FEDERATED TEST-BEDS FOR LARGE-SCALE INFRASTRUCTURE EXPERIMENTS
FELIX EU-JP

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Author list: Roberto Monno (NXW), Gino Carrozzo (NXW), Carolina Fernandez (i2CAT), Umar Toseef (EICT), Takatoshi Ikeda (KDDI), Atsuko Takefusa (AIST), Jason Haga (AIST), Fumihiro Okazaki (AIST), Bartosz Belter (PSNC), Łukasz Ogrodowczyk (PSNC), Damian Parniewicz (PSNC), Vicent Borja Torres (iMinds), Brecht Vermeulen (iMinds)

Dissemination level

☑	PU:	Public
☐	PP:	Restricted to other programme participants (including the Commission Services)
☐	RE:	Restricted to a group specified by the consortium (including the Commission Services)
☐	CO:	Confidential, only for members of the consortium (including the Commission Services)

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Abstract

This document presents the final comprehensive report of all dissemination and standardization activities that were executed by the FELIX consortium during the third and final year of the project. The report details participation to events, conferences and generally the internal and external communication activities developed by the project to increase awareness in the FIRE community and beyond, including presentations at standardization meetings. An overall impact evaluation section is also provided to summarize benefits of the project towards the FIRE/FIRE+ community and for the executing partners.

Excecutive Summary

The FELIX workpackage WP5 has been responsible for ensuring maximum impact for the project outputs through dissemination and standardisation of the produced results.

This deliverable provides a report of the dissemination and standardisation activities carried out by the partners during the third and final year of the project. Based on the successful outreach results of the previous periods, WP5 activities of the third year have been targeted to consolidate project recognition in the wide audience of academic, research and industrial communities interested in large-scale experimental research infrastructures. This awareness has been generated through publications, participation to a number of events with demos, a tutorial session at EWSDN 2015 and various other participations to workshops and conferences from both European and Japanese partners. The FELIX website has been maintained and enriched with news, information on testbeds and software for the maximum project visibility. The third year has been used also to consolidate standardisation activities. FELIX partners have continued to have a leading role in Open Grid Forum Network Service Interface WG (OGF NSI WG) and have presented FELIX architecture and orchestration challenges to IRTF Network Function Virtualization Research Group and Software Defined Networking Research Group.

1 Introduction

The document is the final FELIX Dissemination and Standardization report, detailing all the communication, publication and dissemination activities of the project in its third year. Chapter 2 presents Dissemination activities of FELIX project, with focus on public web site, publications, talks and posters at various meetings. Chapter 3 summarizes standardization activities of the project, whose researchers have continued to be active in OGF NSI-WG and IRTF NFVRG and SDNRG. Chapter 4 provides an overview of impact created by FELIX project on the FIRE/FIRE+ community through the FELIX use cases and the open source Felix Management Stack software. Also partners' exploitation plans are described to highlight strategies to use and take benefit of project outcomes at each institution/party.

2 Dissemination

This chapter presents dissemination activities of FELIX project, with focus on public web site, publications, talks and posters at various meetings. Moreover we described open source code publicly available including FELIX framework stack and software components used for use cases implementation. FELIX visability is highlighted through our partnership with other R&D projects, external companies and FIRE initiative.

2.1 External dissemination actions

2.1.1 Website

The public FELIX project website is the first place for dissemination the newest project information, publications and results. It was started in June 2013 and is available on www.ict-felix.eu address. The website is based on WordPress engine, which is an open source content management system based on PHP and MySQL technologies with many free plug-ins improving basic functionalities. It is hosted on the PSNC servers. When a guest visits Felix main page he or she has the direct access to the most important project information. For that purpose four sections were defined in the structure of website main page (see Figure 2.1):

1. **The Menu** – shown on all the website pages, contains links to the most important subsections:
    - *(new)* **Get started** – contains guides for software developers interested in the enhancement of the Felix Management Stack and guide for deployment of Felix software over the physical infrastructure as well as links for FELIX account registration, user tools and overview about experimenting using FELIX environment.
    - **Press** -- shows up to date information on the highlights of the FELIX project. It is divided into **News**, where all the announcements are placed, **Events** describing all the events Felix is presented on and **They write about us**, where FELIX is mentioned in the media.
    - **Publications** -- downloadable access to the work package official public deliverables, FELIX presentations, information about Felix software components and videos prepared by the project.
    - **Partners** – contains list of FELIX partners and the related contact persons.
    - **About** -- gives a brief overview of the project and its goals
2. The slider illustrating and linking to the latest news and important project articles.
3. **Architecture**, **Testbed** and **Experiments** pictures can be clicked and links to pages providing more details about Felix and its activities.
4. Four most latest news are always presented on top bar of the **Home** page.

In Y3, the FELIX website was enhancement with more detailed description of FELIX islands, FELIX Management Stack software and guides both for experimenters willing to use FELIX environment as well as software developers that would like to reuse FELIX software components. Additionally, the FELIX website was updated with new events on which FELIX was participating, news, article publications and public deliverables produced by the project. Dedicated statistics tools collect statistic for the FELIX website. During Y3, the FELIX website was visited effectively 1076 times (taking into account only those visitors that spend more than 30 seconds on FELIX website). Total number of visits in Y3 was 32,945 performed by 15,865 unique visitors (most of them spent just a few seconds on the FELIX website). Statistics for website visits in the third year of the FELIX project are depicted on Figure 2.2.

