BUILDING AN INFRASTRUCTURE FOR EXPERIMENTATION BETWEEN BRAZIL AND EUROPE TO ENHANCE RESEARCH COLLABORATION IN FUTURE INTERNET

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Abstract
This paper describes the experience of RNP, the Brazilian research and education network, in creating a large-

scale research facility for experimentation on Future Internet as a member of the FIBRE (Future Internet testbeds experimentation between BRazil and Europe) project. Its main goal is to create common space between Brazil and EU for Future Internet experimental research into network infrastructure and distributed applications, by building and operating a federated EU-Brazil Future Internet experimental facility. The FIBRE testbed is currently composed by a federation of 13 local testbeds (a.k.a. experimental islands), located in different R&E organizations. The FIBRE infrastructure combines heterogeneous physical resources and different technologies, including OpenFlow, wireless and optical communications. We also present the architecture of FIBRE, which allows users to access the testbed through an integrated interface for either experimental or control planes, and provides a common access to the different underlying Control and Monitoring Frameworks (CMFs) for Future Internet experimentation.

Keywords

Future Internet, Experimental research, FIBRE project, Testbed, Federation, FIBRE backbone.

1. Introduction

In the last two decades networks, and especially the Internet, have become part of the critical infrastructure of governments, businesses, homes and schools. The current Internet architecture, designed about 30 years ago, has suffered many extensions in recent years, to include new functionalities, which were unforeseen in the original design. Many network experts now consider it is necessary to undertake the study of alternative architectures for the Future Internet as a truly effective way to resolve many of the pressing problems that currently afflict the Internet.

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.

Programmable testbed networks can lower the barrier to entry for new ideas, increasing the rate of innovation in network infrastructure. Virtualisation of networks is accomplished by the use of virtual routers and the multiplexing of links between them. These programmable testbed networks call for programmable switches and routers that, using virtualisation, can process information flows for multiple isolated experimental networks simultaneously. It is envisaged that a researcher will be allocated a slice of resources across the whole network, consisting of a portion of network links, packet processing elements (e.g. routers) and end-hosts; researchers programme their slices to behave as they wish. A slice could extend across the backbone, into access networks, into college campuses, industrial research labs, and include wireless networks, sensor networks, and may (or should) include real users of the applications it supports. Such a testbed facility may serve a widespread community of researchers and users.

This paper describes the experience of RNP, the Brazilian research and education network, in creating a large-scale research facility for experimentation on Future Internet as a member of the FIBRE (Future Internet testbeds experimentation between BRazil and Europe) project. The FIBRE federated architecture allows users to access the testbed through an integrated interface for either experimental or control planes, which provides a common access to the different underlying Control and Monitoring Frameworks (CMFs). In addition, enhancements are being developed for collection and visualisation of performance measurements to help researchers to deal with the experiment as a whole, i.e. providing an integrated view of the experiment.

FIBRE-BR includes leading sites (also known as islands) in each of the initial Brazilian partners in this project.

These sites are interconnected via private (Level 2) channels over wide area and metropolitan networks available to the Brazilian research and education community. These include RNP's national backbone network and the GIGA network testbed operated jointly by RNP and CPqD. RNP's own metropolitan networks are used to connect the last mile where necessary, and the international connections of RNP provide access to other international FIBRE islands located at European partner institutions like i2CAT, University of Bristol and University of Thessaly for purposes of the federation.

The FIBRE testbed is composed by the integration of 13 experimentation nodes (islands) located in Brazilian and European institutions. The integration of these resources creates a large-scale network. The FIBRE testbed is composed of 10 Brazilian islands located in 7 Brazilian states and 3 European islands located in Greece, Spain and the UK (see Section 3.1).

The remainder of this paper is structured as follows. In section 2, we describe the FIBRE project and its objectives. In section 3, we present the FIBRE federated testbed architecture and its main components. In section 4, we turn attention to the FIBRENet, the network that interconnects the federated partners of FIBRE. Section 5 briefly discusses the workflow for using the FIBRE infrastructure. Finally, the conclusions are presented in section 6.

2. The FIBRE project

The FIBRE project (Future Internet testbeds experimentation between BRazil and Europe) is one of the 5 research projects selected in the first EU-Brazil Coordinated Call in ICT in 2010. Pairs of consortia, one each from Brazil and the EU, submitted the same technical proposal for funding, respectively to the Brazilian Council for Scientific and Technological Development (CNPq), and to the EC, and a joint decision was taken by the two funding agencies. The two consortia of the FIBRE project are known as FIBRE-BR and FIBRE-EU, respectively.

