A Time-sharing Remote Laboratory for Hardware Design and Experiment with Shared Resources and Service Management

Norihiro Fujii
Graduate School of Computer and Information Sciences, Hosei University
i02t9013@cis.k.hosei.ac.jp

Nobuhiko Koike
Faculty of Computer and Information Sciences, Hosei University
koike@k.hosei.ac.jp

Abstract - **A new remote laboratory system for learning hardware designs and experiment of digital circuits has been developed. Wide use of the Internet motivated us to develop seamless remote and actual hardware laboratories for hardware design laboratory course. Unlike existing virtual laboratories, the proposed remote laboratory utilizes actual hardware and actual measurement tools in a time-sharing fashion. Hardware experimental environment is usually treated as an exclusive resource, for single user usage. However, the actual test run time is rather short and most of the time is wasted leaving those precious resources idle. To make those resources operate more efficiently, it employs shared resources and enhanced service management scheme based on the Web services. It finds an available service site and schedules the executable processing. The combinatorial use of FPGA/PC connected test hardware and PC-based measurement equipments such as logic analyzer or pattern generator has make it possible to develop a remote multi-user time-sharing hardware experiment system, where students at remote sites can perform actual experiments using actual hardware equipments and tools concurrently. As all students are equipped with high-performance Laptop PCs, CPU intensive tasks such as development of the digital circuits for FPGA can be off-loaded from the server host and can be performed by each student's client PC. A floating license scheme allows students through the Internet to utilize commercial FPGA development tools. Thus, we created Virtual Private Network to access the floating license server over firewalls. Such a rich-client configuration allows the server to concentrate on the service management tasks, such as hardware resource managements. The prototype system is scheduled to be used for the third grade CS students from year 2005.**

Index Terms - Time-sharing remote laboratory, Web services, Shared Resource Management, Shared Service Management, Shared-Lab.

I. INTRODUCTION

As the broadband connectivity to the Internet becomes common, Web based e-Learning and Distance Learning have come to play an important role in self-learning, where learners are given much flexibility in choosing place and time to study. Authors have already developed the prototype of TDeLMS [1]-[3] (Topdown eLearning System) as digital circuit design support system. TDeLMS has been designed for students to do self-learning effectively and contains a database system for circuit modules described by making use of Hardware Description Languages (HDLs). Furthermore, we started researches on realizing a Web based experimental environment that performs the following eight processes: 1) design editor, 2) HDL complier, 3) logic synthesis, 4) logic simulation, 5) placement and routing, 6) implementation to the actual target unit, 7) tests and validations, 8) analysis of obtained data. These steps are all required to complete the digital hardware design cycle and implementation on FPGA (Field Programmable Gate Array) or CPLD (Complex Programmable Logic Device). At the Faculty of Computer and Information Sciences, Hosei University, a hardware experiment laboratory course has been given for the third grade students from year 2002. All students are required to learn CAD-based hardware design process and to acquire enough skills to design 16 bit CPUs. As all experiments take place at an actual laboratory, 70 students are grouped into 20 teams and share 20 sets of hardware equipments, measurement tools, and CAD-tools. As the allocated course time is rather short compared with the amount of work required, home works and extra-hour laboratory works are inevitable. So, the laboratory resource became a bottleneck. In order to overcome current situations, and find a new way to open up a virtual university, the remote laboratory project has started.

The existing laboratory systems such as NetLab [4], the R-Lab [5], the I-Labs [6], the OICLab [7], and the WebLab [8] are examples of the remote laboratory systems.

The authors have focused on the Web-based remote laboratory approach. Although a lot of work should be

required to implement such a courseware, the remote laboratories can take full advantages of the new technology such as network, server-side technology, rich-client technology, the job scheduler, and the distributed resource management. One of the distinguishing features of our Web based experimental environment is its efficient remote-sharing of actual laboratory equipments.

The measurement equipments and test units are so expensive that each student is difficult to occupy equipments for long period of time to set measurement conditions and to analyze the measured data. Our Web based laboratory can offer remote access from everywhere at any time and is suitable for self-learning. Students can set measurement conditions at their local PCs and analyze the obtained actual data without occupying actual measurement equipments. The actual test run time is usually very short and most of the time is spent for measurement condition setting-up and post-experiment analysis. So, occupying time of the equipments for the measurement becomes very short.

