Large and Small Scale Networks of Remote Labs: a Survey

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Abstract

The advantages of networking are widely known in many areas, i.e. from business to personal areas. Another area where networks have proved their benefits is education. Taking the Higher Education level into consideration, it is easy to find many successful and fruitful examples of networks both in the long and short past. More recently, the advent and wide use of the Internet has brought an all new range of opportunities not only to the sustain and expansion of existing networks but also to the creation of new ones. We consider the boom effect the Internet had on educational networks, and the emergence of a new educational resource known as remote experimentation to explain the recent appearance of a new type of network, i.e. remote experimentation networks. After introducing the basic building blocks for this network type, we describe how small and large scale networks of remote labs have been forming actively, since the last decade, and present some illustrative examples. In the conclusion we consider new directions for these networks.

Keywords: *remote experimentation, remote laboratories, weblabs, educational networks, networks of remote laboratories, remote experimentation networks.*

1. Introduction

Education in science and engineering requires practical experimentation. While this has been carried out in laboratory or in the field for ages, the use of computers has recently introduced two new approaches based on simulated laboratories and remote laboratories. A simulated laboratory corresponds to one or more computer applications providing a graphical representation of both the instruments and objects under experimentation, and returning results according to a model description of the behaviour and interaction of those elements. A remote laboratory corresponds to the situation where the control & observation of the physical instruments and objects under experimentation are mediated through a computer and adequate remote access to that computer is provided through a specific communication network. In a recent comparative literature survey on hands-on, simulated and remote laboratories, carried out through a web search in three electronic databases (IEEE, ACM, and ScienceDirect) and several educational journals, Ma and Nickerson [1] were able to identify over 1000 articles related to this issue, with a majority addressing technical implementation issues. From this initial set, Ma and Nickerson extracted around 170 references that provide a good background reading for understanding the educational value of hands-on, virtual, and remote labs. In a second refinement, 60 articles were selected (20 on each category) for full-text review and coding, and for initially observing that "*most of the laboratories discussed fall into the engineering domain*", "*there is no standard criteria to evaluate the effectiveness of labwork*"; and "*there are advocates and detractors for each lab type*". They then discuss: "*the relative educational value of each category; the fact that even hands-on are becoming increasingly mediated, in addition to that of simulated and remote experiments, which are always computer-mediated; how each category relates to the real world and how belief may be more important than technology in understating that link; and finally how collaboration methods may interact with the lab technology type.*" The authors finally present their findings and suggest, as a conclusion, that there is room for more research, namely on the combination of the three lab types and on the interactions that lead students to a sense of immersion.

At this moment, Institutions of Higher Education (IHE) are using one, two, or the three laboratory types, either in an isolated way or in combination, to improve students performance and reduce operational costs. Given the cost factor associated with each lab type, it is easy to perceive that trying out combinations requires a huge investment of both manpower and equipment. We also note that the problem of creating a sense of immersion (common to the three lab types) has not been entirely solved. An abstract view of this panorama allows us to identify two major factors that lead to collaboration among IHEs , as suggested by Reid [2]:

1. sharing of developmental costs; - this can be in the form of material, licences, systems, staff, developmental or management costs;
2. increased range of skills and of curriculum arising from the various strengths of the different partners, and hence an increase in the quality of provision.

Sometimes these collaborative actions assume a formal aspect in the form of a *network*, and in that sense, if virtual and remote labs are in the basis of such collaboration, one may speak about networks of virtual and remote labs. While it is possible to address the two network types (or one, if combined), we will only consider the second one (networks of remote labs) because:

- ultimately, as virtual labs are based on software, they can be replicated and installed at almost no cost, if allowed by its owner. This is not the case with remote labs as equipment is involved and therefore its acquisition cost must always be considered.
- very often the virtual lab acts as an antechamber to the remote lab, allowing the student to practice his/her skills on a safe environment and then, when confident enough, try out the same actions on real equipment and/or devices. Bruns and Erbe, and Noguez and Sucar, provide two very good examples of such combination in [3,4] and [5,6], respectively.

This chapter addresses the formation of networks of remote labs and its added value to education. It starts by identifying several educational networks and the boom effect the Internet had, in such a way that it is possible to distinguish two time periods, i.e. the pre- and post-Web periods, as indicated in section 2. Section 3 presents the building blocks for a remote experimentation (RE) network, which allows to distinguish regional and national networks of remote labs, described in section 4, from continental and intercontinental networks, described in section 5. Finally, section 6 concludes the chapter with the final remarks and some future directions.

