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Design of Virtual Labs : A Step Towards Remote Experimentation

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Abstract—
This research work aims at virtualizing the existing physical lab environment in the Universities by providing students remote access to various labs set up in the domain of engineering education that can be accessed online via internet and offline via sms commands through any modern day device (pc, laptops, smartphones, mobiles, tablets etc.). Virtual labs are an Adaptive Learning Software and an example of Open Educational Resource (OER) available to students anytime, outside university premises and outside regular lab hours to learn and perform experiments at their own convenience without having to download or configure complex software needed to perform the experiments.

Keywords**—***virtual lab; vlab; cloud computing; open educational resource(OER); e-learning; e-lab; remote-lab; Desktop-as-a-Service;CSCL;remote-experiments;internet-based experiments.*

I. INTRODUCTION

Learning must be facilitated among the students by providing them with the practical implementation of a problem rather than only theoretical explanation. Student's laboratory experiments have enormous value for their future engineering ventures .Traditional engineering training labs require complex systems and logistics regarding scheduling, staff, space and security which is not an easily affordable solution for most of the universities [5]. This is one of the major impediments in providing the desired quality of education. As seen in the past few years, the role of the internet in education industry is widespread. So, the motivation behind this research work is to harness the power of the internet to provide a distance education concept to address the issue of outdated physical labs in terms of both software and hardware. This research work aims at building a cost effective solution for interactive experiments to be performed in real world and providing students an advantage of performing the experiments from geographically dispersed location thus eliminating the need to be physically present at the campus in order to use the labs. This helps the students to learn and practice at their own pace and convenience and to develop an engineering approach to solve real world problems. The two main challenges that haunt the present education system from the perspective of training labs are (I) well trained lab assistants. (II) Lack of updated and high performance lab infrastructure. In order to overcome these challenges, Cloud Computing can be used as a paradigm shift instruction principle in learning environments supporting on-demand and self-controlled learning environments. According to National Institute of Standards and technology (NIST) , cloud computing is defined as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (network, servers, storage, and applications) that can be rapidly provisioned and released with minimum management effort or service provider interaction." [9].Utilizing Cloud Computing for building Virtual Labs has the foremost advantage that labs can scale up to the needs of thousands or million online users concurrently enabling wide range of deployment of internet scale solution to large masses of students [3].

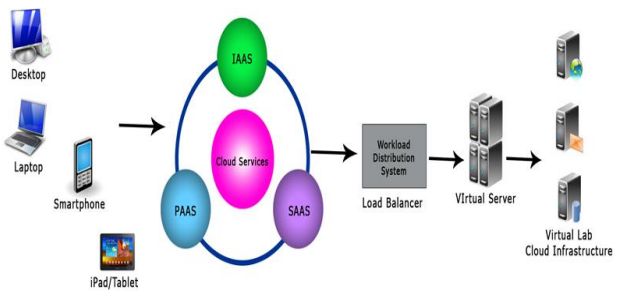

Fig. 1. Logical Diagram of Virtual Labs

The downfalls of traditional physical labs in the universities are:

- If a particular machine goes down or gets corrupted, all the data on it including the OS is lost and the machine has to be re-provisioned which is time taking and not desirable.
- The student might not always get to use the same machine every time, and as such cannot access the files and data of the experiments performed earlier by the student.
- The students are allowed to access the machines on a time slot basis. The students cannot access the machines outside their scheduled lab hours at the university.
- In this rapidly changing world of technology, often the labs do not run latest and updated software and are provisioned on outdated hardware.