FIBRE was launched in October 2011 with the goal of deploying a new experimental facility for Future Internet research in Brazil, federated to European testbeds, both at the physical connectivity and control and monitoring framework levels. The main goal of the FIBRE project is to create a common space between the EU and Brazil for Future Internet (FI) experimental research into network infrastructure and distributed applications. This consists of the design, implementation and validation of a shared FI research facility, supporting the joint experimentation of European and Brazilian researchers. Currently such facilities are already in operation, or are being built following similar designs, by partners in this project from both sides of the Atlantic Ocean. 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 main objective of the FIBRE project is the design, implementation and validation of a shared Future Internet (FI) research facility, enabling experimental research into network infrastructure and distributed applications. Such facilities already are operated by ten institutions in Brazil and 3 in Europe, located in Greece, Spain and the UK. We expect that such a federated large-scale experimental facility will enable and encourage closer and more extensive bilateral cooperation in FI research and experimentation, as well as strengthening the participation of both communities in the increasingly important global collaborations in this important area of network research and development. In order to achieve this goal the project has carried out four main activities:

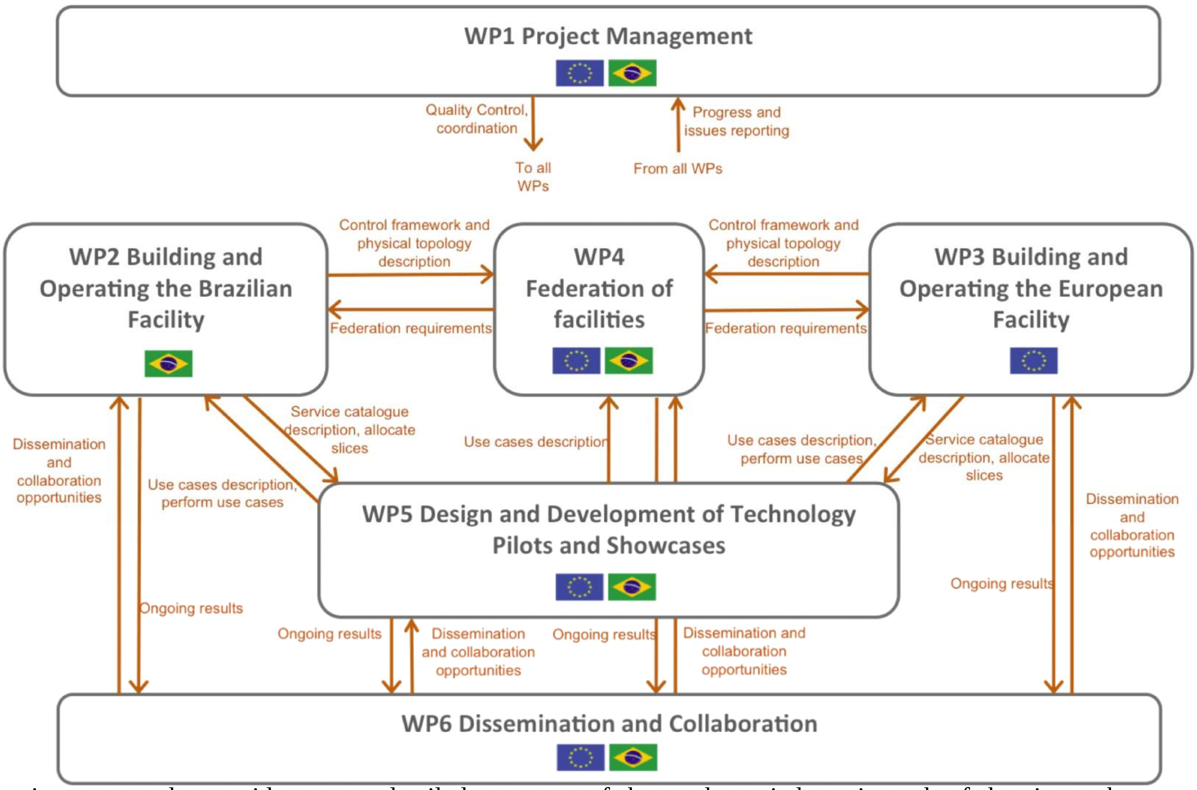
- The development and operation of a new experimental facility in Brazil, including the setup of equipment to support experimentation with various technologies (fixed layer 2 and layer 3, wireless, optical) as well as the design and implementation of a control framework to automate the use and operation of the testbed.
- The development and operation of a FI facility in Europe based on enhancements and the federation of two previously existing infrastructures: OFELIA (OFELIA, 2014) and OneLab (OneLab, 2014). Two

OFELIA islands (i2CAT/Spain and UEssex/UK[1]) and the UTH's Nitos (Nitos, 2014) testbed were enhanced by i) adding more physical resources (servers, OpenFlow-enabled switches and access points) to be able to cope with a bigger number of users and different use cases, ii) improving its respective control frameworks (based on the OFELIA control framework and OMF (Rakotoarivelo, 2010)) and iii) adding more manpower to operate the facilities.

- The federation of the Brazilian and European experimental facilities, both at the physical connectivity and control framework levels, to support the provisioning of slices using resources from both testbeds.
- The design and implementation of pilot applications of public utility that demonstrate the power of a shared Europe-Brazil FI experimental facility.

