Overlay Network Architectures for Peer-to-Peer Remote Access Laboratories

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***Abstract*— Remote Access Laboratories are been used for practical learning activities in engineering education in the universities worldwide. Usually these systems follow a centralised client-server paradigm. This work proposes a peer-to-peer remote access laboratory architecture where participants are both users of experiments as well as makers. The feasibility of a peer–to–peer remote laboratories system is investigated. The system is built around a VPN service that allows direct access to makers' node from user nodes. To simplify the configuration a preconfigured VPN gateway node is introduced. This box is a network router that handles authentication, port forwarding and allocation of address space. The Remote Access Laboratories for fun, innovation and education (RALfie) project is a collaborative research and innovation project with the aim to engage children in STEM topics involving academics from engineering and education disciplines. In the context of RALfie, a prototype system has been developed and trial has been undertaken to establish whether children understand the RAL concept and to test their ability to configure remote experiments on their own. A brief summary trial results for the prototype implementation are reported.**

***Index Terms*—remote laboratories, remote access laboratories, STEM, peer-to-peer.**

I. Introduction

Remote laboratories are increasingly used by universities to address large student numbers, equipment utilization and sharing of unique or costly experimental apparatus [1]. Access issues in the context of distance education are another key driver of RAL deployments [2]. While such remote laboratories are not new [3], more recently projects have looked at remote access laboratories on a large scale [4, 5].

At the school level there is a perceived shortage of students showing interest in Science, Technology, Engineering, and Mathematics (STEM) subjects. Where these have been questioned by some [6], there is a strong perception that there is a need to improve student interest in STEM subject areas [7, 8]. There are also indicators that predispositions towards STEM topics are acquired early [6]. A number of major projects have made a connection between remote laboratories and improved STEM education [9, e.g.]. Another movement that has flourished as a result of the Internet are "maker" communities [10].

Creating meaningful opportunities for communication and collaboration has been identified in the RAL literature as a pedagogical challenge when using labs remotely [11]. There is potential to use quest based learning and gamification techniques, including gamer-style guilds as online communities of learners, to improve the amount of collaboration and communication of the RAL experience especially with school aged children.

The *Remote Access Laboratories for fun, innovation and education* (RALfie) project is a collaborative research and innovation project involving academics from engineering and education disciplines. The project aims to develop children's Science, Technology, Engineering and Maths (STEM) concepts whilst fostering a positive attitude towards STEM learning. To achieve this, the project combines all three areas (RAL; maker communities; and gaming) in a unique learning environment to overcome (technological) barriers.

To achieve this, the project is creating a quest-based game using an innovative online technical system, so children can create and access experiments and activities through RAL structures. The game aims to develop and refine learners' skills of making and using experiments. Learners will advance through a series of levels and achievements rewarded by badges and points. This aims to motivate participation and maintain engagement with STEM content and nurture positive attitudes towards STEM. The project also aims to foster intrinsic motivation to engage with STEM by developing a community called a 'guild'. Guilds allow learners to safely engage with the wider STEM community to get help to meet their learning needs. With the community support in forums and a repository of web based plans and models, as well as peer-to-peer teaching, children involved in the RALFIE Project will be part of a wider community sharing experiments via the Internet for local and remote use.

The RALfie initiative consequently integrates three key focus areas: the technical system to enable a Peer-to-Peer Remote Access Laboratory (P2PRAL); the community to support the notion of peer-to-peer remotely accessible maker communities; and the use of a quest based game strategies to improve communication and collaboration.

This paper focuses on potential peer-to-peer network architectures that are being tested as part of the proposed RALfie system. The novel premise of this approach is that participants are both users and makers in the RAL environment. The generic system model is depicted in Figure 1: a central control gateway and two users that

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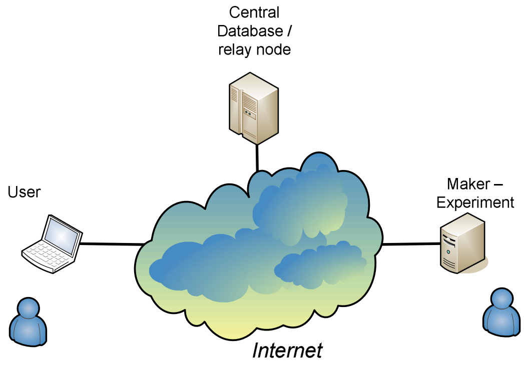

Figure 1. Network environment where RALFIE operates.

want to communicate with each other. The composition of information streams between nodes and communication service details depend on the specific application. Most experiments will require support for system control and system output, video feeds and video conferencing.