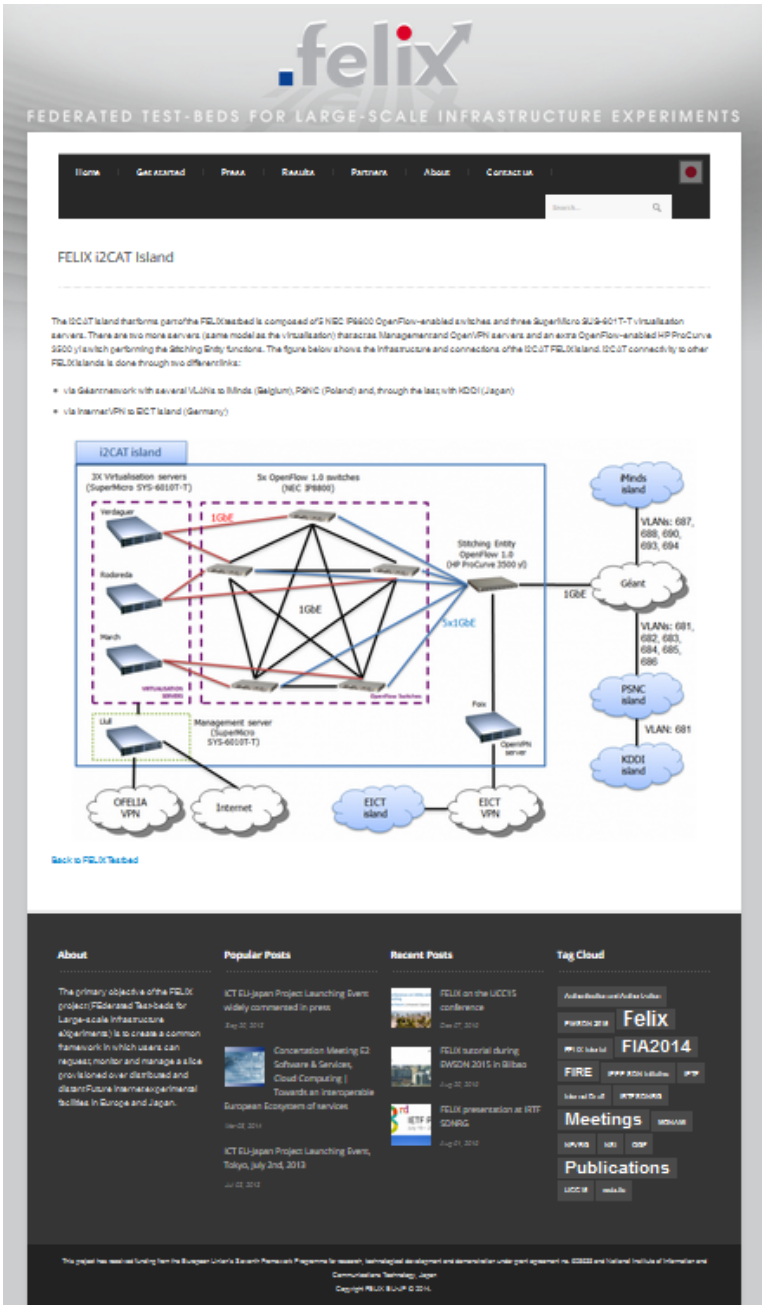

Figure 2.1: FELIX website page

2.1.2 Publications

The FELIX project has been active in the international community during the year 3, through a number of presentations and submissions of papers in international conferences, workshops and events. The focus of the presentations and publications has been the work carried out to integrate an AAA system in the FELIX framework (i.e. C-Bas) and to implement the whole infrastructure for the experimentations of the users. Moreover, we continued to promote the orchestration concept that has been developed in the FELIX software stack. It is worth noting that large part of the publications have been collaborative efforts by several partners, in some cases combining and orchestrating work across WPs.

A detailed list of papers and presentations produced in the third year of the project is reported in the table below.

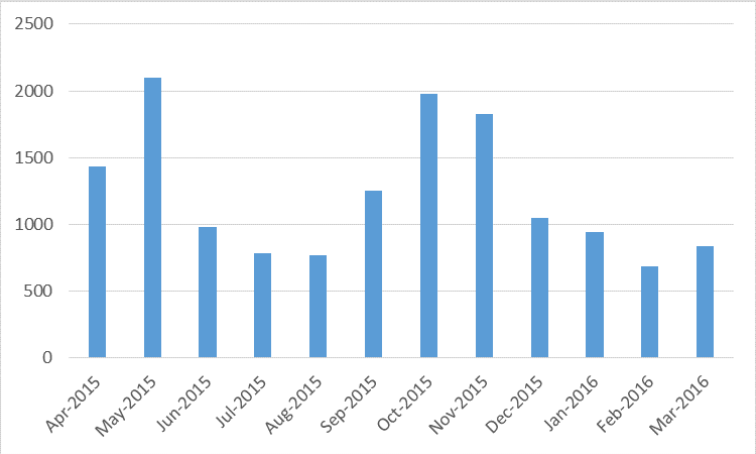

Figure 2.2: FELIX website visitors in Y3

Date	Main Authors	Title	Event	Place
7-10 Dec. 2015	U. Toseef	Authentication and Authorization in FELIX	IEEE/ACM 8th International Conference on Utility and Cloud Computing (UCC 2015)	Limassol (Cyprus)
Sept. 30 2015-Oct. 2 2015	C. Fernandez	Implementation of the FELIX SDN Experimental Facility	Fourth European Workshop on Software Defined Networks (EWSDN 2015)	Bilbao (Spain)
11-12 Jun. 2015	U. Toseef	Implementation of C-BAS: Certificate-based AAA for SDN Experimental Facilities	IEEE Fourth Symposium on Network Cloud Computing and Applications	Munich (DE)
1 Nov 2015	C. Fernandez	A recursive orchestration and control framework for large-scale, federated SDN experiments: the FELIX architecture and use cases	International Journal of Parallel, Emergent and Distributed Systems -- Smart Communications in Network Technologies	Bristol (UK)

Table 2.1: FELIX publication records

2.1.3 Open source code

The source code of the FELIX stack is offered through a public GitHub repository (`https://github.com/ict-felix/stack`), as described in D5.2. Developers have used a GitHub repository throughout the project to share the code of the FELIX testbed on a module-per-branch basis. The code is released mainly under Apache 2.0 for most FELIX developments (M/MS, M/RO, SERM, TNRM), yet some legacy modules and their extensions follow their own license; for instance the OFELIA Copyright affects CRM, Expedient and SDNRM; M/CBAS is released under EICT Copyright, and source code of third party libraries included within FELIX follow their own license.

During Y3 some actions were taken to improve the organisation of the code and the definition of the chosen license(s), the level of detail of the documentation, mostly user-oriented; and also increase the number of sources offered and the visibility of the project.

In this aspect, the license of the sources (i.e. each module) was agreed and clearly defined on a per-module basis at the root of the project. Also, some of the missing sources and their corresponding instructions were released in order to set up GRE-TNRM as well as GRE endpoints for GRE-TNRM. This is available under the "transit-network" module.

To better organise the code, we defined an automated task in the FELIX Jenkins that gathers the contributions pushed to the different branches into the "master" branch, which is directly visible by entering the FELIX GitHub site. Every time a developer pushes changes to a branch, the task will detect latest changes and merge them against the master branch; effectively providing the latest sources to the user on a first sight. This procedure has its drawbacks, though, as it requires trusting the proper functioning of the software modules after each change, and merge conflicts, yet rare, may still arise and have to be manually solved. In FELIX, each developer team is expected to test the proper functioning of their SW module before pushing, otherwise detecting and fixing as soon as possible. This automatic merge procedure provides more benefits for our project than performing a centralised manual code review and testing after each change.

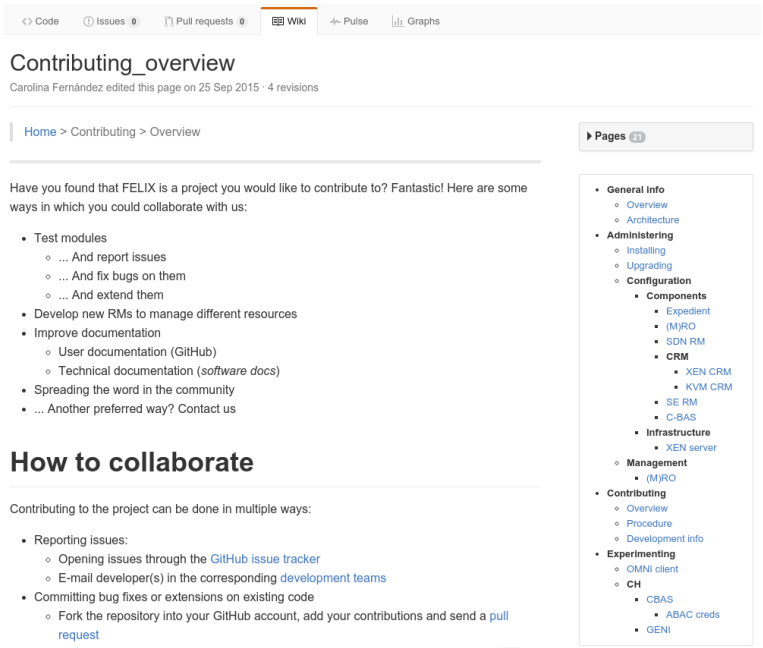

Figure 2.3: FELIX GitHub wiki page.

