FORGE Enabling FIRE Facilities for the eLearning Community

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Abstract. Many engineering students at third-level institutions across the world will not have the advantage of using real-world experimentation equipment, as the infrastructure and resources required for this activity are too expensive. This paper explains how the FORGE (Forging Online Education through FIRE) FP7 project transforms Future Internet Research and Experimentation (FIRE) testbed facilities into educational resources for the eLearning community. This is achieved by providing a framework for remote experimentation that supports easy access and control to testbed infrastructure for students and educators. Moreover, we identify a list of recommendations to support development of eLearning courses that access these facilities and highlight some of the challenges encountered by FORGE.

1 Introduction

Specialised software and hardware equipment required for advanced research and experimentation is expensive to own, complicated to run and costly to maintain for education institutions. As a result, many engineering students do not gain full advantage of real-world physical experimentation, which enables them to fully understand particular architectural designs, their limitations and trade-offs. Additionally, many testbed resources in funded institutions can be underutilised. These disparities have provided the motivation behind the FORGE project.

FORGE[1] transforms FIRE testbed facilities, dedicated primarily for advanced research, into learning resources for higher education. The FORGE framework provides an educational layer over FIRE facilities, enabling educators to easily create experiment-based learning resources. This paper describes how a FIRE facility can be enabled as part of a courseware, how this change affects facility's policies and how FIRE federation broadens the scope for massive experimentation needs. Additionally, it gives feedback on the implementation done towards integrating learning systems with FIRE facilities.

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In accordance with the FORGE architectural design, learners have access to the interactive remote experiments from their third-level course by controlling a set of 'widgets' (i.e. a micro-application that performs a dedicated task) on the platform of their choice (e.g. a web site, a Learning Management System, an iBook). These widgets trigger (backend) scripts that communicate with the resources of a particular FIRE testbed facility. This is supported by a FIRE facility APIs that manage and communicate with their internal infrastructure and resources. However, adaptations are still required to enable widgets to use these prototype courses. These modifications take different forms such as wrapper scripts interfacing with FIRE APIs or extension scripts with added functionality that pre-process (web) requests before forwarding these to (wrapper scripts interfacing) FIRE APIs.

The remainder of the paper is organized as follows. First, FIRE facilities are presented in Section 2. In Section 3 we describe the FORGE Architectural Design. Then in section 4, Recommendations for enabling eLearning with FORGE are proposed. In section 5, we discuss the issues raised by the educational use of FIRE facilities. Finally, we conclude in Section 6.

2 FIRE Facilities

FIRE facilities offer the unique possibility to experiment with cutting edge networks, infrastructure and tools in a multidisciplinary test environment. This is key to investigating and experimentally validating highly innovative and revolutionary ideas for next generation networking and service paradigms at low cost and in a rapid way. For example, multiple European players are now using FIRE facilities to test and develop new protocols and ideas for their own research and development. Moreover, the Fed4FIRE project has harmonized the usage of a lot of these FIRE facilities[3] by offering the APIs and tools to experiment on available testbeds in a uniform way. By creating widgets and adapters to add an educational service on top of the Fed4FIRE APIs and tools, FORGE is catapulting FIRE testbed capabilities into the eLearning domain. This facilitates an enhanced blended learning experience and introduces hands-on 'flipped remote labs' within the context of a 'flipped classroom'[7].

Similar usage patterns exist between FIRE researchers and educational learners of testbed resources and infrastructure. In both cases, the same experiment life cycle is maintained: resources must be first be discovered, selected based on requirements, reserved and provisioned with the appropriate operating system and tools. Next, the experiment itself needs to be executed, controlled, monitored and results need to be gathered and stored. Finally resources are released to be reused by other researchers or learners (using different experiments). When using FIRE facilities for R&D, researchers are typically fully aware of every single step within this life cycle and they have fine grained control using different tools. For educational usage on the other hand, this complexity is typically hidden from the learner by preconfiguring and automating different steps within FORGE widgets and adapters. For example, educators only view a web-based

