The Role of Telematic Practices in Computer Engineering: a Low-Cost Remote Power Control in a Network Lab

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T.J. Mateo Sanguino, D.A. López García and E. Cortés Ancos

University of Huelva, Palos de la Frontera (Huelva), Spain

Abstract— **The present paper describes a practical solution of e-learning laboratory devoted to the study of computer networks. This laboratory has been proven with two groups of students from the University of Huelva (Spain) during two academic years. In order to achieve this objective, it has been necessary to create an entire network infrastructure that includes both the telematic access to the laboratory equipment and the remote power control. The interest of this work lies in an economical and simple system of remote control and telematic access with a twofold objective. On the one hand, to develop distance practices with attendance appearance by means of real hardware systems, not simulated. On the other hand, to reduce the power consumption regarding other proposals of remote labs with permanent power connection, providing herein an on demand connection only when required. As a result, a versatile and flexible laboratory has been put into practice whose basic network topology allows transferring traditional practices to telematic practices in a natural way and without harsh changes.**

Index Terms— **Engineering Education; Networking; Remote Laboratory; Telematic Practice.**

Telecommunication equipments are a critical resource for teaching networking subjects. Their high cost prevents the readiness of a workbench with a specific network topology for each student, which would be the ideal situation. In addition, students cannot develop these skills outside the classroom and all their experience is limited to the scarce sessions they have access, a dozen in a whole semester [1]. For this reason there are some simulators like KivaNS [2], Ns-2 [3], cnet [4], OMNeT++ [5], GNS3 [6], OPNET [7], RouterSim® [8], Boson NetSim[TM] [9] or Packet Tracer [10], among others, that emulate the behavior of network devices. These virtual tools can partially satisfy teaching needs, especially in the initial stage of the student's learning. However, subsequently, the confrontation with real systems is essential.

The high availability of development tools nowadays has prompted universities and research groups to concentrate their efforts on designing new interactive teaching-learning environments [11], [12]. With this idea, a virtual laboratory was created in the University of Alicante (UA) for teaching computer networks [13]. The goal is to dispose a set of compact interactive simulations implemented as portable Java applets combined with KivaNS, which are integrated with Moodle and SCORM documents. More recently, the virtual computation laboratory (VCL) was developed like a novel proposal based on reusable objects in a context of distance learning. One of the main goals of VCL is to provide a specialized environment to a user for a limited time in which the resource offered can be a network of interconnected virtual machines [14]. Also the Universitat of Girona (UdG) has developed a remote laboratory for TCP/IP learning. This laboratory allows the understanding of IP networking concepts, knowing and configuring IPv4/IPv6 protocols, and to solve problems of its combined use [15]. In that sense, a distance teaching environment for the students has been developed in Thailand. The main purpose of this laboratory is the development of different LAN topologies with possibility of configuring routers and switches so that students can learn by manipulating real hardware [16]. Another example of virtual and remote laboratory is TeleLab, dedicated to know and to apply different security policies. The educational goal is to understand, implement and take countermeasures against security attacks [17]. On the other hand, Université Paris 13 has also developed the virtual laboratory Marionnet [18]. This stands for a simulation tool that allows students to define, configure and simulate a complete Ethernet network with computers, routers, switches and more. There is also support for integrating the virtual network to the physical network by means of socket connections. Recently, the virtual laboratory of networks and systems (Altair) has been presented [19]. As the main achievement to highlight, the user can view and manipulate remote routers, carry out cabling configurations between devices and install the OS needed. Finally, other examples of virtual and/or remote laboratories noteworthy are VNLab [20], R-Lab [21], and VITELS [22] among others.

This paper is organized as follows. Section I presents the educational research undertaken for this project and the workbench topology implemented for telematic practices on networking. Section II describes the developed power control system, which is the fundamental objective of this work. The following shows a methodology of minimum guidelines for the telematic access to the remote laboratory. Section III describes a case study conducted by students. Section IV discusses the impact of the telematic laboratory about teaching and learning in two different subjects. Finally, the paper concludes with the reached results. Because of the paper