The wiki documentation has been extended during this last year to include new details on the installation and configurations (KVM-CRM, SERM) of modules, overview on the structure of the code, location of main functionalities and instructions on how to contribute to development, and usage instructions on the FELIX CBAS clearinghouse.

Lastly, we aimed to increase the visibility of the project by creating and migrating the content to a dedicated organisation in FELIX within GitHub (`https://github.com/ict-felix`). All the project-related sources will be exposed there and kept after the end of the project, namely the core software stack and the tools used for the different Use Cases. Other sources or community-driven developments can be added on demand to specific repositories under the FELIX umbrella.

To further support dissemination of FELIX Management Stack capabilities, a dedicated YouTube channel has been created containing video explanations for major use cases and software operations (`https://www.youtube.com/channel/UCDNESRfrC2G6JZP7_J4tVSA`).

2.1.4 Events

In Y3, the FELIX consortium continued active dissemination of project results and FELIX researchers participated in multiple global events. The second year was dedicated to promoting FELIX assets (topics, architecture, use-cases) in correlation with ongoing software developments and test-bed construction. The third year extended these efforts with live demonstrations and tutorial structured workshops to introduce the FELIX software stack to potential users and showcase FELIX capabilities.

The following table provides a list of events attended by FELIX members, outlining the activities performed during these events.

Event	Place	Date	Activity
TNC 2015	Porto (Portugal)	15-18 June 2015	Poster and demonstration
EUCNC 2015	Paris (France)	29 June - 2 July 2015	Booth and demonstration
EWSDN 2015	Bilbao (Spain)	30 September - 2 October 2015	Booth, poster, demonstration, and tutorial
SuperComputing 2015	Austin (US)	16-19 November 2015	Booth and demonstration
UCC 2015	Limassol (Cyprus)	7-10 December 2016	Demo paper and poster session
APAN 2016	Manila (Philippines)	25-28 January 2016	Tutorial workshop and demonstration
Net Futures 2016	Brussels (Belgium)	20-21 April 2016	Booth, posters, leaflets and demonstrations

Table 2.2: FELIX events.

FELIX Tutorial @EWSDN2015

An important and selling point of the whole FELIX project is related to the organization of the EWSDN 2015 conference, held from 30 September to 2 October 2015 in Bilbao, Spain. The European Workshop on Software Defined Networks (EWSDN) was considered by the FELIX project consortium as an extremely important opportunity for dissemination of the project results. This event gathered a large number of specialists and people from industry interested in the area of SDN and OpenFlow. The workshop audience was the main target group for the dissemination task. The FELIX project organized a special session (30 September at 9:00) titled: "Federated Facilities for Large-scale SDN Experiments" the purpose of which was to introduce audience to the FELIX project, starting with the motivation and challenges addressed, and delving into the salient technical aspects. It was jointly organized by Bartosz Belter (PSNC), Gino Carrozzo (Nextworks), Carolina Fernandez (i2CAT Foundation), Jason Haga (AIST), Kostas Pentikousis and Umar Toseef (EICT). This tutorial session was organized into two parts. The first part, targeted for developers of SDN testbeds, offered an introduction to the FELIX

project. The goal was to familiarize attendees with the modular architecture of FELIX with particular focus on the functionalities of the constituent software components, the exported interfaces, the dependencies and the relationship between the internal building blocks. Moreover, broadening the scope on open experimental research environment, an overview was given about Future Internet Research and Experimentation (FIRE) initiative in Europe, FELIX's position within FIRE and its collaboration with other FIRE projects. The second part was mainly targeted to engineers, advanced-degree students and researchers considered to be the potential FELIX testbed users. It provided a comprehensive user guide from creating a user account to setting-up and executing an experiment on the FELIX testbed. Furthermore, attendees were given an overview of the FELIX open-source Github repository and how they could contribute to it by joining the FELIX developers community. In addition, it was shown how following few easy steps they could setup their own testbed and federate with FELIX. In order to make the tutorial more interactive and enjoyable for the tutorial attendees, active Q&A participation was encouraged throughout the session. The session was complemented by a comprehensive demonstration scheduled to the second day of EWSDN 2015, including a use-case created over the FELIX infrastructure.

Figure 2.4: FELIX Tutorial at EWSDN 2015

FELIX Tutorial Workshop @41th APAN meeting

A important related opportunity gave the FELIX project more visibility in the Asia-Pacific region through the organization of a session at the 41st APAN meeting, held from 24-29 January 2016 in Manila, Philippines. This event was well attended with a diverse group of more than 40 people from Asia and the US. It was jointly organized by Takatoshi Ikeda (KDDI), Jin Tanaka (KDDI), Jason Haga (AIST), Atsuko Takefusa (AIST), and Tomohiro Kudo (AIST/Univ. of Tokyo). This tutorial introduced the FELIX project and its activities including technical aspects, instructions for creating a testbed and how to use it. The goal was similar to the EWSDN event and familiarized attendees with the modular architecture of FELIX, the functionalities of the software stack, the exported interfaces, the dependencies, and the relationship between internal modules. Active Q&A participation was encouraged throughout, and the session was complemented by several demonstrations, including the IaaS migration use-case created over the FELIX infrastructure.

2.1.5 FELIX in collaborations between EU and Japan

FELIX has continued participation to the Future Internet Research and Experimentation (FIRE) and EU-Japan coordination and concertation initiatives called by the European Commission also during Year 3. In particular, the two project coordinators (EU-side and JP-side) participated in various events to report on project progresses and key aspects of the international collaboration. FELIX has been explicitly mentioned in new FIRE+ workprogram

Figure 2.5: FELIX Tutorial at APAN meeting

by the EU as a result of the visibility and activity done in these concertation actions. PSNC has also represented FELIX in events between Poland and Japan governments.

2.1.6 Partnerships with other projects

During Year 3, a new liaison has been established with an external project interested in FELIX research and testbed. Thanks to the FELIX tutorial session hold at EWSDN 15 in Bilbao (ES) contacts have been established with the research team on SDN at Salzburg Research (AT), who is involved in the OPOSSUM project (Open Flow based system for multi Energy Domain, `http://www.salzburgresearch.at/en/projekt/opossum-2/`). OPOSSUM provides a Software-defined Networking infrastructure for multiple domains in a heterogeneous telecom infrastructure. With this respect OPOSSUM is very aligned to FELIX goals and potential FIRE services deriving from them. The common interest in joint activities between FELIX and OPOSSUM teams led to discussion on two potential roles of OPOSSUM developers:

- providers of additional testbed infrastructure to be integrated into FELIX orchestration
- act as additional users to validate FMS with FELIX use cases.