2. Educational networks: the e-boom

There are two types of educational networks: horizontal and vertical. These two types are sometimes combined to form a third one that covers the two dimensions. Horizontal networks include institutions providing education at the same level, e.g. high school level or university level. Vertical networks include institutions providing education at different levels. Furthermore, networks may be classified according to their area of influence, i.e. they may be local, regional, state, national, continental, or inter-continental networks. The driving forces for setting up an educational network are multiple and diverse, therefore the following list is only tentative:

- Financial – share a certain needed service or equipment.
- Political / strategic – co-operate with other institutions to increase the educational process quality, by sharing good pedagogical practices, student and teacher mobility, information on funding opportunities that call for consortium proposals, etc.
- Administrative – e.g. the body ruling a set of institutions grouped under a regional area may create a network where students that enter one particular institution, when moving up in their education, are first selected from other institutions belonging to the same network.
- Emotional – apart from the previous rational reasons, the decision to form a network may be based on emotional ones, where the persons responsible for the institutions decide to form a network so as to maintain close relational links, building upon their own personal links[1].

A network necessarily entails communication channels to allow for collaborative work and information dissemination among its members. In that sense, the quantity and quality of the available communication channels influences the number and dimension of existing networks. Building upon this rationale, it is important to consider the most important milestones in communication to evaluate their impact on networks. Leiner et al. [7] refer the 'telegraph', 'telephone', 'radio' and the 'Internet' (for connecting computers) as important milestones in communications[2].

> "*The Internet has revolutionized the computer and communications world like nothing before. The invention of the telegraph, telephone, radio, and computer set the stage for this unprecedented integration of capabilities. The Internet is at once a world-wide broadcasting capability, a mechanism for information dissemination, and a medium for collaboration and interaction between individuals and their computers without regard for geographic location.*"

Considering the scope of this chapter, where computers are omnipresent, we will focus on the Internet appearance and evolution, as depicted in figure 1 ([7]). The Internet, in itself, has appeared in the earlies 70's (20th century) connecting a few computers, at start. Given the fact this was a highly technological achievement, only a few institutions (and staff members) were benefiting from it, at that time. Adding the existence of few tools and standards and the need for technical formation, the impact of the Internet was to remain confined to a rather small community until the emergence of the World-Wide Web (WWW), in the early-mid 90's (20th century), as defended by Segal in [8]. It is precisely the appearance of the WWW[3] that brought this technology to the mouth

1 In all cases, it is difficult to trace apart these reasons, as any document will only refer objective and rational reasons.
2 Although the television may be considered as another important milestone, we are assuming a bidirectional communication channel and in that sense we (and presumably Leiner et al. [7]) excluded it from this list.
3 Associated with the widespread use of PCs and the appearance of web browsers and simple web authoring tools.

of the common citizen and to the everyday language. With this in mind, we describe the overall panorama of educational networks in two distinct sub-sections: one referring to the period before the appearance of the WWW and one referring to the period after.

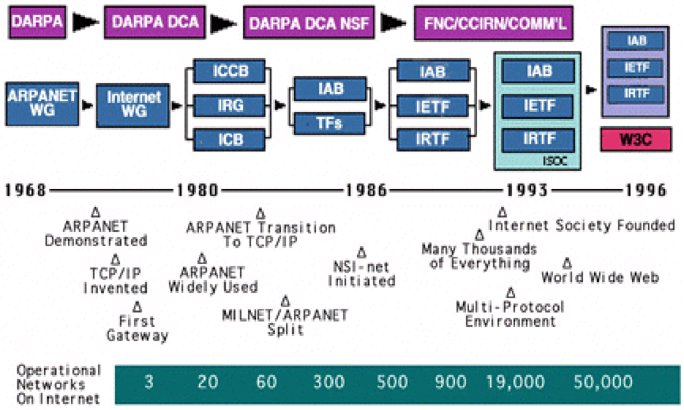

Fig. 1: Internet appearance and evolution in time.

