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HARNESSING CLOUD COMPUTING INFRASTRUCTURE FOR E-LEARNING SERVICES

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Abstract. *This paper introduces an innovative model for harnessing cloud computing infrastructure within an e-learning ecosystem. The main goal was to design a scalable, reliable and secure IT environment that provides a plethora of e-learning services and seamless integration of the heterogeneous e-learning components through IaaS, PaaS and SaaS cloud service models. The e-learning services are tailored to foster courses for IT engineers in the areas of mobile technologies, social computing, Internet of Things and big data. The model was implemented and evaluated in the e-learning ecosystem of the E-business Lab, University of Belgrade.*

Key words: *cloud computing, e-learning services*

1. INTRODUCTION

Nowadays, building an e-learning ecosystem is quite a cumbersome endeavour, as it implies integration of various technologies, platforms, and services. The pervasiveness of internet technologies transforms e-learning ecosystems into dynamic environments that enhance learning processes, leverage collaboration, enable KPI management and allow a use of a variety of resources, software services and applications [1]. Usage of e-learning technologies in the university and lifelong education has increased significantly in the past years; however, various problems have arisen. One of the most critical issues is the underlying infrastructure. Accordingly, this requires innovative models and approaches in designing the infrastructure for e-learning systems.

In this paper, a model for harnessing cloud computing infrastructure within an e-learning ecosystem was introduced. The main goal was to design a scalable, reliable and secure IT environment that enables the provision of a variety of e-learning services and seamless integration of the heterogeneous e-learning components. The model should support e-learning services delivered as infrastructure, network, platform, and software as a service. Further, the results from the paper should raise the awareness of possibilities that cloud computing gives to e-learning, make an impact on the development of advanced

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services for e-learning, and induce the harnessing of cloud computing in implementing the cloud infrastructure within educational institutions.

The research context is focused on IT infrastructure for educational institutions that educate IT engineers in the fields of emerging technologies, such as cloud computing, mobile technologies, Internet of Things, context-aware computing, ubiquitous computing, social computing, big data, and virtual reality. The implementation was conducted in the e-learning processes of the E-business Lab, Faculty of organizational sciences, University of Belgrade.

2. Cloud Computing Infrastructure for E-learning

Research and case studies pointed out that the most common approaches in harnessing cloud computing within universities are private and public clouds [2][3][4]. A private cloud model enables educational institutions to have a complete control of identity management, services, data security, applications, and resources [5]. Specifically, when courses are related to computer science, students can be provided with an appropriate environment for application development, and sophisticated software tools. Recently, the number of private cloud based solutions within e-learning systems has significantly increased, and many examples can be found in the literature [6][7][8].

One of the main challenges in cloud computing environment is designing and managing the network infrastructure that could effectively support all cloud computing models [9] and provide adequate resources for teaching and research groups at universities. Two disruptive technologies that can bring a new paradigm to university clouds are multi-tenancy virtualized clusters, and software defined networking. The concept of multi-tenancy implies that several tenants can use the same cloud infrastructure and share computing, storage, and network resources. In this scenario, each tenant's data and resources are isolated and remain invisible to other tenants. Tenants in an e-learning system can be teachers, students, administrators, but at the same time tenants could be e-learning services and applications. Network-as-a- Service (NaaS) is a new cloud computing model in which tenants have access to additional computing resources collocated with switches and routers [10]. Tenants can use NaaS to implement custom forwarding decisions based on application needs. This enables the design of efficient in-network services, such as data aggregation, stream processing, caching and redundancy elimination protocols, that are application-specific as opposed to traditional application-agnostic network services. For the realization of NaaS, the concepts of software defined networks are used. Software defined networks (SDN) allow network management by abstractions of lower network levels [11]. They are based on the principles of clear distinction among management, service, control and forwarding network layers [12].

The aspects of designing a private cloud within an e-learning system significantly differ from the ones in the business sector. While in the business sector the focus is on costs and security, the e-learning systems require other aspects. Flexibility in service design means that IT infrastructure should be expandable and flexible, so as to support teaching courses in the fields of emerging trends in IT. E-learning ecosystems require efficiency in resource usage and elastic provisioning and release of e-learning services, according to demand. Further, teachers should be enabled to define cloud computing services that will be offered to students according to the specifics of each course. In addition, the provision of self-service should be facilitated in order to allow access to information and applications at any time from any location.

The design and implementation of cloud infrastructure and services for e-learning can be realized through the following steps:

1) Conceptual design with respect to educational needs – this includes activities such as: defining a list of e-learning services and required service models, defining pedagogical aspects and expected workloads;
2) Designing network and cloud infrastructure – several components should be designed: network infrastructure, cloud infrastructure, management and monitoring services;
3) Designing and deploying cloud services – e-learning services deployment on the implemented infrastructure and integration with the learning management system;
4) Testing, tuning and evaluation – testing the infrastructure, tuning the performance, evaluation of students' and teachers' results and satisfaction.

3. Design and Implementation

3.1. Research context

The E-business Lab, University of Belgrade, organizes e-learning courses using a ubiquitous learning concept. More than 1000 students are engaged in around 30 undergraduate and postgraduate studies in the fields of information technologies. The e-learning system is based on the Moodle learning management system (LMS). Some of the courses include Internet technologies, Mobile business, Internet of Things, Cloud infrastructures and services, Computer simulation and virtual reality, and others.

The teaching process in each semester has specific software requirements for laboratory exercises and practical projects. Most e-learning resources for each course are deployed for a specific course assignment. Educational content is various and grows rapidly in amount, requiring scalable storage capacity. Specifically, the requests to education content 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 an IT infrastructure is a competitive access to the shared resources in the higher education institution [13]. In addition to scalability, the efficiency of the existing resources represents another problem.

3.2. Conceptual design

The conceptual model of the e-learning services within a private cloud of an educational institution is shown in Fig. 1.

Infrastructural services can be grouped into: 1) Core infrastructure services – critical services that need to be functional in order to enable efficient functioning of services for teaching and learning; 2) Monitoring services – services for continuous monitoring of network, hardware and services. They are not necessary for functioning of the whole system, however, they enable a fast detection and correction of the problems in the functioning of the infrastructure; 3) Backup services – services for creating backup copies of the system. Their continuous functioning enables a fast recovery in case of disasters; 4) Physically dependant services – group of services related to specific physical or virtual hardware. These services enable functioning, access administration and replication of specific services related to that hardware.