Activities in the context of the FIBRE project were distributed into six work packages, as illustrated by Figure 1. Following the spirit of the rules of the EU-Brazil call, FIBRE can be seen as a coordinated project divided into two subprojects: FIBRE-EU and FIBRE-BR. FIBRE-EU was responsible for building and operating an European FI facility based on the extension of two existing testbeds: OFELIA and OneLab (WP3). FIBRE-BR was also responsible for building and operating a Future Internet Facility in Brazil (WP2), but the Brazilian facility had to be built from scratch as opposed to their European counterparts. All the other activities of FIBRE were carried out as a coordinated effort between FIBRE-EU and FIBRE-BR, including:

i) physical interconnection and federation of the control frameworks of both facilities (WP4);
ii) design and development of new applications that take advantage of the federated FIBRE facilities and showcase its potential (WP5);
iii) dissemination of the project results and collaborations with related initiatives (WP6);
iv) management of the coordinated project (WP1).



The following paragraphs provide a more detailed summary of the work carried out in each of the six work packages of the project.

[1] The University of Essex (UEssex) team moved to the University of Bristol (UnivBrist) in 2012.

WP1 (Project Management): The main objective of this WP is to perform an efficient consortium management for ensuring effective work in the FIBRE project so that the overall project performed by the Brazilian and European partners meets its scientific and technological objectives in a timely manner.

WP2 (Building and operating the Brazilian facility): The objective of WP2 is the development and operation of a new experimental facility in Brazil, including the setup of equipment to support experimentation with various technologies (fixed layer 2 and layer 3, wireless, optical) as well as the design and implementation of a control framework to automate the use and operation of the testbed.

WP3 (Building and operating the European facility): The main goal of this work package is the development and operation of an FI facility in Europe based on enhancements and the federation (interoperability) of two existing FIRE (FIRE, 2014) infrastructures: OFELIA and Open Lab.

WP4 (Federation of facilities): The objective of WP4 is the federation of the Brazilian and European experimental facilities, both at the physical connectivity and control framework level, to support the provisioning of slices using resources from the facilities in both Europe and Brazil. This work package allows FIBRE experimenters to use the FIBRE facility as a unified, intercontinental testbed.

WP5 (Design and development of technology pilots and showcases): This WP aims at the implementation of pilot applications of public utility that showcase the power of a shared Europe-Brazil FI experimental facility.

WP6 (Dissemination and Collaboration): WP6 is about disseminating the results and lessons learned by the project, as well as enhancing the collaboration and exchange of knowledge between European and Brazilian researchers in the field of FI.

3. FIBRE Federated Testbed

The project brings together different technologies, including OpenFlow, wireless and optical communications. The management of such a testbed facility is complex and is automated by means of one or more *Control and Monitoring Frameworks* (CMFs). A CMF allows centralized management of the entire facility, controlling the access to virtualized computing and network resources, as well as providing support for measurement of resource use. It is also possible to extend a CMF in order to provide other functionalities, such as access to integrated emulation facilities.

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. Federation is a key issue in the design of the FIBRE testbed architecture, which is being deployed as a federation of 13 local experimentation nodes (a.k.a. “islands”). As a matter of fact, one of the FIBRE 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 FIBRE the federation approach enables two or more organisations to devote some of their resources to a shared purpose. Each federation technique has two components: a set of standards, which provides connectivity, and a set of policies, which states what levels of connectivity are allowed (e.g., the amount of resources shared between the federated parties). From the technical point of view, FIBRE is adopting a Sliced-based Federation Architecture (SFA) (Peterson, 2010). This concept is already used in GENI (GENI, 2014) and in other testbeds (e.g. OpenLab). Among the provided functionalities, SFA enables federation members to track and exchange services among islands. The idea is to provide a distributed management facility through a common and safe API that builds an extra layer between the CMFs and the users. In fact, features like member authentication and resource discovery and accountability are among the most important characteristics of SFA.

3.1. FIBRE islands

The FIBRE federated testbed is currently composed by ten islands located in Brazil, one per each of the ten Brazilian partners in this project, and three in Europe. Each island is located at the corresponding partner's site. Each individual island has OpenFlow enabled equipments, Orbit wireless nodes (ORBIT, 2014) and a virtualized computer server. The FIBRE-BR island that runs at USP also includes an Emulab (Emulab, 2014) cluster.

Figure 2 shows the geographical locations of the FIBRE islands. The integration of these resources creates a large-scale network. The Brazilian part of the testbed is composed by ten islands widely spread across seven Brazilian states. Five sites are in the Southeast, one in the North, two in the Northeast and two in the Centre-West regions. In Europe, there are three islands: one at Fundació I2Cat (Spain), one at the University of Bristol (UK), and one at the University of Thessaly (Greece).