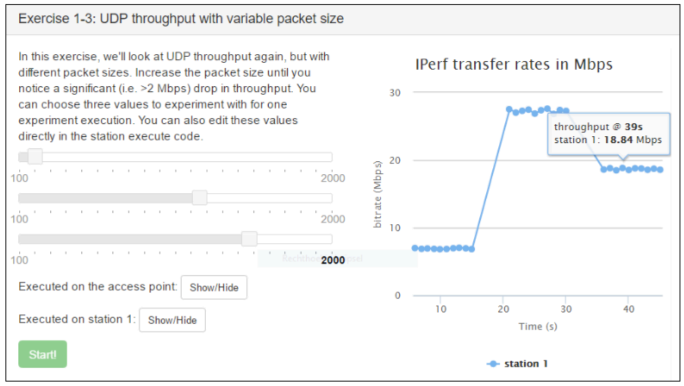

Fig. 1. Screen-shot of a typical widget in the iMinds' Wireless LAN course

calendar to select an appropriate time slot for teaching, without worrying about the details of resource discovery and provisioning. Similarly students only need to use web based control elements (such as buttons, sliders, etc.,) to manipulate and manage experiments. Fig. 2 shows a screen-shot of a typical FORGE widget. This is in contrast to researchers modifying text based configuration files or performing all the steps of the experiment manually via command line tools.

3 FORGE Architectural Design

FORGEBox[4] defines a generic reference architecture for developing widgets that are coupled with FIRE adapters to enable interaction with remote lab resources while integrating modern technologies from the education domain such as Learning Tools Interoperability (LTI) [5] and the Experience API (xAPI) [6]. The proposed architecture is intended as a blueprint and a guide for widget developers that want to achieve the best result of supporting education on top of FIRE testbed resources.

First, widgets used in eLearning courses, illustrated in Fig. 3 are consumable web applications hosted on a web server that interact with remote resources. In FORGE's case, they also bind with FIRE adapters, which are services that handle communication with FIRE testbed infrastructure. In FORGE, when we refer to widgets, we allude to this combination of web content and backend adapters that support remote interactivity with FIRE testbeds.

Next Fig. 3 displays our proposed reference architecture for a widget, with architectural components that a developer would need to implement in order to achieve the most desirable result for combining learning with remote FIRE resource interactivity. Since widgets are web services hosted somewhere on the Internet ready to be consumed by other web content, the architecture defines both the widget UI as well as the backend domain logic and core architectural

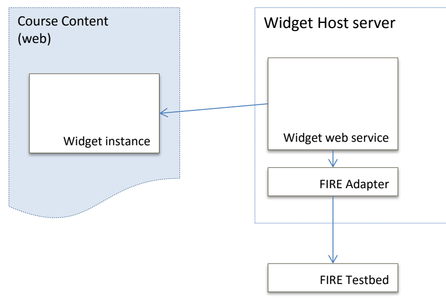

Fig. 2. Widgets are consumable web applications that are hosted in a web server and interact with remote FIRE testbed resources

components. Next we discuss supported usage roles and each architectural component.

From the above it is clear that the facility has to support different roles of users. Apart from the FIRE resource administrator, they need to provide a means for Teachers/Instructors and Learners to access FIRE resources. These users need to have different access roles. For example, a Teacher/Instructor needs to be able to configure and reserve the resources while the Learners will just interact with the defined experiment.

Another issue that a FIRE facility needs to address is the Authentication, Authorization and Identity (AAI) management issue for users. This service is almost mandatory, as it should handle users accessing widget services, while affecting the widget behaviour according to user role (i.e., provide the equivalent user interface). It should be possible to provide an LTI 2.0 implementation that will allow, as discussed previously, better integration of the widgets with existing Virtual Learning Environment (VLEs). Thus we recommend widget developers implement a bridge service between the AAI widget and an LTI 2 .0 support library.

User activity monitoring is typically also a required service when users interact with a FIRE facility, especially if the widget needs to audit users based on their behaviour. Additionally, it can be useful to offer teachers a report on student behaviour when they interact with a facility. So it is highly recommended that widget developers consider the integration of the xAPI and integrate the ability to report user behaviour to an external Learning Record Store. FORGEBox provides a ready-to-use solution when it integrates and deploys a course.

4 Recommendation for Using FIRE Facilities

Depending on the scarcity of resources used by a lab, a reservation mechanism should be in place to guarantee the availability of the interactive exercises during a lab. Especially for traditional labs, where many learners execute the experiments in a classroom there is no room for opportunistic resource management.