2.1. The pre-Web period

Leiner et al. trace "*the first recorded description of the social interactions that could be enabled through networking*" to "*a series of memos written by J.C.R. Licklider of MIT in August 1962 discussing his* "Galactic Network" *concept*" [7]. A lot of collaboration then followed in North America to develop the ARPANET, with some IHEs being involved in the process. As knowledge arises from Research & Development (R&D), the findings associated with computer networking were among the first educational contents to be shared among those IHEs, in a new type of educational network. By that time, Europe was still lagging behind in computer networking, with CERN being the first European institution to be involved in the process, as exposed by Segal in [8]. It was through CERN that Europe first connected to North America, creating the first intercontinental computer network. It was also at CERN that Tim Berners-Lee developed and installed the first web-server in 1991. By that year, Aburdene et al. envisaged "*laboratory experiments being operated remotely and shared among universities*" [9], although at the same time there were already on-going discussions at the U.S. about a network of collaborating laboratories. This idea, coined as "collaboratories", was initially presented in 1989 and can actually be seen as the first national network of remote labs in the broader sense [10,11]. But it was not until 1993, when CERN decided to freely open the WWW to anyone, that *all* IHEs had the opportunity to share knowledge and start working together, without restrictions, in a collaborative way, through the Internet. With a wider dissemination of tools, equipment, and concepts, there was a considerable boom in the formation of educational networks, in general, and RE networks, in particular, as described in the following subsection.

2.2. The post-Web period

Figure 1 illustrates the explosion in the number of operational networks in the Internet, just before 1993. The following years witnessed a considerable growth in activities related to using the web for supporting education, in general, and also experimentation, in particular. Large educational networks started being formed, and activity grew even more with public funds being injected in massive quantities. The following bullet points contain a few illustrative examples:

- European Schoolnet [12] – a network of 28 Ministries of Education across Europe – that also operates the Xplora portal dedicated to science education, in particular [13]. The Xplora portal is supported by the PENCIL project, which is funded by the European Commission's Directorate General (EC-DG) for Research. The PENCIL project is part of the wider Nucleus framework, a cluster of science education projects including Europe's major research laboratories. The EC-DG for Education and Culture supports another large portal dedicated to e-learning [14], and also several projects dealing with RE, run by large consortia, through the Socrates and Leonardo da Vinci programmes. Some of these projects will later be described in section 5.
- PROLEARN [15] – a 'Network of Excellence' (NoE), financed by the EC Information Society Technology (IST) programme, dealing with technology enhanced professional learning. This NoE includes a workpackage dedicated to online experiments, again described in more detail in section 5. The IST programme has also financed several other projects dealing with educational networks, e.g. the K2 project devoted to European E-Learning Networks and Observatories [16].
- The MIT OpenCourseWare (OCW) and iLab initiatives [17, 18, 19]. The OCW is a database with more than 1,100 online courses available to the overall educational community, which was developed in 2001, with an initial funding of US $11 million. According to Wasserstein, OCW users are now spread by more than 215 countries, with more than 31,000 subscribing the monthly update newsletter [19]. The MIT iLab is also a world reference in terms of remote labs and thus will be described in more detail in section 5.

Noticeably, these are a few examples from the all universe returned by a simple web search. Using, for instance, the expression “education network” on a web search with Google® we obtain almost 1 million hits. By applying appropriated filter terms and expressions (e.g. “universities” or “higher education”), it would be possible to narrow down the obtained search results, although it is obvious that a thorough analysis would be quite time consuming and yet would only be based on information available in electronic format. The central point of this section is that educational networks are breading spaces for other types of collaboration, namely for sharing resources related to practical experimentation, particularly in science and engineering fields. As in many other domains, the route to establish such a network may actually come from an initial collaboration in developing something (engineers are particularly keen in building up things, i.e. they enjoy it) and then formalising that relation by forming the network. In this way, one may think of two distinct, yet combinable, approaches to create networks of remote labs: bottom-up, i.e. technology driven, and top-down, i.e. educationally driven. In the first case, collaboration may come from the need to connect different technologies, solve remote control problems, among other reasons [20, 21]. In the second case, collaboration may come from the need to develop practical experiments to support science & engineering related contents, available through e-learning systems [22, 23]. With these two approaches in mind we will describe in the following section the building blocks for a RE network.