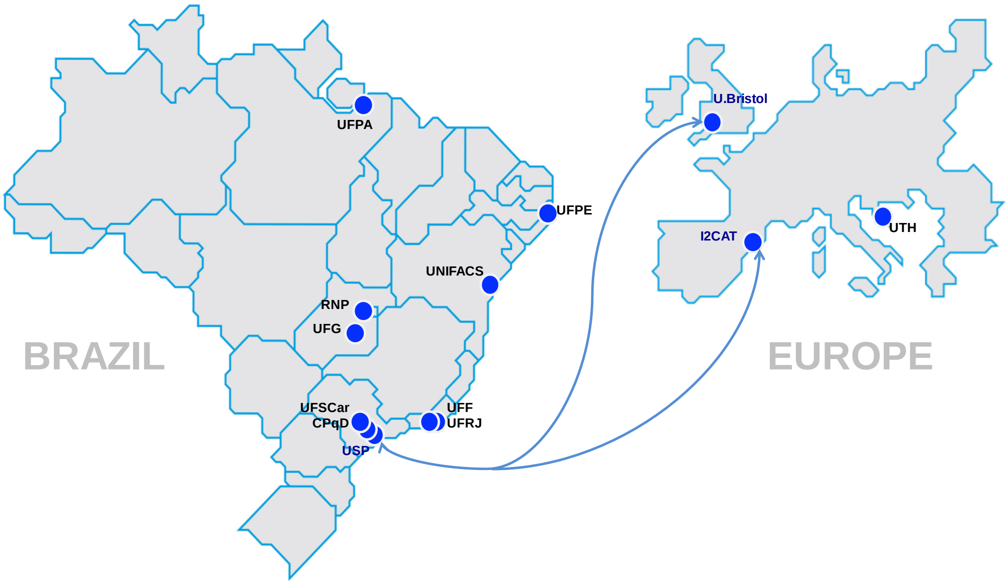


Figure 2. Distribution of FIBRE federated islands.

Each individual site in Brazil runs at least one FIBRE island and has a common set of OpenFlow-enabled core switches, some based on NetFPGA and others on production-quality switches, together with their controller(s), as well as a computer server, appropriately virtualised and physical machines, plus a cluster of Icarus wireless nodes. Each site proposed its own possible extensions, integrating site-specific resources to FIBRE, such as wireless access testbeds (WiFi, WiMax, 3G/4G), OF-enabled equipment, optical networks or more complex testbeds with heterogeneous resources and their own control framework (e.g.: the Emulab cluster at University of São Paulo - USP). Figure 3 illustrates a typical FIBRE-BR island, with its common facilities and external connectivity.

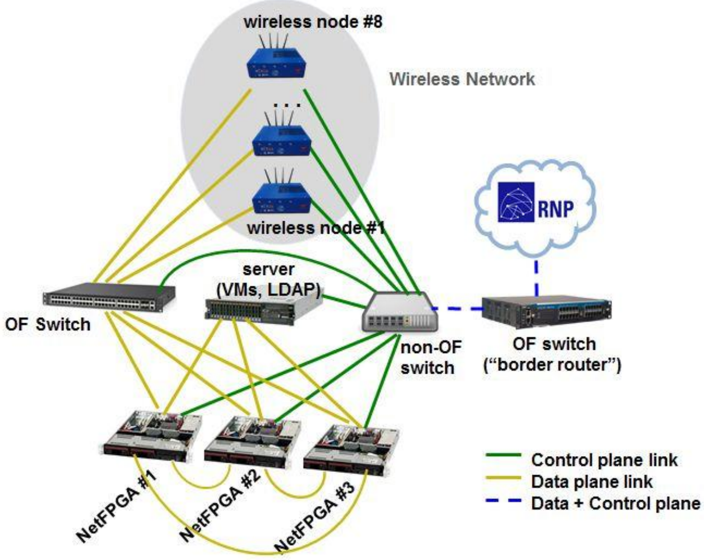


Figure 3. The structure of a FIBRE-BR island.

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 OpenFlow 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 virtualisation 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.

3.2. FIBRE Architecture

The FIBRE architecture, depicted in Figure 4, consists of an expandable collection of components. The set of components chosen for inclusion in the infrastructure at any given time are intended to enable the creation of virtual networks covering the entire range of experiments required by the FIBRE user community. These components are grouped into three categories: the control framework federation, which contains components required to operate the federation of CMFs present in the FIBRE testbed, the physical interconnection layer, which abstract and isolate physical network connections in a higher level overlay network, and the monitoring integration layer, grouping components whose function is to monitor equipment, services and experiments running on the underlying testbed.