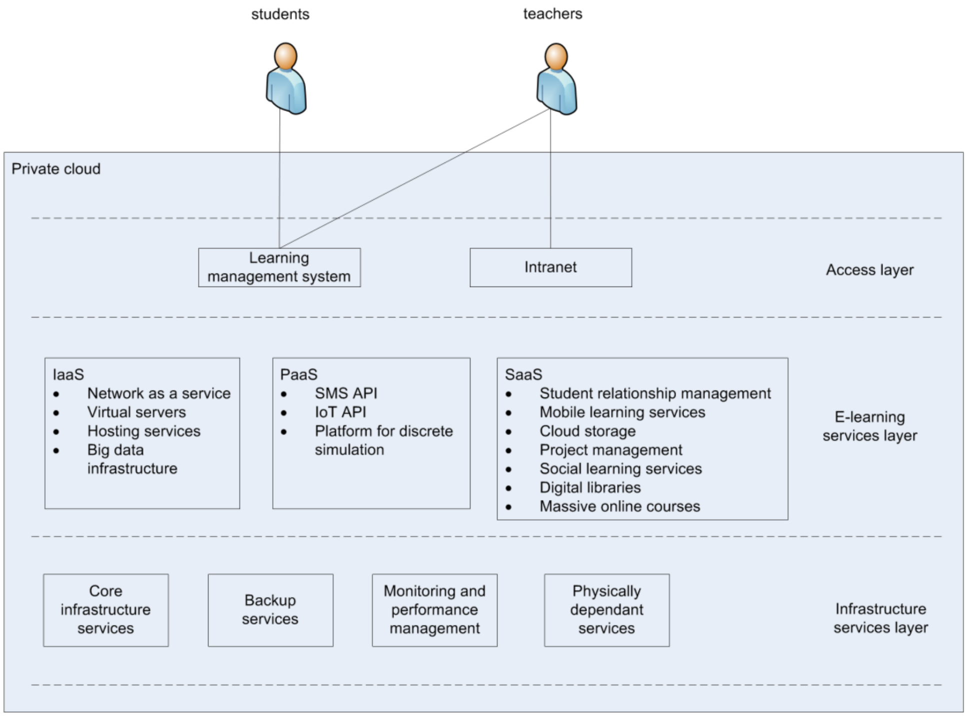

Fig. 1 Types of services deployed on the implemented infrastructure

The e-learning service layer is designed to provide an environment for gaining practical knowledge in the fields of advanced information technologies. All of the cloud service deployment models should be supported, i.e. infrastructure, platform, and software as a service.

Infrastructure as a service (IaaS) provides teachers with an opportunity to design specific infrastructure for each course. This model has been widely used in many educational institutions [14][15], mainly for providing students with virtual machines, where each machine contains all the necessary software and teaching materials for each course. Further, this model can effectively be used to provide students with an IT environment tailored for their own projects in the fields of enterprise networking, big data, distributed simulation, etc.

Platform as a service (PaaS) gives students an environment for developing software as service solutions in different areas, and in different programming languages. Also, the PaaS model is suitable for courses where the emphasis is on software development while hardware layer is highly abstracted [16]. For example, software for mobile business or the Internet of Things projects can effectively be taught using this model.

Software as a service (SaaS) model is highly suitable for courses where students are required to learn to use specific software. This model can also be used to provide teachers and students with services that support educational processes, such as learning management systems, student relationship management, project management, digital libraries, and many others.

Table 1 gives examples of possibilities of use for each cloud services model within the course related to a specific area of modern IT. The areas of IT have been selected according to trends given in [17][18][19][20].

Table 1 IT course areas with IaaS, PaaS and SaaS examples

Course area	IaaS	PaaS	SaaS
Cloud computing	− Virtualization − Software defined networks − Software defined data centres − Cloud storage	− Cloud based simulation − Development of cloud software (Google App Engine, Windows Azure, Amazon)	− Communication apps − Cloud storage apps − Social computing apps − Apps management − Web hosting service
Mobile technologies	− Software defined radio networks	− SMS API − Mobile application development − Mobile agents − Mobile cloud applications	− Mobile commerce apps − M-payment apps − Mobile learning apps − Mobile social apps
Internet of Things	− Software defined wireless sensor networks − Smart environments	− API for accessing the sensor data − API for context-aware applications − API for wearable computing applications	− Software for smart device management
Big data	− Environment for Hadoop projects − Environment for MongoDB projects	− Map-reduce API	− Data analysis − Visualization
IT management	− Cloud management	− Salesforce PaaS − Heroku PaaS	− Project management software − CRM software
Computer simulation and virtual reality	− Resources for simulation execution − Environment for rendering	− API for developing 3D models	− Web simulation software − 3D modelling software tools

Access to all services is managed using a single sign-on concept. The single Sign-On (SSO) concept can be used to solve many problems related to multiple credentials for different applications. SSO is a mechanism that uses a single action of authentication to permit an authorized user to access all related but independent software systems or applications without being prompted to log in again at each of them during a particular session [21]. For instance, when a student accesses an e-learning course web page, they are being transferred to the home page of the e-learning portal that requires authentication (Fig. 2). The e-learning portal component for identity management checks the credentials and sends a message to the learning management system. The student gains access to the e-learning resources that are available to their permissions within the course.

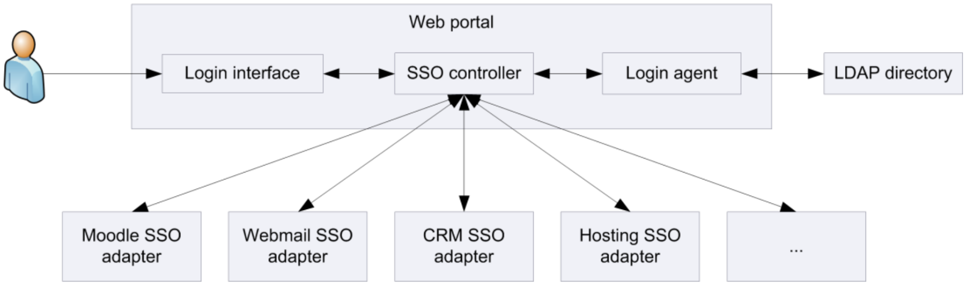

Fig. 2 Architecture of SSO

3.3. Designing network and cloud infrastructure

The hierarchical network model is proven to be a good model for designing the network infrastructure for educational clouds [22]. This model divides the network in core, distribution, and access layers, where each layer performs a specific function. The advantages of using the hierarchical model are numerous. The principle of modularity simplifies the process of designing the network. Testing and troubleshooting are easier, as well as network maintenance. More details on the design of hierarchical network model can be found in [22] .

