Journal of Applied Computing Research, 3(2):87-102
July-December 2013

Adding value to Future Internet Experimental Facilities: Challenges, requirements and recommendations

Alessandro Santiago dos Santos, Mario Yoshikazu Miyake
Instituto de Pesquisas Tecnológicas do Estado de São Paulo. Av. Prof. Almeida Prado, 532, Cidade Universitária, 05508-901, São Paulo, SP, Brasil
alesan@ipt.br, mymiyake@ipt.br

Franck Le Gall, Marianne Baumberger
Inno Group TSD. Place Joseph Bermond, Ophira 1, BP 63 06902, Sophia, Antipolis, France
f.le-gall@eglobalmark.com, m.baumberger@inno-group.com

Rao Sathya, Phillipe Cousin, Jorgen Friis
Intitut Europeen Des Normes de Telecommunication. 650, Route des Lucioles, 06921, Sophia Antipolis, France
rao@telscom.ch, philippe.cousin@eglobalmark.com, jorgen.friis@etsi.org

Alain Vouffo
Fraunhofer Institute for Open Communication Systems. Kaiserin-Augusta-Allee, 31 10589, Berlin, Germany
vouffo.alain@gmail.com

Philip Inglesant
Institute for the Study of Science, Technology and Innovation. Old Surgeons' Hall, High School Yards, The University of Edinburgh, Edinburgh EH1 1LZ, UK
p.inglesant@ed.ac.uk

Paventhan Arumugam
ERNET India. 397, 13th Cross, Sadhashiv Nagar, Bangalore, 560080, India
paventhan@eis.ernet.in

Abstract. MyFIRE, a support action project under the FIRE initiative funded by the EU, was designed to identify best practices, gaps and future challenges for the FIRE Future Internet Experimental Facilities-EFs. Building on these gaps, recommendations are made on how EFs may reach a broader user community, expanding the present internal research community to outside researchers and business communities. The gaps and challenges were elaborated based on the return drawn from a large survey with international stakeholders, on interviews with key personnel from different areas of expertise, on documents provided by Future Internet projects in the European Community, and on especially organized MyFIRE seminars. The study addresses users' and providers' requirements from EFs, public policy in R&D&I, standardization needs and business models for sustainability of the EFs beyond their initial public funding period. In addition, this paper recommends approaches to add value to Future Internet EFs. As a support action project, MyFIRE was not intended as a research project. Therefore, no scientific contribution was expected as an outcome of the project. MyFIRE contribution was to establish a realistic assessment of Fire Experimental Facilities-EFs prospects beyond initial public funding.

Keywords: future internet, experimental facility, FIRE, MyFIRE, testbed.

Introduction

Faced with new challenges and concerns with the evolution and adaptability of the Future Internet, global initiatives are being conducted to study new architectures and technologies, mostly in the United States, Europe and Japan, using evolutionary and revolutionary approaches (Stanton, 2011).

Future Internet Research Experiments (FIRE) initiative in the European FP7 research framework is a unique program allowing the research community to validate future Internet technologies and applications through experiments. A number of testbeds or Experimental Facilities-EFs addressing different challenges have been deployed and are operational (Zahariadis *et al.*, 2011). The European research community is engaged in experiments related with future scenarios involving societal needs, technologies and applications towards innovative products and services to develop the inclusive information society of the future and to ensure European competitiveness in the future Internet.

With a strong network focus, *the first wave* of FIRE projects was launched in 2008, with a budget of 40 million Euros. In 2010, *a second wave* of projects with a budget of 50 million Euros has significantly expanded the scope of FIRE, moving it in new directions taking on technologies such as sensor networks, clouds and also high level service architectures. *A third wave* of Integrated Projects and a Network of Excellence in Internet Science were launched in 2011 (CORDIS, 2014).

FIRE projects, in totality, represent the experimental facilities. Figure 1 provides an overview of ongoing projects and the areas broadly covered by these projects. The support projects, shown in the middle of the figure (MyFIRE included), coordinate different activities of experimental facilities across the facility providers, user community and policy makers and act as facilitators for successful communication and cooperation (Firestation Group, 2009).

More mature testbeds may also involve open calls to include new partners who will propose more innovative real life scenario experiments through partial funding.

There are 13 Integrated projects funded, each of them addressing major challenges such as cognitive mechanisms, wireless technology, new protocols, Internet of things, clouds, content centric networking etc.

Sixteen STREP projects, funded with well-defined topics to be experimented with, are considered as proof-of-concept experiments.

