

Why simulate when you can experience?*

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ABSTRACT

This paper discusses the advantages of using real experiments in networking lectures as opposed to simulation and tcpdump labs. Indeed, we claim that with the inclusion of networking to numerous curriculums the way to illustrate and assess in these courses need to evolve to better take advantage of the on-going research without limiting the top of the class students. In particular we identified five key challenges that needed to be addressed to improve networking education and bring it closer to reality. For that we present the Internet Remote Emulation Experiment Laboratory (IREEL) an e-learning platform designed and developed for the last 4 years. This platform allows the student to configure real network and application characteristics in order to illustrate key concepts of the lecture. In this context, we allow many improvements for labs or assignment in networking courses. IREEL has been previously used in introductory courses to networking and received very good rating by the student for the understanding of general and specific concept of the lecture.

Categories and Subject Descriptors

K.3.2 [Computers and Education]: Computer and Information Science Education

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Experimentation, Performance

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1. INTRODUCTION

During the last decade, general knowledge of networking and internetworking in particular has become a basic component of the many engineering courses, ranging from pure CS courses to aeronautical engineering through electrical engineering. In this context, when teaching introductory or advanced networking subjects, lecturers face the difficulty of illustrating both the concepts and technologies, and assessing students from various backgrounds. In that regard, we can identify several challenges the networking community must address in order to improve networking education and bring it closer to reality. Indeed, we should take advantage of the chance to teach students about an engineering field that they use everyday in their daily lives.

The first identified challenge, shared by numerous fields of CS, is the diversification of the student population. For example, during the second semester 2010 during an hybrid undergraduate-postgraduate course entitled "CS 3331/9331 Computer Networks and Applications" at the University of New South Wales, students from Engineering programs including Computer Science, Bioinformatics, Electrical and Telecommunications Engineering, Mechanical Engineering and Information Technology also were enrolled in this course. The main consequence of this diversification is the fact that some students may not have any programming knowledge.

The second identified challenge is the realism of the lectures illustration. Indeed as we previously stated, the networking community has the chance (or the inconvenience for sceptics) to be part of a discipline used everyday by the students. Therefore, labs and assignments need to reflect this anchorage within reality and propose more realism instead of mock-up scenarios.

The third challenge is to illustrate the network emerging behaviour when changing scale. For example how to show that when using CSMA/CD in a wireless network it works fine with few computers but when the number of computers reach a certain threshold another behaviour appears.

The fourth challenge is provide a tool with good usability for both the student and the teacher. This challenge is generic to any kind of experiment-based teaching and research. How to provide a tool that is able to enlighten a particular network behaviour whilst allowing the student to also have a broader and generic overview? Therefore this kind of tool should ease the shift from introductory to advanced courses on networking.

The fifth challenge of our community concerns the accountability of the students' work and more important the students' capability to demonstrate that they understand

lecture key concepts. Indeed, when assessing student work it is becoming difficult for any lecturer to be one hundred percent sure that the submitted work is original. We do not want here to continue the current suspicion-oriented opinion among the University faculty members made popular by the opinion letter published in the Chronicle about the “pay for assignment” system [11]. Nevertheless, with the ubiquity of Google search, it can be envisioned that for simple assignment such as writing a client/server program some students might just copy their work from the Internet.

We have identified five key challenges we believe our community needs to address. We would like to introduce potential solutions to these challenges in the particular case of real life experiment-based lecture illustration and assignments. Indeed, we strongly believe that while simulation had some advantages over real experimentation in the past, especially in terms of maintenance price, real demonstration can obtain a more emotional engagement from the student and can nowadays be done at a lower cost using either emulation or real large scale testbeds.

In order to address the first challenge one possible solution would be to illustrate the lecture using an instrumented working system. Therefore, such a system should allow to configure real experiments as opposed to just analyse pre-recorded ones. This kind of system requires to have access to a modular measurement architecture in order to better isolate the key parameters for every labs and assignments.

The second challenge can be solved by pushing further the aforementioned solution of the first challenge. Indeed, we believe that realism comes from observing everyday examples such as a facebook page or a bittorrent session. Therefore, when illustrating the lecture students should be able to have access to what is really under the hood of the experiment, such as the experiment script or the source code of the testing program.