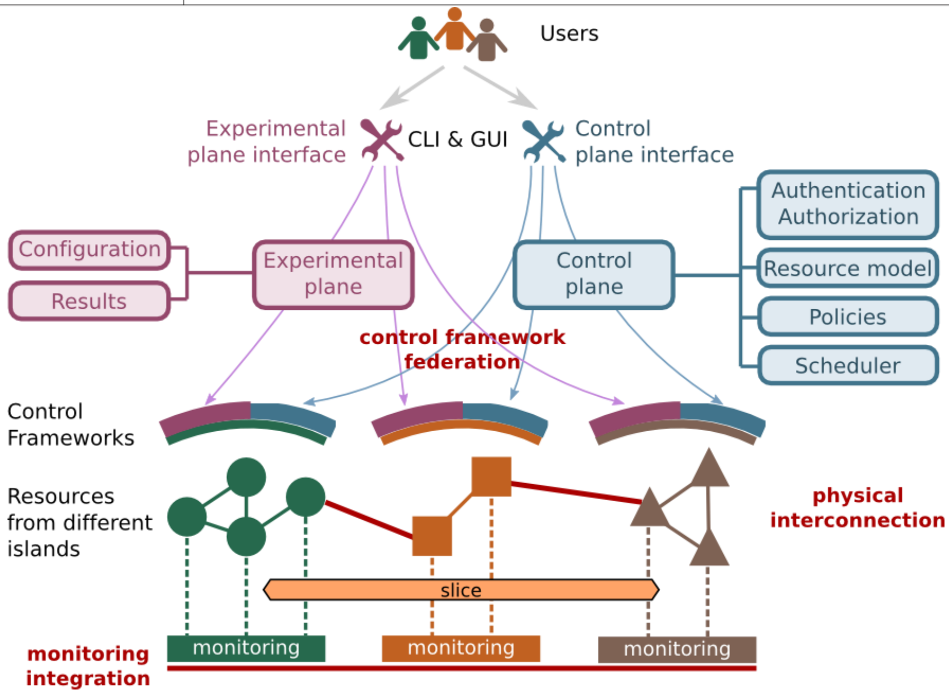


Figure 4. Components of the FIBRE architecture.

The control framework federation category is divided into two planes, the control plane (highlighted in blue) and the experimental plane (highlighted in purple). The control plane is used to control data sharing between islands such as monitoring information, OpenFlow control messages between device and controller or remote access for management equipment of the FIBRE testbed. Furthermore, the control plane includes components of the Network Operation Centre (NOC) of FIBRE, which operates and controls the FIBRE backbone, used by the experimenters during the construction of their inter-island topologies, providing services such as authentication, resource usage policies and experiment scheduling. The experimental plane runs components exclusively related to experiments, and are configured by experimenters. Components running in this plane communicate with each other through an isolated point to point overlay network.

The physical interconnection category comprises physical and virtualised resources (physical servers, virtual machines, OpenFlow resources, etc) of each island. Available resources are managed by a Slice-based Federation Architecture (SFA) (Peterson, 2010), which proposes a secure and distributed thin-waist allowing federation of heterogeneous architectures, and considers the slice (a set of resources associated to users at a given time) as its basic unit. The adoption of SFA is central to the federation effort undertaken within FIBRE (similar to the Aggregate Manager API developed in GENI), and considers as fundamental objects such as resources, users, authorities and slices.

The components of the monitoring integration category deals with the instrumentation and monitoring (I&M) of the FIBRE infrastructure-specific data for distinct federated or individual CMF aggregates. Since each slice on a testbed is an independent overlay network, a Mesh Configuration service is used to manage all inter-CMF measurements inside a slice. Each slice has its own configuration file and all monitoring agents inside the slice follow the definitions of this file. This way, a central Monitoring Orchestration Service is able remotely to monitor experiments running inside any slice.

3.3. Federating Control and Monitoring Frameworks

Each resource in all FIBRE islands is controlled by one or more CMFs. Depending on the physical infrastructure, an island can run different CMFs. Figure 5 shows the proposed testbed structure with the set of CMFs available in each island, together with the network that connects them, called the FIBRENet.

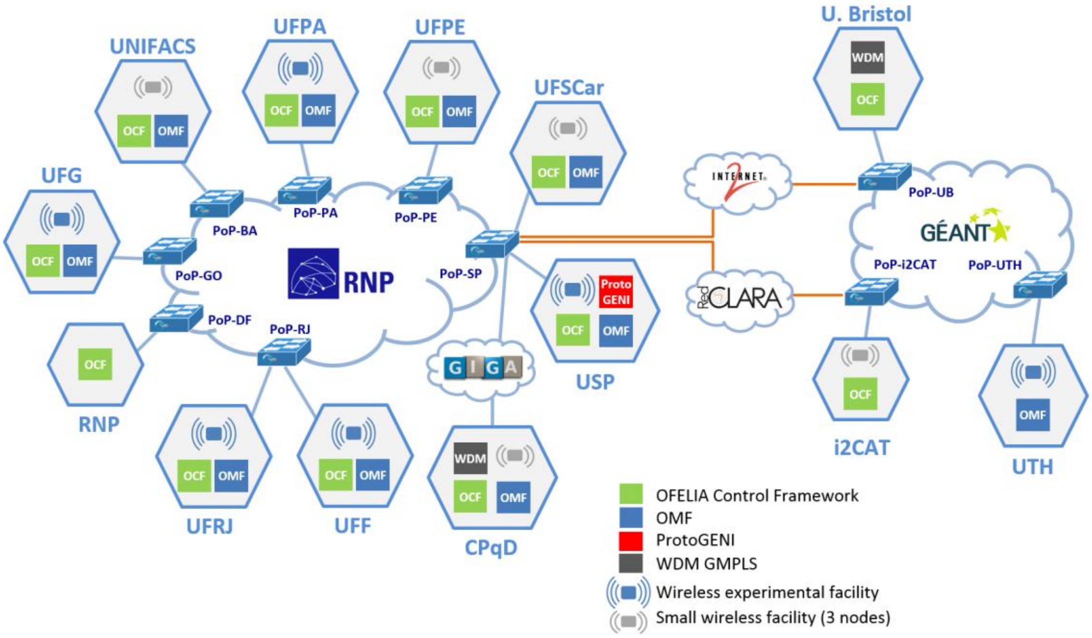


Figure 5. The FIBRE federated testbed.

