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► **To cite this version:**

Tiago Salmito, Leandro Ciuffo, Iara Machado, Marcos Salvador, Michael Stanton, et al.. FIBRE - An International Testbed for Future Internet Experimentation. Simpósio Brasileiro de Redes de Computadores e Sistemas Distribuídos - SBRC 2014, May 2014, Florianopolis, Brazil. p. 969. hal-00990392

HAL Id: hal-00990392

<https://hal.science/hal-00990392v1>

Submitted on 21 May 2014

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FIBRE - An International Testbed for Future Internet Experimentation

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***Abstract.** This paper describes the FIBRE testbed, a large-scale research facility for experimentation on Future Internet. The current testbed is a federation of 13 local testbeds (aka experimental islands), located in different R&E organizations. The FIBRE infrastructure combines heterogeneous physical resources and different technologies, including OpenFlow, wireless and optical communications. This paper discusses the architecture of FIBRE, which includes different Control Management Frameworks, and describes how the testbed can be used in research and education to experiment with networking and distributed systems.*

1. Introduction

The need for experimenting with new protocols and techniques for the Future Internet (FI) led to construction of testbeds, that is, networks totally dedicated to experiments and isolated from the production Internet. The architecture of these testbeds must take a number of issues into account. Researchers must be capable of running their experiments with the scale and heterogeneity of the real environment. Resources must be allocated elastically to different experimenters, but each researcher must be able to replicate the exact environment of previous tests. Testbeds must also offer monitoring and instrumentation tools, and must control access to their resources according to the policy designed for them.

FIBRE (Future Internet testbeds/experimentation between Brazil and Europe) is one of five projects that were approved in response to the 2010 Brazil-EU Coordinated Call in ICT, jointly funded by CNPq (the Brazilian Council for Scientific and Technological Development) and by the European Commission within its Seventh Framework Programme (FP7). FIBRE was launched in October 2011 with the goal of deploying a

new experimental facility for Future Internet research in Brazil, federated to European ones, both at the physical connectivity and control and monitoring framework levels.

With the globalization of experimental FI research, there has been considerable interest in the federation of distinct testbed facilities, in order to permit carrying out experiments that span multiple testbeds. This design, besides addressing the challenge to incorporate resources from legacy projects, enables the extension of the testbed to support new networks and include new research facilities.

Thus, FIBRE is currently deployed as a federation of 13 local experimental facilities (a.k.a. “islands”). One of the biggest challenges is to provide a unified view of resources managed by different organizations, by way of a federation of independent resources.

The management of such a testbed facility is complex. The use of a control and monitoring framework (CMF) can facilitate this task, allowing for its automation. The CMF allows a central management site in the facility to control the access to virtualized computing and network resources and to provide support for measurement of resource use.

The architecture built for FIBRE brings together different technologies, including OpenFlow [McKeown 2008] and wireless and optical communications, as well as different CMFs. In this article we describe the testbed that is available at this point and its use in experiments.

2. FIBRE architecture

The testbed is currently composed of ten islands located in Brazil and three in Europe. In this paper, we will concentrate on the Brazilian side of the testbed.

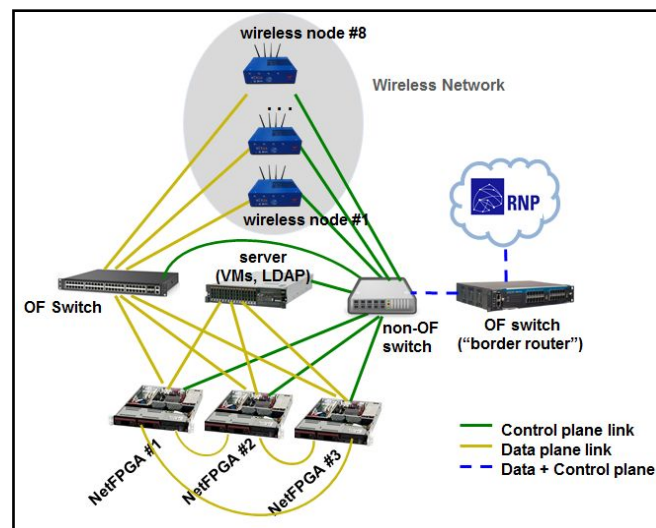


Figure 1. Overview of a FIBRE island.