In the case of the third, as we want to pursue an experiment-based approach with real implementation of protocols and applications, two non-exclusive solutions are possible. The first one relies on the deployment of systems in virtual environments. Thanks to advances on this topic, we think this solution would allow to maintain a low maintenance and deployment cost. The second solution would be to use open large scale testbeds such as PlanetLab or Emulab or Orbit [3, 22, 20].

The fourth challenge can be seen as a multifaceted problem. Indeed, the usability of such a tool for the student means that it should never limit the best students in a class to go further if they want. Furthermore, in the context of large scale networking experiment, an educational tool should separate the measurement collection from its actual location, and thus giving a general overview of networking in a glance.

Finally, the last aforementioned challenge is maybe the more interesting to solve in term of education. Indeed, we think that to solve this problem we have to change the way both labs and assignment are organised in order to come back to a more scientifically oriented method. This is translated by reintroducing the equivalent of a lab book that would take advantage of new technologies. Therefore, the teacher will be able to better track the work accomplished and we think that the student will be able to better understand the key concepts of the lecture through initiation into the art of experimentation.

In [10] and its second version in [15], we proposed a novel approach for teaching networking in undergraduate and post-graduate courses called IREEL¹. This solution originally provided an e-learning platform where students followed a lab description that recalls the lecture and then had to configure experiments to answer related questions. The originality of IREEL consists in offering the ability to run real experiments whilst conserving an easy to use interface. While the two versions of IREEL provide the same basic functionality to the student, the second version [15] offers more flexibility to the instructor. Indeed, we have integrated a state of the art testbed control and management framework called OMF [19] and its companion measurement library OML [23].

During the second semester of 2010, we used IREEL for an hybrid undergraduate/postgraduate introductory course on networking at the University of New South Wales, Australia. In this course, the IREEL platform has been used during two labs whilst the remainder of the lab set used the Wireshark packet analyser. At the end of the course the students were asked to give an evaluation of both the UI and the teaching capabilities of the tool. The analysis of the students’ use of this tool shows that it was able to reach a very high robustness. Furthermore, the evaluation forms showed that the tool was very well rated in terms of overall understanding of key concepts from the lectures and when compared to the Wireshark labs [14].

In parallel to the basic networking courses, we claim that IREEL can ease the transition between an introductory course to networking and a more advanced course. Indeed, the IREEL platform allows us to introduce a new learning plane aiming at facilitating the understanding of basic networking concepts such as reliability or congestion control mechanisms while letting the student access the core components of the protocols. Furthermore, IREEL has been used as the basis for a new kind of experimenter’s portal enabling more rigorous experiment-based networking research [16]. This portal is now operational and will feed back to the e-learning platform in order to bring an online analytical capability to it. As a result, we think that the combination of the two aforementioned tools will be able to accompany the student from introductory courses to advanced via project oriented research over large scale distributed testbeds.

We think, that using IREEL would provide a first attempt to solve the five challenges mentioned earlier. Indeed, as this tool uses a testbed management framework to control experiment and its companion library (OMF & OML), we think that it would be possible to deploy real instrumented systems. Furthermore, we allow the student on IREEL to have access on both the experiment script and the different tools we use during the labs which permit a deeper understanding and allow them to look what is under the hood. In order to solve the third challenge, the IREEL platform is able thanks to the management framework to control PlanetLab nodes, virtual resources and access federated testbeds and thus it would scale to a large number of experiment nodes. We claim that the integration of the OML library would allow to improve the usability of the e-learning platform as it enables the separation between the measurement collection and the observation. Last, we think that the upgrade of IREEL with the functionalities of the portal would enable a better accountability of student work and encourage them

¹The current platform is available on <http://ireel.npc.nitca.com.au/>

to follow a more experiment-based learning and thus better understand the key concepts of the lectures.