Time and resource constraints led to the decision/preference on the latter role (i.e. external users of FELIX FIRE). Researchers from OPOSSUM connected to FELIX testbed and experimented with the FMS and the infrastructure as described in D4.3. The OPOSSUM experiment will measure critical traffic re-route times over long-distance SDN network links in case of detection of the link failure. In order to perform this experiment, FELIX consortium offered access to FELIX islands in PSNC, iMinds and KDDI and opened to OPOSSUM researchers the capability to establish NSI links between those island for purpose of the experiment.

2.1.7 Posters

In Y1 and Y2, the posters focused on the overview of the FELIX project and detailed architecture. In Y3, the posters mainly provided the validation result of the use case. The posters were presented in several events.

1. High quality media streaming over long-distance network using FELIX experimental facility The poster for this use case was presented at TNC 2015 in Portugal on 15-18 June 2015, the International Conference on Utility and Cloud Computing (UCC 2015) in Cyprus on 7-10 December 2015 and the Net Futures 2016 event in Brussels on 20-21 April 2016.

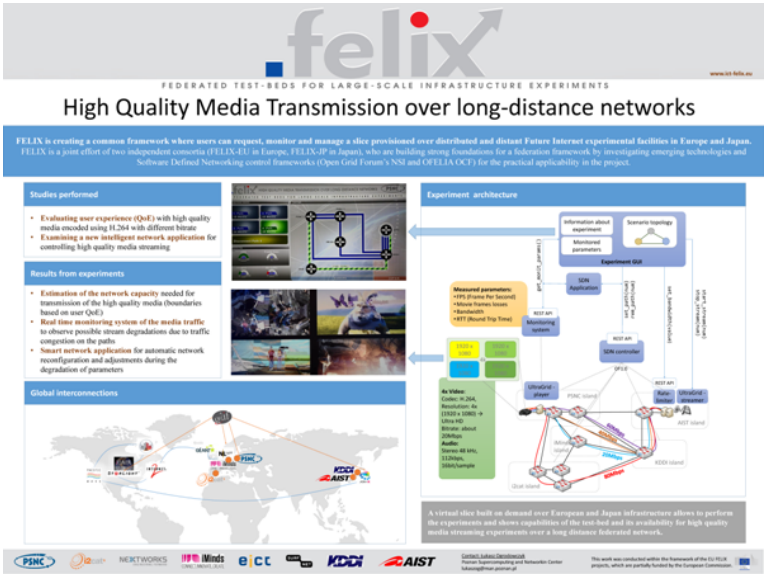

Figure 2.6: High quality media streaming over long-distance network

2. Iaas Migration The poster for this use case was presented at SC15 in U.S. on 16-19 November 2015, the UCC 2015 event and at Net Futures 2016 in Brussels on 20-21 April 2016.

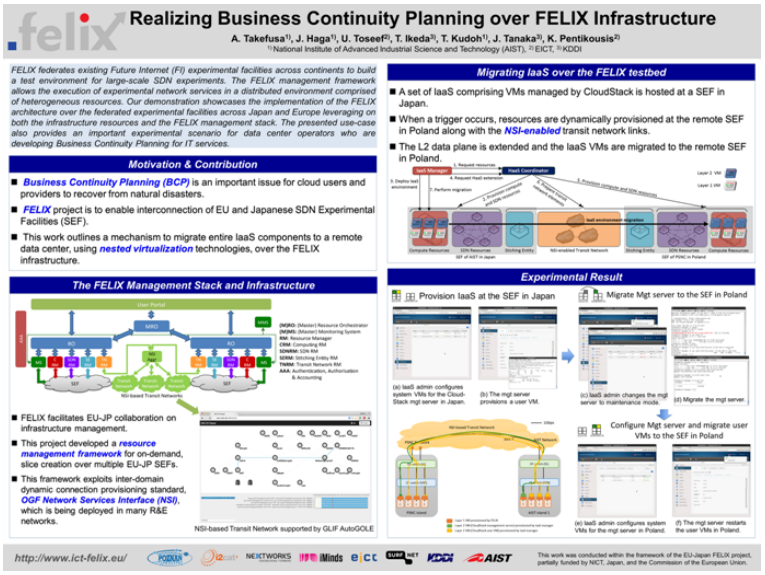

Figure 2.7: Realizing Business Continuity Planning with FELIX

3. Data Mobility Service The poster for this use case was presented at SC15 and Net Futures 2016.

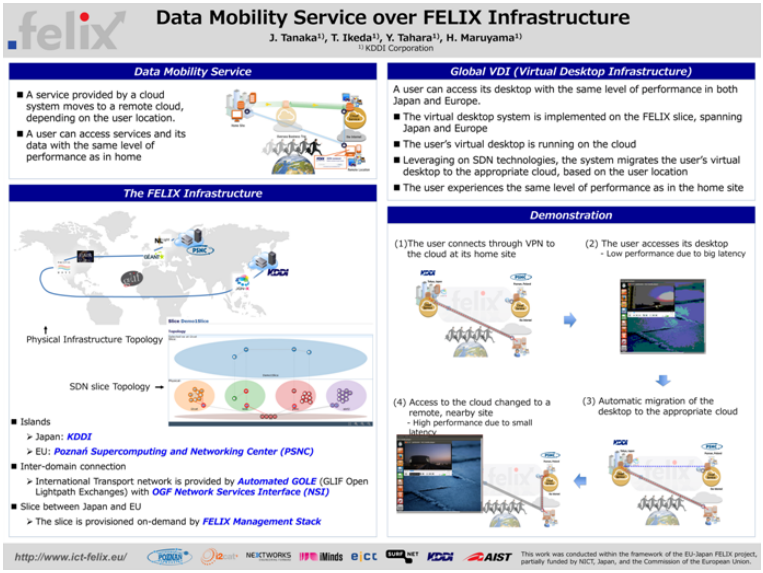

Figure 2.8: Data Mobility Service over FELIX Infrastructure

4. **Data Domain Use Case** The poster for this use case was presented at the Net Futures 2016 event.