TABLE I.
FEATURES OF SOME VIRTUAL AND REMOTE LABORATORIES WITH ACADEMIC GOALS IN COMPUTER NETWORKS

Laboratory	Type	Networking Concept Studied	GUI and/or Access Method	Real Hardware	Year
VNLab	VRL	Routing Administration	Web-based	Yes	2001
VITELS	RL	IP Security	Remote Desktop / WebCT	Yes	2002
R-Lab	RL	Computer Network & Wireless Systems	Web-based	Yes	2003
Marionnet	VL	Ethernet LAN	GTK+ / Virtual Machine	•	2007
VCL	VRL	TCP/IP Architecture	Remote Desktop / X-Server	•	2008
UdG	RL	IPv4/ IPv6 Interconnection and Configuration	Web-based	Yes	2009
KivaNS	VL	IP Routing Operation	Java	•	2009
Thailand	RL	Switching & Routing Administration	Web-based	Yes	2010
TeleLab	VRL	Security Policies	Remote Desktop / Virtual Machine	•	2010
Altair	VL	Configuration of Network Virtual Host	Web-based / Virtual Machine	•	2010
UA	VL	TCP/IP Protocols in LAN	Easy Java Simulations / SCORM	•	2010
UHU	RL	Switching & Routing Administration	Java / Moodle & Remote Desktop	Yes	2011

RL=Remote Laboratory, VL=Virtual Laboratory, VRL=Virtual and Remote Laboratory, • = NO

contains a large amount of acronyms, a list of terms for easier reading is given at the end.

I. E-LEARNING LABORATORY IN COMPUTER NETWORKS

The research undertaken for this project arises from the initiative of a team of teachers within the Department of Electronic Engineering, Computer Systems and Automatics at the University of Huelva (UHU). As part of a larger educational project, the system herein proposed has been tested in a networking laboratory. The ultimate goal is to have an e-learning laboratory on computer networks to perform practices at distance with real hardware. This remote laboratory aims to improve various aspects of the labs mentioned in the Introduction section. In order to assess the contributions that this work makes to the field of virtual and/or remote laboratories, Table I shows a comparison of the features and capabilities of our lab (UHU). The truly distinguishing element of this system regarding others is its simplicity and low cost, which pursues a double contribution. On the one hand, to provide telematic practices with a more realistic presence than simulators and virtual labs; on the other, to reduce power consumption regarding remote laboratories which require a permanent connection for their access.

A. Network Infrastructure

An outline of the networking laboratory is depicted in Fig. 1, which consists of 2 communication racks, a teacher workstation and 5 workstations for students. The wiring is formed by two independent connection lines devoted to the network communication and the power control of the hardware —power wires are not shown. On the one hand, the red line symbolizes the control cable that connects the power strip of the hardware equipment with the power control device at closet 1. Each communication closet has a box for the power control that allows both user-manual and remote control. Specifically, this is connected with a parallel Centronics interface to the lab server where the remote control application is running. On the other hand, the blue line stands for the communication wiring that interconnects the workbenches.

The telematic practices have been designed under the concept of generic and flexible hardware setup, so they do not require physical manipulation of the wiring by the students. To do this, a basic network topology has been designed and, from it, different challenges in terms of connectivity, enabling protocols, security, etc. have been proposed to the students. Thus, each computer can be remotely managed while participating in the network connection of the hardware. As a result, the versatility of the remote laboratory has made possible to carry out some of the traditional practices in a telematic way with minimal changes. The fact is that the network infrastructure allows this translation in a natural way, being the only requirement that the wiring stays fixed during the practice sessions.

B. Workbench Topology

Figure 2 shows an outline of the physical network topology corresponding to each workbench. These consist of 2 Cisco 2801 routers, 1 Catalyst 2960 switch, and 2 PCs equipped with 2 Gigabit Ethernet cards. Thus, each PC is always connected to both the LAN at the laboratory and the hardware workbench. This way, a network card is used for remotely accessing while the second one is used for administrating the hardware during practice sessions. Furthermore, all hardware is connected to the same power strip. This strip —which can be controlled by a manual switch during the classroom practices— also has a parallel switch controlled by a relay. The activation of this relay depends on the power control server of the laboratory.