These downfalls have been overcome in Virtual Labs using the Cloud Computing Model. The advantages of Virtual Labs over traditional labs are:

- Virtual Labs will be powered on Virtual Machines running on Cloud servers, as such , it will be possible to have the backup of each running VMs . So if something wrong happens with a particular machine, it can be restored using the latest healthy snapshot image instead of full re-provisioning manually.
- All the practical's data and output will be stored on the VM under the account of students. Hence the students can access data from previous experiments for download and review purposes.
- Students can access the Virtual Labs at anytime, anywhere, and from any modern day client device which makes the virtual labs platform independent and helps students to perform experiments at their own convenience.
- Several independent universities may collaborate to develop centralized virtual labs utilizing latest software and hardware. This will reduce cost of individually deploying the latest equipment, and it will be possible to share the equipment with those universities which cannot afford to do so.

Thus Virtual labs are a step towards 'student-centric' pedagogy where the student decides the pace of learning. Virtual labs can be accessed outside college premises (say from home or anywhere else), outside regular lab hours (say during breaks), at any desirable time by the students through any client device (pc, laptops, smartphones, mobiles, tablets etc.,) Thus Virtual labs are extremely useful when physical distances and lack of good resources often make it difficult to perform experiments especially when it involves sophisticated software and hardware [1]. Virtual Labs allow the students and faculties all over to interact with each other to develop a healthy competitive approach to extend lifelong learning and education opportunities and be successful in global education marketplace.

II. METHODOLOGY

Modern day learning theories are based on promoting collaboration among the students. Hence, the design of Virtual Labs must be such that they reflect a perfect example of Computer Supported Collaborative Learning (CSCL). CSCL aims at making students learn from their own observations, using discussion with teachers but also with their peers [8]. The solutions for E-learning that are embraced by the education sector are very old fashioned and outdated that provide inconvenient desktops or Web 1.0 interfaces that are not at all user friendly. Moreover, now a day's people like to spend much of their time on social media than on online education systems. Thus a blend of educational systems and social media is definitely needed to enrich the user experience of Virtual Labs and enhance the efficiency of educational process. Following this pedagogy, a practical approach to implement Virtual Labs is explained in this paper.

A. Design Objectives of Virtual Labs

Any proposed software solution must define some technical objectives in order to meet the required goal. The design objective of Virtual Labs are:

- Building a cloud based Learning and Management System that has an extremely user-friendly and customizable modular design and a multi-lingual Web based front-end GUI build via modern cutting edge web technologies like HTML5, CSS3, JQUERY, AJAX etc.
- Offer on-demand instances or virtual machines to serve the purpose of virtual labs and integrate these VMs with the Learning and Management system to provide an interactive and intelligent training environment to students of different engineering domains.
- Building support for the virtual labs to be used via mobile phones and smartphone applications in order to leverage the capabilities of these devices available in the market today.
- Provide mechanism to perform experiments even to those students who use older mobile phones or GSM based devices which do not have capabilities to connect to the internet.
- Provide mechanisms for the students to save their work on a highly redundant storage

server for later download and analysis by the students.

B. Proposed Architecture of Virtual Labs

Implementation: The proposed architecture intends to build and configure a cloud computing system that delivers a wide range of functionality and services that map well onto the design objectives of the Virtual Labs. Virtual Labs will be powered on a high configuration Private Cloud, publicly accessible to students, through high-speed and high-throughput redundant internet connection. The 3 stacks of cloud computing system will be used to deploy the Virtual Labs on the Cloud.

Infrastructure as a Service (IAAS) stack of cloud computing will provide Virtual Machines to the students, running on cluster of physical servers that have been virtualized using KVM or XEN hypervisors. Each VM will be customized for courses and lab exercises and provisioned to build virtual laboratories for a particular engineering domain. IAAS stack also provides RAID protected, highly redundant storage servers attached to the VMs to backup and save the data running on the VMs. The IAAS stacks will power each of the VM on isolated Content Delivery Networks for infinite scaling, faster speed and enriching user experience while using Virtual Labs.

Platform as a Service (PAAS) stack of cloud computing goes a step further to offer students a framework to perform the experiments remotely on the Virtual Machines. Each VM will be running a webserver for the students to connect to virtual labs, a database server for access control and for storing and retrieving experiments data by the students, and set of software and programming language compilers that the university has in its curriculum for a particular engineering domain..