The remainder of this paper is organised as follows. Section 2 presents the general vision behind the introduction of IREEL. In Section 3, we first present the general architecture of IREEL and introduce a new learning abstraction. Section 4 presents its current use for beginners and report an overview of student ratings and we then discuss our vision for its more advanced use. Section 5 reviews some of the related works. Finally, Section 6 discusses the general idea of the IREEL approach and presents some potential future works.

2. MOTIVATION

We envision the future of network-course e-learning platform as depicted in Figure 1. We believe this architecture provides four improvements compare to the state of the art.

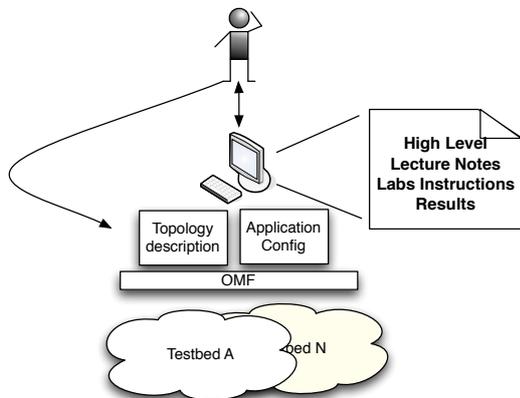


Figure 1: General Architecture of the Future e-learning Environment.

Firstly, we think that lecture notes and lab instructions must be accessible directly on the web interface that pilots the possible configurable experiments. This feature is necessary to allow student to work efficiently. Furthermore, the configuration of these experiments must be available in a high-level interface to allow students with no programming language skills to participate in these lectures and the teacher to add easily new experiments.

Secondly, the architecture should have a low-deployment cost and a large range of network configurations. This requirement leads us to consider an emulation solution for the basic platform.

Thirdly, with the recent advancement in the worldwide deployment of network testbed, the future e-learning platform must facilitate the reproducibility of simple experiments over multiple testbed. In Figure 1, this is illustrated by OMF’s capability and current deployment over multiple testbed.

Finally, this new e-learning architecture should facilitate the shift from a beginner to advanced user of testbeds as illustrated by the left arrow in Figure 1.

3. BACKGROUND: THE IREEL PLATFORM

3.1 IREEL Overview

IREEL provides a way to achieve experiments with real Internet applications and protocols in the context of networking courses. IREEL has been designed to overcome the difficulties of achieving experiments using real protocol and application implementations. The originality of IREEL is to provide an easy experiment configuration interface whilst maintaining a modular backend to add new labs and experiments for the teacher. Indeed, the main drawback of the first IREEL was the difficulty for the teacher to deploy new experiments. The new architecture presented in [15] enables the teacher to use the OMF Experiment Description Language to test and deploy new experiments on the testbed and thanks to plugin developed on top of a wiki the teacher is able to use the same script to generate the configuration front page for the students. Thus, the cycle to deploy new lab material is shortened as follows: write wiki description of the labs; write control script using OMF; upload the script and finally an automatic generation of configuration page for the student.

From a student point of view IREEL provides a private space to run experiments based on the labs requirements. This private space is also accessible by the tutor and the lecturer in order to verify that the students did the experiments. In the upcoming new release of the platform, which will integrate improvements from the testbed portal we have developed for the NICTA testbed and described in [16], students will also be given a private wiki interface. Using this interface, the student will be able to directly analyse experiments’ measurements using the R language [7] and thus answer the labs’ question.

3.2 Introducing a New Learning Plane

As illustrated on Figure 2, the integration of IREEL with OMF provides a new *learning plane*, which serves as an interface between students/lecturers and the bare resources of a testbed platform. This plane provides a seamless access from a user-friendly graphical front-end to the full visualisation/editing of an OMF Experiment Description. This caters both for undergraduate basic courses and postgraduate advanced ones. Indeed, students of the former courses use graphical menus to develop, run, and analyse experiments, thus focusing on the networking concepts without the difficulty of a steep usage learning curve, nor the need for any programming skills. Students of the latter courses or of research-oriented courses have access to the full semantic richness of the ED domain specific language to realise more complex experiments, e.g. involving their own cross-layer protocols, or their own peer-to-peer applications [24].