In order to automatically choose the Service Provider with the different kinds of measurement equipments and the target devices, we employed the Web Services Registry Technology. Furthermore, In order to achieve an efficient equipment-sharing in case of multiple student requests arriving at once, a job management system plays an important role. Therefore, we adopted the Job Managing Technology and Shared Resource and Services Management (SRSM) Technology to our project and implemented as Shared-Lab. The Shared-Lab allows handlings of actual equipments in the actual laboratory from remote personal computers via the Internet using virtual instruments facility. The Shared-Lab also enables students to send test configuration data and to receive experiment result data for further analysis. The students can locally view experimented results and analyze them on their own remote PCs using this virtual instruments facility.

The aim of this paper is to present a technological basis for the Shared-Lab: A Web based Distance Laboratory and Education, featuring a time-sharing remote laboratory and a self—learning support system called TDeLMS, we developed [1]-[3]. The paper is organized as follows. Section II explains how to realize the multi-user remote laboratory. Section III shows an overview of Shard-Lab. Section IV describes expected evaluations about Shard-Lab. Finally, we will conclude this paper at section V.

II. THE MULTI-USER REMOTE LABORATORY

I. Approaches

Recently, a large number of students own laptops or desktop computers and have access to the Internet using the broadband connectivity from home, on-campus or off-campus. That leads us to organize them as usable remote laboratory environment and to achieve a self-learning system across the Internet. To realize the remote laboratory features using these networking environments, we should consider the following technologies:

1) Multi-User Support
2) Job Scheduling and Job Management
3) Shared Resource and Service Management (SRSM)
4) Service Provider
5) Sharing and occupancy of service
6) Service Registry

The overview of the proposed architecture of multi-user remote laboratory system, which is taken into account of the above mentioned technologies, is shown in the Figure 1.
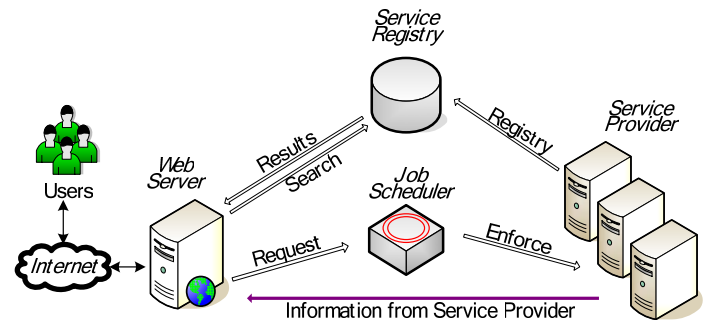

FIGURE 1
ARCHITECTURE OF MULTI-USER REMOTE LABORATORY

II. Multi-User remote laboratory

Existing other remote laboratories usually limit the number of users to the number of actual available resources [4]. Because, these systems are simply client-server systems [7], [9] and the scheduler for processing user requests are not fully functional to support the multi-user time-sharing system. The combinatorial use of FPGA/PC and PC-based measurement tools has made it possible to develop a remote multi-user time-sharing hardware experiment system, where students can perform actual experiments using actual hardware equipments and tools concurrently. The distributed remote laboratory system can deliver high performance in multi-user environments. The following sub-sections discuss functions to realize efficient sharing of actual resources.

III. Job scheduler and Job management

The multi-user remote laboratory has the ability of Job Management and Distributed Resources Management. It resolves conflicts among users, when many users request the same services at the same time. Job management prevents competitions and arranges the service scheduling.

IV. Shared Resource and Service Management (SRSM)

The multi-user remote laboratory includes Shared Resource and Service Management system, namely SRSM (see Figure 2) to perform allocations of the restricted shared services. SRSM controls service providers which provide the sharable services. It finds out an available service, which satisfies the user's request and instructs the selected service provide to begin an immediate processing. It then returns the service

results to the user. Furthermore, SRSM performs other tasks such as management, registration, health checking, and observation of what the service provider is being used for processes.
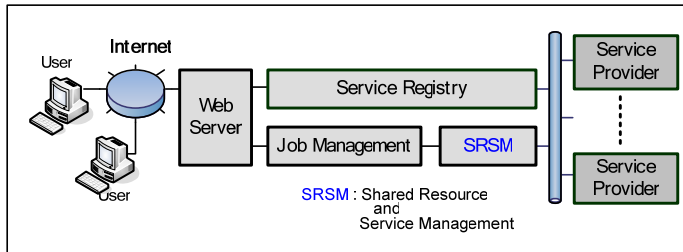

