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## DESIGNING NETWORK INFRASTRUCTURE FOR AN E-LEARNING CLOUD

BOŽIDAR RADENKOVIĆ

Faculty of organizational sciences, University of Belgrade, boza@elab.rs

MARIJANA DESPOTOVIĆ-ZRAKIĆ

Faculty of organizational sciences, University of Belgrade, maja@elab.rs

ZORICA BOGDANOVIĆ

Faculty of organizational sciences, University of Belgrade, zorica@elab.rs

VLADIMIR VUJIN

Faculty of organizational sciences, University of Belgrade, vujin@elab.rs

DUŠAN BARAĆ

Faculty of organizational sciences, University of Belgrade, dusan@elab.rs

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**Abstract:** This paper discusses the aspect of designing network infrastructure for e-learning private clouds. The aim is to build a comprehensive, stable, scalable, reliable and flexible infrastructure that will effectively support all models of deploying cloud computing services in academic environment. Main component of the infrastructure is a network organized in three logical layers: core, distribution and access. Functions of the access and distribution layer are integrated in the cloud. OpenFlow protocol was used as an interface for software switches in cloud. The implementation of the model and the system for network management in an educational institution are described in details. The developed infrastructure can host numerous services for learning and collaboration for both students and teaching staff.

**Keywords:** network infrastructure, e-learning services, e-learning cloud

### 1. INTRODUCTION

Modern e-learning systems provide diverse services, environments, resources and content for both facilitators and students in educational process. Accordingly, requirements for design and implementation of e-learning environments become more cumbersome. These systems are facing problems related to optimizing resource management, managing dynamic concurrency requests, providing scalability, availability, sustainability and equilibrium of services and storages and cost management. Current models of information systems for e-learning lack the support of underlying infrastructures [1]. There is a need to redesign existing approaches and paradigms in developing and maintaining e-learning systems.

In this paper, we propose a model for designing the network infrastructure for educational clouds. The solution was implemented using advanced network protocols in the model, such as OpenFlow. Main goal was to provide teachers and students with comprehensive, scalable and flexible infrastructure for e-learning, foster setting up new services, and enable efficient and cost-effective usage of software and hardware resources. The research is directed towards making an impact in practice. The results described in the paper should leverage dissemination of knowledge and awareness of potential benefits of cloud computing in academic environment.

### 2. E-LEARNING INFRASTRUCTURE

Recent researches in e-learning focused on the reuse of learning material, but not on IT infrastructure, services and applications. IT Infrastructure include set of networks, IT facilities, hardware and software that underlies e-learning system and enable managing, developing and testing all e-learning services. Figure 1 depicts the model of IT infrastructure that includes basic elements of the infrastructure (horizontal blocks), users of the infrastructure, and qualitative performance indicators (vertical blocks). These interconnected components represent a basis for all the processes, services and application software in e-learning system [2]. Vertical blocks, i.e. indicators that measure security, availability and performance are related to the quality of each component in the model. They are considered as the most important factors of the whole infrastructure, as they should be designed and implemented so to provide availability, scalability, reliability, and self recovery. Values of the performance indicators are directly related to the overall usability of the infrastructure. Another important component is related to system management that provides mechanisms for monitoring and managing each component of the infrastructure.

In further text, cloud computing is discussed as a solution for achieving the quality of the IT infrastructure for e-learning.

