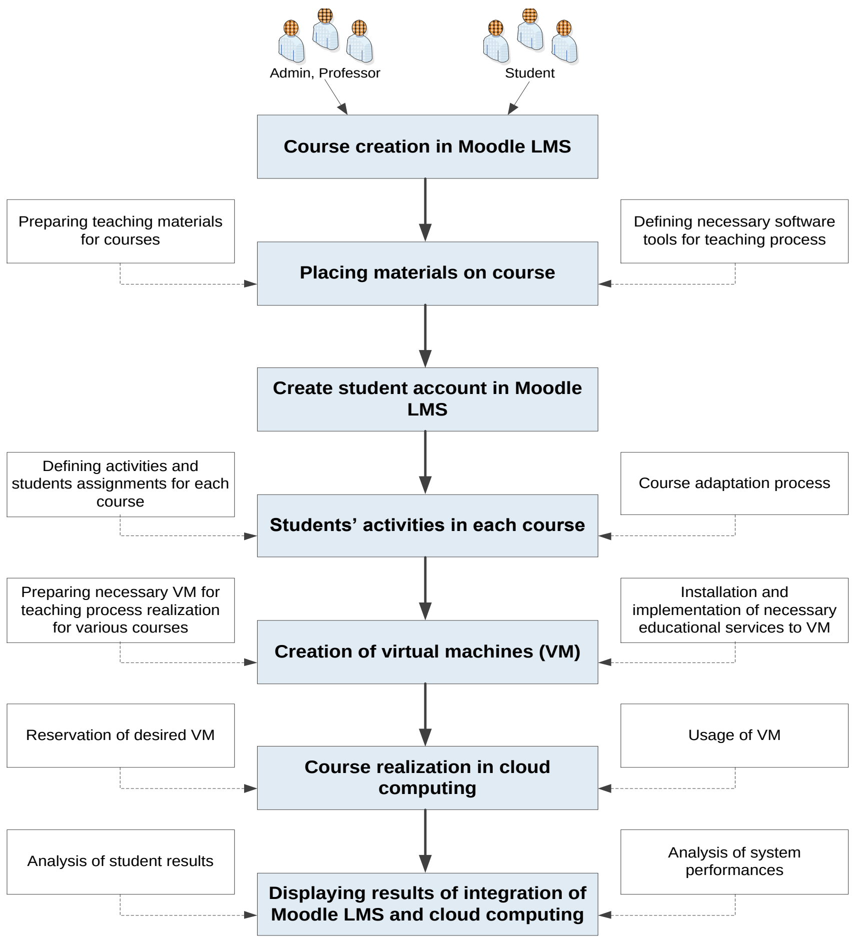

Figure 3. A process of integration of e-learning services with cloud computing.

Table 4. Students grades on knowledge tests.

Course	N	Mean	Std. Deviation
E-business			
EG	461	7.98	0.961
CG	470	7.72	0.949
Internet technologies			
EG	256	8.09	1.032
CG	228	7.88	1.262
Simulation and simulation languages			
EG	176	8.22	1.059
CG	171	7.98	0.994

prepared. The prepared virtual machines are stored into the clod computing infrastructure. Students use a specific web interface to reserve any of the provided virtual machines for the Moodle LMS course they are enrolled in. Finally, professors and administrators of the system can view and analyze students' results and the performance of the system.

RESULTS

Results on knowledge tests

Table 4 shows means and standard deviations for

Table 5. The results of the questionnaire for teachers (Scores: 5-Strongly agree; 4-Agree; 3-Neither agree nor disagree; 2-Disagree; 1-Strongly disagree).

Score:	**5**	**4**	**3**	**2**	**1**
Q1: Working on e-learning infrastructure based on CC contributes to higher productivity in the process of course preparation					
E-business	3	3	3	2	0
Internet technologies	2	2	1	3	0
Simulation and simulation languages	3	2	0	2	0
Q2: Working on e-learning infrastructure based on CC contributes to higher productivity in realization of courses					
E-business	5	4	2	0	0
Internet technologies	5	1	2	0	0
Simulation and simulation languages	5	2	0	0	0
Q3: Technical support is on adequate level					
E-business	3	4	2	1	1
Internet technologies	2	3	2	1	0
Simulation and simulation languages	2	3	2	1	1
Q4: E-learning analytics is on adequate level					
E-business	2	3	5	1	0
Internet technologies	0	5	3	0	0
Simulation and simulation languages	0	4	2	1	0
Q5: In my opinion, developed infrastructure based on CC is suitable for e-learning process					
E-business	5	4	2	0	0
Internet technologies	6	1	1	0	0
Simulation and simulation languages	4	2	1	0	0
Q6: Identity management system is efficient and provides single sign on for all necessary resources					
E-business	4	5	2	0	0
Internet technologies	4	3	1	0	0
Simulation and simulation languages	5	1	1	0	0

students grades achived on knowledge tests. For testing if there are statistically significant differences between results achieved by students in EG and CG, we have used analysis of variance (ANOVA). Results show that there are statistically significant differences between results achieved by students in EG and CG for all three considered subject:

1. E-business: $F(1,929) = 16.648$ ($p<0.05$).
2. Internet technologies: $F(1,482) = 4.130$ ($p<0.05$).
3. Simulation and simulation languages: $F(1,345) = 4.930$ ($p<0.05$).