Through the use of OMF’s systematic descriptions and automatic executions of experiments, this learning plane further introduces new students to scientific concepts, such as reproducibility, statistical significance, or peer-verification. For example, students can easily cross verify their results, or run multiple trials of the same experiment with/without parameter modifications, and observe the effects on their result statistics. This feature also benefits advanced and research students, as they have now an uncomplicated tool to produce more accurate scientific results.

Another major benefit of this learning plane is that through the use of OMF as the interface with the underlying testbed, it potentially gives students and lecturers access to a large number of heterogeneous resources within many different

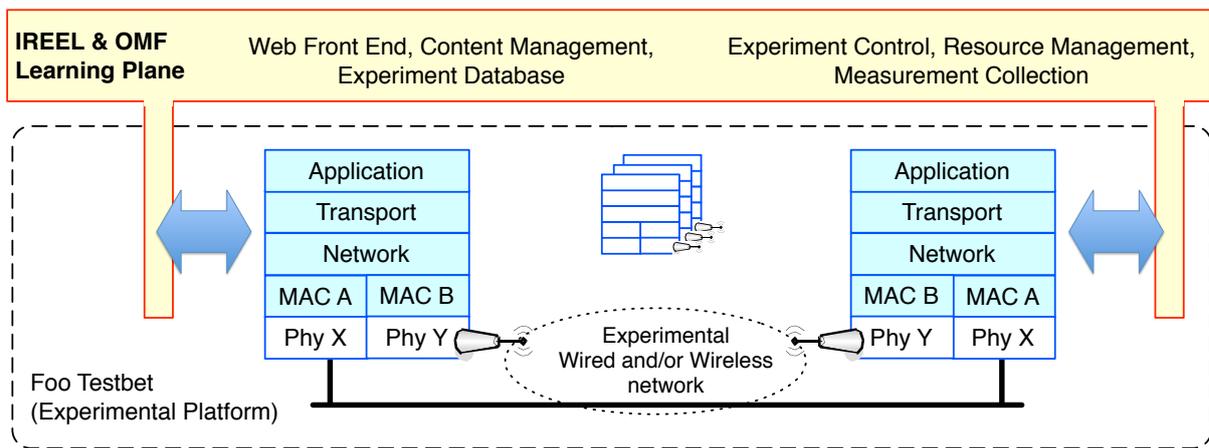


Figure 2: New Learning Plane

testbed platforms. Indeed, OMF is currently used to control experiments and manage various resources at many institutions. For example, the particularities of an existing protocol (e.g. TCP) can be illustrated on real PC-based resources connected via links with Internet-like characteristics, and then seamlessly evaluated on real mobile wireless resources connected via ad-hoc 802.11 links. Comparison between results from both environments would give students valuable insights into the studied protocol. An example of such a case is developed in the next section.

4. STUDY CASE: FROM INTRODUCTORY TO ADVANCED NETWORKING COURSES

4.1 Currently Available Labs for Introductory Courses to Networking

Currently, two labs are available on the IREEL platform. These two exercises illustrate fundamental concepts from a lecture that follows [17]; the evolution of HTTP, referred to in the following of the document as the first lab, and the illustration of Reliable Data Transfer, referred to as the second lab in the remainder of this article².

During the first lab, students, after a reminder of the lecture, were asked to analyse the difference in the performance of the two versions of HTTP (1.0 and 1.1). The experiments consisted of downloading several HTML pages with a varying number of embedded objects using the two versions of HTTP and comparing the total end-to-end delay. Overall, in this lab, students had to configure and analyse the results of 13 experiments.

In the second lab, students analysed the performance of different reliable data transfer mechanisms; Stop and Wait, Go-back-N and Selective Repeat. In this lab, the students were able to analyse the effect of the retransmission time-out based on the end-to-end delay and the effect of the packet loss rate in the transmission of a stream of packets. During this lab, students had to configure more than 30 experiments. However, due to the randomness of the packet loss rate the number of experiments is expected to be greater.