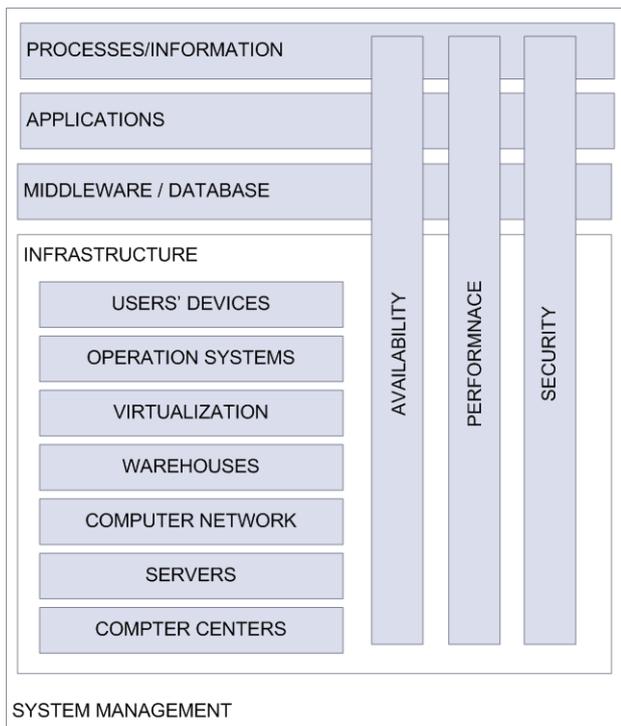


Figure 1: Model of IT infrastructure for e-learning

### Cloud computing for e-learning

Harnessing cloud computing within educational institutions enable efficient usage of existing resources and gives a new perspective to scalability and reliability of educational services, software and a system for e-education [3]. Researches and case studies pointed out the most common approaches, not only within universities, but in general, are private and public cloud [3]. Public clouds are owned and operated by cloud service providers. Opposite the public cloud model, a private cloud model enables educational institutions to have complete control of identity management, services, data security, applications and resources that are provided to their users. Recently, the number of private cloud based solutions within e-learning systems has been significantly increased [4]. Managing infrastructure and access control for e-learning applications remains one of the emerging challenges in IT area today. Further this problem became more complex in e-learning systems, where different resources and educational services are deployed through private clouds.

The main reason for implementing a private cloud is that the existing IT resources can be used in a more effective way. Private cloud would enhance research and educational processes and enable seamless integration of the cloud paradigm in the e-learning system. Specifically, when teaching courses related to computer science, students can be provided with an appropriate environment for application development, and sophisticated software tools. One of the main challenges in cloud computing environment is designing and managing the network infrastructure that could effectively support all cloud computing models [5].

## 3. NETWORK INFRASTRUCTURE FOR AN E-LEARNING CLOUD

### Model of network infrastructure for a cloud

Network infrastructure of a modern academic institution needs to provide modern ICT services to teachers, students and administrative staff. Information system should enable access to information and educational contents in real time and 24/7. Therefore, the network infrastructure should provide a basis for e-learning services with high level of availability, scalability and reliability. Flexibility and high level of security are also important requirements, as well as possibility for quick, simple and fast installation of new software and hardware systems. Therefore, cloud computing architecture is a viable approach for academic community [6][7][8].

Conceptual model of the network architecture for an educational cloud is presented in Figure 2. Hierarchical network model [9] has been used for designing the model. This model is based on the principles of hierarchy and modularity. Complex networks are divided in layers, where each layer performs the specific function.