Finally, Software as a Service (SAAS) stack of cloud computing provides software services and development tools, optimized for a multi-user environment, available to the students to connect to and use the virtual labs. SAAS provides students a customized, user-friendly GUI to interact with the underlying PAAS architecture to deploy their developed programs and codes related to the lab exercises on a well-defined production environment. The advantage of SAAS is that it is a low bandwidth solution for using any software over the network, providing abstraction from the complex design of the software without limiting the functionality of the software.

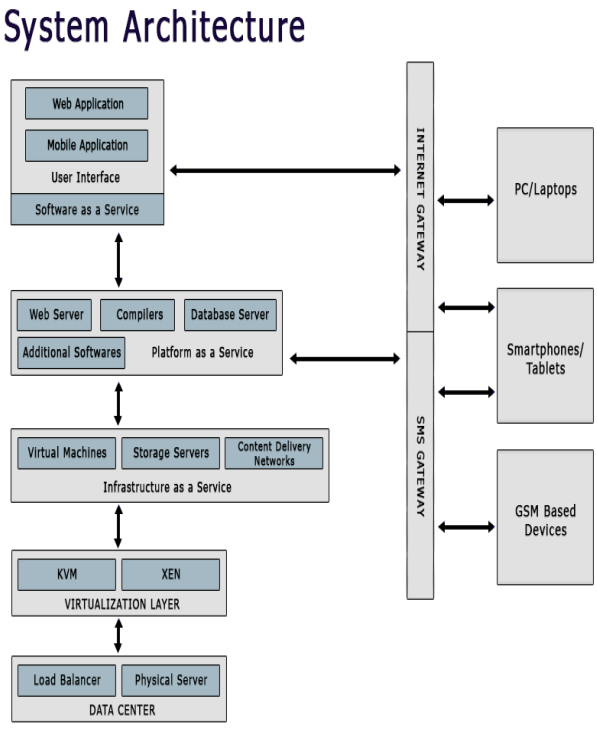

Fig. 2. System Architecture of Virtual Labs

Procedure: Students who want to use the Virtual Labs will have to undergo an online registration process with the university. Upon successful registration, the student receives a user ID and password. With that identification, the student can login to the server and read and download the instruction manual on how to connect and use the virtual labs to perform experiments. Having gone through the manual, the student connects to the virtual lab's user-interface provided by the SAAS stack, typically a web application using the World Wide Web (www) as the communication medium and the web browser as the user-interface on the client side. The Web Application will provide an online Integrated Development Environment (IDE) to the students to write codes or upload already prepared data to start the experiment. The Web application will also provide mechanisms to store and retrieve the data to and from the cloud. The web application will be light weighted so that it can be easily opened in the browsers and thus serve the purpose of not having to download and configure complex software in order to perform the experiment. Since the students are using a Web Browser (Http:// protocol) to perform the experiments the performance of virtual labs depends more upon the strength of the student's internet connection as opposed to the operating system or processing power of their local machines, so even students with outdated computers or desktops can also perform the experiments on the advanced software.

But in today's world when the internet and communication has been revolutionized to a 360 degree, PC (Web browsers) alone are not the only medium to access information to and from the internet. More and more people now a days use smartphones for day to day tasks. This has an advantage of accessing the internet at any time, without the need of personal computers (desktops, laptops etc.). A normal person spends

more time with the smartphones than a PC or Laptop. So if the aim of Virtual Labs is to provide students with unlimited access to labs anytime and anywhere it's very important to bring the Virtual Labs to smartphone devices. Thus the proposed architecture includes building of smartphone application as one of the components. The application serves the same functionality as that of the web application that is to present the students with an IDE to write codes to perform the experiments. The mobile application will be available for all modern mobile operating systems (iOS, android, blackberry, Symbian etc.). This clearly has the advantage of accessing the labs 24*7, even when the student is not in front of the PC for some reason (e.g. travelling).