²These two labs are accessible on <http://ireel.npc.nicta.com.au>

We have used these two labs at the UNSW during the second semester 2010 in the context of an introductory course to networking. This course, entitled “COMP 3331/9331, Computer Networks and Applications”, provides an in-depth overview of computer networks and the Internet and follows the Top down approach [17]. At the end of the semester, after the conclusion of all lab exercises, students were asked to fill in a written questionnaire to provide feedback on the UI and effectiveness of IREEL as a learning tool. Based on the quantitative data we obtained, we found that our platform is robust even when stressed to a very high degree, for example we conducted nearly 5500 experiments in less than a week. The analysis of the evaluation forms was very positive overall, as the students rated that our platform was more effective to promote the understanding of specific and general concept than Wireshark-based labs. For further analyses and recommendations based on our experiment with IREEL please refer to [14].

4.2 Going further in scale and knowledge

4.2.1 Introduction to networking

In the first version of the IREEL platform [10], a particular focus was given to multimedia traffic in order to illustrate the importance of the codec and transport protocol choices. As a result, we provided two possible experiments, for video and audio traffic, where the user was able to select the aforementioned choices. This kind of experiment aimed at illustrating chapter 6 of [17]. During the upgrade towards OMF [19], this set of experiments was deactivated but could easily be re-installed.

Another set of experiments that would enhance the introductory courses to networking consists in illustrating the specific behaviour of TCP congestion control and its different versions; Tahoe, Reno, New Reno and BIC. Indeed, thanks to the integration of OMF within IREEL, it is easy to implement a script that will at run time select the TCP congestion control algorithm in the Linux kernel and then start several FTP session using Iperf traffic generator³ [1]. Then using either the recorded trace from the transfer using

³A modified version of iperf integrating DCCP and OML is available at <http://mytestbed.net/projects/iperf/>

the libpcap [5] or using tools provided by OML, the students will be able to better identify the different characteristics of these mechanism. Furthermore, in the case of several TCP sessions in parallel the student would have a good illustration of the fairness of TCP congestion control.

4.2.2 Advanced Networking

In the previous sections, we have described networking course labs or assignments that do not require a large number of computer and can mainly be instantiated on a topology comprising two end-systems configuring an emulation engine such as netem or dummynet [13, 18] between them as they consist to client/server experiments. Nevertheless, in order to illustrate advanced course in networking a teacher should have access to more end-systems and underlying technologies.

Thanks to the modularity of the OMF scripting languages and the current efforts in both the EU and the US with the FIRE and GENI initiatives, it is now possible to use the OMF scripts used during the introductory course over numerous and different testbeds. In particular, as it is very difficult if not impossible to model wireless networks, we think that the use of real testbeds and implementation is becoming mandatory.

Another example where the use of a platform such as IREEL or the Seattle testbed [4] or Plush [9] could be beneficial for the student is the access to the PlanetLab infrastructure[3]. In the context of the Onelab2 EU project, OMF has been extended in order to support PlanetLab and vice-versa. Therefore deployment of large overlay network would be possible. We think that the advantage of IREEL over the two previously mentioned proposal consists in offering a better resource description and does not require student to know any programming language as a prerequisite for the course.

4.2.3 Project Management

In numerous engineering curriculums, students can earn credits by developing a large scale project. In the context of networking this kind of project has to be tested and marked on a real deployment. Based on our experience with IREEL, we have developed a new type of testbed portal⁴ aiming at facilitating collaboration and the setting of rigorous hypothetico-deductive method in experiment-based networking research [16]. This portal has been designed around the well-known hypothetico-deductive method first described by Whewell in [21]. As a result, a user once registered will receive his own personal and private project and will be able to configure experiments described using the OMF scripting language. Once the user has configured and queued experiments, the portal will run them and collect the measurement automatically. Finally, once all the measurements are performed, the newly introduced portal offer an extension able to load the different measurements and analyse them with the R language [7]. Therefore the user is able to match the scientific method as depicted in Figure 3.

As a results, we claim that the portal would allow students to manage private educational project. Based on the portal we introduced in [16], we claim that using IREEL would encourage students to follow more rigorous methodology and thus follow the aforementioned method.