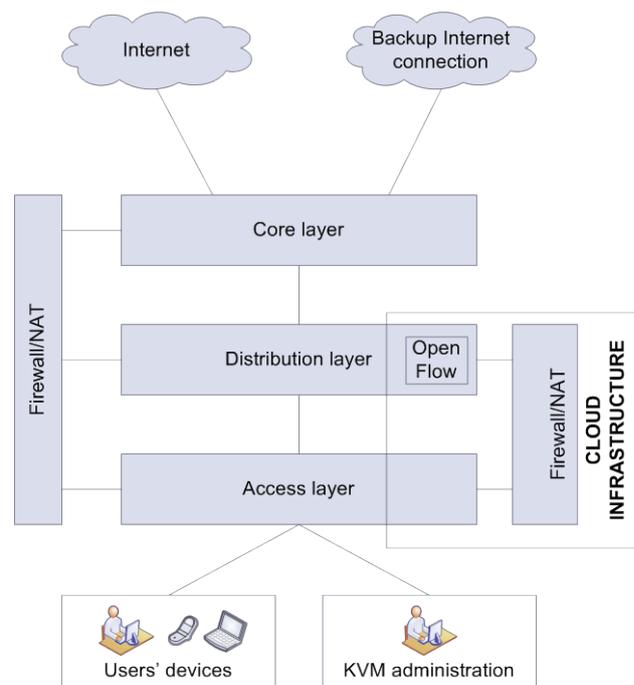


Figure 2: Conceptual model of the network architecture for educational cloud

Core layer is a backbone of the network and the most critical layer in the network. It provides connectivity between devices on distribution layer, therefore, high availability and redundancy are very important. This layer aggregates the traffic from all devices on distribution layer. Devices on the core layer (switches and routers) need to support high throughput with low latency. This layer is also used for connecting to Internet, so the security aspects are also important. Large data quantities and Internet connection require devices with high performances. Core devices in educational institutions are used to connect to backbone of academic networks.

Distribution layer is an interface between access and core layers. The main task of the distribution layer is to provide aggregation of data from the access layer before forwarding the data to core layer. The core layer then sends data to its final destination. Distribution layer controls the network traffic by using policies and defining broadcast domains, which can be achieved by implementing routers and VLANs. Distribution layer should consist of high performance devices. Redundancy can be achieved by using multiple devices, with redundant connection among themselves, as well as toward the core devices. In the cloud computing environment, some of the distribution functions are implemented within the cloud, as virtual network devices.

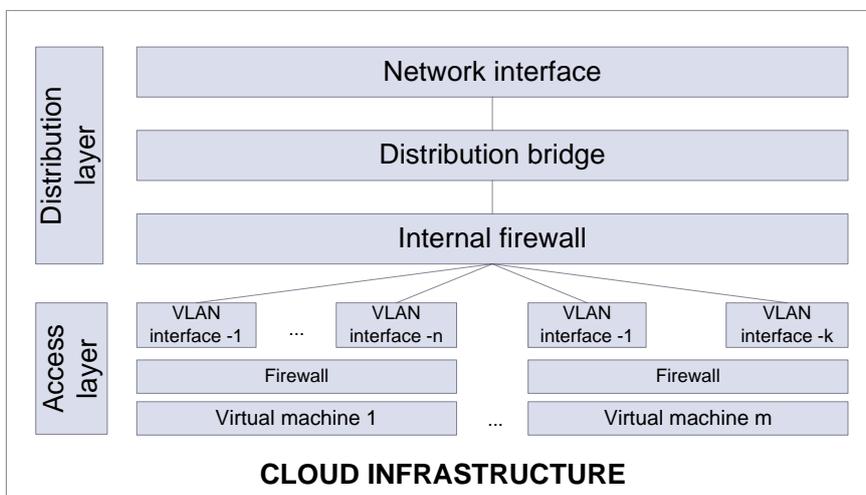
Access layer is an interface to end users. It is a link between end user devices and the rest of the network. This layer includes devices such as desktop computers, printers, IP phones, as well as routers, switches, hubs, access points, etc. used to connect those devices to the network. Another important task of this layer is access control, realized through defining which devices are allowed to access and communicate through the network.

Firewall/NAT is a software or hardware component of the network infrastructure that controls the incoming and outgoing network traffic. The main task of this network component is control of the packages by using the defined rules. NAT (Network Address Translation) is a process of modification of IP addresses in IPv4 header while passing through the routing device.

Part of the network infrastructure is realized as traditional network infrastructure. The other part is realized within the private cloud of an educational institution. Cloud network infrastructure includes parts of distribution and access layer. This approach enables effective further development of cloud e-learning services.

Organization of the network part of the cloud infrastructure is show in the Figure 3. One physical host can include many virtual machines, i.e. virtual hosts. For each virtual host its own firewall should be configured. Each virtual host has several VLAN interfaces, in order to enable network traffic between different VLANs. VLAN interfaces of virtual host are connected to network interfaces of physical hosts. Each physical host has its own internal firewall and distribution bridge for connecting to the other parts of the network.

Advantages of using the hierarchical model are manifold. This model can efficiently solve the problem of redundant network broadcast, and lower the CPU load of network devices. Also, the cost of the implementation can be significantly reduced by using this model. For each layer, devices with clearly defined functionalities can be planned, so costs of unnecessary functionalities can be avoided. The principle of modularity simplifies the process of designing the network. Testing of the network, as well as troubleshooting is easier. Network maintenance is also easier, because changes affect smaller number of devices and services.