Few years back, SMS had been the most popular medium for the people to communicate with each other. With the invention of smartphones and different messaging applications the use of SMS has been set-a-back but it is not dead yet. The medium still is popular among the Banking Systems, Online booking systems, Television operators to send important alerts and provide their users to communicate with their systems through sms commands. The power of SMS cannot be ruled-out from perspective of the aim of the Virtual Labs. Thus the proposed architecture also includes building of a system where the students have the option of communicating with the virtual labs using pre-structured sms commands. For this purpose a SMS Gateway will be configured and setup on the Private Cloud along with a Virtual Machine dedicated for sending and receiving the SMS to and from the students. Sms command can serve the purpose to compile programs, change user details, 2 step login verifications, receive important alerts from the university and much more. In order to compile program through sms (for e.g. a program written in C/C++/JAVA), students need to write the whole program in SMS and send it to the sms gateway number .The program will be then stored on the VM as a file under the account of the user, which will get compiled automatically and the output of the program will be sent back to the student in the form of the SMS. (Along with the errors during compile time or run time, if present).

C. Advantages of deploying Virtual Labs on Cloud

The Virtual Labs have its roots in Cloud Computing. The principle of Cloud Computing says that as soon as a client signs up for a particular cloud service, that service is setup and ready to be used by the client. Similarly, the Virtual Labs on different engineering domain will be setup and ready to be used. Students who want to use the labs will have to go through a sign up process and after getting validated they can perform the experiments on the virtual labs. Cloud computing paradigm delivers the required software and hardware to end users at low cost with an exceptionally user-friendly interface through the commonly available internet [2]. Advantages of Cloud Computing in Virtual Labs are:

- Device and Location independence: Cloud computing infrastructure systems can accessed by the users from anywhere over the internet regardless of their location or type of client device used (e.g. PC, mobile phones etc.).
- Virtualization: The virtualization technology isolates the VMs running in cloud systems, as such, if there is a fault or something wrong happens with a particular machine it does not affects the other machines. Since the fault is localized administrators can rectify the issue easily or restore the VM from its image.
- Load Balancing: Load balancing is a technique to increase user capacity (concurrent connections) and reliability of applications. Many cloud service providers integrate load balancers with their private or public cloud products to distribute the workload between two or more servers.
- Utilization and efficiency: The dynamic environment of cloud computing systems allows servers and storage devices to be shared over the network and increase in the utilization of applications.
- Peak-load capacity: Virtual labs are built on Virtual Machines running on different isolated networks, where each VM corresponds to a particular engineering domain. Thus the end users of Virtual labs will not connect to a single machine but to different VMs. Since each VM has its own set of resources (webserver, Ram etc.) the load average on the server will not throttle and the labs will function efficiently and faster in comparison to a scenario if there would have been a single machine to handle the request for all the labs.
- Organized Structure: Last but not the least, running different isolated VMs, one for each engineering domain, provides a better organizational structure. Universities function in the same way by dividing different engineering branches into various departments each having its own staffs and governing rules. Thus, it will be easier to apply security policies on the VMs depending upon the type of applications running on it and also it will be easier to appoint support staffs for particular labs.