3. Building blocks of a RE network

Irrespectively of its dimension, a RE network contains a discrete number of basic building blocks. Figure 2 illustrates a general architecture indicated by Schmid in [24], which includes the following ones:

- An experiment or instrumentation server – this connects directly to the experimental apparatus either through an Ethernet port (in which case one may consider being an Intranet) or through other computer communication ports. If there are several remote experiments available at the same time, from one single place, then one may speak of a remote lab, in which case it may contain several experiment servers, or, more recently, several micro web servers, which reduces the overall costs [25].
- A media server – this provides audio and/ or video feedback from the remote experiment. Sometimes this is not present as the remote experiment may not imply such a feedback, e.g. a purely electronic experience in which the inputs and outputs are electrical signals. The experimentation server may also accumulate this function, but this option is avoided in most situations due to performance penalties, which also suggest placing the collaborative tools on a different server. An aspect not depicted in figure 2 is the presence of a lab tutor, which may be in another location. This is another potential collaborative aspect in a network of remote labs, where one institution (not having a single remote experiment) may also contribute with manpower in the form of a lab tutor, or more recently with the development and provision of an intelligent tutor system [26].
- A web server – this contains all the information the student (or any other user) needs for running the experiment. It also provides the situated learning environment that places the remote experiment within a certain theoretical background.
- An access server – this prevents unauthorized users from accessing the remote experiment, by requiring a login and password. It may also contain a booking system that allows managing the access from various students. Although it may be implemented on a different server, there are examples of installing the booking system into the web server. For instance, Ferreira and Cardoso have developed a booking system that may be attached to the Moodle Learning Management System (LMS) and that is available as shareware [27].
- A provider server – this acts as the portal providing access to a pool of remote experiments supplied from different. It is the front page of what can be a small or large network of remote labs.
- The user client(s) – these can either be students, running the remote experiments so as to do the practical work associated with a given theoretical content, or lecturers, using the remote experiment within a certain lesson to stress the practical effect of a taught theory or formula.

The building blocks depicted in figure 2 can be spread by many IHEs, with the possibility of some being replicated, namely the experiment server, as a network may share more than a single remote experiment.

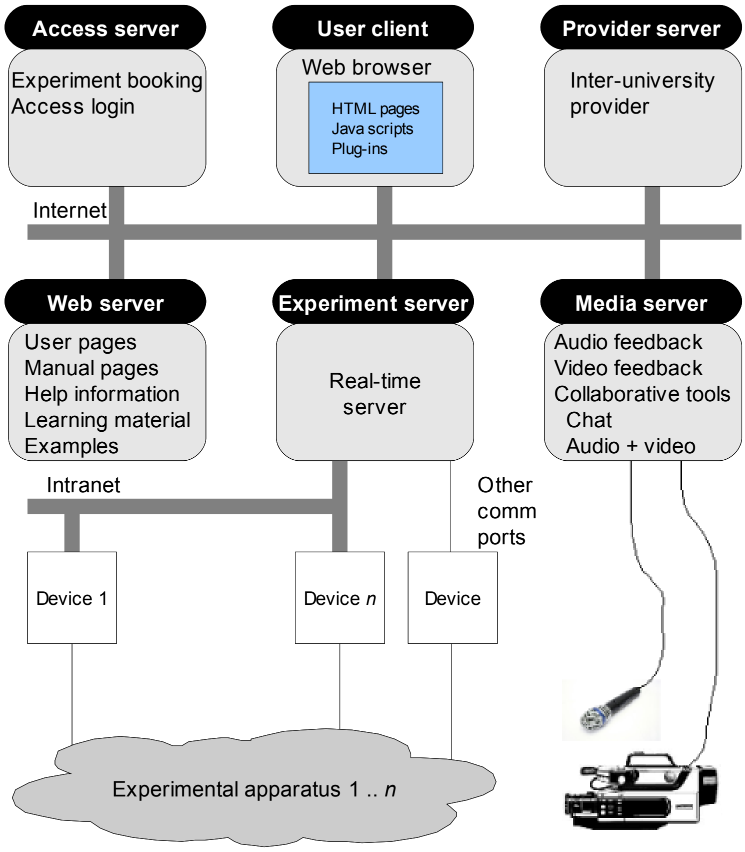

Fig. 2: General architecture of a remote lab (network)