In order to make possible the telematic access by the users, each PC has a permanent connection through the communications wiring (blue line) that comes from the main switch lab through the LAN. This switch serves to the whole laboratory and interconnects the rest of the equipment. Due to the physical network connection shown in Figure 2, it is possible to setup a different logical topology for each practice. In this case, each PC has a RS-232 console cable (CON) dedicated to the administration tasks of each router. At the same time, each PC forms an individual LAN with its router by means of the second Gigabit Ethernet (GigaE) connection. Thus, the computers serve both to configure the routers and have a different role to carry out each practice (web server, FTP client, SNMP network monitor, diagnostic tools, etc.). A third GigaE cable is available to make an Internet connection through the switch of each
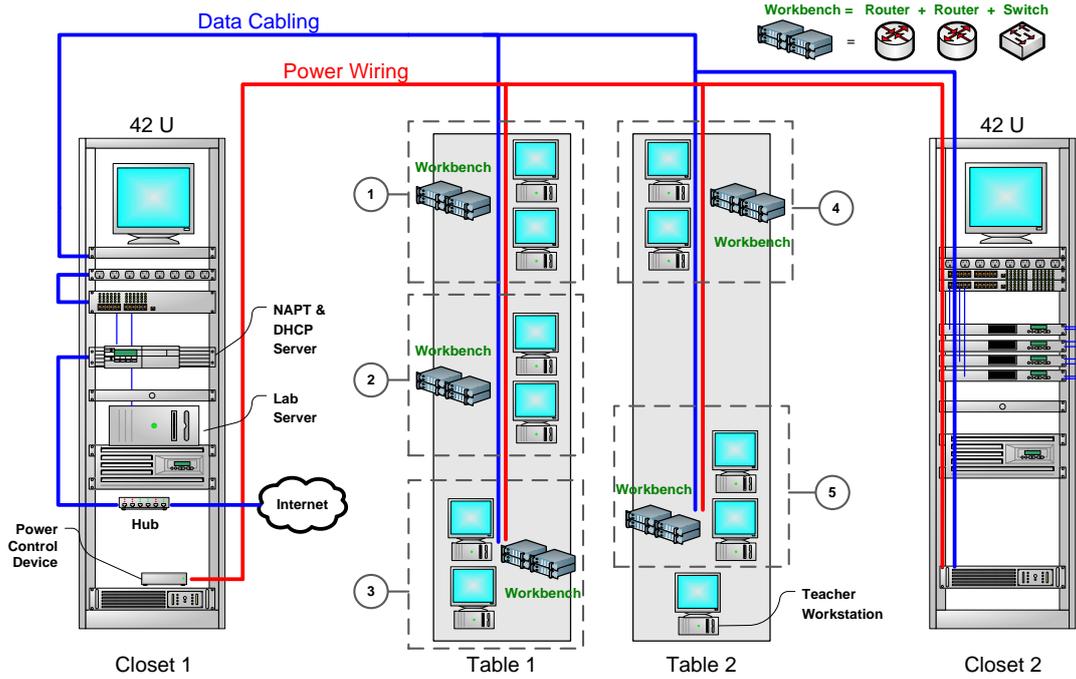
Figure 1. Layout of the workbenches and wiring system of the networking laboratory

workbench. This way, it is possible to complete additional challenges for each particular practice.

II. TELEMATIC ACCESS TO THE LABORATORY

This section describes the power control system and the methodology of telematic access to the network lab in more detail.

A. Power Control System

In most cases, remote laboratories requires their equipment always powered and this means a permanent

Figure 2. Outline of the basic physical topology of each workbench

energy consumption. Because laboratories —either in person or remotely— are used by students only a few hours a week, a power control system will save a significant amount of energy. A few Ethernet-controlled power strips are commercially available but they are costly (more than 500 €) and their features do not allow customized functions as needed in a remote lab. From this idea, the approach proposed in this work is based on taking advantage of a device continuously operating in a lab —such as a common server— where these functions could be implemented by means of an specific application. This is the idea that will be detailed below.

The power control system consists of 2 different types of devices, one connected to the server and the other connected in paralell to the power strip of each workbench. Firstly, the power control device connected to the server (see Fig. 3) consists of a transformer, a power supply circuit (1 A and 12 Vdc) and a module with 8 relays controlled by a Centronics port. This device is completely under the control of the lab server by means of an application developed in Java for this purpose. Its function is to send the control order to the second device of each power strip by means of an electrical signal. The role of the second power control device located on the tables —one per workbench— is to operate as an electronic switch and provide power to the lab equipment. Thus, each workbench is controlled by an independent relay whose control circuit is electrically isolated from the power source to provide safety. By means of the proper wiring, each workbench is turned on/off either manually —pushing on each mechanical switch— or remotely by controlling the relays.