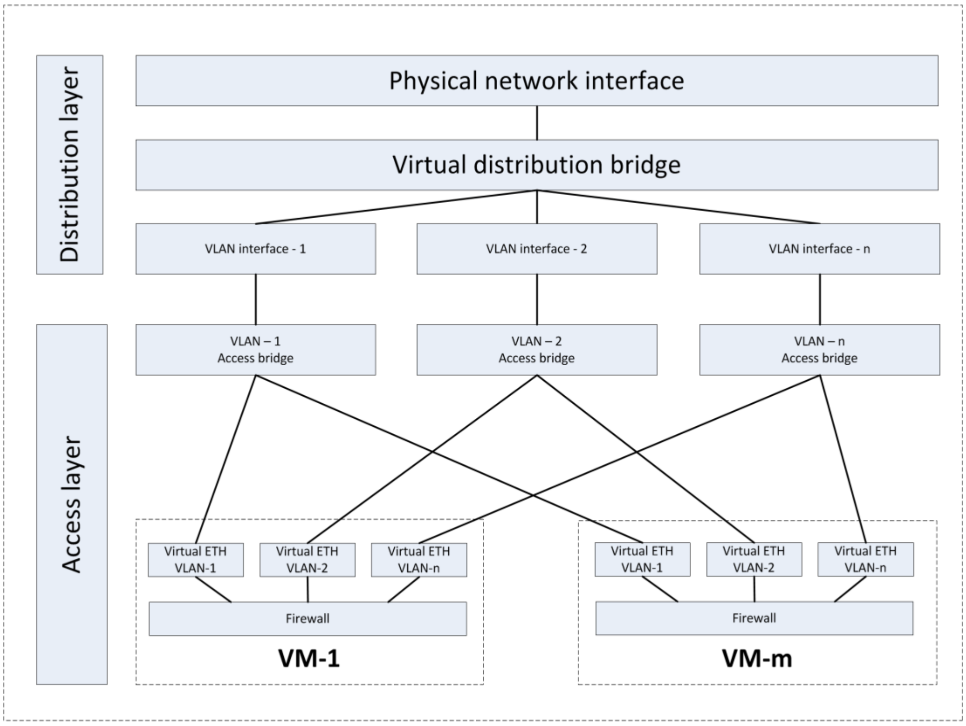

Fig. 3 Conceptual model of the cloud infrastructure

The hierarchical network model allows realization of a part of the network infrastructure within a private cloud. The cloud network infrastructure includes parts of distribution and access layers. The concept of virtual local area networks (VLAN) is used, since within the cloud infrastructure it is important to isolate network traffic for each tenant. All servers are connected to access ports within the same VLAN, so the communication between servers and virtual instances flows within the same network [23][24]. The usage of VLANs enables a simple, flexible, and inexpensive way to administer the network; it provides a segmentation of virtual servers, and secures isolated network traffic between instances [25]. In addition, multiple VLANs can be created for each instance [26]. This approach allows flexibility in the development of cloud e-learning services, because students can be provided with network, infrastructure, development platforms, and software as a service, according to the specifics of each course. The organization of the network segment of the cloud infrastructure is shown in Figure 3.

After setting up the network infrastructure, the main issue is to enable an efficient and comprehensive management of the network resources. Considering the heterogeneity of e-learning systems' components and a need for delivering resources and services on demand, the idea was to find and customize a tool that fulfils all the mentioned requirements.

OpenStack is an open source cloud computing platform for public and private clouds primarily focused on Infrastructure as a service [27]. It provides software, control panels, and APIs required to orchestrate a cloud, including running instances, managing networks, and controlling access. The communication of OpenStack services is realized through public APIs. The main features of the OpenStack include: multi-tenancy, massive scalability, multiple network models, pluggable authentication, block storage support, control panel, hypervisor support [28][29].

OpenStack Networking adds a layer of virtualized network services. This gives tenants the capability for designing their own, virtual networks. Neutron, OpenStack project that provides networking as a service, allows users to create multiple tenant networks [30]. A single open-switch bridge can be utilized by multiple tenant networks using different VLAN IDs, allowing instances to communicate with other instances across the environment. Neutron has an API extension to allow administrators and tenants to create routers that connect to L2 networks. Neutron uses the Linux IP stack and iptables to perform L3 forwarding and NAT. In order to support multiple routers with potentially overlapping IP addresses, the Linux network namespaces are used to provide isolated forwarding contexts. Like the DHCP namespaces that exist for every network defined in Neutron, each router has its own namespace with a name based on its UUID.

Giving each application its own virtual infrastructure, including its own network, leads to simplified security configurations, and gives developers additional flexibility. Application owners in this case do not use the shared infrastructure, but instead each has their own end-to-end infrastructure, isolated from the others, and with few or no interaction points. The flexibility and automation that comes with virtualization of the network allows both network administrators and application owners to respond more quickly to educational needs. For instance, in periods of high usage of the e-learning system (during labs, tests, upload of assignment, etc.) using OpenStack, an IT administrator can easily reserve additional computing resources on the infrastructure and add new instances of the needed server. At the same time, when a new course opens, services and applications tailored to the course' requirements can be delivered in real time. In the periods of the reduced activities, some server instances can easily be removed. In that way, computing resources are set free and can be used for other purposes. Using OpenStack reporting services, teachers and administrators monitor performances of the systems, track ways that students use the system, and notice the most important constraints and factors that influence the outcome of the teaching and learning processes. Integrated dedicated and virtual servers in cloud infrastructure are shown in Fig. 4

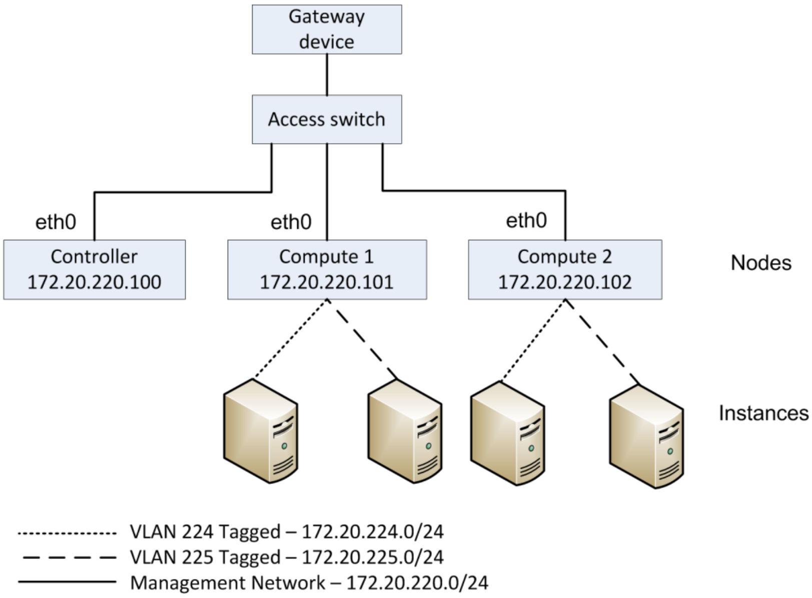

Fig. 4 Integrated dedicated and virtual servers in cloud infrastructure

3.4. Designing big data infrastructure

The concept of big data refers to large, diverse and distributed datasets that cannot be handled using conventional hardware and software infrastructures [31]. The term big data also refers to reliable, distributed and scalable infrastructure for managing large datasets [32]. The main problems in big data are related to gathering, storing, searching, analyzing, and visualization of large datasets. The cloud computing infrastructure is considered an adequate solution for these issues.

The big data platform in the E-business Lab is based on Hadoop framework, which provides storage for large datasets, and large scale processing by using the map-reduce approach. The big data platform is realized using Savanna plugin for OpenStack. Savanna enables easier installation and management of Hadoop stack. In addition, Savanna enables easy service management. The implemented Hadoop cluster is currently based on three hosts. The master host includes services for managing Hadoop virtual functions. Host nodes store data, and contain client services, such as Pig, Hive, Hbase, which are used for data analysis. Big data infrastructure is shown in Fig. 5.