Each island has a common nucleus of OpenFlow-capable switches, together with their controller(s), as well as a cluster of compute and storage servers, appropriately virtualised, and (usually) a cluster of virtualised wireless nodes. Each site integrates its own site-specific resources to FIBRE, such as wireless access testbeds (WiFi, WiMax, 3G/4G), OF-enabled equipment, optical networks or even more complex testbeds with

heterogeneous resources and their own control framework (e.g.: the Emulab cluster at USP). Figure 1 illustrates a typical FIBRE island, with its common facilities and external connectivity.

One of the challenges for network environments for experimentation is scale. Because experimentation networks are supported by real hardware, a large topology requires controlled multiplexing of the resources of the underlying physical system, to provide manageable virtual resources. The FIBRE testbed uses multiplexing techniques to slice control and data traffic based on a specific OF controller, the FlowVisor [Azodolmolky 2012] or channel scheduling for wireless, in order to virtualize resources like processing nodes, network devices and networks. It is worth mentioning that virtualization does not provide strict scientific fidelity, because the experiments are based on shared, rather than dedicated, physical resources. However, there are good reasons for relaxing this constraint: 1) some applications, like peer-to-peer systems, even though requiring large topologies are not resource-intensive; 2) the strict scientific fidelity requirement might be dispensable for many applications; and, 3) multiplexing allows more efficient use of limited hardware resources.

From the start, the project team decided that FIBRE should include the following CMFs: OFELIA Control Framework (OCF), OMF and ProtoGENI. The use of different CMFs represents a gain for the project as it allows the simultaneous orchestration of three complementary classes of resource: OpenFlow resources, wireless resources, and emulated resources. All CMFs were customized for use in FIBRE.

OCF [Sune 2013] was originally created in the context of the OFELIA testbed project¹, but today it is supported by a wider community in which FIBRE and GEANT participate. From the point of view of experimenters (or network researchers), the available underlying network substrate is fully controllable using explicit and dynamic configurations based on OpenFlow abstractions like FlowSpace. Once a FlowSpace is set up, the researcher can proceed with the allocation of a controller, either remotely or in a local virtual machine, to test his new Internet research project.

OMF [Rakotoarivelo 2010] is a framework with the focus on controlling and managing network devices. It was developed based on XMPP (eXtensible Messaging and Presence Protocol) in the Ruby language. The OMF suite also provides OML (OMF Monitoring Library), which allows instrumentation of applications for collecting measurements.

ProtoGENI [Duerig 2012] is a CMF from the University of Utah. It is based on an enhanced version of the Emulab testbed management software. The Emulab testbed is used to perform experimental network research on distributed systems. ProtoGENI was created to provide the integration between Emulab and other testbeds in order to build the Cluster C facility of GENI.

As aforementioned, federation is a key issue in the design of the FIBRE testbed. In fact, one of FIBRE's goals is to design a framework where all the CMFs adopted can work together complementing each other, in addition to federating different instances of the same CMF. In its first phase, the FIBRE testbed is being accessed through a simple web

¹ <http://www.fp7-ofelia.eu>

interface (see Section 3). An important component in FIBRE's architecture will be MySlice [Augé, 2013], a software layer that enables the creation of a federation abstraction, integrating the different FIBRE testbeds using the Slice-based Federation Architecture (SFA) [Peterson, 2010]. This interface is based on a web client that allows users to interact with the great volume of results generated by each testbed island.

The distribution of FIBRE islands is shown in Figure 2. The integration of these resources creates a large-scale network. In Europe, there are three islands: one at Fundació i2CAT (Spain), one at the University of Bristol (UK), and one at UTH (Greece). The Brazilian part of the testbed is composed of ten islands widely spread across seven Brazilian states. Each island is controlled by one or more CMFs. Figure 2 shows the set of CMFs available in each island, and the network that connects them, called the FIBRE backbone.