The existence of a provider server (1), the number of available experiments (2), and the number of user clients (3) could be part of the criteria to distinguish "large" from "small" networks of remote labs. While the first two elements are easily recognisable and measurable from the outside, the third one is somewhat more difficult to control or measure. Even if the network defines an initial target audience, including its size, it is not clear if all potential clients will actually use the resource, the point being that usage is a very dynamic parameter. Another problems is that sometimes it is difficult to trace apart who provides what in a network. Therefore, and although we have used the title "large and small networks of remote labs" for this chapter, we decided to distinguish regional and national networks from continental and inter-continental ones, in the two following sections, the reason being precisely the facility to catalogue them according to this criteria, from the information that is usually available in electronic format. An inevitable criticism is that it is difficult to compare networks of remote labs established in one country such as the U.S. from another one established in, for instance, Germany, given the significant differences in area and population. Notice that in both cases we will be referring to a national network of remote labs, as all nodes pertain to a single country, even though it may have a continental dimension.

4. Regional and national networks of remote labs

While it is easier to identify regional and national networks of remote labs when the interfaces and contents are written in English (or in any other language familiar to the authors), there are many networks of this type that use the native language of the region or country they are implemented in. Very often, this happens when:

- the institutions or groups owning the remote labs received funds from state or national

funding agencies, and internationalisation is not a key factor;
- the resources are to be made available to students who are not fluent on a foreign language;
- there is an intention to preserve resources available on the web from a wider (ab)use.

Apart from political or strategic reasons, there are presently few arguments to sustain the decision of restricting the use of one web-based educational resource, like a remote lab, to a single region or country. Even if initially built with no internationalization requirements, it would take one single remote lab from a certain regional or national network to enter into a continental or intercontinental network to blur the initial definition. At this point it is easy to accept that remote labs developed in English-speaking countries will have an higher potential degree of internationalization, with less development costs, as the local students will already be able to use them and also adhere to groupwork with other English-speaking foreign students, willing to practice their social skills in a wider context. In the following paragraphs we provide three illustrative examples: an U.S. regional network, a German regional network, and a Brazilian regional network. To finish the section, we refer the U.S. National Collaboratories system [10], which corresponds to one of the largest national networks of remote labs.

- The Interactive Nano-Visualization in Science and Engineering Education (IN-VSEE) project is run by a consortium of institutions belonging to different states in North America [28,29]. IN-VSEE has made available through the Internet a set of Scanning Probe Microscopy (SPM) experiments, with image broadcasting and control of the instrument on a real-time basis, for supprting the teaching of nano-science and technology concepts in upper-division high school classes and lower-division college lectures. The project was funded by the Applications of Advanced Technologies (AAT) Programme of the American National Science Foundation (NSF). An interesting note about this project is that it makes available, on a remote fashion, a technique that was awarded the 1986 Nobel prize in Physics, on the persons of its co-inventors, Heinrich Rohrer and Gerd Binnig, together with Ernst Ruska. Noticeably, H. Roher is actually a member of the External Advisory Board associated with this project.
- Learnet and Controlnet24 are two German regional networks of remote labs on the subject of control engineering [30,31]. Most of the remote experiments made available to the consortium were the result of pioneer work and were developed for a closed user community, because of safety issues. The websites of both networks are written in German, and so little information can be extracted from there by those who are not knowledgeable on that language. However, one of the partners, C. Schmid [24] from the Ruhr-Universität Bochum, later integrated a wider European network, named ReLAX (described in more detail in the next section) and thus it was possible to track down his former work at national level, within the Learnet project. This note corroborates the previous assertion that it takes one single remote lab from a certain regional or national network to enter into a continental or intercontinental network to blur the differences between these dimensions, even if that particular remote lab may have initially been built with no internationalization requirements.
- The Remote Experimentation Laboratories (RexLab) of the Federal University of Santa Catarina (UFSC) and of the University of Southern Santa Catarina (UNISUL) are two core nodes of a Brazilian regional network of remote labs in the area of microcontroller-based applications [32,33]. Again, the websites of both remote labs are not in English (i.e. they are

in Portuguese) but this fact has not prevented the two labs to join, in 2004, a larger, intercontinental network of remote labs named RexNet, which will also be described in more detail in the next section.

The U.S. National Collaboratories system provides the basis for intensive collaborative work among many different American IHEs, in many different scientific and engineering areas. Its implementation by the U.S. Department of Energy is one of the best documented ones and includes many success stories, available at the corresponding website [34]. We decided to reproduce one of those stories here just to stress the point of how personal relations may establish unsuspected collaborative directions for a particular remote lab (see 1st footnote).