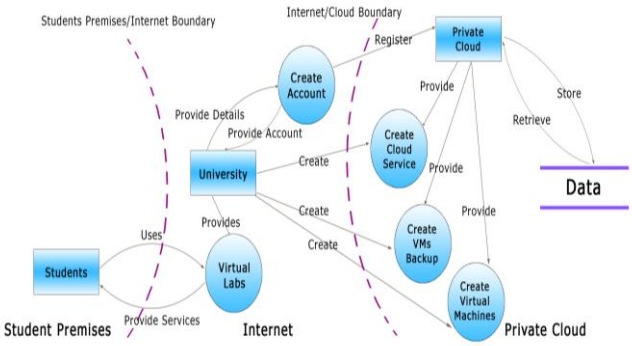

Fig. 3. Data Flow in Virtual Labs

D. Desktop Virtualization

Virtual labs provide students an interface to write code and perform the experiments over the network. The user interface simulates the software required to perform a particular experiment. The students do not interact with the real software directly. The user interface behaves as a receiver system to accept user input from the students via network, perform specific action on the input, and send the response or output back to the student via same network. Though, most of the experiments in engineering domain can be performed well over the network, there are few software or experiments where it is not possible to include all environmental parameters in virtualization especially when a graphical input or output is required or expected hence simulation cannot replace experiments in real plants [4]. A virtual lab in this case will react differently than a real one. Another problem that can be attributed to performing experiments over the network is computationally intensive processing required to get the final result from an experiment. An event that may occur instantaneously in the real world, may actually take quite some time to be mimicked in a virtualized environment. This delay may be due to complex interactions that occur between the entities within a system. In order to combat with this issue, the proposed architecture of Virtual Labs includes creating and maintaining a Virtualized Desktop Environment pre-installed with different advanced software that the university has in its curriculum for the students of the various engineering domain which are difficult to simulate, purchase and configure.

Virtual Desktops is a concept of separating the operating system and set of applications from the client that is used to access it. Operating system and applications, especially graphical applications, run remotely on the server while being displayed locally on the client machine [6]. The Virtual Desktop is stored on centralized server or a remote server and served to the client over the network through any Remote Display protocols. The popular remote display protocols are: Remote Frame Buffer (RFB) protocol used in Virtual Network Computing (VNC) environments, Microsoft's Remote Desktop Protocol (RDP), Teradici PC-Over-IP (PCoIP) protocol, Citrix HDX protocol etc. The university need not built their own Virtualized Desktop Infrastructure (VDI) but can leverage the existing Cloud solutions for Virtualized Desktops. This converts the capital expenditure to operational expenditure thus proving a cost effective solution for Virtual Labs. The Cloud solutions available in the market are: Amazon Workspaces that are cloud-based desktops or Desktop as a Service (DAAS) that is a cost-effective, secure and a scalable way to provide users with a secure high performance computing infrastructure.

VMware Horizon Air Desktops that are VMware managed offering that delivers the desktops as a cloud service to end users on any device.
Thesesolutions utilizes the Teradici PCoIP protocol, which is a new generation protocol, to server the Virtual Desktops. . The three main advantages of PCoIP are:

- PCoIP uses host rendering which fully preserves the PC environment and broadcasts the encoded pixels and not the data. Hence it is possible to have stateless true zero clients and it decreases maintenance and increases security as only the image is being transferred and not the actual data.
- PCoIP is uniquely multi-codec. It analyzes and decomposes and compresses image elements with the correct codec pixel by pixel in order to minimize network bandwidth utilization.
- PCoIP dynamically adapts to network conditions to automatically adjust graphics quality on congested networks. It utilizes User Datagram Protocol (UDP) to reduce latency and ensure a responsive and interactive user experience.