The main contributions of this paper include a methodology to enable peer-to-peer network access to laboratory activities; a prototype implementation; and initial trail results with children using the system. The key research question addressed in this paper is which overlay network architectures can be used to build a peer-to-peer remote access laboratory and how end points can be authenticated?

Related technical work is discussed in Section 2 and the educational framework is briefly discussed. The RALfie project and the resulting system requirements are discussed in Section 3. The overlay network methodology is discussed in Section 4 and user testing and the trail results are summarised in Section 5.

II. Related Work

Several RAL systems that have been deployed and used by universities have many similar characteristics. The technical implementation and the pedagogical aspects of these RAL systems are described here.

A. *Technical Aspects of existing RAL Systems*

Most of the widely used RAL started with an aim to increase accessibility with a rising number of students and limited resources at universities [12]. Other aims include sharing scarce resources and expertise between institutions. For RAL activities the pedagogies that are used often resemble face-to-face teaching. Several high level languages are being used to program rigs and create the user interfaces. Most RALs currently being used for practical purpose are targeted to undergraduate engineering students. The pedagogical design of RAL activities for one-to-one use of RAL systems have limited collaboration opportunities between students.

Several innovative features have been developed that exploit the additional capabilities of computer-based information system such as:

- Virtual reality environments [13]
- Remote co-operation between students in experiments [14]
- Dynamic components assembly for electronic devices [15]
- Reconfigurable laboratory kits [16]
- Advanced scheduling schemes [17]
- Mobile phone-based lab platforms [18]

Currently RAL activities are developed and deployed by expert developers and teaching staff for their student cohort. This involves costly and complex instruments and devices that use industrial standards for communication and measurement. Remote Laboratory Management Systems (RLMS) are predominantly client-server in nature with an aim of achieving a long period of operation and availability. A detailed comparison of the various system architectures is presented in [12]. Users of such systems do not get the chance to setup the experiments and are merely able to trigger the experiments and collect data.

B. *Pedagogical Aspect of RAL Systems*

Practical learning activities are an important part of Engineering Education [19] and there have been a number of initiatives and activities to involve school children in remote laboratories. Previous researchers [20-23] have made available 'ready-to-go' experiments situated in the universities to primary and secondary schools. These studies have reported that while children participating in the study achieved the intended outcomes, they were missing two key components of traditional science experiments in schools, the ability to setup and configure the experiment. In this context, the “maker” approach is very relevant [10].

Collaboration forms an important part of learning and teleconferencing solutions are another option to enhance both users and makers to communicate online. Previous research [24] has used *Moodle* and *Easy Java Simulations* software to create a system where a user can invite others, both teachers and students, into a collaborative experimental session for sharing experience or supervision. The systems implemented the practice of reciprocal teaching, problem-based learning (PBL), and cooperative work into the RLMS. The collaborative features have been reported to improve students’ engagement in experiments [24].

To allow shared peer-to-peer remote laboratories that support both student users and maker requires new paradigms in remote laboratory access and networking.

III. Context

This section discusses the underlying assumptions and requirements that form the basis of the RALFIE project. Besides the very specific online safety requirements for children, the assumptions in regard to network environment and services are applicable in a general context.

A. *Network Environment*

Due to the network connectivity of participating sites, not all nodes will have unrestricted, direct access to the Internet. Some nodes will reside on private networks and require Network Address Translation (NAT) to access the Internet. For example, most home networks fall into this category as a home networking router manages connection between the residents and outer world. There are a number of options to overcome the limitations that are imposed by the widespread use of NAT in most home gateways and many other locations:

- One option is to setup port mapping either manually or automatically using Universal Plug and Play (UPnP). In corporate environments, nodes are often located behind proxy servers and are not able to make direct connections.
- The peer-to-peer community has developed mechanisms that are able to overcome such limitations (Skype, JXTA etc.) where the restricted nodes use unrestricted nodes to exchange data between them.