From the start, the project team decided that FIBRE should include the following CMFs: OFELIA Control Framework (OCF), OMF (Rakotoarivelo, 2010) and ProtoGENI (ProtoGENI, 2014). 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. These CMFs were customized for use in FIBRE and are discussed in the following paragraphs.

OFELIA Control Framework (OCF): The OCF (OCF, 2014) was originally created in the context of the OFELIA testbed project 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 idea. The resources are reserved according to the experiment needs and accountability is performed through the extended slice abstraction.

OMF: OMF is a CMF 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. Currently, OMF depends on a suite of software components in order to provide services such as dynamic IP addressing, remote booting, remote OS imaging, data archiving, etc. Another important feature is the capability to visualize the measurements at real-time on the experimenter's Web browser. This is useful for the beginners, but it can also help the experts to easily verify if the expected results are being generated at very begin of an experiment.

OMF combines a set of management services into an Aggregate Manager (AM). Thus, the AM is a collection of services, which can be deployed across multiple servers for performance and redundancy reasons. AM accepts request from the experimenter or the testbed operator, and sends corresponding commands to the controller running on each resource.

ProtoGENI: ProtoGENI (ProtoGENI, 2014) is a CMF developed at the University of Utah. It is based on an enhanced version of the Emulab testbed management software. The Emulab testbed (Emulab, 2014) is used to perform experimental network and research about distributed systems. ProtoGENI was created to provide the integration between Emulab and other testbeds in order to build the Cluster C facility of GENI. This control framework design was based on SFA for federation among the testbeds. The Clearing House behaves as a central registry, coordinating the federation. The Aggregate Manager and Slice Authority are responsible for the operation and resource control. Finally, the RSpec is a data interchange format to describe resource properties consistently between testbeds.

An important component of FIBRE’s federated testbed is MySlice (Augé, 2013), a software layer that enables the creation of a federation abstraction, integrating the different FIBRE testbeds and their CMFs using SFA. This interface is based on a web client that allows users to interact with the great volume of results generated by each CMF of all islands.

MySlice is a project aiming to support researchers throughout the life cycle of experiments that run on different testbeds spanning different administrative domains and networking technologies. The coexistence of a highly heterogeneous set of experimentation practices and information coming from a wide variety of sources and administrative domains is a rather challenging task due to the different semantics and terminology, different usage models (best effort versus reservations), different authorisation policies, and more.

MySlice follows a bottom-up approach by starting simple and exposing the resources made available through SFA to the users through its web interface and providing all the necessary information and the corresponding tools for annotating and filtering them “manually” (there is no automatic mapping from a high-level experiment description to substrate resources as in OMF).

Through this process the objective is to learn from the users about the requirements of cross-technology FI research and add complexity along the way. There is also an effort to engage testbed owners and developers into a collaborative open source development, which will enable developers with expertise in different testbed technologies and experimental practices to work in parallel, optimizing the tools presented to the users by allowing them a wide range of choices according to their own requirements.

For this, the MySlice web framework provides a modular implementation of independent plugins and a message passing interface shared between them. They are divided into three main categories: 1) query editing, the type of resources that the user is interested in; 2) data display, the visualisation of resources that match the selected query; 3) and resource allocation, the selection and reservation (if needed) of resources. The information on which these tools operate come from a backend system which collects and represents in a standard format (i.e., a dictionary) the available SFA resources (MySlice API) and all available monitoring information about them (TopHat API).

These two APIs are completely independent of the web framework, and are the providers of the raw information available globally using exactly the same XMLRPC APIs. Then a thin web framework is responsible for authentication and authorization issues, for presenting the above information to users, and enabling them to choose the most suitable resources for their experiment.

4. FIBRENet Backbone

The development of the proposed interconnection of experimental environments inside FIBRE islands began with an analysis of the available infrastructure that consists of a national backbone, metropolitan networks and campus networks. The backbone of the Brazilian National Research and Education Network (RNP), called the Ipê network, encompasses 27 Points of Presence (PoPs), one in each state, providing connectivity to more than

900 educational and research sites in Brazil (Stanton, 2010). The current version of the IPê backbone is shown in Figure 6.