In order to implement the power control system two different solutions have been considered. These are based on the use of triacs and relays. The latter was selected
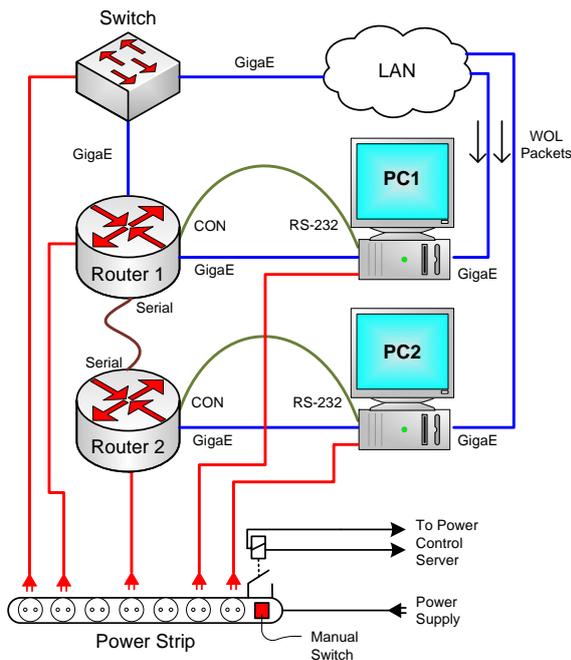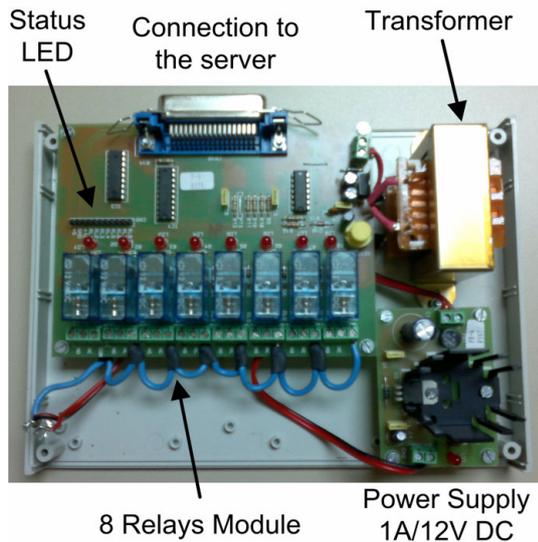
Figure 3. Components of the power control device at the server side

Figure 4. Electrical scheme of the power control system at the server and the workbench

Figure 5. Drive current behavior during the switching process

since it provides fewer problems of current stability and less consumption compared to triacs. Furthermore, no heat sinks and switching speed are required for relays as the state (on/off) will be held for hours. Figure 4 shows the implemented electrical design. When the control order is sent by the power control device, the first relay closes the K_1 switch. The second relay (K_2) is controlled by a timer that delays the switching; thus the drive current initially crosses K_1 and R_1. Since all devices of each workbench use switched-mode power supplies (SMPS) —two routers, one switch, and two PCs— high peaks currents are involved when powered on simultaneously. This is due to the internal capacitors of this type of power supplies, which are all of them discharged at the beginning. Thus, the functions of R_1 are to slow down the capacitor charging process and to reduce the activation peak current. As a result, the current that crosses the K_1 switch is lower; this allows choosing relays less costly. When the timer expires, K_2 switches on and connects the workbench to the power source directly. As the capacitors are partially charged at this time, the drive current is limited. Therefore, this second relay has not to achieve high requirements in terms of current.

On the contrary, an electrical design that included a single relay would bear very high currents. As an example, Figure 5 shows the behavior of the drive current during the switching process. The first transitory of the current ($t = 26$ ms) is due to the turning on (the slight shift in the ordinate axis is due to the used sensor). As tested in the laboratory, high current peaks are obtained with maximum values close to 100 A. As a consequence, the metal contacts in a low-cost relay may melt. Therefore, a specific device as described above must be designed to solve the problem.