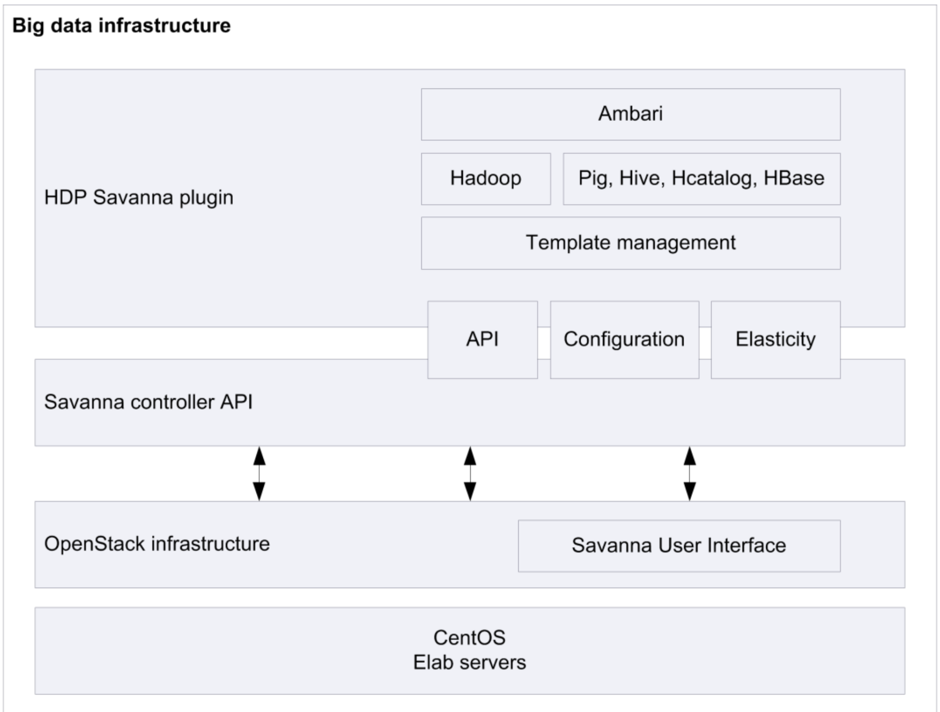

Fig. 5 Big data infrastructure

3.5. Deploying cloud services

Services implemented on the cloud computing infrastructure are classified into two groups: services for students and services for teachers. Some of the services are used by both students and teachers, such as Moodle learning management system, which provides a variety of services that facilitate the learning process: course management, learning resources and activities management, collaboration tools, etc. The following text provides a brief description of the most frequently used services for teachers and students that are implemented on the cloud infrastructure.

Services for teachers include services that support teaching and administrative processes. Intranet portal is a single access point to all the services and applications for the teachers. The portal was designed using the Wordpress content management system. Authentication is based on LDAP. Based on users' requirements, the Intranet portal communicates with the LDAP server and provides users with appropriate services and information.

The service for project management enables planning, tracking and reporting about projects within the Laboratory. The service provides features such as role management, reporting services, Gant chart and calendar, time tracking, wikis and forums per project, etc. The Laboratory's staff takes part in several projects at the same time and there is a strong need for a comprehensive project management solution [33][34]. The service is implemented using Redmine software solution.

Teachers are also provided with an adapted Pydio tool that enables complete file management via web browser from any place. Pydio (formerly Ajaxplorer) is an open source software that enables any server (on premise, NAS, cloud IaaS or PaaS) to be turned into a file sharing platform. It is an alternative to SaaS Boxes and Drives, with more control, safety and privacy. Advantages of this approach for file management are explained in [35][36].

A Visual tool for easy management of the events in teaching, business, collaboration processes within Laboratory is implemented using a Wordpress plugin. The Event management service is fully customizable and personalized according to the teachers' preferences. Further, the calendar content is provided on mobile devices, too. The notifications from the calendar are sent via email and SMS as remainders.

Nurturing good relationship with students before, during and after their studies becomes a challenging issue [37]. In order to attract, engage, retain students and promote our activities we have developed comprehensive student relationship management services that have been implemented using a SugarCRM software solution. The SugarCRM is chosen because it is an open source, customizable, and easy to use. The module for managing activities related to students contains information about each student, contact details, additional comments (remarks, suggestions, topics of final thesis, notes, etc.). The goal is to raise a relationship management system between students and educational institutions on a higher level in a simple and quick way by the use of high availability and prompt exchange of information. An example of using SRM concept in e-learning management could be seen in [38].

The cloud infrastructure enables seamless design and development of e-learning services. These are numerous services for students implemented and evaluated within the private cloud of the E-business Lab: services for adaptive e-learning [39], a platform for discrete event simulation [40][41], services for learning continuous simulation [42], services for mobile learning [43], services for mobile language learning [44], services for social network learning [45], and services for visualization [46]. Hereinafter, we focus on services related to the usage of cloud resources, and platforms for learning the concepts of mobile technologies, the Internet of Things and big data.

Cloud resource reservation service

Although theoretically cloud infrastructure gives a possibility for an elastic and seamless provisioning and release of e-learning cloud resources, there may be situations where students are required to book the needed cloud resources. Fig. 6 shows the activity diagram for booking cloud resources. A teacher defines virtual machines (VM) according to the needs of each course; students can view the available virtual machines for each course they attend to, and reserve IT resources, that will be allocated for them. Teachers' and students' actions are handled through the Moodle interface, while the scheduling and allocation of cloud resources is handled by the OpenStack. This approach enables educational institutions to use their cloud resources efficiently, even in cases when these resources are not as elastic as with commercial cloud providers.