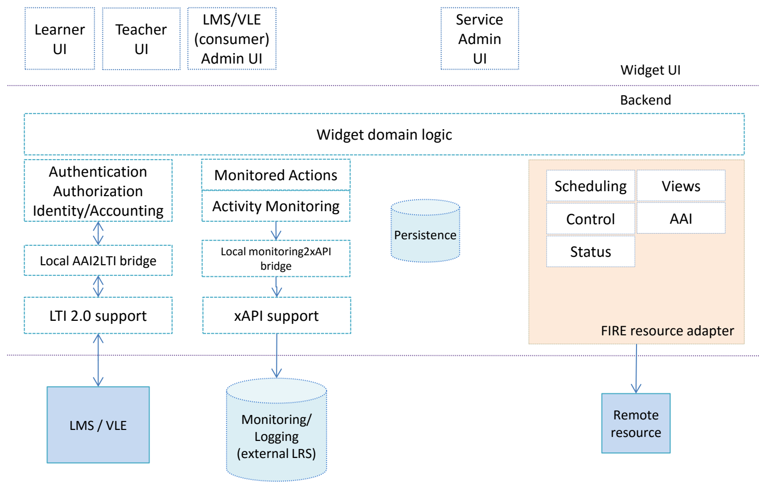

Fig. 3. Reference architecture for exposing FIRE remote resources via a FIRE Adapter and a Widget

Since not all FIRE facilities offer guaranteed resource availability and reservation this should be carefully considered in the requirements phase of a new lab course. Also, since it is not guaranteed that learners can interact with the FIRE facility via the same mechanisms as researchers, it is recommended that the specific reservation mechanism be hidden from the learner and also integrated in a FORGE widget and adapter.

To further alleviate the scarcity of resources it can also be interesting to offer an additional layer of multiplexing or queuing on the widget side so multiple learners can independently use the same FIRE resources. However, this requires that during the design phase of the lab every exercise has a clearly defined pre and post state, with well defined transitions between post and pre states of different exercises if it is not possible to guarantee that the resources return to the same state after each exercise. Additionally, a reasonable maximum duration for exclusive access (this normally coincides with the experiment duration) should be defined and enforced to limit the frustration of the learner. This also implies that a maximum number of simultaneous users per resource should be defined. For example, for a Wireless LAN lab, we were able to define a maximum experiment duration of one minute and three simultaneous users to be within the limits of what learners found comfortable.

One should also consider the differences in level of control between a learner using the FORGE tools and a direct testbed user for which a FIRE facility was envisioned. This is especially relevant when considering troubleshooting possible software and hardware failures that are often unavoidable when using state of the art research equipment and immature technologies. When a learner has only access via a web interface, a series of watchdog programs and actions should be defined to recover the experiment state in case there is a deviation of the expected experimentation path. Even when giving learners direct access to the experimentation machines at least a series of recovery scripts or instructions should be provided since absolute knowledge of the underlying system and quirks cannot be expected.

Another aspect that we recommend (apart from what is stated above and below) is to focus on multi-platform approach and easy integration on existing eLearning platforms. Educators desire a good integration within the platforms they are using already. By supporting the creation of widgets that use their FIRE facility, one supports the inclusion of FIRE functionality via the widget in different Learning Management Systems or other digital media (such as eBooks). For example, this has been applied by the inclusion of FORGE widgets into the Moodle-based legacy eLearning LMS of Universidad do Brasilia and by the coupling of the Central Authentication Service (CAS) mechanism for student accounts of Ghent University. This allowed the learners seamless access to the lab, while also maintaining both user authorization and authentication.

All interactions of the learner with the widgets and underlying FIRE facility should be collected using Learning Analytics, from the initial reservation of resources to the actual interactions during the lab. All learners should be uniquely identified so the full learning path can be analysed and where possible, technically and legally, the learner should be coupled to his/her real-life identity and university account if applicable. For example, for remote labs at Ghent University, this was handled behind the scenes by the integration of the Central Authentication Service (CAS) mechanism, which allowed seamless tracking of the entire lab learning experience and spotting possible cheaters or improper usage of resources.