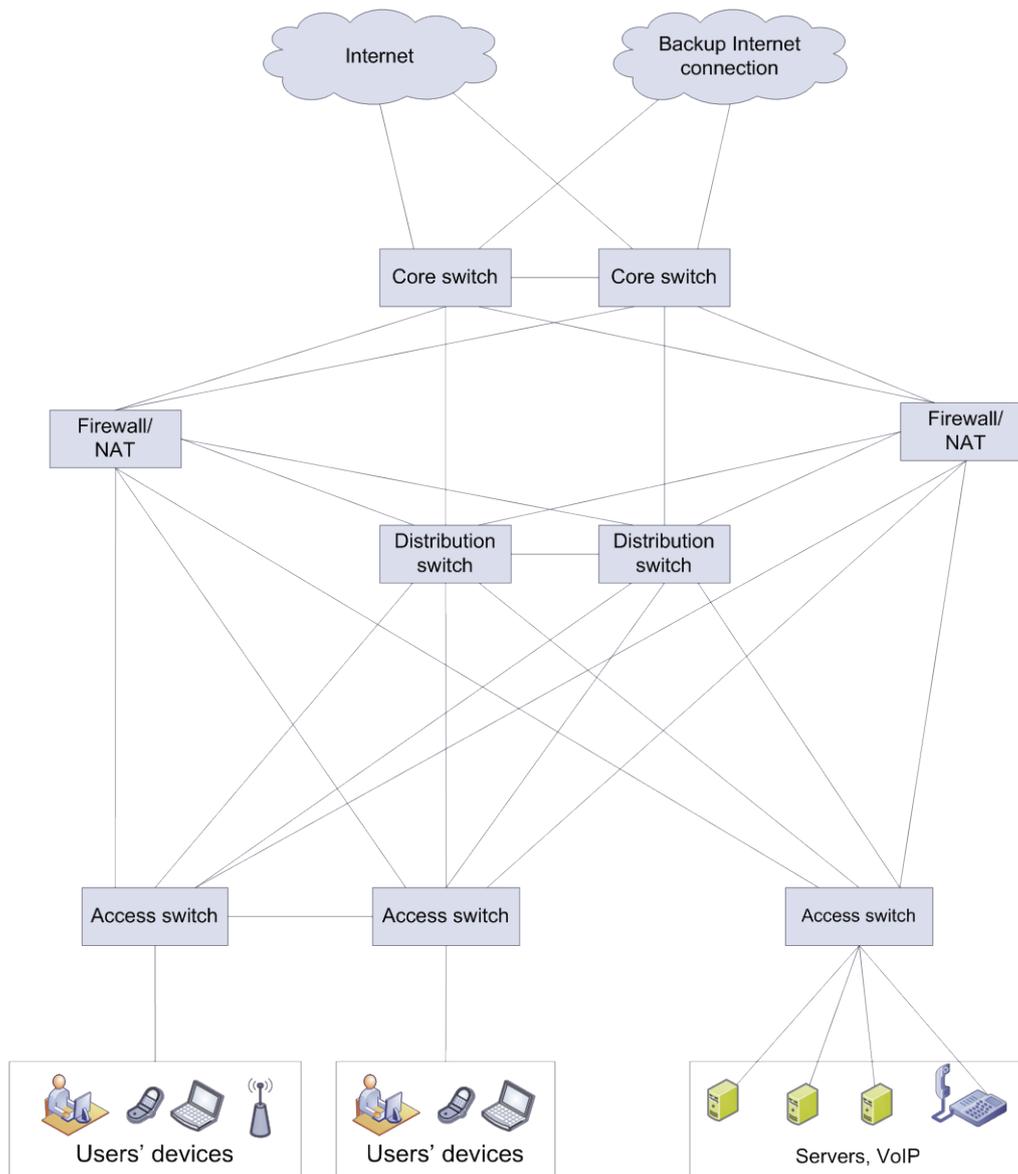
**Figure 3:** Conceptual model of the cloud infrastructure

### Implementation

The presented model is implemented in the Laboratory for e-business, Faculty of Organizational Sciences, University of Belgrade. Laboratory for e-business organizes e-learning courses using blended learning concept [10]. More than 700 students attend over 20 undergraduate and postgraduate studies each year. System for e-education is based on Moodle Learning Management System. Besides Moodle, the Laboratory for e-business provides student with numerous educational services [11] including web hosting for students' projects,

CRM services, communication and collaboration services, and many others.