B. *Supported (Telecommunication) Services*

To undertake practical real-time learning activities remotely, a number of network services are required. These include the experiment control where control commands are sent from the user to the experiment and the experiment returns the results in the form of web pages or screen images. The Internet bandwidth available to the users, along with large scale relay of data between nodes, could increase the latency and reduce the system performance and thus affect user satisfaction and understanding of the concepts. With the introduction of the National Broadband Network (NBN) in Australia most users are expected to have a good quality service to enable them use the peer to peer system effectively.

Many experiments rely on a video feedback for visual confirmation and high fidelity of experience of the events with the rig. The number of video feedback devices required may be one or more. Live or real-time video transmission between two nodes consumes massive bandwidth and to accurately establish reality, there must be minimal delay in the video stream.

Some of the other challenges of the RALfie distributed RAL environment include catering for child safety and security; integration with the game system and community tools.

IV. P2P Network Architecture

Traditionally RAL systems have been based on the client-server paradigm with one or more central nodes controlling the system and providing functionality such as authorisation, authentication and broker services. In a P2PRAL system, two distinct remote nodes can be identified: user sites and maker sites. User sites consist of a computer with Internet access. Maker sites also require Internet access and feature a computer system that controls experiments and provides an interface to the experiment, cameras and any other equipment required to complete the rig. These nodes are geographically distributed.

Figure 2 depicts two maker sites (green clouds on the right) that connect to a central Virtual Private Network (VPN) via *User VPN Gateways*. The local network that makes up the site connects the computer that is controlling the experiment as well as cameras and other networked equipment. An *Access Gateway* with an associated user and site database is also connected to the VPN and this gateway is also connected to the public Internet. Two users are shown on the right hand side.

The core of this P2PRAL is a peer-to-peer virtual private network. Previous work has demonstrated that latency is critical [25] and P2P communication is essential for real-time interactive applications [26]. In the context of an Australia-wide system, relay nodes can introduce considerable network delays which results in unacceptable lag for users. If users and makers communicate directly, the effect of network latency is minimised. As a secondary effect, access traffic is distributed to many nodes and not concentrated at one particular gateway. There are two options for users to access experiments.

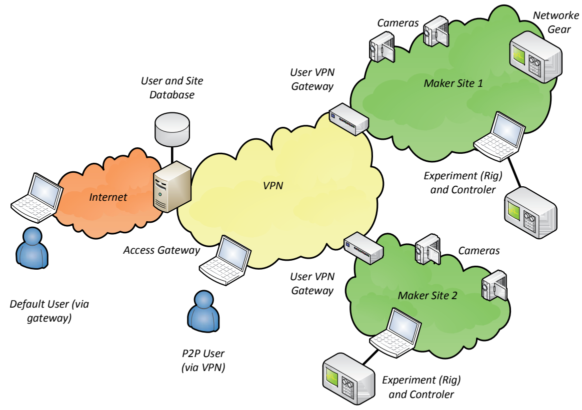

Figure 2. P2PRAL Network Configuration.

Default access is via the public Internet and the web server that is hosted on the *Access Gateway*. The web server authenticates users and redirects requests via the VPN to the *User VPN Gateway*. This in turn redirects requests to equipment and cameras. This first option is not a true peer-to-peer environment as all requests and responses have to be sent via the *Access Gateway*.

For the second option, users are connected to the VPN and directly access maker sites. Users are still authenticated by the *Access Gateway*. The main difficulty with this option is the need for all users to install a VPN client before the system can be accessed. The first option works with standard web browsers without the need to install additional software. The main advantage of the direct P2P access is performance, as this approach minimises latency (lag) for users [26]. Because of this trade-off, a system that supports both access paradigms is being proposed.

The diagram omits the Internet that is required to setup the VPN between the sites. From the perspective of the devices, i.e. the *Access Gateway* and the *User VPN Gateway*, these are connected to the same IP subnet and can be reached directly.