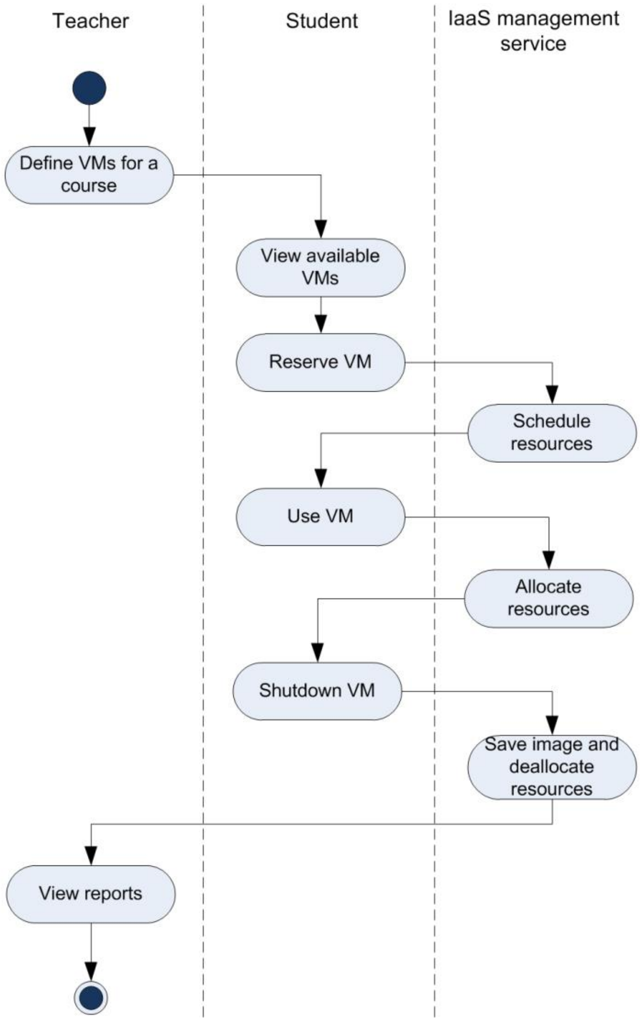

Fig. 6 Cloud resource reservation service

Internet of Things, SMS, and Big Data platforms

In order to conduct courses in the field of the Internet of Things several platforms have been developed: IoT, BigData and SMS platforms. Each platform provides REST APIs, which enable a set of functionalities that can be integrated in students' web and mobile applications. Students' applications are hosted on web hosting services that are also provided to students as cloud services. Fig. 7 illustrates the architecture of the designed system.

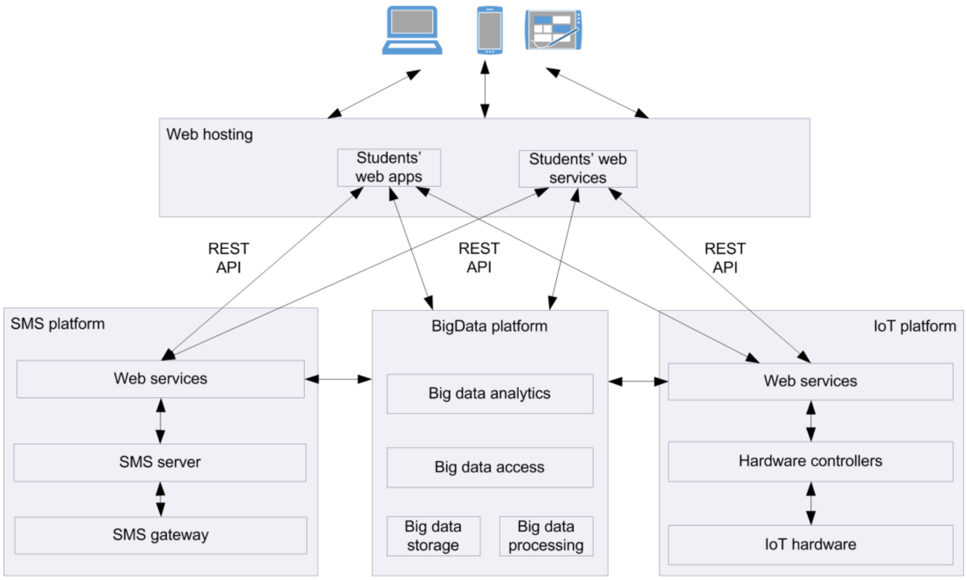

Fig. 7 Architecture of the SMS, IoT and Big Data platforms

The IoT platform is developed in order to support the education in the field of designing Internet of Things applications [47][48]. During the lectures students gain an insight into the hardware aspects of the Internet of Things; however, the focus of the course is on the software aspects. Therefore, the platform abstracts the hardware layer, and consists of: IoT hardware that includes Raspberry PI and Arduino devices [49] connected with a number of different sensors and actuators; hardware controllers that include pre-programmed features necessary for gathering sensor data and manipulating the actuators; web services available to students to integrate them into their own applications.

The Internet of Things projects in time can generate large quantities of data. Therefore, big data infrastructures are often used to store and search sensor data. Students can use the big data platform to store and analyze their data. The architecture enables real time analytics that students can implement within their projects.

In order to support the development of SMS based applications for courses in the fields of mobile technologies and the Internet of Things, an SMS platform has been developed. The platform provides REST API for the integration of SMS services into students' web or mobile applications. An SMS gateway device connected to GSM network is used to send and receive SMS messages. Gnokii is used as an SMS server. It runs on a virtual machine connected to an SMS gateway device. The SMS application has been developed with the aim to sort the received SMS messages to separate users' inboxes and generate API keys. These features are provided to students through a web portal. Students can login by using their Moodle credentials. After login, students can view their personal API key which is used for authentication to the web service. Using the REST API, students can integrate SMS services into their application.

4. EVALUATION AND DISCUSSION

The evaluation of the performance and benefits that cloud computing brings to educational institutions may be as complex as designing and developing the cloud infrastructure itself. Most of the models for evaluation of the cloud are created for business environments, where the main KPIs are related to costs, ROI, availability, and scalability. Although these factors are important in the educational contexts, factors related to pedagogical aspects and flexibility in the design the e-learning courses are more important. Students' and teachers attitudes towards cloud services have been studied by many researchers [14][50], as well as the metrics for high performance systems within educational and research institutions [51]. However, a good method for an overall evaluation of usefulness of educational clouds and flexibility in designing e-learning courses cannot be found in the literature yet. Therefore, in this paper we will focus on three aspects:

1) Analysis of data related to internal metrics for cloud provisioning, such as networking, storage and processors. This information should provide a base for better utilization of the available resources.
2) Analysis of results that students achieve when using the developed SMS and IoT PaaS. These results should encourage teachers to use cloud services more frequently.
3) Discussion of benefits that cloud services bring to e-learning environments. This analysis should contribute to a better incorporation of cloud services as integral elements of e-learning courses.

4.1. Analysis of cloud performance

The performance of a cloud computing system is determined by the analysis of the characteristics involved in performing an efficient and reliable service that meets requirements under stated conditions and within the maximum limits of the system parameters [52].

In order to measure the performance of the developed cloud computing infrastructure, a performance measurement framework has been applied. The framework defines qualitative and quantitative concepts as well as basic measuring functions (Fig. 8). To measure the resource utilization four functions are used: Failure function, Task function, Time function and Transmission function. The Time function is based on different methods for gathering data related to CPU user utilization, job duration and response time. The measurement procedure is similar for all the functions. The measures are then grouped together, depending on the desired perspective: user, developer, or maintainer.

Finally, the performance analysis is supported by an analysis model to help interpret the results by relating them to the initial performance requirements.

Cloud performance has been measured through load, CPU, and memory usage. Networking metrics include parameters related to type of traffic, latency, throughput, and reliability. Cloud storage is usually evaluated through availability and reliability which can be unambiguously measured, but also through security, simplicity and usability for users that are harder to quantify. For processor usage in private educational clouds, we can choose processor utilization or idle time as metrics, since these might give us an insight into how to improve the usage of available resources. Parameters should be measured on the levels of physical and virtual resources, in order to enable a better utilization of all resources on all levels.