FIGURE 2.
SRSM: SHARED RESOURCE AND SERVICE MANAGEMENT SYSTEM ORGANIZATION

V. Service Provider

The Service Provider consists of laboratory equipments such as measurement equipments, test units and so on. In our proposed remote laboratory system, plural of service providers work together in order to achieve multi-user time-sharing functionality. Each service provider contains a control PC with JTAG interface, a logic analyzer, a pattern generator, a target hardware unit including FPGA and support software.

VI. Sharing and occupancy service

To realize the remote laboratory features using these networking environments, we should consider the following technologies: distributed service, occupational services and sharable services.

- **Occupational services and sharable services:** The remote laboratory provides two kinds of services; local services and remote services. The local services can be categorized as computation-intensive services and the remote services as sharable services. The local services take forms of the rich client organization, and are named as Occupational services, where CAD tools and measurement remote control service packages run by down-loading either from CAD vendor sites or from the remote site. The remote site takes the form of a Service Provider and implements multiple sharable services as the Web Services.
- **Service depending on the implementation place:** In the proposed multi-user remote laboratory, the user sites where students access to the Internet are called local sites. Moreover, the system sites where actual laboratory, database and Web server reside, are called remote sites. Users can get access to laboratory facilities through the multi-user remote laboratory procedures both from local sties and from remote sites.

VII. Service registry

The service registry specifications define a way to discover information about the Service Provider. The specification consists of several related documents that define the Provider ID, The IP Address, Domain, the supported target devices, the measurement equipments and so on. It provides a mechanism for users to dynamically find out the service providers necessary to perform a scientific experiment.

III. SHARED-LAB'S SPECIFICATION AND FEATURES

In this section, an overview of Shared-Lab, as remote laboratory we proposed, is presented.

l. Overview of Shared-Lab

Figure 3 shows the overview of Shared-Lab. Shared-Lab is configured following blocks:
   a)   Client site
   b)   Network
          Web server
          VPN (Virtual Private Network)
   c)   Job scheduler and Job management
   d)   Service Registry
   e)   Service Providers
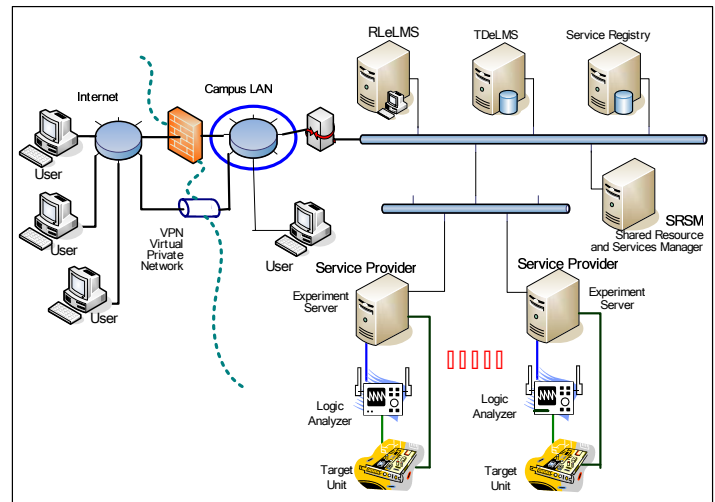   Materials for hardware experiment
   f)   TDeLMS