At the local maker site, the experiment and other equipment has to be connected to the P2PRAL network. There are potentially two options to achieve this: use existing local networking infrastructure or set up a separate local network. The former requires less additional infrastructure, but potentially means that a third party has access to the local network and the computers that are connected to this network. As security settings for local networks are often permissive, this can be a security concern. This option also requires considerably more configuration and requires the correct setup of the local network. Furthermore, settings will have to be adapted to existing local configurations. Another issue is that both experiments and video feeds need to be authenticated and this has to occur transparently and independent of the networking environment.

To overcome these issues and to make the deployment as seamless as possible, the proposed system will (initially) use a separate local network. This also implies a separate IP subnet for maker sites. To ensure the separation between of the local private network that provides Internet access and the local experiment network, the experiment will be placed in a Demilitarized Zone (DMZ).

All participants, including users and makers, need to be authenticated to connect to the P2PRAL system and in essence gain access to nodes connected to the VPN. The *Access Gateway* maintains both user/maker and experiment databases. It is also the network node that authenticates users. Authentication details are outside the scope of this paper; however, standard web authentication mechanisms are used.

Whereas authenticating users via a central web gateway is straight forward, authenticating peer-to-peer connections is more complicated. Both users and makers generate a public and private key pair at the time of registration and the public keys are known to the central broker node. Once a peer-to-peer session for a particular user has been authenticated, the broker node has to distribute the respective public keys to the node that are party to the transaction. For the maker site, the key of the user has also a Time to Live (TTL). The session is active, as long as the key at the experiment site is valid. If the session is terminated prematurely, the keys are revoked.

V. Implementation

This section discusses specific details of a P2PRAL system as it is being developed for the RALfie project. Besides all technical and project specific requirements, usability and simplicity of setup and configuration are paramount for this implementation. Most users of the system, including children and teachers, are expected to have very little computer and networking expertise initially.

A. *User VPN Gateway (RALfieBox)*

From a participant's perspective, the *User VPN Gateway* or RALfieBox, is the core of the system. Technically, these systems operate the local network that hosts the experiment, connect to the VPN overlay and authenticate user access.

These systems are based on common low cost home gateway devices ("routers") and run custom Linux firmware. These devices are preconfigured in a way that automatically joins them to the overlay network once the node is connected to the Internet on the WAN port. The LAN ports are used for RAL appliances such as cameras and controllers. Initially, the wireless interface is not used to avoid interference and configuration problems.

The systems are based on OpenWrt firmware (http://openwrt.org/) and specific hardware is not required. For the trial, three different hardware platforms with different versions of OpenWrt were used. During the trial all worked equally well.

In the first instance, all devices come preconfigured and users have no administrative access to the RALfieBox. The WAN port is connected to the Internet and the VPN client establishes one external connection to the VPN note on the *Access Gateway*. The daemon also listens for incoming VPN connections on one port. All other incoming traffic on the WAN interface is dropped. If makers are concerned about the RALfieBox accessing the local network, it can be to move to a DMZ.

Local traffic on the local RALfie network is allowed by default, but external traffic is not allowed. Makers can use the local network to configure the local activity and setup the camera etc.

B. *Address Spaces*

The P2PRAL system consists of the VPN network and the local experiment networks. Both networks require an IP address space that does not overlap with the private address space that is being used by the local network that provides Internet access to the RALfieBox. Home Internet gateways will generally use private IP addresses on the 10.0.0.0/8, 172.16.0.0/16 or 192.168.0.0/24 subnets [RFC 1918].

The VPN overlay network therefore uses the Shared Address Space of 100.64.0.0/10 [RFC6598]. There is a small possibility that the gateway operates as the customer premise equipment (CPE) and the internet service provider uses the Shared Address Space. The gateway has to be setup in a way that this does not affect the traffic that is routed via the VPN. This is possible as the notes on the private network do not see the public IP address of the Gateway. On the local network IP addresses on the 100.64.0.0/10 subnet refer to hosts on the VPN.