Some FORGE courses, such as the TCP Congestion Control course deployed by UoP, were also enabled with Learning Analytics. From experienced gathered in early executions of the course, we found the need to introduce some specific actions (i.e. xAPI verbs such as user launched the page, or the user answered question) and timestamps inside widgets. This feedback information was carefully placed in the course material and was presented to FORGEBox when users encountered them in the courseware. FORGEBox also offers the opportunity to pass user identity inside widgets, which is useful to know the entry and exit timestamps for learners. Moreover, is possible to calculate from action to action the time spent by the learner on a specific part of the course material. This was useful when redesigning some parts of the course in order to allow the learner to spend a specific amount of time on a particular experiment. For example, this was crucial when limiting the amount of time a user can interact with a widget (e.g. 30 minutes) to solve and answer a question. In our case, if a remote learner spends more than 30 minutes inside a widget for a particular problem resulted in a fail grade. A generic recommendation derived from this experience is the careful planning of the course verbs and timestamps needed to measure interactivity.

Finally, it will be really useful in future if FIRE facilities themselves become Learning Analytics compliant. This would allow us to know what exactly happened during a learner's session and even reproduce all the actions performed.

5 Challenges Raised by FORGE

The usage of FIRE facilities for educational purposes also raises issues not encountered by FIRE before and that should be make transparent by FORGE.

A first challenge is security related. For eLearning purposes, FORGE has created different web based widgets. These run on a web server, which can be part of the experiment itself. The experiments are thus executed and manipulated by the web server (via web based requests on behalf of the learner) rather than directly by the learner. The resources and accompanying widgets/adapters on the web server might furthermore not have been reserved by the learner him/herself, and the learner might thus be controlling (via a web server) resources that were reserved by someone else (typically by the educator). This requires using a kind of 'proxing' or 'speaks-for' mechanism, securely allowing the sharing of resources amongst multiple FIRE accounts.

Currently, there is no standardized reservation system in place for all FIRE facilities. Since the complexity of resource reservation and allocation should be hidden from the learner. Per our recommendation, every FIRE facility would need a specific FIRE adapter to overcome this hurdle. A common reservation API would solve this additional complexity and would also provide an incentive and clear implementation path for FIRE facilities that currently provide no such mechanism.

Another challenge deals with the resource occupation. When a group of learners (e.g. all students within the same classroom) are following the same course and executing the same experiments, a large number of FIRE resources will be required at the same moment of time. When the specific FIRE resources required are scarce, a (very) high resource occupation will be imposed on the hosting FIRE facility. In order to accommodate the experiments of the different learners while not overloading the facility, FIRE facilities need to elaborate their policy strategy into different categories (e.g. 'best effort' or 'premium') to force a more well-thought usage of the facility by learners and experimenters alike. A FIRE facility would also need to provide some sort of reservation mechanism to guarantee resource availability to the learner in case of pre-planned lab sessions, while the FORGE widgets and adapters hide the specific reservation and scheduling mechanism from the learner. These policy strategies and associated business models are subject to the sovereignty of the different FIRE facilities. To limit the number of simultaneously used FIRE resources by different learners, some of the FORGE adapters also add intermediate functionality. For example, such as implementing a scheduling or queuing mechanism to allow multiple learners to share the same FIRE resources.

Since most FIRE facilities only offer 'best effort' resource availability, even with reservation, there is always the possibility of a resource or total testbed failure. Even if there is no possible resource to alleviate these kind of failures, a graceful degradation system can lessen the impact on the learner. A fallback mechanism to a non-interactive version of the lab with a clear message to the learner can significantly increase the user experience. Ideally this fallback mechanism would also allow them to be seamlessly switched back to the interactive version once connectivity is restored to the FIRE facility resources and retain any previous experiment results. FORGE can solve this challenge using existing load balancing techniques and software for redundant web services.

6 Conclusion

FORGE has successfully created several prototype courses using FIRE facilities covering wide a ranging list of topics in networking from Wireless LAN to TCP Congestion Control. These courses are now integrated to the courseware of the partner universities and also taught worldwide. To date, more than one thousand students across ten countries have taken part in nearly twenty experimentation courses. With the success of initial prototype courses, FORGE also created several advanced electrical engineering courses covering topics such as LTE and OFDM. The on-going FORGE open call courses such as MOOC[8], partnership with Cisco[9] and GoLab[10] also prove its continuing progress. Learning Analytics has also been integrated to analyse students' behaviour towards the courses studied.

In spite of these successes, there are several aspects that can be improved. The authentication system should be improved in order to find out who is actually using the course material. Security on the testbed side should be put in place to block anonymous access. Testbed resource availability, scalability, and scheduling issues need to be reassessed and redesigned. Finally, a sustainable solution should be put in place in order to keep the courses running beyond the project duration.

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