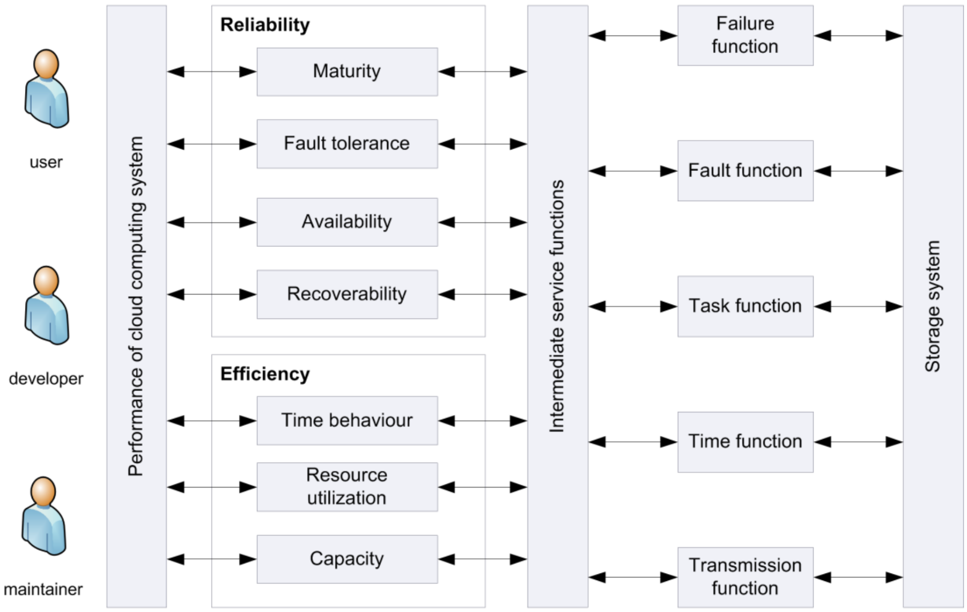

Fig. 8 Performance measurement model for cloud computing

Table 2 shows parameters related to resource usage within the developed private cloud of the E-business Lab. Parameters are shown for three representative services: Moodle, Hosting service (virtual machine which hosts most of the mentioned teaching and learning services), and Students' hosting service, where all students projects are hosted. Maximum and average parameters are shown for the semester period and for the exam period.

Table 2 Performance metrics of the private educational cloud

		During semester		During exam period	
Service	Metrics	Max	Average	Max	Average
Students' Hosting service	CPU Utilization	55%	7%	65%	32%
	Load	17.3M	145K	21.4M	612K
	Memory usage	7.9G	3.72G	8.1G	5.87G
Moodle	CPU Utilization	20%	2%	55%	13%
	Load	8.61M	182K	36.69M	2.61M
	Memory usage	14G	6G	23.7G	11G
Hosting service	CPU Utilization	48%	5%	86%	28%
	Load	4.8M	124K	7.4M	419K
	Memory usage	5.5G	3G	8.8G	4G

The results in Table 2 show that all the parameters are in the acceptable range. A detailed analysis showed that maximum values were achieved in expected cases, e.g. during classes where around 60 students use the services concurrently, or during the exam when around 500 students access the Moodle service simultaneously. High values of average memory usage are due to the reasonably high level of cached data.

4.2. Analysis of students' results

In order to evaluate the students' satisfaction and results when using the developed IoT and SMS PaaS, research has been conducted on a test sample of 8 students who attended a Mobile Business course at the master studies in E-business. The students were asked to participate in a workshop, where they were required to develop mobile applications using IoT and SMS PaaS. The task was to develop a mobile application for managing the air condition within a smart house. Students' applications should enable functionalities to read the sensor data, turn on and off the air conditioning system, through an Android application and through SMS. Students were grouped into four groups with two members in each group.

Students were provided with a preconfigured IoT hardware based on Arduino microcontroller connected with a temperature sensor. The Arduino microcontroller was connected to a Raspberry PI microcomputer, which was configured as an Arduino controller and as a web server. Raspberry PI was also connected to a LED diode used to simulate an air conditioning system. In addition, students were provided with the functionalities of the IoT platform that enable students' applications to read the sensor data, and to turn on or off the air conditioning. Functionalities of the SMS platform included features to send and receive SMSs.

The goal of the study was to examine the students' impressions about the IoT and SMS platforms, as well as the attitudes towards this type of learning. Two instruments were used in the research: a questionnaire for gathering data on students' attitudes about the IoT platform and learning of the IoT, and a test for assessing the students' knowledge. The questionnaire required students to grade the ease of use, quality of documentation, impacts on knowledge and motivation.

An average grade that students achieved on the test is 8.31, with a standard deviation of 0.66. The analysis of questions showed that students had the most problems with questions related to hardware issues, while the questions related to software aspects were answered correctly by most of the students.

Scores that students assigned to each considered aspect of IoT and SMS platforms are shown in Table 3:

Table 3 Students' impressions about IoT and SMS platforms

	High Score=5	Neutral Score=3	Low Score=1	Average
Ease of use	6	2	0	4.5
Documentation	8	0	0	5
Impact on knowledge	8	0	0	5
Impact on motivation	6	1	1	4.25

The data in Table 3 show that students are generally satisfied with the designed platforms. All of the students thought that the documentation and the impact on the knowledge were adequate. An average score for the impact on motivation was lowest, although every result above 4 can be considered as satisfactory.

Some of the students' impressions were:

- "It is intriguing, interactive, and fun. It was very motivating."
- "I could gain useful and applicable knowledge."
- "I liked that I could see the results of the programming at once."
- "Documentation should contain more code examples and video tutorials."

The main deficiency of the pilot class was the fact that only eight students participated. Still, currently there are not many research papers concerning the aspects of teaching and learning the IoT using PaaS, therefore some general remarks useful for future research and teaching can be given. The students suggested the help from the teachers was important for the completion of their tasks; this especially needs to be considered if future classes are performed with a larger number of students. IoT exercises that attempt to encompass both the hardware and software aspects of IoT should likely be of longer length, as the students were mostly in favour of 3-hour classes over those twice as short. The SMS service that was provided for sending and receiving SMS messages was very well liked, although it was not a core part of the IoT. This is probably due to the fact that SMS messages are a very familiar concept, and it allowed the students to envision IoT integration in a more realistic manner. The students should therefore be provided with as many other services as possible in order to widen the possibilities and increase motivation. Students also felt that seeing the results of programming immediately was very motivating, so IoT exercises should be designed in such a way to provide directly verifiable results, and preferably a direct impact on the physical world in some way.

4.3. Discussion

The cloud infrastructure brings educational institutions commonly known benefits such as using services on demand, resource elasticity, and mechanisms for measuring the usage of resources by numerous parameters [15][46]. Specific benefits are reflected in the fact that cloud is suitable for cases when processes, applications, and data are largely independent, for example in different e-learning courses [6]. This can be effective in cases where cloud resources are needed for a course during the semester, but less needed when the semester is over. In this way, the same resources can be used for teaching different courses, without major infrastructure changes [15]. Also, points of integration are well defined, and lower level of security is acceptable.