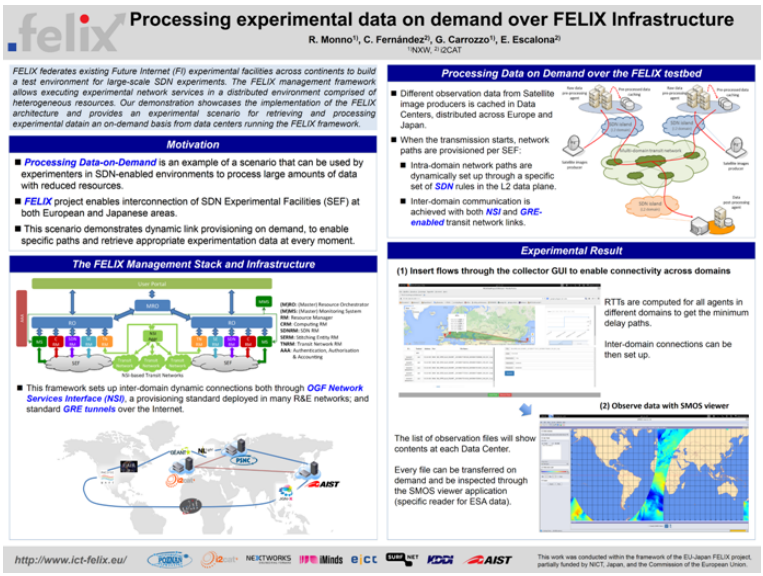

Figure 2.9: Processing experimental data on demand with FELIX

2.1.8 FELIX within FIRE

FELIX project was described in FIRE brochures for years 2014 and 2015 as presented in Figure 2.10 and Figure 2.11.

Net Futures 2016 conference was an important event on which FELIX project was exchanging experiences with other FIRE projects about building multi-site FI facilities. During this event, the FELIX team was visiting other FIRE projects exhibitions, advertising FELIX solutions for FI facilities federation with usage of GENI AM v3 API, leaving informational leaflets and asking to visit EU-Japan exhibition. On Figure 2.12, FELIX team within EU-Japan booth.

Figure 2.10: Felix in the FIRE brochure 2014

Figure 2.11: Felix in the FIRE brochure 2015

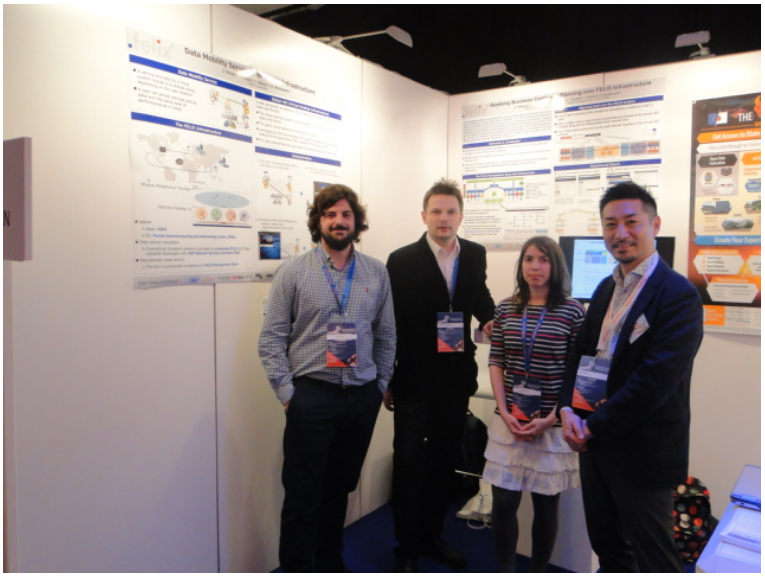

Figure 2.12: FELIX within many FIRE project on EU-Japan booth on NetFuture 2016

2.2 Internal networking

Internal communications among partners for design discussions and data collection continued also during Y3 with a central role continued to be played by the wiki platform. For other communications, weekly conference calls on Gotomeeting platform were done, complemented by intense mailing list traffic and skype live chat among developers for live joint works on testbed and use cases roll-out. Both wiki and mailing list are hosted and operated by PSNC on their servers. Services will remain accessible to FELIX partners for a minimum period of 6 months after the completion of the project.

2.2.1 Face to face and remote meetings

In order to coordinate the extension of the development activities in WP3 and the software implementation of the use cases in WP4, a face to face meeting has been organised during the Y3. Moreover, the second review meeting is also prepared to summarise the project status and the achieved progresses of the second year of the project.

In addition, the partners have actively participated to weekly conference calls though which it has been possible to coordinate the overall software development activities and monitor progress against planned deliverables and milestones.

The following table summarizes meetings organized during the third year of FELIX.

Meeting	Date	Venue	Purpose
Year 2 EC Technical Review and preparation Meeting	20-22 May 2015	Poznan, Poland, hosted by PSNC	Project review meeting
7th FELIX Technical Meeting: Use-Case consolidation	26-27 October 2015	Pisa, Italy, hosted by NXW	Use-cases implementation meeting

Table 2.3: FELIX project meetings.

2.2.1.1 Year 2 EC Technical Review and preparation Meeting

The 2th FELIX review meeting was held on 22 May 2015 in Poznan-Poland at PSNC premises. The meeting was organized to present the overall achievement of the project during the Y2, and particularly:

- Project Coordinator presented overall summary of the project status, details of the project management and progress reporting.
- WP Leaders presented changes in the FELIX architecture, software implementation and testbed setup progress and project promotion efforts.
- First live demonstrations of working functionalities of FELIX components were also presented.

All the partners were represented at the meeting and actively participated to discussions and sessions.

2.2.1.2 7th FELIX Meeting: Use-Case consolidation

The 7th FELIX meeting was held on 26-27 October 2015 in Pisa-IT at "Le Repubbliche Marinare" hotel. the meeting was mainly focused on development work and on interconnection problems between the islands that are part of the infrastructure for the use cases. In particular, the major objectives of the meeting have been to:

- Present actual state of work progress of software components implementations, FELIX testing environment setup and preparations for use cases implementation.
- Refine use case scenarios, discussing more sophisticated functionalities and modifications of the FELIX Management Stack components.
- Discuss about possible cooperation with OPOSSUM research team from Salzburg.
- Analysis of the perspectives and limitations of FELIX testbed maintenance after end of the project.

All the partners were represented at the meeting and actively participated to discussions and sessions.

3 Standardization

During the third year of the FELIX project under the leadership and active participation of AIST, NXW and EICT, FELIX has been contributing to various standardization platforms like OGF and IRTF. This includes text contributions, editorial responsibilities, discussion and participation in the mailing lists, teleconferences and physical meetings. It is important to note that the aforementioned contributions are both well-aligned and assisted towards final FELIX framework. In short, standardization actions and architecture specification moved forward in a coordinated fashion.

3.1 FELIX activities in OGF NSI WG

As in previous years, FELIX continued its presence and activity in the OGF NSI working group. This was achieved by FELIX's active use of the NSI-based transit network infrastructure operated by GLIF AutoGole task force. GLIF (www.glif.is) is the Global Lambda Integrated Facility, is an international consortium that promotes the paradigm of lambda networking. GLIF provides lambdas internationally as an integrated facility to support data-intensive scientific research, and supports middleware development for lambda networking. The GLIF participants are National Research and Education Networks (NRENs), consortia and institutions working with lambdas.

The GLIF AutoGole task force is actively working on the deployment of NSI and the results from operation experiments have been reported back to the OGF NSI WG. Some of the issues reported based on FELIX experiments included the importance of network/infrastructure monitoring, the importance of error code and error handling, and how to maintain the stability of service. These issues have been discussed both in AutoGole TF and OGF NSI-WG.