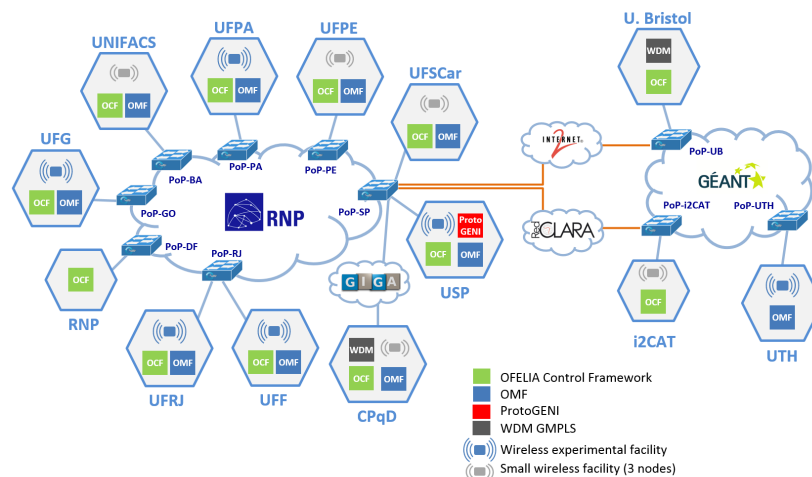


Figure 2: The FIBRE testbed.

Each island in FIBRE monitors its resources using Zenoss, an open-source application for network management. Zenoss provides a web interface that allows administrators to monitor availability, performance, and events. Using Zenoss, a publicly available web page with information about network and virtual machines is made available to experimenters.

3. Using the FIBRE testbed

Because the MySlice portal is in final stages of development, FIBRE is at the moment accessed through a simpler web page, maintained by the FIBRE NOC (Network Operation Center)². The NOC is responsible for controlling and monitoring the network assets of the testbed and for monitoring the provided services. User authentication is carried out using an LDAP directory in each island synchronised with an LDAP directory at the NOC. LDAP allows authentication with all CMFs (OMF, OCF, and ProtoGENI)³. To obtain access to the FIBRE testbed, a user should either contact the

² <https://portal.fibre.org.br>

³ The roadmap for authentication is to migrate to a federated model using the Brazilian Academic Network Federation, CAFé.

local island administrator, if he/she is associated to one of the institutions maintaining an island, or contact the NOC at info@fibre.org.br.

Previous to conducting an experiment, the user will have developed or selected the software he/she desires to experiment with. This may be user-level software (a peer-to-peer content distribution system or a mobile app) or system-level (modified kernels with new or modified communication protocols, or reimplementations of well-established protocols, in the case of educational experiments). Software may be completely agnostic of the environment on which it will be running or may include calls to libraries that collect measurement. OMF, for instance, includes the OML framework for collecting measurements [Singh 2005]. Once the user has the software ready, he/she must design the (set of) experiments to be conducted [Jain 1991].

Due to lack of space, we describe here the setup of an experiment using only the OCF control framework. Documentation about experimentation with the other frameworks is available online at the FIBRE wiki⁴.

Figure 3 illustrates the lifecycle of an experiment in the testbed. Initially, the user must provide an "experiment description", which includes the desired nodes and the links between them, as well as the desired timeslot for the experiment. Given this description, the testbed portal will handle the reservation of resources. At the arranged time, the user will initiate the experiment, uploading the desired code and configuration to the reserved nodes. During the execution of the experiment, both the user and the framework can monitor and control it, generating data that can be used either interactively or off-line.