One of the main challenges in designing the private cloud for e-learning is that it is rather complex and requires specific expert knowledge [16]. Highly skilled staff is needed to design, implement, and maintain the network, cloud, and e-learning services. In the described approach, it is assumed that these experts can be found within educational institutions that realize study programs in the fields of information technologies and computer sciences.

In addition, initial costs required for the realization of a private cloud can be significant, and in some cases, it may be less expensive to use services provided by a commercial cloud provider. However, private clouds provide high flexibility in designing e-learning courses [6][8]. The concept of network as a service gives possibilities to organize and use the physical infrastructure through heterogeneous logical infrastructures, where each user, i.e.

student, within each course can be provided with a required infrastructure [10]. Finally, introducing new services within a private cloud is expected to have lower costs in comparison with public clouds.

5. CONCLUSION

The main contributions of the paper are reflected in an innovative model of the cloud-based infrastructure that enables hosting of a corpus of e-learning services. Using hierarchical model in network design enables a high level of scalability and reliability. Further, the model of infrastructure based on a private cloud is suitable for educational institutions. Learning services are provided as infrastructure, platform or software on demand. In addition, software defined networks provide multi-tenancy and network as a service. The model is especially suitable as a support to study programs in the fields of emerging information technologies, where applications and usage scenarios are new and often experimental. The model has been implemented and used within the e-learning system in the E-business Lab, the Faculty of Organizational Sciences.

Future research is directed toward mainstreaming the infrastructure for big data into other areas of application, and improving the platform as a service for projects in the area of the Internet of Things. Also, modern pedagogical approaches, such as game based learning, learning in context, etc., that include advanced IT services are going to be applied and evaluated.

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REFERENCES

[1] J. C. Marcos Recio and J. Alcolado Santos, "A New Educational Paradigm: From E-learning to Cloud Learning (C-Learning). Knowledge in the Cloud.," in *EDULEARN11: 3RD International Conference on Education and New Learning Technologies*, 2011, pp. 4932–4941.
[2] N. Sultan, "Cloud computing for education: A new dawn?," *Int. J. Inf. Manage.*, vol. 30, no. 2, pp. 109–116, 2010.
[3] N. Radhakrishnan, N. P. Chelvan, and D. Ramkumar, "Utilization of Cloud Computing in E-learning Systems," in *2012 International Conference on Cloud Computing Technologies, Applications and Management (ICCCTAM)*, 2012, pp. 208–213.
[4] M. H. Sqalli, M. Al-saeedi, F. Binbeshr, and M. Siddiqui, "UCloud: A Simulated Hybrid Cloud for A University Environment," in *2012 IEEE 1ST International Conference on Cloud Networking (CLOUDNET)*, 2012.
[5] V. Vujin, "Cloud computing in science and higher education," *Management*, vol. 16, no. 59, pp. 65–70, 2011.
[6] M. Despotović-Zrakić, V. Milutinović, and A. Belić, Eds., *Handbook of Research on High Performance and Cloud Computing in Scientific Research and Education*. IGI Global, 2014.
[7] L. Xu, L. Liu, and C. Wu, "Services Enhancing Usage of Large Equipments in a Private Cloud," in *2013 International Conference on Service Sciences (ICSS 2013)*, 2013, pp. 118–122.
[8] F. Doelitzscher, A. Sulistio, C. Reich, H. Kuijs, and D. Wolf, "Private cloud for collaboration and e-Learning services: from IaaS to SaaS," *Computing*, vol. 91, no. 1, pp. 23–42, Jan. 2011.
[9] B. Radenković, M. Despotović-Zrakić, Z. Bogdanović, V. Vujin, and D. Barać, "Designing network infrastructure for an e-learning cloud," in *The Fourth International Conference on e-Learning (eLearning-2013)*, 2013.
[10] P. Wolf, C. Matteo, M. Peter, and A. L. Pietzuch, "NaaS: Network-as-a-Service in the Cloud." [Online]. Available: http://research.microsoft.com/en-us/um/people/pcosta/papers/costa12naas.pdf.