FIGURE 3.
OVERVIEW OF SHARED-LAB

ll.   Client Site

Web based systems are able to
   1: entry to service request from local PC's browser.
   2: receive collected service results (measurement data)
   3: analyze these data with GUI at local site.
Complete integrated design environment (IDE), named FPGA Advantage from Mentor Graphics Corp. [11], targets multi-discipline concurrent FPGA device design. Figure 4 shows a screen shot of FPGA Advantage. The IDEs can be allowed to run their CAD tasks both on desktop computers at the remote

site and local PCs, after getting the floating licenses form the license server. Local PC also displays measurement data using TLAVu from Tektronix, Inc [10]. Figure 5 shows the screen shot of TLAVu.
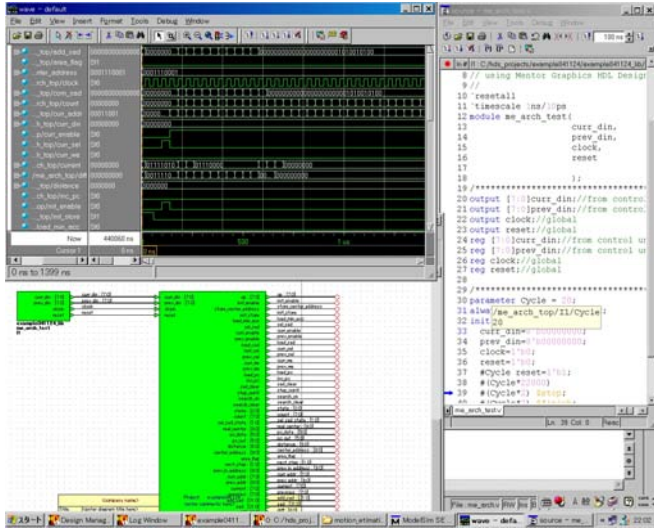

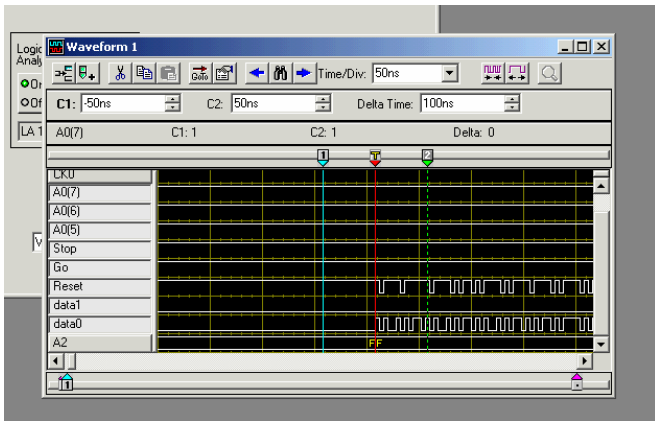
FIGURE 4.
IDE(INTEGRATED DESIGN ENVIRONMENT) ON LOCAL SITE

FIGURE 5.
LOGIC ANALYZER SNAP-SHOT (TLAVU) ON LOCAL SITE

III. Network

This section explains about network control of Shared-Lab.

- **Web Server:** The roles of the Web server are authentication, election of service, managing measured data and sending back service results to the service requestor.
- **Virtual Private Network (VPN):** A Virtual Private Network is a private data network that makes use of the public telecommunication infrastructure, maintaining privacy through the use of a tunneling protocol and security procedures [12]. The usage of VPN allows students to enable direct access to the server on the campus LAN from the off-campus sites.

IV. Job Scheduler and Job Management

Shared Resources and Services Management (SRSM) is employed for the job scheduler to process the user requests. SRSM controls service providers which provide the sharable services, retrieves a service provider which is able to process user's requests, instructs to begin an immediate process and finally reports the service results to user.

V. Service Provider

The Service Provider (see Figure 6) for an experiment is organized, as a control PC with JTAG interface, a logic analyzer, a pattern generator, a target unit including FPGA and software. The combinatorial use of FPGA/PC connected test hardware and PC-based measurement equipments such as logic analyzer or pattern generator has make it possible to develop a remote multi-user time-sharing hardware experiment system, where students can perform actual experiments using actual hardware equipments and tools concurrently.
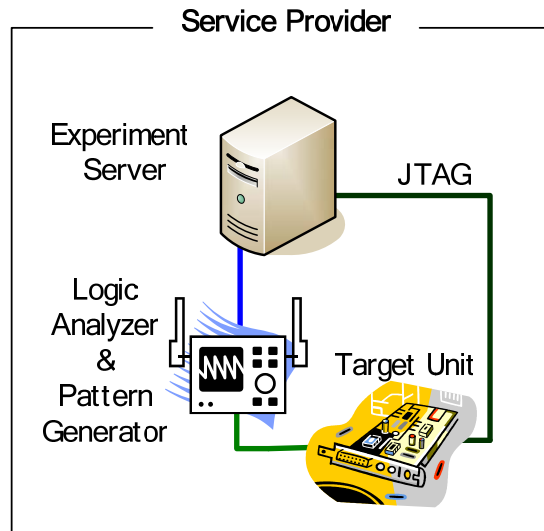