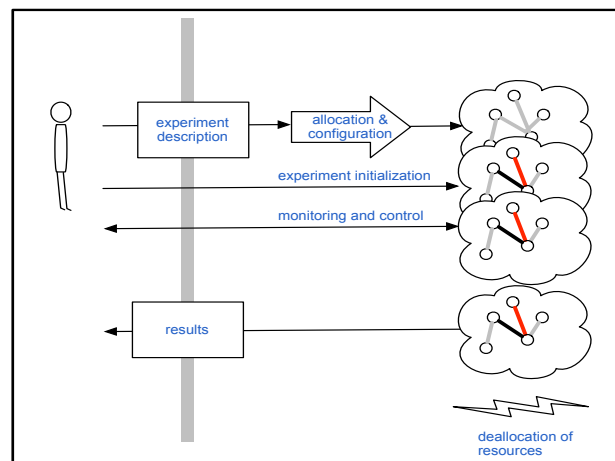


Figure 3: The lifecycle of an experiment.

Setting up an experiment in OCF

Resources in OCF are managed by so-called Aggregate Managers (AMs). Aggregates encompass one or more instances of a single type of resource (OpenFlow resources, Virtual Machines, etc.). They are created by the island managers and are local to their respective island. Each island runs local instances of OCF subcomponents, which

⁴ wiki.rnp.br/display/fibre/

manage its local resources and externalize their AMs to the OCF instance that runs on the NOC site.

To set up an experiment, users must first request access to a project in the OCF interface. Users can see and modify configurations in projects for which they have been granted permission. These permissions are usually granted by the project owners. For new projects, permission is usually granted by the island manager.

The user must begin the setup of the experiment by making a reservation of the desired resources on the appropriate OCF instance. For cross-island experiments, users must access the OCF instance running at the NOC and add to their project the necessary aggregates from all desired islands; experiments configured by an OCF instance running at an island may use only its own local resources.

OCF uses the concept of *slice* to describe an experiment. Slices describe the resources to be used and the associated configurations, and encompass the state of the experiment. Once the user has permission to participate in a project, he can either use existing slices associated to this project, or create new ones. When creating a new slice, information such as name, description and expiration date (the slice life-time) must be provided. After slice expiry, the island manager may deallocate the reserved resources.

On the Slice Management page (Figure 4), the Topology panel shows the physical topology of the resources in the aggregates available to the slice. These resources may comprise the available OpenFlow switches, virtualization servers, and the connections between switches and servers.

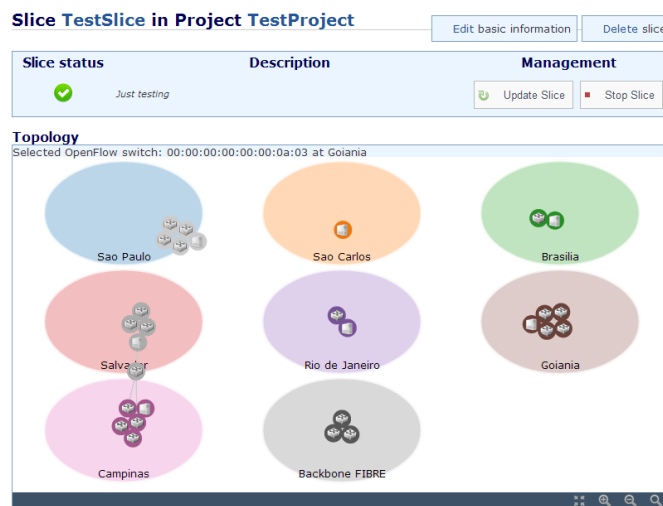


Figure 4: Topology of a slice.

VMs for experiments are created in a Computational Resources area on the Slice Management page. During the creation process, the VM will be granted an IP, which will be displayed in the Topology Panel and the Computational Resources area. This IP is only reachable through FIBRE's VPN. VMs may be started, stopped, rebooted or deleted by clicking on the respective action link in the Computational Resources area. Users can create as many VMs as needed for their experiment.