⁴ Accessible on <http://norbit.npc.nicta.com.au/portal/>

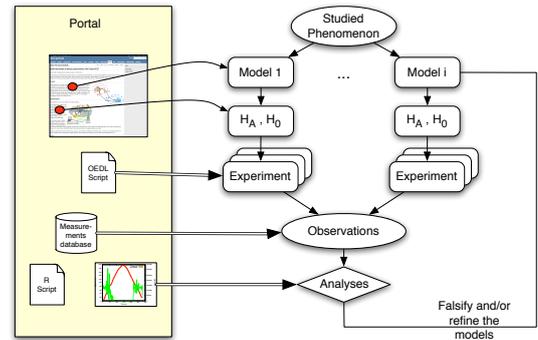


Figure 3: The hypothetico-deductive scientific method and its support by the Portal.

5. RELATED WORK

Few initiatives currently provide software services and tools to control experiment executions, access, and manage resources on networking platforms. Some examples of such software suites are the Emulab [22], the PlanetLab [3], and the OMF frameworks. These frameworks were primarily designed to address the experimental needs of the networking research community. Although, some of them could be used in an educational context, their usage requires a learning curve which is not suitable nor necessarily relevant to a semester-based academic course focusing on networking concepts and technologies.

Emulab [22] is a large network emulator. It provides experimenters with a set of computers, which can be configured into various topologies through emulated network links. The Emulab control framework supports three different experimental environments: simulated, emulated, and wide area networks. It unifies all three environments under a common user interface. Emulab provides tools to describe a required experiment topology and map it to actual resources. Some control tools are also provided, but with minimal features. Emulab and OMF share many design principles with the differences primarily shaped by a focus on different hardware and a different user community.

PlanetLab [3] is a global research platform based on more than 1000 distributed computers, which are hosted by independent organisations. It is the primary large-scale testbed used for experimental overlay and service oriented systems (e.g. distributed storage, peer-to-peer content distribution). PlanetLab provides a suite of software, which uses virtualisation tools to efficiently share the global resources among simultaneous short or long-lived experiments. Similar to Emulab, these tools are essentially focused on resource allocation and access, and only provide minimal supports in describing, controlling and measuring experiments. PlanetLab is also limited by its default offered layer-3 abstraction, i.e. it could not be used to illustrate layer-2 schemes (e.g. wireless MAC mechanisms) to networking students.

The Open Network Laboratory (ONL) [12] is a testbed-based educational resource, which has been used in the teaching of several academic networking courses. It consists of several computers interconnected by multiple extensible routers, which can be linked in various network topologies through a central virtual network switch. ONL allows the users to extend the routing functionalities through software plugins

insertion. A user (e.g. a student) remotely access the platform through a stand-alone graphical interface, which easily allows the construction of various topologies, their configurations (e.g. route, bandwidth), and their monitoring. Similar to PlanetLab, the current ONL platform is limited to the illustration of layer-3 and above networking concepts.

Academic and industry research communities have developed many networking simulators, which provide inexpensive alternatives to testbed platforms as educational tools. Some of these simulators (e.g. OPNET [6]) have been successfully used in academic courses as the base of complementary laboratory activities [8]. Others (e.g. the ns-3 network simulator [2]) requires similar learning curves as the frameworks mentioned earlier, which may impede the learning of networking concepts. In any case, the inherent model assumptions within simulators limit the illustration of some networking aspects, e.g. there is no accurate simulation model for losses on wireless channels.

6. DISCUSSION & CONCLUSION

We have presented in this position paper our view on the current and future challenges facing the education networking community. In particular, we identified five key challenges that should require the more attention. In order to solve these challenges we proposed some possible generic solutions. We then presented the IREEL platform which we think would allow a first attempt to implement these solution.

We have then presented in more details the architecture of the e-learning platform, and the different available and possible future experiments. We have also given a brief overview of students ratings of this tool when used in the context of an introductory course to networking.