B. Power Control Software

The software developed to control remotely the power control system consists of 2 different applets (see Fig. 6). The simplicity of the applets allows very simple and intuitive functions such as establish the TCP/IP connection with the server lab or connect and disconnect the workbenches by means of sockets. As a part of the objectives pursued in this project, one of the functions implemented in the applet is the prerecorded programming of the power control. The application allows the computer to start in both weekly and on-demand modes. This way, the turning on is scheduled 15 minutes before the beginning of each lab session. The operation is carried out by means of a series of commands sent from the server. Every order is recorded in a line that can later be modified or eliminated. When the orders are incorporated into the system, the events are registered in a sorted list. These orders generate two possible events: on and off. A low priority thread is responsible for comparing the server clock continuously with the next event. When the scheduled time arrives, the action associated to the event is executed (e.g. turn off a workbench, turn on the whole laboratory, etc.). As a result, energy savings and an increase of the service life of the equipment are obtained when not needed permanent turning on.
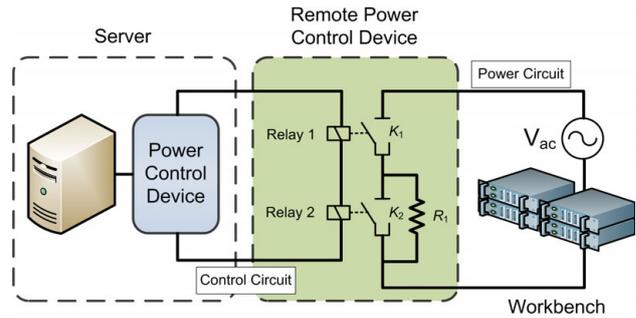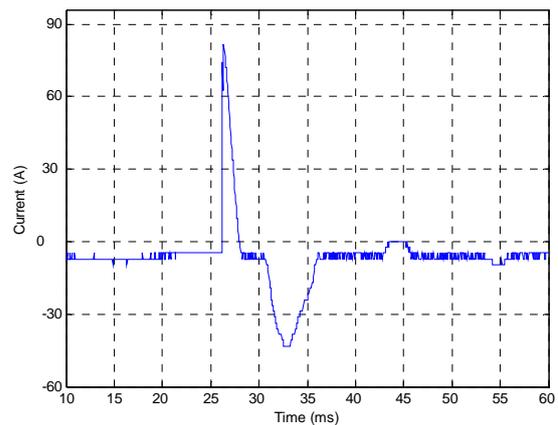
C. Methodology for Telematic Access

Figure 7 outlines the server responsible for carrying out the remote power control and the telematic access. The process of telematic access that a user must perform is as follows:

1) Connect to the lab server via the public IP using a specific client application developed in Java (see Fig. 6).
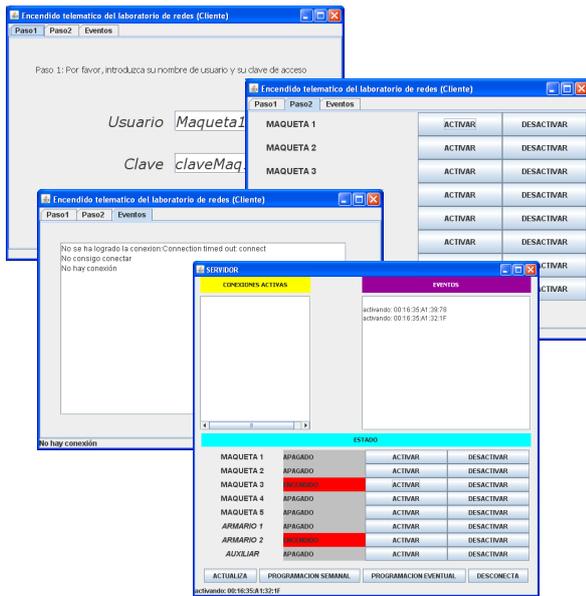
Figure 6. Administration dialogues for the power control applets

The server also has an application developed in Java that authenticates the user, checks the key and enables functions. A dialogue display with the status of the corresponding workbench and three buttons appear at the bottom of the applet: activate, disable and status update.

2) Depending on the user's profile (student or teacher), the server will allow to activate a unique hardware or any of them accordingly. When the user orders the activation of a workbench the server activates the corresponding relay supplying all hardware.

3) If the turning on is successful, the server application sends bursts of WOL magic packets —Wake-on-LAN— to the GigaE cards of the PCs. To this end, computers must have enabled this feature; otherwise they ignore such functionality. Depending on each PC, a wake up period takes place (typically between 5s and 45s) during which the server application monitors the status of the

process.

4) When the PCs are ready for their remote access, the user is notified by the server displaying this information at the client applet.

5) By means of the educational web platform of the UHU available in Moodle, the user can access with his account and password the connection enabled for his practice. There, the user has a client applet of remote desktop that enables the telematic access to his workstation. To access the hardware, a remote desktop server has been installed in each computer lab. Each of them has been configured with a different socket that allows listening remote connection requests. In this regard, it has been necessary to configure access policies by means of ACLs in the router of the UHU and port forwarding the main router of the lab. So, depending on the address and port assigned to each PC, remote connection requests coming from outside are forwarded toward the laboratory. Finally, the user can use the laboratory's PCs as whether they were attending the classroom and accomplish the proposed practice. For security reasons, each computer has been set up using different keys, so that authorized personnel will only be able to consent its configuration.