The network infrastructure of the Laboratory is based on Ethernet technology. Physical model of the implemented network is shown in the Figure 4. The network equipment includes devices of different vendors: Cisco Systems, TP Link, MikroTik. Multi-vendor approach affects the choice of network technologies and protocols. Redundancy is achieved by implementing redundant devices and redundant connections between devices.



**Figure 4:** Physical model of the network architecture

In order to eliminate at second layer of OSI model, MSTP (Multiple Instance Spanning Tree) protocol has been implemented. With respect to complexity of the network, several MSTP instances have been implemented. VLANs were mapped into MSTP instances. Additional features of spanning tree protocol have been configured.

In order to enable high capacity for data transfer link aggregation has been implemented using EtherChannel technologies. LACP (Link Aggregation Control Protocol) was configured on distribution switches. Beside aggregation on the ports that are used for connecting these two switches, the aggregation is defined on the ports toward FW/NAT router.

OpenFlow protocol was implemented in distribution layer as interface of the MikroTik router. In common scenario the high level routing decisions and packet forwarding occur on the same device. An OpenFlow Switch separates these two functions. This protocol is used for providing

mobility of virtual machines, high level security networks, etc.

VLANs were created with aim to enable logical separation of traffic in computer network. Ports of the switches on access layer are configured as access ports. Ports used for interconnecting of the switches, as well as their connections toward routers are configured. Ports that are used for interconnecting of switches, as well as their connections toward routers, are configured as trunk. In this way much more traffic for many VLANs can be transferred.

Layer 3 functionalities within network are implemented on Core and Firewall/NAT routers. Connections among these devices and switches of distribution layer are realized as 802.1Q trunks, through which traffic of many VLANs is transferred. These VLANs are terminated in different interface VLANs and in that way inter-VLAN routing has been implemented.

## Network management, monitoring and security

Implementation of the adequate system for network management is an important factor for achieving this goal. Proactive network management leads to shorter time of network unavailability, prompt problem solving, higher availability of services and lower costs.

One of basic requirements for network management system is security of transfer of data for network management. There are two approaches for increasing the security of transfer of network management data [12]: Out-Of-Band-Management (OOBM), and communication protocols for network management data transfer

OOBM approach is based on using two different networks for production and management. This approach requires completely separated network infrastructure, i.e. dedicated network devices and interfaces for management of network traffic. OOBM part of the network is not connected to Internet, so the security of the system is increased. Disadvantage of this approach is that it is expensive and complex for administration.

Communication protocols for network management provide secure data transfer by using authentication and encryption. The most frequently used network management protocol is SNMP (Simple Network Management Protocol).

In practice, in many cases hybrid approach is used, i.e. a combination of OOBM and communication protocols approach.

Modern information systems have become very complex and it is impossible to manage the network infrastructure without the appropriate network management system. The network management system can be defined as a set of activities, procedures, and tools that enable control, supervision and administration of network resources. Components of the network management system are shown in Figure 5.

In the Laboratory for e-business, the implemented network infrastructure is monitored using the SNMP. Cacti application has been implemented as a performance management system. The main task of the Cacti application is monitoring of parameters of network devices and servers [13]. Most of the devices within the network support SNMP. Also, some parameters can be acquired by creating and executing specific scripts.

SNMP is used for monitoring the network devices (switches, routers). Whenever possible, SNMP v3 should be used. For security reasons, SNMP access should be limited only to management pages, which can be realized by configuring access lists. Parameters that are most frequently monitored are traffic on interfaces and CPU usage. The SNMP protocol also enables monitoring of

different network services. Figure 6 shows an example of the chart showing the mail statistics.