Results on teachers satisfaction

Data collected by surveying teachers is shown in Table 5. Analyzing data gathered through the questionnaire for teachers, we can conclude the following:

1. Most of the teachers agreed or strongly agreed that CC infrastructure contributes to higher productivity in preparing e-courses. However, there were few teachers that disagreed on this. These were mainly teachers responsible for specific course topics that require more effort for preparing virtual machines.
2. Considering applicability of CC infrastructure for realization of e-courses, most of teachers agreed or strongly agreed that CC infrastructure contributes to higher productivity in realization of e-learning courses.
3. Technical support for using CC infrastructure is on adequate level for most of teachers. However, there were several teachers who were not satisfied with the quality of technical support
4. E-learning analytics is on adequate level for most of teachers. However, there is a significant number of teachers who do not have opinion on e-learning analytics. These are mainly teachers who did not need to use

Table 6. Performance indicators.

Variable	Peak hours	Off-peak hours
Max. number of concurrent access	80	32
Stability (number of system failures)	1	0
Availability (in percents)	98.75 %	100 %
Speed (response rate in milliseconds)	15 ms	7 ms
CPU performance (Average CPU performance in %)	65 %	22 %

analytics services.

5. Finally, there were no teachers who thought that implemented CC infrastructure is not suitable for e-learning process. Most of the teachers strongly agreed that the infrastructure is suitable for e-learning process.

6. Teachers are satisfied with the quality of identity management system. Most teachers agree or strongly agree that all necessary resources can easily be accessed through integrated identity management system.

Results on performance of infrastructure

Table 6 shows values for each considered performance indicator. All indicators are shown for winter semester of the school year 2011/2012, including exams. Upon results shown in Table 6, we can conclude that all considered indicators are on satisfactory level.

Parameters were measured during the period of the highest system load (peak hours) and during the period of normal system load (off-peak hours). Peak hours include performing exams and performing the teaching process. During off-peak hours students can access the system from their homes.

The measured parameters include the maximal number of students which access the system simultaneously (number of access), the number of system failures (stability), system availability in percents, system response rate in milliseconds (speed) and average CPU performance in percents.

System availability can be computed using the following formula:

$$AV = \frac{NA - ST}{NA} \cdot 100\ [\%]$$

Where are: AV = availability, NA = number of access, ST = stability.

In peak hours, during the teaching process or during exams, 80 students averagely accessed the system in the period of 2 h without interruption. During lab exercises, there was only one system failure when one student wasn't able to access his virtual machine. Availability was 98.75% during peak hours. Response rate (speed) of the system is measured using the ping command. It was 15 ms during the peak hours and 7 ms during off-peak hours. Finally, CPU performance wasn't greater than 65% in any moment. Thanks to these parameters, we conclude that the system is stable. Figure 4 shows CPU performance during the period of the highest load.

DISCUSSION

Given the existing body of research, cloud computing has been demonstrated to add new possibilities to the e-learning systems (Nabil, 2010; Ercan, 2010). Our study demonstrates a measurable improvement of the e-learning system by deploying private cloud. Our unique research context is that implemented cloud computing infrastructure provides integrated approach to educational resource pool. Presented approach is oriented towards making an impact on practice, as a good practice in application of cloud computing for improving teaching and learning process.

We feel that the result of this research is a worthwhile contribution to the fields of both clouds computing and e-learning, as much research work focuses only on applications of public clouds as support for e-learning process.

The evaluation of results shows that students achieve better results when studying in the environment empowered with cloud computing services. Positive outcomes are attained in terms of better results that students achieved in different areas of study, as well as positive attitude of teachers toward working in the new e-learning infrastructure. The findings suggest that system performance is on adequate level, and that the system is stable even during the periods of the highest load. We conclude that cloud computing infrastructure can effectively be used for improving the teaching and learning process, which conforms to findings reported in (Khmelevsky and Voytenko, 2010; Doelitzscher, 2011).