III. ROUTE DISCOVERING: A CASE STUDY ON NETWORKING

In order to reinforce the knowledge acquired during the previous sessions of theory, the students conducted a telematic practice at the remote lab. The aim of the proposed practice was deliberately simple so that the learning process of the students prevents influencing the results of the subsequent validation questionnaires (see section IV). The remote practice consisted in discovering the route between the LAN at the laboratory and the connection at the students' site (mostly their homes). By means of this proposed challenge, the students learned a working methodology consisted in inspecting the IP configuration of both local and remote computers, using
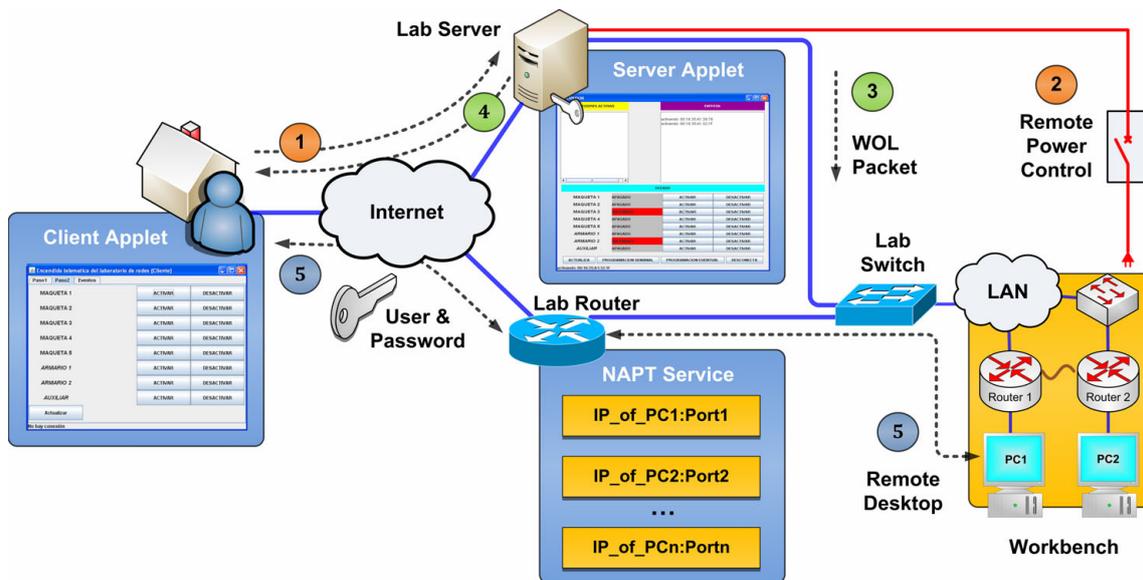

Figure 7. Methodology for the remote access to the networking laboratory

tools to test connectivity with hosts —ping and tracert applications—, and understanding the communication processes involved in the Internet. The educational goal was that the students study the Internet Control Message Protocol (ICMPv4) as a Layer 3 protocol in the TCP/IP suite in a practical way. Through this experience, novice engineers learn to figure out essential information for testing and diagnosing network failures. As an example, among the goals achieved, students discover how to locate a problematic router on the path observing the round-trip times (RTT) and monitoring lost packets on the network. Furthermore, students learn that high response times and data loss obtained in a particular node is an indication that the resources or connections in a router may be stressed. This information is a valuable experience for the training of both future analysts and administrators on computer networks.

IV. VALIDATION AS E-LEARNING LABORATORY IN COMPUTER ENGINEERING

The telematic access methodology to perform the case study presented in this paper has been put into action in two different subjects at the University of Huelva (UHU). The subject "Networking Technology" is optional for students of 3rd course in the Computer Engineering degree and it is being taught for 13 years. The subject "Computer Network Fundamentals" is mandatory for students of 2nd course in the new Computer Engineering degree and it is being taught for 1 year since it belongs to the European Higher Education Area (EHEA). This different nature has provided a scenario for various educational goals that have been addressed with the same practical solution. This has provided the teachers valuable information to meet new challenges on computer networks.