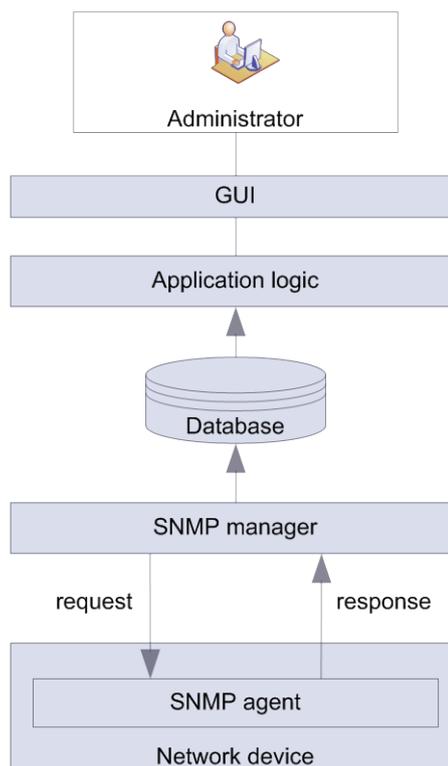


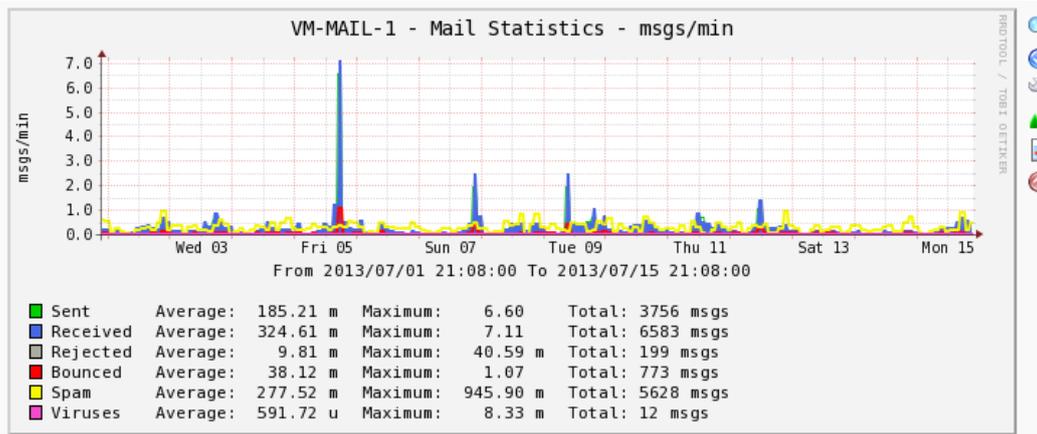
Figure 5: System for network management

The security of the computer network is implemented on several levels: access control, filtering of the traffic, and disabling the services that are not used.

Access control is realized by defining credentials (username and password) for accessing all devices. Administration access for all the equipment is provided only to authorized users. For remote access, SSH protocol is used, as it gives higher level of security comparing to Telnet. Additionally, execution timeout is defined for SSH sessions.

For Cisco devices “enable secret password” feature has been defined. This password is required for accessing the privileged mode of the device, where the configuration of the device can be changed. Also, Cisco devices have a configured option for service password-encryption, which encrypts all passwords in configuration files.

Additional level of protection is achieved by defining access lists (ACL). In this way, administration access to network devices can be given only to defined network addresses. Also, traffic filtering towards backbone of academic network and Internet is defined.