The local experiment networks also require an IP address space. All local sites use the TEST-NET-3 address space of 203.0.113.0/24 [RFC6890]. This address space has been reserved for documentation and is unlikely to be used by private networks.

All RALfieBoxes use the same local IP subnet. By using the same address space across all local P2PRAL networks configurations, instructions and support are simplified. Sub-domain names are used to identify the devices that are connected locally. If the RALfieBox is connected to the Internet, makers do not have to deal with IP addresses. While testing, dynamic DNS names are used, but these will be migrated to ralfie.net domain in the next development set. Examples of the name allocations that are currently being used include ralfie-loc-exp.dyndns.org for the experiment and ralfie-loc-cam1.dyndns.org for camera one.

C. *Access Control and Port Forwarding*

There are a number of ways experiments can be controlled including custom software, web service and remote desktop control. The details of this are outside the scope of this paper, but it is assumed that experiments are controlled by computers and the computers in turn host a VNC server. To enable access to experiments and cameras that are located on the local network, port forwarding is used.

The VNC server, as well as the web camera webservers operating on the local network, is exposed on the VPN interface of the Local Gateway. This means that local services are accessible on a distinct set of ports on the VPN interface. The VNC session can be accessed on port 5901, a web interface of the VNC session on port 5801 and cameras on ports 8001-8004, for example. Authenticated users can access these interfaces on the VPN network. To allow external connections on the

Access Gateway, a second set of forwarding rules are used.

At the *Access Gateway* the VPN addresses are mapped into a public domain name and the different streams can be accessed via port mapping that match both the source address and the destination address.

D. Authentication, Security and Safety

As this system will be used with (primary school) children, safety considerations are an important aspect of the system design. Users are authenticated at the RALfie *Access Gateway* using common mechanisms. Once authenticated, users are able to access experiments that they have permission to access and that are not currently being used by any other party. Only RALfie participants are allowed on the RALfie VPN and only authenticated users with authenticated sessions are granted access to experiments.

VI. TRIALS AND FINDINGS

Children as the primary users is the key target group of the overarching research project, so it was important to gain a better understanding of the feasibility of this approach with this exact demographic. Whilst the focus of the trial was related to configuring networking components and setting up the experimental equipment, to make the activity appealing to children three experiments were provided:

- 'Mouse in the House' was a control only activity with the aim to investigate whether a real-time controlled experiment can be run through the remote desktop method and students' interest in it.
- 'All the Way Home' was a basic programming activity with the aims to see if the children could establish connection to a rig (Lego Mindstorms NXT) download a program and then have the robot follow a pre-existing track.
- 'Shrimp Ahoy' was an observation activity to demonstrate that Shrimp move towards the light. This experiment had the most complex setup phase involving 4 cameras at particular positions for best view.

Each of the three "maker" sites was provided with a pre-configured RALfieBox connected to an Internet gateway via a network emulator, a laptop, a number of cameras and the actual experiment rig described above. Figure 3 shows a group of children configuring a remote activity ("Mouse in a House") and researchers observing the process.

Artefacts collected from students included drawings by the students depicting each child's conceptual understanding of the initial RALfieBox and RALfie network configuration as well as individual discussions as each child explained their drawing. For instance, Figure 4 shows one participant's drawing depicting "configuring the RALfiebox and activity". This particular example provides insight into child's understanding of not only the physical connections required, but of the overall conceptual landscape on which the P2PRAL system relies. It shows that this participant understands the physical network connection layer, and the need for the local computer to control these components, as well as (more importantly) there is more to RALfie than just the local activity.

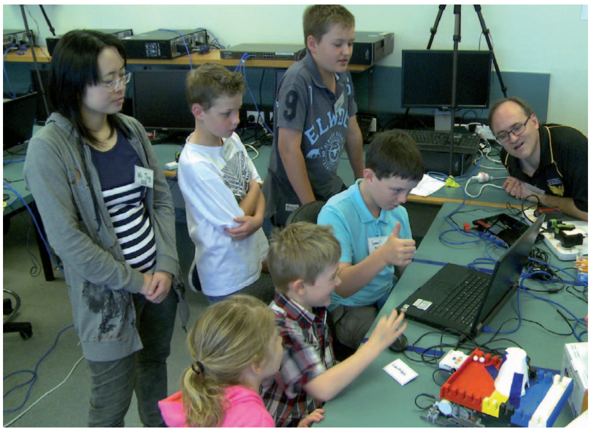

Figure 3. Participants configuring the activity.