FIGURE 6.
SERVICE PROVIDER ORGANIZATION

- **Experiment Server:** As previously mentioned, the service provider contains laboratory equipments and a target unit including FPGA or CPLD chips. Moreover the service provider includes an experiment server. This experiment server controls laboratory equipments and the JTAG interface to program to a target chip. This server is connected to SRSM and the service registry to inform about health checking and observation of what the service provider is being used for processes.
- **Logic Analyzer and Pattern Generator:** We adapted TLA714 as a logic analyzer from Tektronix, Inc [10]. Figure 7 shows an overview of TLA714. This PC-based measurement equipment is comprised of a portable mainframe, benchtop mainframe, expansion mainframe, and all of the accessories and supports. Moreover, this equipment is built upon the Windows operating system

[13] which allows users to install any PC-compatible, third party hardware and software on the instrument. Also, TLA714 has network capabilities. Shared-Lab is built with them. Furthermore, TLA Application software called TLAVu allows the other PC to have a role of the local PC in the Shared-Lab.

FIGURE 7.
PC-BASED MEASUREMENT EQUIPMENT (TLA714)

- **Target Units (Board):** Figure 8 displays a target hardware unit with FPGA. The Shared-Lab supports two different configurations of the target boards: FPGA-based target boards suitable for complex CPU designs, and CPLD-based boards for smaller scale logic circuit designs. At a modern logic circuit design classroom, the use of hardware description languages (HDLs) is becoming very popular. They contribute to reduce design effort and design time. The designed and verified circuits are then put into a programmable logic device, such as FPGA and CPLD. In hardware class for 3rd grade students, a student can complete the design of a 16 bit RISC CPU containing several hundreds of thousand logic gates, within a half year course. The designed and verified circuits are then put into a programmable logic device, such as FPGA and CPLD (Complex Programmable Logic Device). The final verification is carried out by running actual FPGA. should be 8 point, Times New Roman, left justified, no space between the paragraphs. This style is defined under the style menu of this document as "Footnote text".

FIGURE 8.
TARGET UNIT WITH FPGA

- **The usage of JTAG (Joint Test Action Group):** In the 1980s, the Joint Test Action Group (JTAG) developed a specification for boundary-scan testing that was later standardized as the IEEE Std. 1149.1 specification [14]. This boundary-scan test (BST) architecture offers the capability to efficiently test components on PCBs with tight lead spacing. PCBs as well as semiconductor devices such as FPGAs and CPLDs have a interface complied with JTAG's standards. As JTAG interface is a primitive hardware interface using the parallel port of PC, JTAG Software Interface has been designed by Java, JNI (Java Native Interface), C language. This Java based JTAG software is called J2TAG. It is easy to access FPGA and CPLD through the Internet by J2TAG.

VI. TDeLMS (Top-Down e-Learning Management System)

TDeLMS is a system which is specialized in logic circuit design learning. TDeLMS dynamically selects the necessary contents from the cellular database [1]-[3], and generates navigation paths according to the understanding level of the learner. This system is especially useful for assisting and guiding learner's design of the digital circuits in HDL. This system allows learners to learn digital circuit design by self-learning and help them design digital circuits. Our next plans about developing additional functions will be to implement functions of registration the circuits design information and collection of the experiment reports.

IV. EVALUATIONS

Section IV describes expected evaluations about Shard-Lab. Shared-Lab allows students to:
   a) use and share the experiment equipments.
   b) conduct the hardware experiments quickly.
   c) share the expensive measurement equipments more efficiently.
   d) collect the actual measurement data to analyze the digital circuit designed.
   e) access measurement equipments from everywhere at any time.

The advantages of the simultaneous use of Virtual World and Real World can be listed as follows:
   a) Obtained results in the virtual environment can be corroborated by the actual experiment in the real world.
   b) Actual data obtained at the actual experiment can be evaluated by the virtual tools such as TLAVu, which realizes an experimental environment in Cyber Laboratory.
   c) For scientific educations, both virtual and actual laboratories have their-own roles and are equally important. As the cyber laboratories combine them in a seamless way, it is possible to take full advantage of them.