On the one hand, the simple name of the word network was attractive to the students of the subject "Networking

Technology" at the beginning. However, almost none of them were able to foresee that this subject hid hard concepts on protocols together with a highly specific terminology of acronyms and specifications. By that reason, formal learning in networking can be hard and reduce motivation for those novice students that seek to administrate networks without covering the previous stages; this is LAN and WAN technologies, switching and routing protocols, as well as all issues of network operation (e.g. cabling, security, etc.). As a result of trying to maintain a formal teaching in this subject, perhaps excessive, the number of students enrolled has been reduced gradually since traditional teaching is not seen so attractive. On the other hand, the subject "Computer Network Fundamentals" has been designed following the European Credit Transfer and Accumulation System (ECTS) according to the Bologna declaration. This requirement has been the guiding thread for designing a subject based on the student-centered teaching process with particular emphasis on that education is conducted by students —as learners— instead of teachers. The analysis of the described situation led the group of teachers who coordinates this subject to the conclusion that we should make compatible an attractive subject with the commitment that it was formal and suitable for a university level. For this purpose, it was created a work team within teaching innovation projects (funded by the UHU) whose first outcome —we hope to offer more in successive stages, just as the current developments go concluding— is the remote lab presented in this paper.

A. Evaluation of the Telematic Practices

With the aim of showing the contributions and capabilities of this remote laboratory, a statistical study was completed along the years 2010/11 and 2011/12 for the subjects "Networking Technology" and "Computer

TABLE II.
EVALUATION QUESTIONNAIRE OF THE REMOTE LABORATORY

| Question	Requested Features and Capabilities	2010/11	2011/12
1	Telematic practice experience promotes motivation and interest in the subject	3.82 ± 0.41	4.05 ± 0.62
2	The use of the system presents a clear and intuitive way of access	3.65 ± 0.40	3.75 ± 0.56
3	The system has not presented technical problems during the development of the sessions	2.76 ± 0.74	3.00 ± 0.93
4	Do you consider telematic practices an advantage over traditional sessions?	3.41 ± 0.71	4.05 ± 0.47
5	Telematic practices allow to acquire new theoretical concepts	3.88 ± 0.50	3.95 ± 0.50
6	Telematic practices allow to consolidate theoretical concepts	4.06 ± 0.42	3.90 ± 0.48
7	Theoretical concepts are learned only studying, without needed of telematic practices	3.06 ± 0.49	1.75 ± 0.60
8	The use of online real hardware instead of simulators increases student's professional training	4.12 ± 0.35	3.45 ± 0.62
9	The use of the lab workbench without the limitation time in the classroom allows to finish long practices before and improve learning efficiency	4.29 ± 0.35	4.55 ± 0.30
10	Telematic access to networking laboratory equipment provides greater readiness and, therefore, greater experience in their handling	4.40 ± 0.26	4.35 ± 0.37
11	The readiness of optional telematic practices would increase the predisposition to be made by the student interested in improving their qualification and formation	4.00 ± 0.18	4.25 ± 0.36
12	If optional telematic practices can be carried out in group, their resolution would be easier	4.18 ± 0.41	4.05 ± 0.47
13	If optional telematic practices could be carried out in group, it would encourage the student's interest to carry out them	3.71 ± 0.35	4.50 ± 0.38
14	Teamwork can be encouraged thanks to this remote laboratory	3.47 ± 0.44	4.30 ± 0.49
15	I would be more interested in optional practices achievable from home that having to go to the laboratory	2.83 ± 0.71	4.10 ± 0.56
16	The remote laboratory is feasible for implementation in the university context	3.53 ± 0.47	3.85 ± 0.75
17	Overall, telematic practices at home are beneficial for your training and formation	3.35 ± 0.61	4.10 ± 0.48
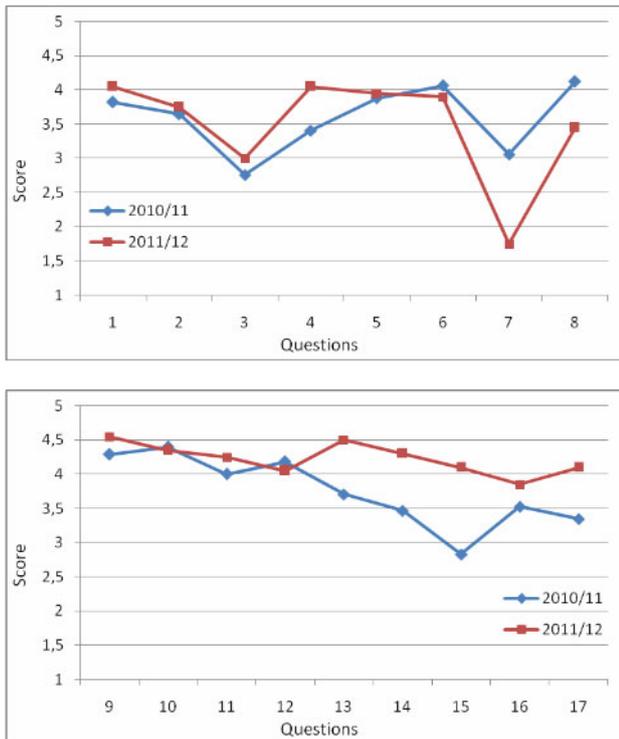
Figure 8. Comparison of students' opinion along two academic years

Network Fundamentals" accordingly (see Table II). With this purpose, it has been considered a total of 36 students —16 and 20 students for each subject respectively— during an optional practice session of 1.5 hours. The experience with the remote laboratory has been rated with a score ranging between 1 (strongly disagree) and 5 (totally agree) and it includes issues referred to the laboratory's features, acceptance and use (see Fig. 8).