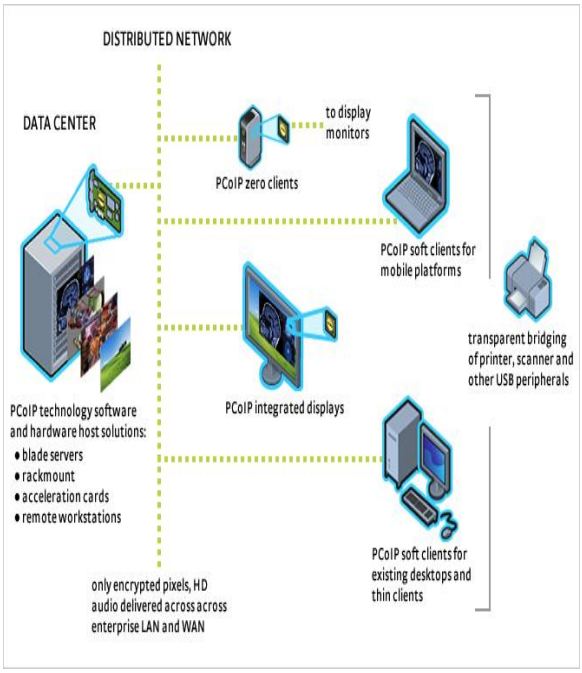

Fig. 3. Teradici PCoIP System Diagram

PCoIP protocol compresses and encrypts the image of the software running on server at the data center and transfers it across standard IP network to stateless PCoIP enabled desktop devices or end-points. From the user's perspective there is no difference between working with a local computer loaded with software or a zero client receiving the image of the software running via PCoIP. It supports high resolution, full frame 3D graphics, full USB peripherals support and High Definition audio for all types of LAN and WAN networks even that with low bandwidth and high latency. PCoIP can be enabled and used to serve Remote desktops through thin clients, desktops, laptops and even android tablets [10]. Thus, the students can access the virtual desktops through any client device following the 360 degree concept of Virtual Labs.

III. CONTRIBUTION TO EARLIER WORKS

Virtual Labs have been deployed earlier by different authors [1-5],[7]. However, these earlier works have not addressed specific issues pertaining to:

Security: The earlier works in area of virtual labs do not have any documented security procedures. Since most of the labs were deployed long back as stand-alone initiatives, they lack modern security implementation for surviving web attacks and mitigating system and network failures.

Usability: The earlier works in area of virtual labs lack modular design and are client dependent. The labs cannot be accessed through modern day client devices like smartphones and tablets. This contradicts the aim of virtual labs to be used from anywhere and anytime.

No real software: Some of the earlier works in area of virtual labs have proposed a solution to map instructional and functional aspects of labs to some kind of simulation technologies (for e.g. Java Applets). They do not provide any mechanisms to students to gain hand-on experience on real software owing to the fact that not each and every aspect of labs can be virtualized.

Virtual Labs architecture deployed in this research paper significantly contributes to the existing virtual labs education research by addressing the discussed issues.

- Security: Virtual Labs are designed keeping in mind the modern day issues relating to security. The main security issue pertaining to Virtual labs project is execution of some malicious code supplied as user input. The strategy to deal with such an attack can be that every code will be stored in a file in a specific directory and will not allowed to open /modify files outside its own directory (system files) nor it can make outgoing network connections .This can be made possible by running strict chroot jail environment with system levels calls to be dropped. Also the file size of the code taken as user input can be limited to so as to exclude malwares and viruses which generally tend to have a larger file size than normal university level program codes. Besides this the various strategies to secure a webserver and other cloud security mechanisms along with configuring a firewall can be applied. Discussing these strategies is not the scope of this paper.
- Usability: The proposed architecture of Virtual Labs in this research paper intends to build support for all types of modern day client devices to be able to connect to and use the labs. The proposed architecture also provides mechanisms to interact with the labs offline through sms commands, thus making the labs an all-rounder solution for remote experiments.
- Real software: The proposed architecture of Virtual Labs in this research paper provides mechanisms to students to perform experiments on real software, which cannot be fully simulated, through Desktop Virtualization. The students need not download or configure these advanced software, they can connect to the Virtualized Desktop through Pc, Laptops and tablets and start using the software.