Detailed results are outside the scope of this paper, but the key outcomes can be summarised as follows:

- Most participants had no difficulties with setting up the individual "maker" sites, even with very little documentation.
- Despite all activities having comprehensive instructions, these were largely ignored, where participants concentrated on the larger issues of establishing connections, and basic control of the activity.
- Participants had no difficulties in accessing the activities "remotely" from nearby isolated spaces where no direct line-of-sight of the activity was possible.

The key outcome from the trial was that participants in the target age range did not have any difficulties or insurmountable issues with the required concepts. They were able to build, use, and remotely control the available experiments. Participants were then also able to extend the activities and move towards the "maker" realm of the project by modifying these previously unseen activities.

VII. CONCLUTIONS

The aim of this study was to develop a peer-to-peer RAL system that can be used by children to share their own experiments. The design philosophy of the system was to develop an easy to use, scalable peer-to peer remotes access system. From the children's perspective, key part of this distributed system is the RALfieBox which makes the communication between user and the maker very simple. Users only have to setup their rigs and connect them to their own computers and share them through the internet by plugging them to the RALfieBox.

The trial with 15 school age children has shown that students can configure and use observational, interactive control and programming activities. The children were undertaken the activity as groups and the collective conceptual understanding of computers and networking were sufficient to setup the activities. Students had the most fun when testing the activities remotely from a room next door.

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REFERENCES

[1] J. Ma and J. Nickerson, V., "Hands-On, Simualted and Remote Laboratories: A Comparative Literature Review," *ACM Computing Surveys,* vol. 38, pp. 1-24, 2006.

[2] A. A. Kist, P. Gibbings, A. D. Maxwell, and H. Jolly, "Supporting remote laboratory activities at an institutional level," *International Journal of Online Engineering,* vol. 9, pp. 38-47, 2013.

[3] G. V. Kondraske, R. A. Volz, D. H. Johnson, D. Tesar, J. C. Trinkle, and C. R. Price, "Network-based infrastructure for distributed remote operations and robotics research," *Robotics and Automation, IEEE Transactions on,* vol. 9, pp. 702-704, 1993.

[4] D. Lowe, S. Murray, L. Weber, M. De la Villefromoy, A. Johnston, E. Lindsay, W. Nageswara, and A. Nafalsk, "LabShare: Towards a National Approach to Laboratory Sharing," in *20th Annual Conference of the Australasian Association for Engineering Education (AaeE)*, University of Adelaide, 2009.

[5] V. J. Harward, J. A. del Alamo, S. R. Lerman, P. H. Bailey, J. Carpenter, K. DeLong, C. Felknor, J. Hardison, B. Harrison, I. Jabbour, P. D. Long, M. Tingting, L. Naamani, J. Northridge, M. Schulz, D. Talavera, C. Varadharajan, W. Shaomin, K. Yehia, R. Zbib, and D. Zych, "The iLab Shared Architecture: A Web Services Infrastructure to Build Communities of Internet Accessible Laboratories," *Proceedings of the IEEE,* vol. 96, pp. 931-950, 2008.

[6] R. N. Charette, "The STEM crisis is a myth," *Spectrum, IEEE,* vol. 50, pp. 44-59, 2013.

[7] G. N. Masters, "Title," unpublished|.

[8] S. Thomson, N. Wernert, C. Underwood, and M. Nicholas, "Highlights from TIMSS 2007 from Australia's perspective: Highlights from the full report, Taking a closer look at mathematics and science in Australia," 2008.

[9] O. Dziabenko and J. G. Zubia, "Secondary School Needs in Remote Experimentation and Instrumentation," *International Journal of Online Engineering (iJOE),* vol. 8, 2012.