Finally, we acknowledge some limitations of our approach. Several teachers reported that working within CC infrastructure for e-learning decreases their productivity. However, although implementation of the private cloud requires more effort from faculty's administrative, teaching and IT staff, comparing to public

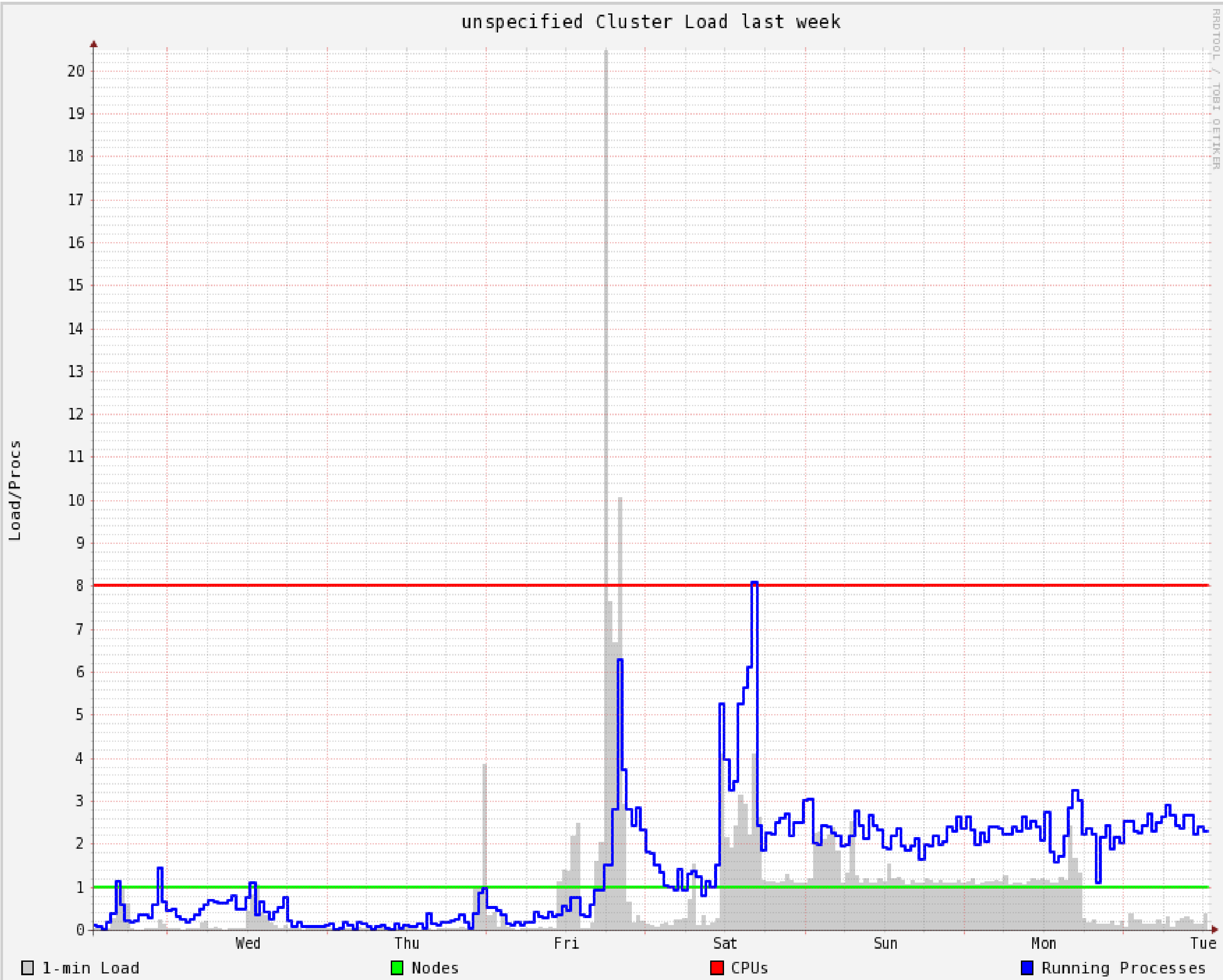

Figure 4. CPU performance during the period of the highest load.

clouds it provides more flexible e-learning infrastructure and better usage of existing resources. This has been verified by other researches, conducted both in the field of e-education (Doelitzscher et al., 2011) as well as applications of CC infrastructure in other areas (Iosup et al., 2011).

Conclusion

This paper presents an implementation of e-learning based on the cloud computing concept. The approach uses the existing software and hardware resources of the higher education institution. The suggested approach is complex, comprehensive and can easily be modified and adjusted for different educational institutions.

The authors believe that the important advantage of this model is that it solves problems of scalability with a more efficient use of existing resources within the private infrastructure. The authors also believe that the implementation of this model can bring specific benefits especially to faculties and departments involved in teaching engineering disciplines and other disciplines where specific computational environments are required not only as support in education, but also for the purpose of the teaching and learning processes.

Future research will be directed mainly toward improving the system for integrated resource management within the educational cloud. Integrated resource management should be realized through a web application that would enable administrators to deploy VMs for courses with respect to teachers' requests, and students to make reservations for these VMs. Furthermore, efforts will be made to develop an efficient algorithm for automatic scheduling of VMs usage.

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