IV. CONCLUSION

The Virtual Labs are an Open Educational Resource (OER) and an Adaptive Learning Software

for carrying out internet based remote experiments. Virtual labs are cloud based, on-demand, customizable and user-friendly training solution for hands on experience on various software and collaborative learning environment for students. Gone are the days of downloading and configuring complex software for carrying out experiments or for providing on-site training to students. The Virtual labs provide affordable and flexible solution to take the headache out of universities in providing the desired quality laboratory experience to its students. Virtual labs are a paradigm shift in the area of distance learning by rising above the instructor-led classroom experience to hosted labs powered by cloud computing technology. Virtual labs project is based on student-centric pedagogy which increases the curiosity among the students towards practical knowledge of which is essential for future engineering ventures. The effectiveness of virtual labs is evident from the fact that the virtual labs can be accessed from anywhere around the globe, anytime be it early morning or late at night and through any client device (Pc, laptop, mobile phone, smartphones) with or without internet connection.

V. FUTURE SCOPE

The future work in the area of Virtual Labs can be amongst the following:

- Enhance the scope of the Virtual Labs to cover as much technical or educational domains as possible apart from only engineering domain.
- Integrate Virtual Labs with the existing social networks to be able to share and connect with friends or family and communicate with different students or learners around the globe having similar domain or learning interests.
- Data Mining can be applied to Virtual Labs to build lists of popular courses provided by the university and recommend courses for personalized training based on the types of interests and interaction the students are doing with the data mining tools and Virtual Labs.
- Building Procedures and Programs to automatically manage the working of Virtual Labs and the entire Cloud Computing infrastructure with least human intervention and regular auditing of the running virtual machines to discover new threats or challenges by logging all types of attack data to ensure a highly secure, scalable and high performance implementation of Virtual Labs.
- Create a Virtual Machine Appliance consisting of virtual machine image file with pre-configured OS and the various architectural components discussed above to simplify delivery and operation of virtual labs. Any organization which intend to build virtual labs simply can download the virtual image file and install and run the Virtual Labs without having to install and configure all the components individually.

VI. REFERENCES

[1] R. Bose, "Virtual Labs Project: A Paradigm Shift in Internet-Based Remote Experimentation," *IEEE Access*, vol. 1, pp. 718–725, 2013.

[2] Dr. Deepak Arora, Varun Kumar, B. Jagdeep, PrabhatVerma, "Proposed Model For Virtual Labs Interaction With Openstack Integration Using KVM Hypervisor," *International Journal of Scientific and Technology Research*, volume 3, issue 7, July 2014.

[3] H. A. Ali, Haitham A. El-Ghareeb, "Implementation of Cloud-based Virtual Labs for Educational Purposes," *IJCSNS International Journal of Computer Science and Network Security*, VOL.14 No.7, July 2014.

[4] C. Rohrig, A. Jochheim, "The Virtual Lab for controlling real experiments via Internet," in *Proc. IEEE Int. Symp. Comput. Aided Control Syst.Design*, Aug. 1999, pp. 279-284.

[5] Yi Yang; Zhongyin Xiao; Jian Cui; Xin Lin, "Virtual laboratory for optical communication engineering education," *Technology Enhanced Education (ICTEE), 2012 IEEE International Conference on* , vol., no., pp.1,4, 3-5 Jan. 2012.

[6] Manvar, D.; Mishra, M.; Sahoo, A., "Low cost computing using virtualization for Remote Desktop," *Communication Systems and Networks (COMSNETS), 2012 Fourth International Conference on* , vol., no., pp.1,2, 3-7 Jan. 2012.

[7] S. Sivakumar, W. Robertson, M. Artimy, and N. Aslam, "A web-based remote interactive laboratory for internetworking education," *IEEE Trans.Educ.*, vol. 48, no. 4, pp. 586598, Nov.2005.

[8] Christophe Gravier, Jacques Fayolle, Bernard Bayard, Mikael Ates, Jeremy Lardon, "State of the Art about Remote Laboratories Paradigms - Foundations of Ongoing Mutations," *International Journal of Online Engineering, International Association of Online Engineering (IAOE)*, 2008.

[9] P. Mell and T. Grance, "The NIST Definition of Cloud Computing, National Institute of Standards and Technology, USA2009.

[10] PCOIP TECHNOLOGY [Online] Available: http://www.lg.com/us/commercial/display/pcoip