> *"One of the members of the Materials Microcharacterization Collaboratory (MMC), Edgar Voelkl, visited his hometown of Regensburg, Germany, to attend a conference a couple of years ago. The conference organizer became quite excited when Edgar suggested operating his U.S. based electron microscope remotely during the program. Edgar encountered a lot of skepticism, but he didn't let that influence his plans. The local newspaper announced the remote operation as one of two highlights of the upcoming meeting: "World premier at the University: A highly sophisticated instrument in the American Oak Ridge (Tennessee) will be operated live through the Internet." On the night of the session, the lecture hall was almost filled. It was obvious that many came to scoff - but it was all in vain. Toward the end of Edgar's talk, the connection to ORNL was established and the microscope was used remotely to obtain high-resolution images of gold particles. Astigmatism and focus were corrected live, and the final image was downloaded to a laptop in Regensburg. The connection was great - throughput of greater than 1 image per second. The outcome of the session exceeded expectations, and surely converted many skeptics that night."*

5. Continental and intercontinental networks of remote labs

An anecdotal observation from the previous story is that the U.S. have progressed more rapidly than Europe in the area of RE. One possible reason may be that the funding mechanisms for joint European projects have been scattered, in the recent past, for many different programmes managed by different EC-DGs, not mentioning bilateral agreements between two or more European countries. This means that it is possible to trace back to the first years of these large funding programmes one same project (or idea around a project with touch-ups on the consortium working on it) being funded by a series of, sometimes overlapping, programmes. It is not our goal to describe the EC research funding structure, neither in the past nor in the present, but nevertheless it is important to have an overall idea to understand how continental and intercontinental networks of remote labs involving European countries have been emerging.

- Education and Training programmes, managed by the EC-DG Education and Culture
  - SOCRATES I and II (1995 – 2006)
  - LEONARDO DA VINCI (1995 – 2006)
- Research programmes, managed by the EC-DG Research, with contributions from other DGs, namely Information Society and Media
  - 4th Framework Programme (FP) (1994 – 1998)

5th FP (1998 – 2002)
6th FP (2002 – 2006) - IST is one of the 7 key thematic priority areas
7th FP (2007 – 2013)

- Co-operation programmes with other world regions, managed by the EuropeAid – Co-operation Office
  ALFA – Supports the co-operation between European and Latin-American IHEs
  ASI@ITC – Supports the co-operation between European and Asian IHEs
  EDULINK – Supports the co-operation between European and ACP IHEs

Within the projects funded by the 4th FP, namely by the Telematics Application Programme, launched after the Web being made freely available to everyone, the RE 1008 – Remote Experiment MOnitoring and conTrol (REMOT) project [35] was one of the first European wide projects to deal with remote access to expensive equipment (i.e. an astronomical telescope and a tokamat). It run from January 1996 till December 1997, and included institutions from Germany, Italy, Netherlands, and Spain. Project RE 4005 – DYNAmical COnfigurable Remote Experiment Monitoring & Control System (DYNACORE) [36] followed from 1998 to 2000 with further developments in the software architecture used for accessing and controlling the remote equipments. Currently there is a similar accessible network of astronomical telescopes that allow remote access to anyone, through the Discovery Space (D-SPACE) project, which is co-financed by the EC – DG Information Society and Media within the framework of the eTEN Programme eLearning Action (6th FP) [37]. The project website is accessible through the Xplora – Megalab – Web Experiments portal [38], which also provides access to remote expensive electronic microscopes, a robot in a maze, and an industrial robot, among other apparatus.

The EC-DG Information Society and Media has also financed many other similar projects dealing with remote experiments. The following list was extracted from [39], by searching through all projects dealing with weblabs, remote experiments, or remote experimentation:

- The Collaborative Learning and Distributed Experimentation (COLDEX) project started in June 2002 and ended in May 2005. It involved the use of a remote sites, mainly in Chile, for providing real experimental data for a community of learners in Europe. Among those sites were an observatory with a high quality telescope and a seismic measurement station, as Chile is situated in an "active" zone. Again, the remote access to a rather expensive and unique equipment was at the centre of yet another project [40].
- The Collaborative Laboratories for Europe (CO-LAB) project started in April 2001 and lasted for 39 months, with a total budget of 2.12 million euro. It built on the same concepts of the U.S. Collaboratories system, by offering access to remote laboratories [41].
- The Educational Network Structure for Dissemination of Real Laboratory Experiments to support Engineering Education (eMerge) project started in October 2002 and finished in October 2004 [42]. It was funded by the European Socrates programme, through the MINERVA action line, and involved partners from nine different educational institutions, from eight European countries. Cabello et al. indicate in [43] that "*the actual work was based on previous experiences like Retwine, the Lab-on-Web and the Socrates RichODL projects, where prototypes of virtual laboratories were realized (...). By using Web technologies and computer controlled instrumentation, students could access to these remote laboratories. The main objective (...)* was *to extend these technologies out of the*

individual institutions, making the services available to the European students. In the project, the consortium *emphasized the creation of a variety laboratory experiments, and the development of supporting course material and educational practices.*"

- The goal of the UNIVERSAL project (5th FP) was to develop a brokerage platform for distant course units, including remote experiments. It later provided the ground for the EducaNext initiative [44], which is now also supported by PROLEARN [15]. Presently the EducaNext portal contains hundreds of course units in several different science and engineering areas, many supported by remote experiments, including those developed in the scope of the Workpackage "Online Experiments" of the PROLEARN project.
- The Remote LAboratory eXperimentation trial (ReLAX) project, also funded by the IST programme (5th FP), under the action line "New market mediation systems", run from October 2000 till June 2002, with a budget contribution from the EC of half million euro. Cyberlab, a Norwegian company, integrated the consortium responsible for this project. It now provides tools and services for web-based sharing and operation of online laboratory resources via a global laboratory network and the accompanying Experiment Service Provider business model, which the company claims to have been tested during ReLAX [45]. An interesting note about ReLAX was the underlying idea of a business model associated with the delivery of remote experiments, able to accommodate different interests ranging from academia to industry, as expressed by Eikaas in [46].
- The Practical Experimentation by Accessible Remote Learning (PEARL) project run from April 2000 till February 2003 and aimed to develop and share several remote experiments, namely: one visual inspection system for Printed Circuit Boards, one Remote Electronic Workbench, one electronic microscope, and several remote modules for teaching physics and chemistry, e.g. spectrometry [47]. Although it envisaged a unique system for accessing remote experiments, at least two different approaches were used for that purpose: one based in CORBA and XML and another based on LabVIEW. While the first approach proved feasible (a similar approach was used in the previously referred DYNACORE project) it was somewhat discontinued in face or other web technologies (e.g. Java), with the second one being now a commercial-of-the-shelf solution, used by many weblabs. The consortium included IHEs from England, Scotland (University of Dundee), Republic of Ireland, Portugal (University of Porto), and a robotics company from Greece.
- Lab@FUTURE and DERIVE were other two IST-funded projects also dealing with remote labs and involving several European partners [48,49]. An interesting note was the participation of the University of Bremen (Germany), through ARTEC, on both projects, which developed a mix of a virtual and remote laboratory in mechatronics, later shared with other European IHEs within the MARVEL project [50], financed by the Leonardo da Vinci programme. The MARVEL project gathered institutions from six European countries, including again the University of Porto, from Portugal.
- The Remote Experimentation Network (RexNet) project run from January 2005 till December 2006 and was funded by the ALFA programme. It gathered a consortium of 12 IHEs from both Europe an Latin American, including again the University of Dundee, Scotland, the University of Porto, Portugal, and the University of Bremen, Germany [51]. The project goal was not to discuss the technical, pedagogical, or economical strengths of remote experimentation, but rather to raise and try to answer some questions about the underlying benefits and challenges of establishing a peer-to-peer network of remote labs,

and in particular the added value to education. An important aspect of this network was that it built on partners with a vast and rich past experience in the field, with some of them acting as promoters of similar local, regional, or even continental networks of remote labs, as depicted by figure 3. The cases of UFSC and its regional network at Brazil, and the Universities of Porto (Portugal) and of Bremen (Germany) and their continental network established around the MARVEL project, are just two illustrative examples in RexNet, among others.