At GLIF 2015, September 28-30, 2015 in Prague, Czech Republic FELIX use of NSI was discussed. Further discussion was had at SC 2015 in the US. Based on FELIX experiences with NSI, an updated state machine was proposed and accepted for NSI Connection Service 2.1.

3.2 FELIX activities in IRTF NFV RG

The standardization work from FELIX partner during Y3 has also been target to IETF/IRTF, with activities mainly implemented by EICT and NXW.

The newly formed and definitely very active IRTF Network Function Virtualization Research Group was the main collector of FELIX contributions. Work consisted of:

- an initial Internet Draft entitled "Recursive orchestration of federated virtual network functions", draft-felix-nfvrg-recursive-orchestration-00, submitted for 93rd IETF/IRTF meeting in Prague (CZ) and discussed over the mailing list
- joint work between NXW, EICT and Ericsson (FP7 UNIFY Technical Manager) for a joint IRTF NFVRG draft on recursive orchestration challenges
- submission of a new IRTF NFVRG Internet Draft entitled "Network Function Virtualization: Resource Orchestration Challenges", draft-caszpe-nfvrg-orchestration-challenges-00, which was discussed by EICT at the 94th IETF/IRTF94 meeting in Yokohama (Japan)
- A subsequent flash update by NXW on this merged I-D for the IRTF NFVRG interim meeting in Heidelberg (DE) 2/Dec/2015

FELIX testbed has also been presented to the IRFT SDN RG community through a presentation “Framework for large scale-SDN experiments", discussed at 93rd IETF/IRTF meeting in Prague (CZ), 20-July-2015

These activities, and in particular the one on NFVRG, have potential to continue beyond FELIX, because they evolved during Year 3 in a way which was aligned to the various groups agendas.

4 Impact Evaluation

This section summarises the key points and the most valuable aspects of the software developed during the FELIX project life-cycle. In particular, we present the added value of the FELIX Management Stack and its modules and applications. We detail also the particularities of the FELIX use cases as demonstrated during some events and conferences. Particular attention has been paid on the FIRE community to guarantee the federation of the FELIX infrastructure within the other projects or activities in the same area. The last part of this section is completely focused on the exploitation plans of each partner of the project.

4.1 FELIX and FIRE/FIRE+

4.1.1 Usage of jFED GUI in FELIX

FELIX has been using jFED as the simplest way to validate new RSpec specifictions (RSpec in FELIX were mostly prepared by hand) and activate slice over FELIX resources using prepared RSpec specifications(see Figure 4.1).

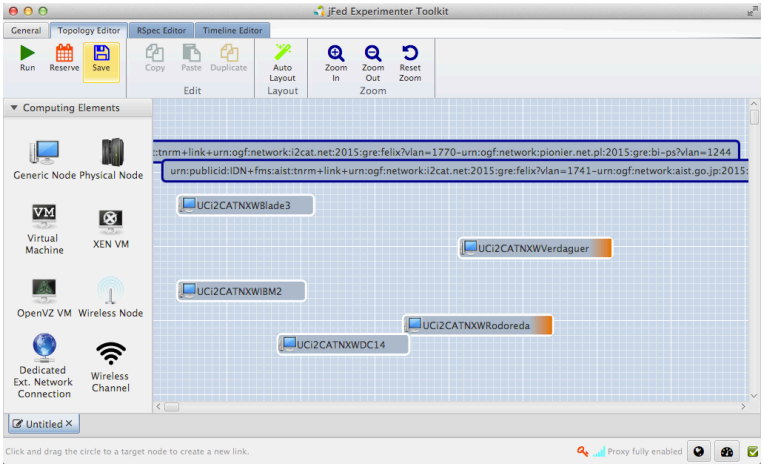

Figure 4.1: jFed used for setting FELIX Use Case slice

4.1.2 Usage of FELIX TNRM component in Fed4Fire Open Call

PSNC prepared a project proposal named "Dynamic allocation of backbone optical channels in emergency deployment of wireless-enabled robotic swarms" for the 5th Fed4Fire Open Call for experiments. In this proposal, a set of robots within the w.iLab-t testbed (iMinds) will be used to simulate the wireless networking communication of robots within a swarm, and connecting it to a simulated Disaster Operational Center (DOC) located within PL-LAB2020 (PSNC). The connection between the swarm and DOC will be done through a backbone network. For this purpose, Transport Network Resource Manager (TNRM), developed in FELIX and deployed within the Fed4Fire federation will be used. The TNRM will be responsible for the dynamic creation of high-bandwidth connections using the GÉANT Bandwidth-on-Demand infrastructure. The overview of the project is presented in Figure 4.2. The goal of the experiment is to verify the effectiveness and usability of this newly developed TNRM for dynamic and on-demand provision of infrastructure capable for transporting video streaming from the robot swarm to DOC, with a possible use of cloud services for the real-time video analysis. Furthermore, we will evaluate the parameters such as time required to dynamically increase the channel allocated for the emergency scenario (i.e. in a situation when the given emergency situation required deployment of further robotic unit into the swarm). In this project, Felix C-BAS component will be also used as Clearing-House for certificates. PSNC proposition of the project was finally accepted and work started in March 2016. Final result of the project must

be delivered to Fed4Fire consortium till September 2016. Depending on results of this project and interest from other Fed4Fire partners and users, PSNC could start providing the connectivity service offered by GENI-compliant TNRM service as production-level service and offered to other interested users. In this case, PSNC will also enable SERM component for Fed4Fire environment, which will provide more flexibility and decoupling of transport VLANs and experimenters VLANs.

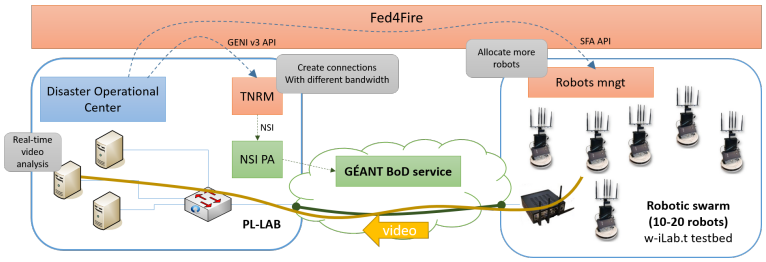

Figure 4.2: Overview of Fed4Fire Open Call project using TNRM module

4.1.3 Usage of FELIX TNRM, SERM and C-BASE components in PL-LAB2020 for next FIRE (Fed4Fire follow ups) activities

PL-LAB2020 provides an access to distributed laboratory, spread around Poland and interconnecting major academia institutions and offering variety of equipment with different functionalities at a large scale. PL-LAB2020 is composed of many Future Internet facilities (wireless networks, network virtualization and management, information centric networks, IoT and Clouds) located in Poland and interconnected by PIONIER network operated by PSNC. PL-LAB2020 is part of Fed4Fire community and GENI AM API can be used to request resources within PL-LAB2020. PL-LAB2020 is also using VLAN tags are techniques to distinguish virtual infrastructures for different experiments. This makes SERM and TNRM functionalities corresponding to PL-LAB2020 environment. PSNC is planning to use SERM and TNRM as a mechanism to interconnect any FI facility within Poland to any facility outside of Poland:

- Facilities connected to GÉANT/GLIF network by NSI service or L2 static links (or GRE tunnels during GÉANT/GLIF services downtime or lack of free bandwidth)
- Facilities not connected to GÉANT/GLIF network by Internet GRE tunnels (the remote facility will be requested to install just OVS and Ryu software).