In accordance with the recent advancements in the Internet, such an experiment in Cyber laboratories as Shared-Lab will play an important role in scientific educations.

V. CONCLUSIONS

The proposed Shared-Lab architecture is developed by making use of the Web services and the distributed resource and services. One of the successful ideas obtained through the development of the system is its generic use of job management organizations. It resulted in effective and practical operations of a remote multi-user time-sharing hardware experiment system. Also, SRSM and Service Registry scheme allow us to implement new services and to integrate them into the target experiment system with minimum efforts. Our next approaches are to realize participating new service provider in this system from an off-campus site and to support other kinds of target units with different FPGAs.

VI. REFERENCES

[1] Norihiro Fujii, Shuichi Yukita, Tosiyasu L. Kunii, and Nobuhiko Koike, "TOP-DOWN EDUCATION FOR DIGITAL LOGIC DESIGN COURSE BASED ON CELLULAR METHODS", 33rd Frontiers in Education Conference 2003 (FIE2003), Bolder, Colorado, USA, November 5-8 2003.

[2] Norihiro Fujii, Shuichi Yukita, Nobuhiko Koike, and Tosiyasu L. Kunii, "Top-Down eLearning Tools for Hardware Logic Design", International Conference on CyberWorlds (CW2003), Singapore, December 3-5. 2003.

[3] Norihiro Fujii, Shuichi Yukita, Nobuhiko Koike, and Tosiyasu L. Kunii, "An E-Learning System Based on the Top-Down method and the Cellular Methods", *International Journal of Distance Education Technologies*, Idea Group Publishing, Vol. 2, No. 4, PP77-93, Oct-Dec 2004.

[4] Zorica Nedic, Jan Machotka and Andrew Nafalski, "REMOTE LABORATORIES VERSUS VIRTUAL AND REAL LABORATORIES", *33rd Frontiers in Education Conference (FIE2003)*, Bolder, Colorado, USA, November 5-8 2003.

[5] Dervis Z. Deniz, Atilla Bulancak and Gökhan Özcan, "A NOVEL APPROACH TO REMOTE LABORATORIES", *33rd Frontiers in Education Conference (FIE2003)*, Bolder, Colorado, USA, November 5-8 2003.

[6] Nils Faltin1, Andreas Böhne, Jörg Tuttas and Bernardo Wagner, "Distributed Team Learning in an Internet-Assisted Laboratory", *International Conference on Engineering Education (ICEE2003)*, Manchester, U.K., August 18-21, 2002.

[7] Joar Rusen and Sigbjørn Kolberg, "Online FPGA laboratory for interactive digital design", *International Conference on Engineering Education 2004 (ICEE2004)*, Gainesville, Florida, USA, October 16-21, 2004.

[8] J. A. del Alamo1, J. Hardison, G. Mishuris, L. Brooks, C. McLean, V. Chan, and L. Hui, "Educational Experiments with an Online Microelectronics Characterization Laboratory", *International Conference on Engineering Education 2002 (ICEE2002)*, Manchester, UK, August 18-22, 2002.

[9] Ainhoa Etxebarria, Inigo J. Oleagordia, and Manuel Sanchez, "AN EDUCATIONAL ENVIRONMENT FOR VHDL HARDWARE DESCRIPTION LANGUAGE USING THE WWW AND SPECIFIC WORKBENCH", *31st ASEE/IEEE Frontiers in Education Conference (FIE2001)*, Reno, NV, USA, October 10-13, 2001.

[10] Tektronix, Inc., http://www.tektronix.com/ retrieved at December, 2004.

[11] Mentor Graphics Corp., http://www.mentor.com/ retrieved at December, 2004.

[12] The Virtual Private Network Consortium, http://www.vpnc.org/, retrieved at August, 2004.

[13] Microsoft Corporation http://www.microsoft.com/, retrieved at November, 2004.

[14] The IEEE Std. 1149.1 specification, http://www.standards.ieee.org/reading/ieee/std_public/description/testtech/ 1149.1-1990_desc.html, retrieved at April, 2004.