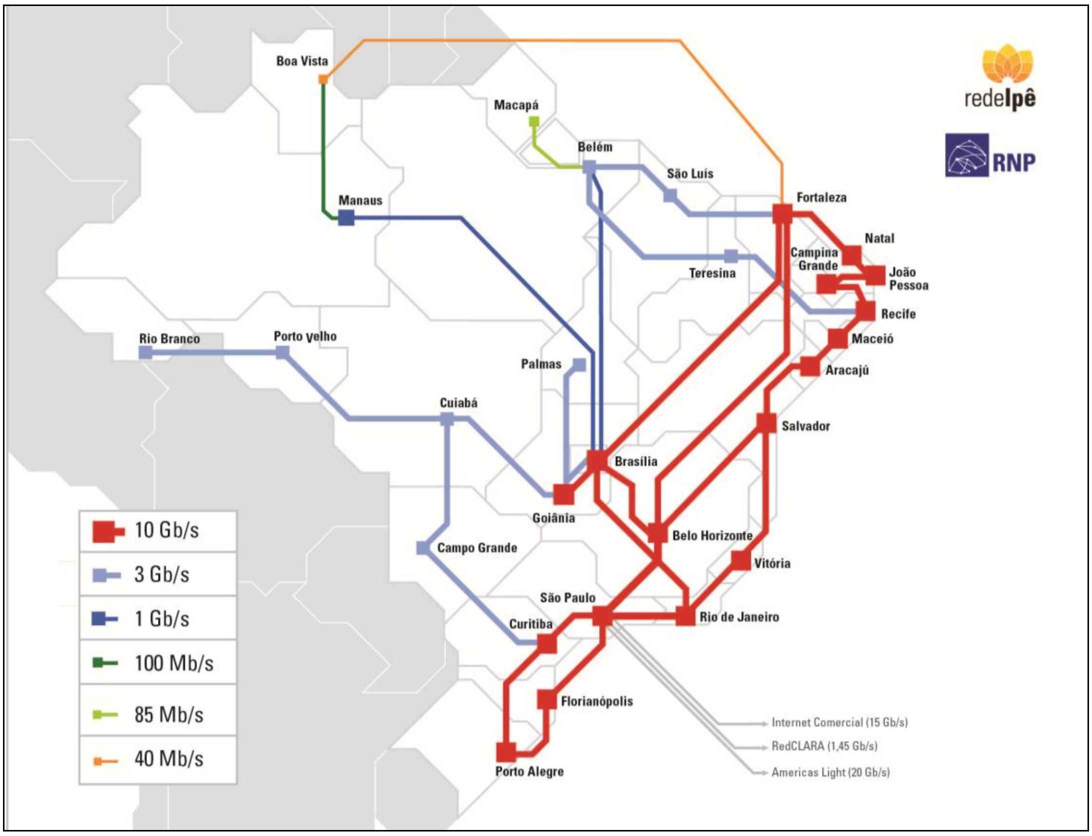


Figure 6. RNP backbone topology as in December 2013.

Acting as an agent of integration for academic initiatives in Brazil and Latin America, RNP has an important role in Latin American Cooperation of Advanced Networks (RedCLARA). The Ipê is connected to the RedCLARA network, which currently includes 15 countries in Latin America. Additionally, through four 10 Gbps connections between São Paulo and Miami (USA) operated in partnership between RNP and the Academic Network at São Paulo (ANSP), the Ipê network connects to other international academic networks throughout the world, as well as to the global commodity Internet.

FIBRE islands are currently interconnected using private (level-2) channels over wide area and metropolitan networks made available to the Brazilian research and education community. These include RNP's National Ipê backbone network and the GIGA testbed network jointly maintained by RNP and CPqD. RNP-owned metropolitan networks are used for access where necessary, and RNP international connections provide access to other international testbeds, such as FIBRE-EU for federation purposes.

The FIBRENet is an overlay network created upon the RNP's backbone (Ipê network), in which the network plane is divided in two parts: a data plane and a control plane. The control plane in FIBRENet is prepared to offer control through a central FIBRE-BR Network Operation Centre. Thus the experimenter can manage and monitor control information among FIBRE-BR islands. In other words, this channel allows communication between control frameworks of all islands and to collect monitoring information. For this an overlay network was built on the backbone of the RNP.

The control plane network is a MPLS based Layer 2 VPN (IETF, 2014) mesh network used to traffic the data corresponding to the communication of the control frameworks, like OCF and OMF, and the gathering of monitoring information from the components used in the testbed. The control plane is also used for routing

OpenFlow control messages between device and controller or remote access for management equipment FIBRENet. Furthermore, the control plane network includes the NOC FIBRE-BR, which operates and controls the FIBRENet backbone, used by the experimenters during the construction of their inter-island topologies.

The data plane network is a VPLS (RFC 4761 and RFC 4762) overlay point-to-point network used to switch traffic among participants of the experiments using circuits established between PoPs of the RNP backbone. Figure 7 demonstrates the topology of the current data plane network of the FIBRENet.