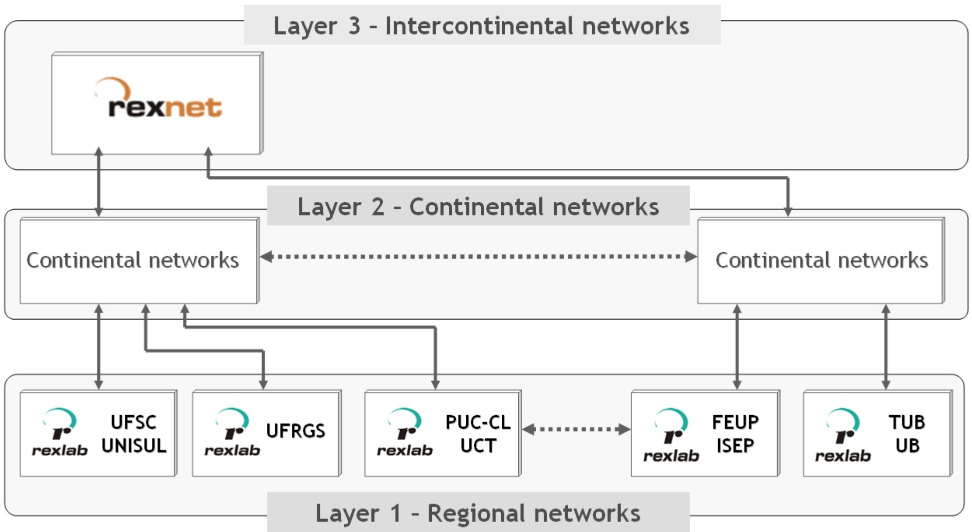

Fig. 3: Multilevel networks of remote labs: the RexNet experience

To conclude this section we refer the iLab Project at MIT [52], in which several iLabs for instruction in Electrical Engineering and Computer Science, Civil Engineering and Chemical Engineering were developed. According to its mentor, del Alamo [19], some of these labs have been shared with students from universities in North America, Europe, Asia, and Africa. Although centred around one single institution, the MIT, this network is probably one of the best well-known cases for the RE community. One of the reasons for its success may come from the fact it is well supported by an IHE, the MIT, that in due time took the decision to promote the dissemination of its courses through the Web [18].

6. Conclusion and future directions

The former case is an example of one IHE that is now in the 5th and last stage of development in a progress scale presented by Bates in [53]. Although this distinction was originally devised for the general e-Learning area, it can also be used for RE, as this is considered to be a subset of e-Learning. Bates establishes the following stages: “(1) *lone rangers, individual people enthused by the technology, working on their own and experimenting*; (2) *lone rangers putting pressure on the university administration to provide help and resources;* (3) *rapid uncoordinated activity, and lots of things happening all over the place and lots of problems as a result;* (4) *focus, policies and priorities, i.e. institutions start thinking strategically;* and (5) *the sustainable and high quality use of e-learning in selected areas or for specific target groups.*” It is possible to distinguish situations falling into each one of these stages from the illustrative cases presented in sections 4 and 5. For instance, many of the remote experiments made available through the EducaNext portal [44], where the result of actions undertaken by R&D groups, without the structural support of their Institution Administrations. A fact supporting this affirmation is that some still struggle with problems related to their Institution policy in relation to firewalls, which is likely to affect the access from the outside to the experiment server, when some particular TCP/IP ports are used.

At this point, we believe that both directions will co-exist, i.e. some IHEs will start to support their groups currently working on RE, as part of an overall e-Learning strategy, giving them the conditions to provide high-quality remote experiments as a sustainable service, while new situations falling into the initial stages will emerge as a result of (1) adoption of new technologies, like Web 3.0; (2) new combinations types between virtual and remote labs being proposed and demonstrated; (3) further developments on the sense of immersion and the collaborative nature associated with RE; (4) the m-learning area being also considered as appropriated for the introduction of RE (in which case some authors defend the expression "mobile experimentation"; finally (5) unpredicted proposals resulting from human ingenuity.

To conclude, we think it is possible that a new IHE like the European Institute of Technology (EIT), being now proposed by the EC [54], may actually consider e-Learning and RE as key e-services that must be provided to, or shared with, the many IHEs of other world regions that now co-operate with Europe through, for instance, the ALFA, ASI@ITC, or EDULINK programmes. In such case, the EIT may adapt the successful example of the MIT i-Lab, counting on the experience of many other European IHEs already participating on inter-continental networks of remote labs.

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