C-BAS component will be also used as supporting software required for handling AAA issues as expected by Fed4Fire environment and its users.

4.1.4 Advertisement of FELIX TNRM and SERM components for other FIRE facilities

FIRE project very frequently must solve problems on interconnecting facilities provided by different project partners. Example of such projects are FLEX [**?**] and SMARTFIRE [**?**] projects which solved this issue establishing static connections using Internet tunnels or GÉANT static vlans. FELIX members will be monitoring new FIRE project and advertise FELIX components during any kind of meetings to those project which will challenge such interconnecting issues.

4.1.5 Looking for researchers interested in OpenFlow/Cloud experiments

FELIX members will be looking (during conferences, workshops, other project meetings) for network/cloud/5G researchers interested in performing OpenFlow experiments. Researches that will be interested in usage of op-

erational OpenFlow-based FELIX testbeds (also PL-LAB2020 and other FIRE+ facilities optionally) will be granted access and supported in slice creation over operational part of FELIX infrastructure.

4.2 Impact of FELIX use cases

From the beginning of the FELIX project it is been clear that one of the main outcomes would be the Use Case execution and that would be the summary of all the objectives previously planned for the project. At this point, close to the project ending we are satisfied reaching that big objective with 3 different use cases that demonstrate how all the work before is validated in different areas and more important we have been able to draw attention and interest from different external projects.

Use Cases have demonstrated that our approach to reduce the complexity of working and experimenting in a heterogeneous environment and solving the problem of the inter-domain connectivity is on the right way, and ready for a level up. That new step will be conducted by the upcoming projects that saw on the FELIX Use Cases and example of the problems already solved and learn from our experience to improve the path that the project opened. Otherwise, opening alone the developed software without giving a clue of what is possible to afford and how flexible can be would not have the desired impact and visibility among external projects and potential users.

A total of 3 Use Cases have been executed with different scopes in mind to show most of the capabilities that the FELIX framework have to offer:

- High Quality Media Transmission over long-distances network:

A Provider is interested in running a service between Europe and Japan. Would like to rent the network from commercial providers and assumes multiple streams running in parallel on top of existing infrastructures so he/she plans to examine long distance network capabilities for media streaming. The Provider would also like to test an application for an intelligent network adjustment with end-to-end performance over the network infrastructure during multiple streams transmissions.

- Infrastructure Domain:

FELIX allows the business/operators to test migration of applications and data and how to optimize their performance. They can also optimize various parameters that affect the migration, such as size of the data/applications to be migrated, network bandwidth required for the migration, re-establishment of services, overall time required to migrate and resume service.

- Data Pre-Processing on Demand:

This use case shows the satellite images which are generated by the ESA Earth portal. The huge flow of data can be processed in a data centre close to the producer and then compressed with proper algorithms. In other words, the traffic load that the transit network should support has enormously decreased. In this context, the FELIX framework can reserve the computing resources at the source and destinations islands and can schedule the configuration of the network paths on demand allowing the experimenters to choose the minimum required bandwidth or the maximum guaranteed delay.

A detailed description of each use case can be found on the deliverable D4.2 and D4.3. Also we have published several videos of the execution of the Use Cases on the FELIX youtube channel.

Results from the implementation of the FELIX Use Cases were useful for NSI community and their development team. During the FELIX experiments, we collected some performance measures that may be reused in the future publications or during next experiments. Also, some additional software components were developed and they are available on the public FELIX GitHub account under their respective repositories.

During the execution of the Use Case validation phase, a external project interested in the FELIX infrastructure and approach also started the execution of they own Use Case: OPPOSUM that will be finished after this report was submitted. As mentioned before, without the Use Cases executed this last example would not be possible as we gained the expertise an experience to help and that is the real value.

4.3 Impact of FELIX software

A FELIX test-bed requires multiple elements interconnected. Some of them are borrowed from previous projects or shared between different projects. To assess the value provided by the FELIX software, we refer to the software modules developed within the lifetime of the project or introduced from scratch.

In this aspect, we believe that FELIX can provide some specific value to the FIRE ecosystem:

Multiple (recursive) layers on top of the RMs

The introduction of RO and MRO provide a number of extra layers on top of the genuinely distributed SFA architecture. This layer on top has been used in FELIX to i) aggregate information intended for or received from the lower layers and use it for global monitoring purposes and decisions on the orchestration on lower layers, ii) control access to the RMs within an island by means of deploying trusted certificates at the level of RO and MRO, and iii) define policies based on the user or client's request and on the credentials provided.

Dynamic provisioning of high-bandwidth network over NSI-based R&E networks

NSI-TNRM was deployed in FELIX to provide inter-domain connectivity for bandwidth demanding experiments. We believe this is one of the key added values in the FELIX project. However, access to the NSI data plane may not be available to every domain, nor it is more reliable than a standard connection over the Internet. Because of this, and due to previous recommendations, GRE-TNRM was developed to create GRE tunnels on demand across islands with proper configuration (i.e. registered its GRE endpoints in the GRE-TNRM). This extension complements the inter-domain connectivity with two different kinds of connections.

Related to the inter-domain connection set-up is the SERM, whose added value is to fully abstract the stitching or inter-connection of the SDN plane with the TN plane. This achieves an easier usage by the user who prefers a simpler scenario; though it remains possible to explicitly define the low-level details for scenarios that require full control.

Incorporated management for certificate issuing and revocation

The M/CBAS clearinghouse module is integrated with FELIX following a structure similar to M/RO or M/MS; allowing distributed management of credentials on a per-island basis by each CBAS and centralising them in the master layer, MCBAS. The inter-operation between the CBAS and MCBAS allows to renew or revocate certificates as required and distribute them across the connected clearinghouses. Such behaviour ensures a consistent access control across the FELIX test-beds.

Easy integration with other FIRE test-beds

A considerable effort was set into the development and improvement of GENIv3-capable APIs, which is the standard at the moment for inter-federation between experimental test-beds. For new parties interested in offering their platforms within a FIRE federation, it is possible to reuse the northbound API and only develop the internal management of their resources. The language used in this APIs (Python) provides a number of bindings with other languages such as Java, which can reduce the development effort.