**Figure 6:** Mail statistics report

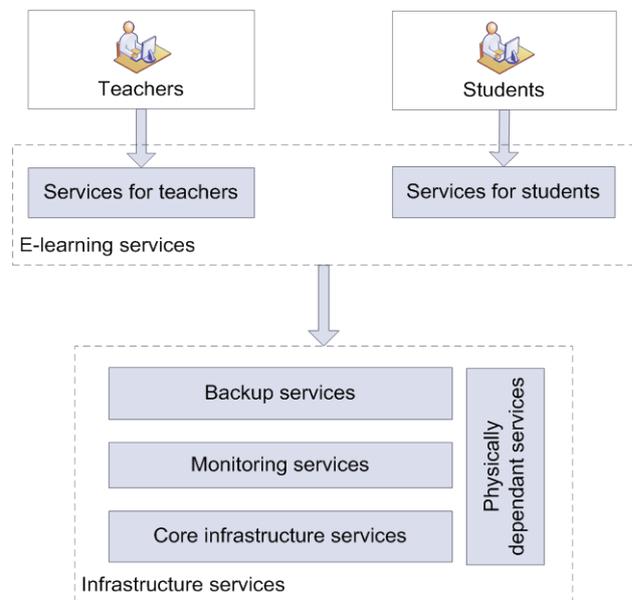
#### 4. E-LEARNING CLOUD SERVICES

Nowadays, in educational institutions, there are numerous services that can be provided to students through Internet. Some of the most commonly used educational services can easily be deployed on the implemented infrastructure: system for e-education, identity management, e-mail, ftp, customer relationship management [14], portal services, services for communication and collaboration, document management system, decision support system, services for scientific research [15], services for teaching support [16], administrative services, etc. Collaborative services for example enable various functionalities related to collaboration of users: information on the various activities and events, information management, project management, user groups, workshops, calendar, discussion forums, team work and so on. Document management system is system used to track and store electronic documents and/or images of paper documents. CRM (in the case of educational institution) is a coherent and complete set of processes and technologies for managing relationships with current and potential students and associates of the educational institution. It represents the permanent care of a relationship between the university and students, where service quality is becoming an ever more interesting question.

Network infrastructure of the Laboratory for e-business is a basis for many services for both teachers and students. These infrastructural services can be grouped as follows (Figure 7):

- Core infrastructure services – critical services that need to be functional in order to enable efficient functioning of services for teaching and learning.
- Monitoring services – services for continuous monitoring of network, hardware and services. They are not necessary for functioning of the whole system, however, they enable fast detection and correction of the problems in the functioning of the infrastructure.
- Backup services – services for creating backup copies of the system. Their continuous functioning enables fast recovery in case of disasters.

- 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.



**Figure 7:** E-learning services deployed on implemented infrastructure

A number of services for students and teachers are deployed on the described infrastructure. Intranet portal is the aggregator of several services used by lab staff. The portal integrates many heterogeneous applications that require different platforms, operating systems and deployment environments. Lightweight Directory (LDAP) server is used for centralized authentication of all users in the system and single sign on is provided through the Intranet portal. Radius server was deployed for controlling the access to different services. Mail and file servers used by a big number of students and staff were installed, too. These types of servers requires secure, reliable and scalable infrastructure. Some additional services for supporting the education process, such as CRM and project management services, are hosted on the implemented infrastructure, too.

Learning management system Moodle provides students and teachers with a variety of services that facilitate learning process. This platform serves a big number of user requests every day and it requires powerful underlying infrastructure. Hosting platform provides students with possibilities to host their own sites and applications. Further, students are provided with services and applications for mobile learning, such as: mobile quizzes, Android OS application for foreign language learning, etc. Several specific applications for teaching and learning specific courses are hosted on the infrastructure, too. For instance, web application for discrete event simulation enables students to design, test and execute their own simulation models. This application needs a lot of computational power of the hosting devices, but the infrastructure fulfils all the requests.

## 5. CONCLUSION

This paper presents a model of network infrastructure designed to support educational cloud services. The use of hierarchical model in the network design makes the designed solution highly scalable and reliable. Modern network protocols and concepts such as OpenFlow were used.

Implementation of the proposed model is applicable and cost effective, and it can be used within any educational institution. As a proof of concept, the designed model was implemented in the Laboratory for e-business, University of Belgrade, where it effectively supports a number of educational services. Further research is needed to evaluate performances of each of the deployed services.

Finally, the authors acknowledge the limitations of the suggested approach. The described solution is complex, and it requires significant engagement of highly qualified human resources. In case of educational institutions where these resources are not available, a public cloud approach might be more suitable.

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