[10] S. L. Martinez and G. S. Stager, *Invent to Learn: Making, Tinkering, and Engineering in the Classroom*. Torrance,CA: Constructing Modern Knowledge Press, 2013.

[11] C. Bright, D. Lowe, S. Murray, D. Liu, and E. Lindsay, "Title," unpublished|.

[12] A. Maiti, A. D. Maxwell, and A. A. Kist, "An Overview of System Architectures for Remote Laboratories," presented at the IEEE International Conference on Teaching, Assessment and Learning for Engineering (TALE 2013), Bali, Indonesia, 2013.

[13] C. David, Gustavo, Alves, Paulo, Ferreira, Juarez, Silva, "Remote Labs Accessible through 3D environments A Case Study with Open Wonderland," in *REV 2011 Proceedings*, pp. 191-196.

[14] Z. Nedic, J. Machotka, and A. Nafalski, "Remote Laboratory NetLab for Effective Interaction with Real Equipment over the Internet," *2008 Conference on Human System Interactions, Vols 1 and 2,* pp. 858-863, 2008.

[15] J. A. Asumadu, R. Tanner, J. Fitzmaurice, M. Kelly, H. Ogunleye, J. Belter, and K. Song Chin, "A Web-based electrical and electronics remote wiring and measurement laboratory (RwmLAB) instrument," *Instrumentation and Measurement, IEEE Transactions on,* vol. 54, pp. 38-44, 2005.

[16] D. A. H. Samuelsen and O. H. Graven, "Design of a general purpose platform for easy setup of low-cost remote laboratories in electronics," in *Remote Engineering and Virtual Instrumentation (REV), 2013 10th International Conference on*, 2013, pp. 1-6.

[17] P. Orduña and J. Garcia-Zubia, "Scheduling schemas among Internet Laboratories ecosystems," presented at the REV 2011, July 2011.

[18] P. Garaizar, M. Á. Vadillo, and D. Lopez-de-Ipina, "Benefits and Pitfalls of Using HTML5 APIs for Online Experiments and Simulations," *International Journal of Online Engineering (iJOE),* vol. 8, 2012.

[19] L. Feisel, G. D. Peterson, O. Arnas, L. Carter, A. Rosa, and W. Worek, "Learning objectives for engineering education laboratories," in *Frontiers in Education, 2002. FIE 2002. 32nd Annual*, 2002, pp. F1D-1 vol.2.

[20] D. Lowe, P. Newcombe, and B. Stumpers, "Evaluation of the Use of Remote Laboratories for Secondary School Science Education," *Research in Science Education,* vol. 43, pp. 1197-1219, 2013/06/01 2013.

[21] M. Kostelníková and M. Ožvoldová, "Remote Experiments in Primary School Science Education," *International Journal of Online Engineering (iJOE),* vol. 9, pp. 39-44, 2013.

[22] A. Maxwell, R. Fogarty, P. Gibbings, K. Noble, A. A. Kist, and W. Midgley, "Robot RAL-ly International - Promoting STEM in elementary school across international boundaries using remote access technology," presented at the REV2013 Sydney, Australia, 2013.

[23] A. A. Kist, A. Maxwell, P. Gibbings, R. Fogarty, W. Midgley, and K. Noble, "Engineering for primary school children: Learning with robots in a remote access laboratory," presented at the 1st World Engineering Education Flash Week, SEFI Annual Conference (European Society for Engineering Education), Lisbon, 2011.

[24] L. de la Torre, R. Heradio, C. Jara, J. Sanchez, S. Dormido, F. Torres, and F. Candelas, "Providing Collaborative Support to Virtual and Remote Laboratories," *Learning Technologies, IEEE Transactions on,* vol. PP, pp. 1-1, 2013.

[25] A. A. Kist and A. Maxwell, "Performance and Quality of Experience of Remote Access Laboratories," presented at the IEEE TALE 2012 Hong Kong, China, 2012.

[26] A. Maiti, A. A. Kist, and A. Maxwell, "Estimation of Round Trip Time in Distributed Real Time System Architectures," presented at the Australasian Telecommunication Networks and Applications Conference (ATNAC2013), Christchurch, New Zealand, 2013.

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