Following the results in the figure, it can be observed that the trend line of the two groups of users is similar, being more positive for those students belonging to the course 2011/12. The reason is due to a direct relationship among the students' motivation for telematic practices and the interest for the subject (Q1). Considering the aspects related to the remote access, its ease of use and interactivity are remarkably stood out (Q2). However, diverse technical problems were presented along with other contingencies (e.g. power outages, server failure, etc.) which hindered the realization of the practices and, therefore, have been reflected in the questionnaires (Q3). Despite this, students still consider that telematic practices represent an advantage over traditional sessions (Q4). Regarding the teaching and learning of networking, students confirm, by means of high scores, that these concepts are strengthened and favored by the use of the remote laboratory. As a result of having the laboratory during more time, students acquire more experience with the hardware and, therefore, develop their skills with greater confidence and guarantee (Q5-Q7).

In general, students consider that the development of telematic practices regarding traditional sessions supposes an advantage for both academic and professional formation (Q8-Q11). On the other hand,

when facilitating remote work, practices can be developed in groups, letting students the management of their organization and, therefore, to foment team works, leadership and initiative (Q12-Q14). The analysis carried out leads the teachers to conclude that the students have a greater willingness to accomplish practices from home instead of carrying out in person at the laboratory (Q15). In this sense, students consider the project viable for implementing in a university context (Q16). These results are validated in Q17, in which the general assessment was rather high since practices were more pleasant and appealing.

V. CONCLUSIONS

This work intends a simple and low-cost solution devoted to the power control of telematic practices. The main objective of this system is to allow access on demand to an educational laboratory dedicated to computer networks. As a part of the deployments carried out in this project, several client and server applications of power control have been presented. Their main function is the remote starting of the lab hardware, both delayed and on demand. Energy savings and an increase of the operation life of the hardware are obtained as a result of not requiring a continuous electric supply (only the server). This experience has been tested with a group of students of Computer Engineering. The network infrastructure and methodology for telematic access to the laboratory have been presented. With this purpose, the capabilities and features as educational laboratory have been validated.

NOMENCLATURE

ACL	Access Control List
CNET	Computer Network
CON	Console Cable
ECTS	European Credit Transfer and Accumulation System
EHEA	European Higher Education Area
FTP	File Transfer Protocol
GigaE	Gigabit Ethernet
GNS3	Graphical Network Simulator
GTK+	GIMP Toolkit
ICMP	Internet Control Message Protocol
IP	Internet Protocol
LAN	Local Area Network
NS-2	Network Simulator
OMNet	Objective Modular Network Testbed in C++
OPNET	Optimized Network Engineering Tool
RL	Remote Laboratory
RTT	Round Trip Time
SCORM	Sharable Content Object Reference Model
SNMP	Simple Network Management Protocol
SMPS	Switched Mode Power Supply
TCP	Transmission Control Protocol
VITELS	Virtual Internet and Tel. Lab. Switzerland
VL	Virtual Laboratory
VRL	Virtual and Remote Laboratory
WAN	Wide Area Network
WebCT	Web Course Tools
WOL	Wake on LAN

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AUTHORS

T.J. Mateo Sanguino is with the University of Huelva, Department of Electronic Engineering, Computer Systems and Automatics, Ctra. Huelva-La Rábida S/N, 21819, Palos de La Frontera, Huelva, Spain (e-mail: tomas.mateo@diesia.uhu.es).

D.A. López García is with the University of Huelva, Department of Electronic Engineering, Computer Systems and Automatics, Ctra. Huelva-La Rábida S/N, 21819, Palos de La Frontera, Huelva, Spain (e-mail: diego.lopez@diesia.uhu.es).

E. Cortés Ancos is with the University of Huelva, Department of Electronic Engineering, Computer Systems and Automatics, Ctra. Huelva-La Rábida S/N, 21819, Palos de La Frontera, Huelva, Spain (e-mail: estefania.cortes@diesia.uhu.es).