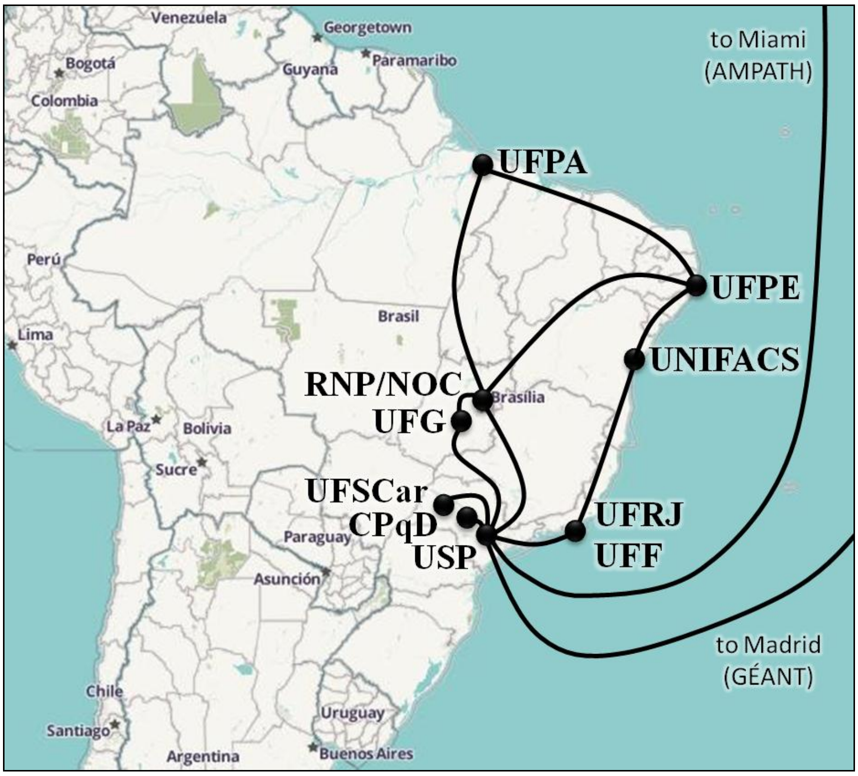


Figure 7. Current topology of FIBRENet data plane network.

Inside the data plane network, the Flowvisor software component is responsible for isolating the network of experiments from each other through the creation of dedicated circuits inside the data plane network. These circuits are segregated by identifiers called VLAN IDs.

5. Using the FIBRE testbed

FIBRE is at the moment accessed through a web page, maintained by the FIBRE NOC (Network Operation Centre)[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 a LDAP directory in each island synchronised with a 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 local island administrator, if he/she is associated with one of the institutions maintaining an island, or contact the NOC at info@fibre.org.br.

[2] https://portal.fibre.org.br

[3] The roadmap for authentication is to migrate to a federated model using the Brazilian Academic Network Federation, CAFe (reference).

Before 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 re-implementations 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 measurements. 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). Figure 8 illustrates the lifecycle of an experiment in the testbed.

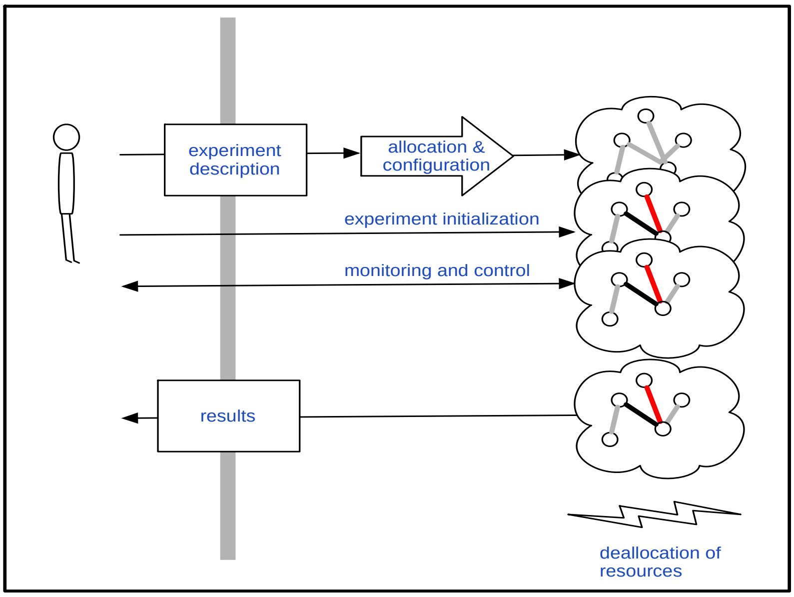


Figure 8. The life cycle of an experiment.

Initially, the user must provide an "experiment description", which includes the desired nodes and the links between them, as well as the desired time slot 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.

6. Conclusion

With the globalisation 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. The implementation of new experimental facilities in Brazil, as well as their integration with European facilities, offers a valuable infrastructure for research and education.

The infrastructure provided by FIBRE allows 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 data centre 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.

FIBRE researchers are facing the big challenge of federating autonomous islands - managed by different CMFs -

while providing a single infrastructure view for the users. In the proposed architecture, depicted in Figure 2, physical resources are shared between federated islands and all CMFs are federated through a Federation Control Plane. An instrumentation and measurement framework, able to integrate data from the different islands and CMFs is also being provided through MySlice.

FIBRE is a showcase project in international collaboration in Future Internet and demonstrates the capacity of Brazilian research groups to collaborate with leading European projects in this important area. Through its experimental facilities, researchers can validate and demonstrate new FI proposals. The FIBRE project promotes involvement of and technology transfer to the industrial sector, to prepare for Future Internet needs, especially involving OpenFlow and SDN approaches.

Once the FIBRE facility is fully operational, experimenters will be offered with a transparent federation of heterogeneous platforms across continents. Any researcher is welcome to submit proposals to run experiments over the FIBRE infrastructure.

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