[11] S. Paul, R. Jain, M. Samaka, and J. Pan, “Application delivery in multi-cloud environments using software defined networking,” *Comput. Networks*, 10.1016/j.comnet.2013.12.005, Feb. 2014.
[12] C. J. S. DeCusatis, A. Carranza, and C. M. DeCusatis, “Communication within Clouds: Open Standards and Proprietary Protocols for Data Center Networking,” *IEEE Commun. Mag.*, vol. 50, no. 9, pp. 26–33, Sep. 2012.
[13] V. Vujin, A. Milić, M. Despotović-Zrakić, B. Jovanić, and B. Radenković, “Development and Implementation of E-Education Model in a Higher Education Institution,” *Sci. Res. Essays*, vol. 7, no. 13, Apr. 2012.
[14] M. Despotović-Zrakić, K. Simić, A. Labus, A. Milić, and B. Jovanić, “Scaffolding Environment for e - Learning through Cloud Computing,” *Educ. Technol. Soc.*, vol. 16, no. 3, pp. 301–314, 2013.
[15] L. M. Vaquero, “EduCloud: PaaS versus IaaS Cloud Usage for an Advanced Computer Science Course,” *IEEE Trans. Educ.*, vol. 54, no. 4, pp. 590–598, Nov. 2011.
[16] M. N. Ameen, H. A. Sanjay, and Y. Patel, “A Service Provisioning and Managing Framework for Platform as a Service in Educational Cloud,” in *2012 2ND IEEE International Conference on Parallel, Distributed and Grid Computing (PDGC)*, 2012, pp. 262–267.
[17] Gartner, “Gartner Identifies the Top 10 Strategic Technology Trends for 2014,” *Gartner, Orlando, Florida*, 2013. .
[18] IEEE Spectrum, “2014 Top Tech to Watch,” 2014. [Online]. Available: http://spectrum.ieee.org/static/2014-top-tech-to-watch.
[19] D. Milojičić, “IEEE Computer Society 2022 Report,” in *Joint Seminar on Computer Science and Applied Mathematics, 30.12.2013.*, 2013.
[20] European Commission, “Horizon 2020 Work Programme 2014-2015,” 2013.
[21] S. Suriadi, E. Foo, and A. Jøsang, “A user-centric federated single sign-on system,” *J. Netw. Comput. Appl.*, vol. 32, no. 2, pp. 388–401, Mar. 2009.
[22] B. Radenković, M. Despotović-Zrakić, Z. Bogdanović, V. Vujin, and D. Barać, “Designing network infrastructure for an e-learning cloud,” in *The Fourth International Conference on e-Learning (eLearning-2013)*, 2013.
[23] Y.-W. E. Sung, X. Sun, S. G. Rao, G. G. Xie, and D. A. Maltz, “Towards Systematic Design of Enterprise Networks,” *IEEE/ACM Trans. Netw.*, vol. 19, no. 3, pp. 695–708, Jun. 2011.
[24] Z. Xiyang and C. Chuanqing, “Research on VLAN Technology in L3 Switch,” in *2009 Third International Symposium on Intelligent Information Technology Application*, 2009, pp. 722–725.
[25] X. Wang, H. Zhao, M. Guan, C. Guo, and W. Jiyong, “Research and implementation of VLAN based on service,” in *GLOBECOM ’03. IEEE Global Telecommunications Conference (IEEE Cat. No.03CH37489)*, vol. 5, pp. 2932–2936.
[26] M. Yu, J. Rexford, X. Sun, S. Rao, and N. Feamster, “A survey of virtual LAN usage in campus networks,” *IEEE Commun. Mag.*, vol. 49, no. 7, pp. 98–103, Jul. 2011.
[27] M. Bist, M. Wariya, and A. Agarwal, “Comparing delta, open stack and Xen Cloud Platforms: A survey on open source IaaS,” in *2013 3rd IEEE International Advance Computing Conference (IACC)*, 2013, pp. 96–100.
[28] A. Corradi, M. Fanelli, and L. Foschini, “VM consolidation: A real case based on OpenStack Cloud,” *Futur. Gener. Comput. Syst.*, vol. 32, pp. 118–127, Mar. 2014.
[29] J. Bernal Bernabe, J. M. Marin Perez, J. M. Alcaraz Calero, F. J. Garcia Clemente, G. Martinez Perez, and A. F. Gomez Skarmeta, “Semantic-aware multi-tenancy authorization system for cloud architectures,” *Futur. Gener. Comput. Syst.*, vol. 32, pp. 154–167, Mar. 2014.
[30] “Neutron’s Developer Documentation.” [Online]. Available: http://docs.openstack.org/developer/neutron/.
[31] L. Liu, “Computing infrastructure for big data processing,” *Front. Comput. Sci.*, vol. 7, no. 2, pp. 165–170, Apr. 2013.
[32] H. Chen, R. H. L. Chiang, and V. C. Storey, “Business Intelligence and Analytics: From Big Data to Big Impact,” *MIS Q.*, vol. 36, no. 4, pp. 1165–1188, Dec. 2012.
[33] N. G. Hall, “Project management: Recent developments and research opportunities,” *J. Syst. Sci. Syst. Eng.*, vol. 21, no. 2, pp. 129–143, Jun. 2012.
[34] M. Braglia and M. Frosolini, “An integrated approach to implement Project Management Information Systems within the Extended Enterprise,” *Int. J. Proj. Manag.*, vol. 32, no. 1, pp. 18–29, Jan. 2014.
[35] V. Stantchev, R. Colomo-Palacios, P. Soto-Acosta, and S. Misra, “Learning management systems and cloud file hosting services: A study on students’ acceptance,” *Comput. Human Behav.*, vol. 31, pp. 612–619, Feb. 2014.
[36] D. Dunford, “Managed file transfer: the next stage for data in motion?,” *Netw. Secur.*, vol. 2013, no. 9, pp. 12–15, Sep. 2013.
[37] M. B. Piedade and M. Y. Santos, “Student Relationship Management: Concept, practice and technological support,” in *2008 IEEE International Engineering Management Conference*, 2008, pp. 1–5.

[38] B. Radenkovic, M. Despotovic-Zrakic, Z. Bogdanovic, A. Labus, and M. Milutinovic, "Providing services for student relationship management on cloud computing infrastructure," in *2013 11th International Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Services (TELSIKS)*, 2013, pp. 385–388.

[39] M. Despotovic-Zrakic, A. Markovic, Z. Bogdanovic, D. Barac, and S. Krco, "Providing Adaptivity in Moodle LMS Courses," *Educ. Technol. Soc.*, vol. 15, no. 1, pp. 326–338, 2012.

[40] M. Despotović-Zrakić, D. Barać, Z. Bogdanović, B. Jovanić, and B. Radenković, "Integration of web based environment for learning discrete simulation in e-learning system," *Simul. Model. Pract. Theory*, vol. 27, pp. 17–30, Sep. 2012.

[41] M. Despotović-Zrakić, D. Barać, Z. Bogdanović, B. Jovanić, and B. Radenković, "Web-based Environment for Learning Discrete Event Simulation," *J. Univers. Comput. Sci.*, vol. 18, no. 10, pp. 1259–1278, May 2012.

[42] M. Despotović-Zrakić, D. Barać, Z. Bogdanović, B. Jovanić, and B. Radenković, "Software Environment for Learning Continuous System Simulation," *Acta Polytech. Hungarica*, vol. 11, no. 02, Feb. 2014.

[43] Z. Bogdanović, D. Barać, B. Jovanić, S. Popović, and B. Radenković, "Evaluation of mobile assessment in a learning management system," *Br. J. Educ. Technol.*, p. n/a–n/a, Feb. 2013.

[44] M. Milutinović, A. Labus, V. Stojiljković, Z. Bogdanović, and M. Despotović-Zrakić, "Designing a mobile language learning system based on lightweight learning objects," *Multimed. Tools Appl.*, Sep. 2013.

[45] A. Labus, K. Simić, M. Vulić, M. Despotović-Zrakić, and Z. Bogdanović, "An Application of Social Media in eLearning 2.0," in *Proceedings of the 25th Bled eConference eDependability: Reliable and Trustworthy eStructures, eProcesses, eOperations and eServices for the Future*, 2012, pp. 557–572.

[46] Z. Bogdanovic, M. Despotovic-Zrakic, M. Milutinovic, M. Andjelic, and S. Milinovic, "Model for Enhanced Data Management, Visualization, and Adaptation in e-learning," *Manag. - J. theory Pract. Manag.*, vol. 18, no. 69, pp. 5–14, Dec. 2013.

[47] J. Carretero and J. D. García, "The Internet of Things: connecting the world," *Pers. Ubiquitous Comput.*, vol. 18, no. 2, pp. 445–447, May 2013.

[48] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of Things (IoT): A vision, architectural elements, and future directions," *Futur. Gener. Comput. Syst.*, vol. 29, no. 7, pp. 1645–1660, 2013.

[49] A. D'Ausilio, "Arduino: a low-cost multipurpose lab equipment.," *Behav. Res. Methods*, vol. 44, no. 2, pp. 305–13, Jun. 2012.

[50] W.-W. Wu, L. W. Lan, and Y.-T. Lee, "Factors hindering acceptance of using cloud services in university: a case study," *Electron. Libr.*, vol. 31, no. 1, pp. 84–98, 2013.

[51] T. R. Furlani, M. D. Jones, S. M. Gallo, A. E. Bruno, C.-D. Lu, A. Ghadersohi, R. J. Gentner, A. Patra, R. L. DeLeon, G. von Laszewski, F. Wang, and A. Zimmerman, "Performance metrics and auditing framework using application kernels for high-performance computer systems," *Concurr. Comput. Pract. Exp.*, vol. 25, no. 7, pp. 918–931, May 2013.

[52] L. Bautista, A. Abran, and A. April, "Design of a Performance Measurement Framework for Cloud Computing," *A J. Softw. Eng. Appl.*, 2011.