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7. REFERENCES

- [1] NLANR/DAST : Iperf - the TCP/UDP bandwidth measurement tool.
<http://dast.nlanr.net/Projects/Iperf/>.
- [2] NS3 Network Simulator. *at*:
<http://www.nsnam.org/>.
- [3] PlanetLab Testbed. <http://www.planet-lab.org/>.
- [4] Seattle, Open Peer-to-Peer computing.
<https://seattle.cs.washington.edu/html/>.
- [5] Tcpdump/libpcap public repository.
<http://tcpdump.org>.
- [6] The OPNET Network Simulator. *at*:
<http://www.opnet.com/>.
- [7] The R Project for Statistical Computing. *at*:
www.r-project.org/.
- [8] E. Aboelela. *Network Simulation Experiments Manual, 2nd Edition*. Morgan Kaufman, 2008.
- [9] J. Albrecht, C. Tuttle, A. C. Snoeren, and A. Vahdat. PlanetLab Application Management Using Plush. In *ACM Operating Systems Review*, 2006.
- [10] L. Dairaine, G. Jourjon, E. Lochin, and S. Ardon. IREEL: Remote Experimentation with Real Protocols and Applications over Emulated Network. *Inroads, the SIGCSE Bulletin*, 39(2):92–96, June 2007.
- [11] E. Dante. The Shadow Scholar. *The Chronicle of Higher Education*, Nov. 2010.
- [12] J. DeHart, F. Kuhns, J. Parwatikar, J. Turner, C. Wiseman, and K. Wong. The Open Network Laboratory. In *Proceedings of SIGCSE'06*, Mar. 2006.
- [13] S. Hemminger. Network emulation with netem. In *Linux Conf Au*, April 2005.
- [14] G. Jourjon, S. Kanhere, and J. Yao. Impact of IREEL on CSE Lectures. In *Proceedings of ACM ITiCSE 2011*. ACM, Jun. 2011.
- [15] G. Jourjon, T. Rakotoarivelo, and M. Ott. From Learning to Researching, Ease the Shift through Testbeds. In *Proc. of TridentCom 2010*,, volume 46 of *LNICST*, pages 496–505, Berlin Heidelberg, May 2010. Springer-Verlag.
- [16] G. Jourjon, T. Rakotoarivelo, and M. Ott. A Portal to Support Rigorous Experimental Methodology in Networking Research. In *Proceedings of Tridentcom 2011*. Springer-Verlag, Apr. 2011.
- [17] J. F. Kurose and K. W. Ross. *Computer Networking: A Top-Down Approach, 4th Edition*. Addison-Wesley, 2008.
- [18] L. Rizzo. Dummynet: a simple approach to the evaluation of network protocols. *Computer Communication Review (CCR)*, 27(1), jan 1997.
- [19] T. Rakotoarivelo, M. Ott, I. Seskar, and G. Jourjon. OMF: a control and management framework for networking testbeds. In *SOSP Workshop on Real Overlays and Distributed Systems (ROADS '09)*, page 6, Big Sky, USA, Oct. 2009.
- [20] D. Raychaudhuri et al. Overview of the ORBIT Radio Grid Testbed for Evaluation of Next-Generation Wireless Network Protocols. In *proc. IEEE Wireless Communications and Networking Conference (WCNC)*, 2005.
- [21] W. Whewell. *History Of The Inductive Sciences From The Earliest To The Present Time*. Kessinger, May 1837.
- [22] B. White, J. Lepreau, L. Stoller, R. Ricci, S. Guruprasad, M. Newbold, M. Hibler, C. Barb, and A. Joglekar. An integrated experimental environment for distributed systems and networks. *SIGOPS Oper. Syst. Rev.*, 36(SI):255–270, 2002.
- [23] J. White, G. Jourjon, T. Rakotoarivelo, and M. Ott. Measurement architectures for network experiments with disconnected mobile nodes. In *Proc. of TridentCom 2010*, volume 46 of *LNICST*, pages 350–365, Berlin Heidelberg, May 2010. Springer-Verlag.
- [24] H. Yoon, J. Kim, T. Rakotoarivelo, and M. Ott. Mobility emulator for dtn and manet applications. In *4th ACM Workshop on Wireless Network Testbeds, Experimental Evaluation and Characterization (WiNTECH)*, 2009.