It is important to highlight also the sustainability aspects of a FELIX testbed. Different types of costs incur for the construction, operations and maintenance of a SDN testbed similar to FELIX:

- Infrastructures require continuous funding to be available over long terms (OPEX)
- Infrastructures (hardware) require continuous update over time (CAPEX)

Typically, these costs are covered via own investments and public funding (e.g. H2020, National/Regional programmes, etc.), and very rarely evolved towards a pay-per-use model fo rexperimenters, who should be “invoiced” for the usage of infrastructures. Sustainability of FIRE infrastructures over the long term would need to be based on external funds incoming to cover expenses, but in reality

- FIRE/FIRE+ experimenters seem not keen to pay for access to infrastructure
- Law restrictions in some countries limit the commercialization of FIRE (e.g. infrastructures built from public funds cannot be offered as paid service on the market)

As such, it seems that sustainability of FELIX infrastructure is bound to the continuation of consortium cooperations for new co-funded projects through which evolve and maintain FELIX infrastructures and services.

4.4 Partner Exploitation plans

The FELIXManagement Stack is definitely the core joint exploitation item of the project, together with its set of auxiliary tools to implement the use cases of the project.

The joint exploitation of the FMS will leverage on two main pillars:

- *Open source community*. The FSM will continue to be open source and hosted on GitHub to progress via community efforts its functionalities.
- *Standardization*. The FELIX concept of recursive orchestration well applies to the areas of NFV resource policy which are in scope of the activities of teh IRTF NFVRG for potential standardization. Similarly, the concept of slicing and resource abstraction developed in FELIX can be new stimulus to progress and evolve OGF NSI specification.

Obviously, the maintenance of FELIX testbeds and inter-domain links, e.g. for demonstrations in public events,can further support exploitation actions on software,being them the main channel through which capturing community interest.

PSNC

PSNC is willing to use TNRM and SERM FELIX software components in Poland's PL-LAB2020 distributed laboratory for new FIRE/FIRE+ activities in order to interconnect any PL-LAB2020 facility to any FIRE facility outside of Poland:

- Facilities connected to GÉANT/GLIF network by NSI service or L2 static links (or GRE tunnels during GÉANT/GLIF services downtime or lack of free bandwidth)
- Facilities not connected to GÉANT/GLIF network by Internet GRE tunnels (the remote facility will be requested to install just OVS and Ryu software).

One of FIRE activity is just started Fed4Fire Open Call named "Dynamic allocation of backbone optical channels in emergency deployment of wireless-enabled robotic swarms" in which TNRM component deployed in PSNC part of PL-LAB2020 will allow for on-demand interconnection of Disaster Operational Center interconnected to PL-LAB2020 in PSNC with w.iLab-t testbed containing remotely controllable robots (iMinds).

NXW

NXW will mainly exploit the FELIX architecture and in particular the concepts of recursive resource orchestration. NXW will try to apply the M-RO approach in NFV contexts, where the company has developed a Virtual CPE prototype and is working on NFV Management and Orchestration tools for multi-tenant networks. The FELIX M-RO with its concepts of slicing and resource policy can be used to build a NFV orchestrator to be deployed at various layers of the MANO, in parent-child mode.

NXW will also take advantage of the scientific and inter-continental dimension of the project, made of outstanding and renowned network researchers. Through FELIX NXW has increased its visibility in the wider research community active on Future Internet and SDN, thus opening further business opportunities for specialized training on SDN tools to vendors, system integrators and network operators/IT departments of government agencies (e.g. ESA).

i2CAT

i2CAT will exploit key assets provided by FELIX through its software stack and tools developed, in order to enhance i2CAT experimental test-bed; used for FIRE+ environments as well as SDN and 5G related research projects. Specifically, i2CAT is willing to further use the different types of interconnection implemented during the project (NSI, easy set up of GRE tunnels between domains and static VLANs between i2CAT and other infrastructures through GÉANT network), the extended federation features added on the OFELIA Control Framework and the intelligent network mapper developed within the orchestrator.

The technical knowledge acquired during the development and deployment on the stack, along with the observation on both physical and software limitations (both from internal deployment of the Use Cases and external feedback) will be taken into account for improvements; i.e. the upgrade of firmware and software layers in devices and the replacement of software with up-to-date tools offering more capabilities. All of this will be required for future added value and sustainability of the experimental infrastructure. Finally, the outreach through dissemination events within the project will be leveraged in the future for related research in fields of SDN, NFV or 5G.

EICT

The strategy of EICT with regards to Future Internet Experimentation is to exploit developed FELIX facilities within a number of surrounding and contributing projects. The recently started COHERENT project is contributing to 5G architecture that substantially exploits SDN technologies. Being a consortium member, EICT will be offering support to COHERENT project members in conducting SDN experiments on FELIX infrastructure. Moreover, CBAS software developed during the FELIX project is seen to have new usability horizons in NFV context, e.g. its usage within currently running UNIFY project that deals with service chaining.

iMINDS

iMinds is an independent research institute focusing on creating economic and social value through excellent research and creation of human capital in the ICT domain. Participation in the FELIX project will allow iMinds to extend its expertise in SDN research and facilities and its experience in federating testbeds, gained from its involvement in OFELIA, Fed4FIRE and other projects. The effort and cooperation resulting from the FELIX project will strengthen the international position of iMinds in the field of experimentally driven research. Additionally, the research is fully embedded in Flemish universities, leading to an efficient exploitation of knowledge. Lessons learned in this facility project, and the availability of the FELIX framework and facilities will be very beneficial to advanced courses in engineering as well as PhD programs. Also different developed modules within the FELIX project will be used to extend new funcionalities of current projects like Fed4FIRE and as an asset to continue working with new projects on the topic. The participating iMinds group (IBCN) is part of Ghent University and is responsible for the Bachelor and Master courses on distributed software and telecommunication networks, organizing lab sessions through which this knowledge can be transferred.

Acronyms

AAA Authentication, Authorization and Accounting

AM Aggregate Managers

APAN Asia Pacific Advanced Network

API Application Programming Interface

C RM Compute and storage Resource Manager

DWDM Dense Wavelength Division Multiplexing

ETSI European Telecommunications Standards Institute

EWSDN European Workshop on Software Defined Networks

f2f face to face

FIA Future Internet Assembly

FIBRE Future Internet Testbeds Experimentation between Brazil and Europe

FIRE Future Internet Research & Experimentation

GENI Global Environment for Network Innovations

GLIF Global Lambda Integrated Facility

HaaS Hardware as a Service

I2RS Interface to the Routing System

IEICE Institute of Electronics, Information and Communication Engineers

IETF Internet Engineering Task Force

IPOP International Conference on IP + Optical Network

IRTF Internet Research Task Force

ITRC JSPS 163rd Committee on Internet Technology

JSPS Japan Society for the Promotion of Science

NML Network Mark-up Language

NREN National Research and Education Network

NSI Network Services Interface

NSI CS NSI Connection Service

OCF OFELIA Control Framework

OF OpenFlow

OFELIA OpenFlow in Europe: Linking Infrastructure and Applications

OGF Open Grid Forum

QoE Quality of Experience

RM Resource Manager

RO Resource Orchestrator

SDN Software Defined Networking

SDO Standards Developing Organization

TERENA Trans-European Research and Education Networking Association

TN RM Transit Network Resource Manager