To use OpenFlow resources, users are required to add OpenFlow resources to their slice and specify an OpenFlow Controller for the experiment. On the Slice Management page in the OpenFlow Aggregate area (Figure 5), data paths (consisting of *id* and port

number) that are available in the slice can be selected to define a FlowSpace for the experiment. Once the FlowSpace is selected and the VMs are created, the user must set the controller IP address to match to the VM that will host the OpenFlow controller.

The screenshot shows a web interface titled "OpenFlow Aggregate UFG OpenFlow" with a sub-header "Aggregate physical location: Goiania." Below this is a table with two columns: "Datapath ID" and "Connections (Port and Remote Port)".

Datapath ID	Connections (Port and Remote Port)
00:00:00:00:00:00:0a:01	<input type="checkbox"/> Port 1
	<input type="checkbox"/> Port 2 Connected to datapath 00:00:00:00:00:00:0a:03 at port 3.
	<input checked="" type="checkbox"/> Port 3 Connected to datapath 00:00:00:00:00:00:0a:02 at port 3.
	<input type="checkbox"/> Port 4 Connected to datapath 67:8c:08:9e:01:62:d6:42 at port 25.
	<input type="checkbox"/> Port 65534
00:00:00:00:00:00:0a:02	<input type="checkbox"/> Port 1
	<input type="checkbox"/> Port 2 Connected to datapath 00:00:00:00:00:00:0a:03 at port 2.
	<input checked="" type="checkbox"/> Port 3 Connected to datapath 00:00:00:00:00:00:0a:01 at port 3.
	<input checked="" type="checkbox"/> Port 4 Connected to datapath 67:8c:08:9e:01:62:d6:42 at port 26.
	<input type="checkbox"/> Port 65534

Figure 5: OpenFlow datapath

To effectively run the experiment, the user starts the slice on the Slice Management page. This will trigger a FlowSpace request to the island manager and make sure all the VMs in the slice are active. Until the user receives the FlowSpace approval by the island manager, their FlowSpace has not yet been granted and cannot be used. Only granted FlowSpaces are installed/known in the FlowVisor that handles the slicing of the overall FIBRE OpenFlow resources.

Within the slice, the user can use the VMs as end-hosts and the FlowSpaces (allocated on the OpenFlow switch fabric) as the network data-plane. Users can access the running VMs through ssh, using their FIBRE username and password over FIBRE's VPN. Users can then install on the VMs any OpenFlow controllers or arbitrary software that is needed for their experiment (A set of OpenFlow controllers are pre-installed in the VM images, but users can also provide their own controller implementation.).

In the demonstration at the tool session, we will go through the procedures described in this Section in a step-by-step fashion, setting up an experiment that spans multiple islands and going through the configuration steps that are necessary to access the virtual resources and to run an experiment.

4. Final Remarks

The implementation of new experimental facilities in Brazil, as well as the integration with European facilities, offer a valuable infrastructure for research and education. The infrastructure provided by FIBRE will allow researchers to evaluate and benchmark innovative algorithms, techniques and approaches for the Future Internet. The collapsing of network and compute resources, and the ability to instantiate virtual infrastructures dynamically using such resources, allow for experiments of interest not only to the academia (e.g., new Internet architectures where the intelligence is at the edge, in cloud datacenter VMs), but also to the industry (e.g., network functions virtualization composition and service chaining). On the other hand, students can experiment with well-known protocols and algorithms, implementing them from scratch if so desired.

The FIBRE project was recently extended to last until September 2014. The Brazilian partners are organizing themselves to keep the testbed operational beyond the project lifetime. At the moment, the project team is working on further support for instrumentation and monitoring (I&M). The basic requirement for the FIBRE I&M Architecture is the capability to configure, monitor, collect, and display both infrastructure and experiment-specific data for distinct federated or individual CMF aggregates. Additionally, with the conclusion of MySlice deployment, FIBRE users will be able to access both the experimental and control planes, with a common access interface to the different underlying CMFs. MySlice will also allow the I&M activities to be carried out through this same interface.

We welcome new institutions willing to join the testbed. For further information, please go to the project website: <http://www.fibre.org.br>

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