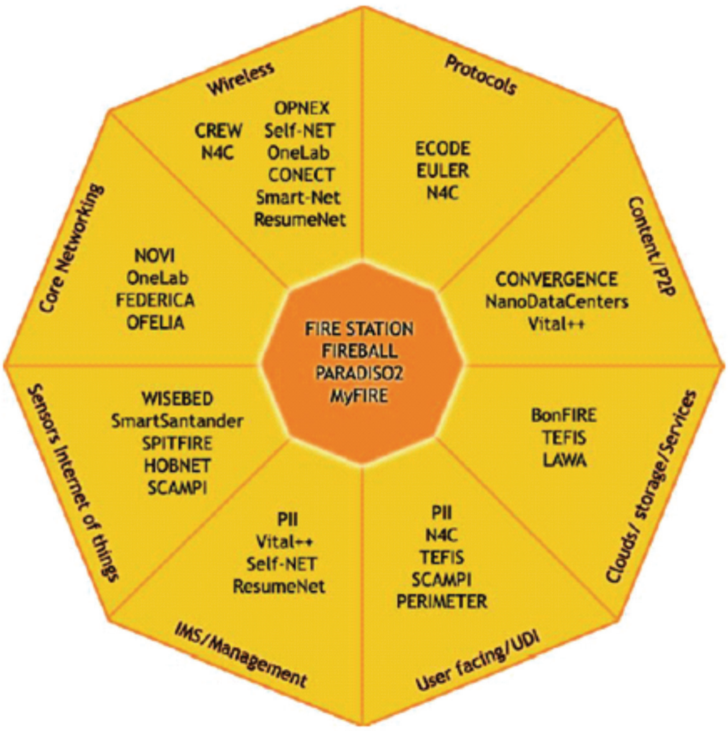

Figure 1. Fire technical testbeds and coordination and support projects.

Each of them is used by the consortium partners to test the projects pre-defined technical concepts. In general, these projects are not accessible by external partners, though, in principle, it is possible to do experiments if the project consortium accepts the proposal, when it is well targeted with the configured testbed scenarios.

One of the main ideas behind FIRE is to share the best practices and methodologies among projects and the research communities, to avoid duplication of work by working across the projects.

Federation of testbeds for user driven innovative experiments is another major attraction to the research community, since the FIRE experimental facilities provide access, as a whole and separately, to many more underlying testbeds. Federation may take the form of a common interface to multiple underlying testbeds that can offer, for example, the possibility of experimenting on multi-site virtualisation in the context of quality of service on Cloud computing platforms. This common interface can consist of a portal for registration and for running experiments.

Other aspects that would be important in developing effective FIRE are:

- standards development as a route to innovation, including APIs front-ends to enable unified access to multiple testbeds;
- testing of conformance to standards; and
- the use of standardised testing methodologies and benchmarking.

The various international Internet standards-setting organizations, such as IETF, W3C, and ITU, take different approaches and have different conditions of entry, but in general are quite open. It is also important to develop specifications from the industry point of view outside these organizations when necessary. It is important that the research community actively participate in developing interoperable standards and specifications, so that more innovations can be tested by the use of experimental facilities provided by FIRE.

One major concern from the European Community with respect to testbeds deployed under FIRE and other FP7 calls is related with their sustainability thereafter. The user communities must be enlarged, attracting researchers outside initial participants, including firms interested in test and deployment of innovative applications on Future Internet.

Ultimately, the aim is to make FIRE evolve into "*a sustainable, dynamic, and integrated large scale experimental facility supporting academia, research centres and industry*" and to move towards a unified federation of Future Internet experimental facilities in Europe. This would facilitate building the capacity of testbeds - in human expertise as well as technology – which is in itself an important contribution to innovation arising from the FIRE programme.

The objective of this paper is to present the main findings of the MyFIRE Support Action project (MyFIRE, 2010), funded under the FIRE initiative. The authors of this paper, as members of the MyFIRE project team, studied the portfolio of all FIRE projects to identify the strengths and weaknesses of ongoing testbed projects in relation with innovation, sustainability and standardization aspects.

As a support action project, MyFIRE was not intended as a research project. Therefore, no scientific contribution was expected as outcome of the project.

MyFIRE contribution was to establish a realistic assessment of Fire Experimental Facilities-EFs prospects beyond initial public funding.

To complement the study on European projects, considerations are made on the situation of similar initiatives on Future Internet in the BRIC countries.

Section "MyFIRE project" presents project objectives and methodologies.

Section "Challenges on Future Internet Testbeds" presents main findings of the MyFIRE project on challenges faced by Future Internet EFs.

Section "Recommendations and way forward" presents the view of MyFIRE project members regarding future sustainability, standardization and innovation issues for EFs.

Final Section presents conclusions.

MyFIRE project

MyFIRE was launched through the EU 7th framework Programme, under the ICT thematic priority theme "Future Internet experimental facility and experimentally-driven research". The goal of the project was to increase the benefits of Experimentation in the field of Future Internet Research by: improving the functionality of experimentation, stimulating the use of experimentation and understanding the expected outcomes.

The project had three main topics:

- Research and technology, by identifying the real needs from the researchers and

industry communities to use experimental facilities in the future;
- Standardisation, by identifying standardised methodologies and approaches supporting testbeds users to promote innovation and leverage the research results;
- Innovation process and social and economic impacts, by identifying economic costs and benefits, results of using the testbeds for validating research results, and requirements of business models applied to testbeds.

The MyFIRE project paid special attention to the development of international cooperation with other initiatives similar to FIRE, especially in the four BRIC partner countries of the MyFIRE consortium.

The MyFIRE project methodology, summarized in Figure 2, was based on a broad survey applied to Future Internet stakeholders (Santiago *et al.*, 2011), interviews with key personnel from different areas of expertise, FIRE projects documentation analysis, and on especially organized seminars.

Broad survey

To identify the real needs and expectations from main stakeholders of Future Internet projects, an extensive questionnaire was designed and applied to an audience including EFs internal users, EFs providers, potential external users, policy makers and influential personalities identified by MyFIRE project participants, including some from BRIC countries.

The purpose of the survey was to identify the existing gaps between offer and demand of services in ongoing FIRE testbeds.

The survey, conducted via web by MyFIRE project team members, was designed to collect quantitative data on several aspects related to Future Internet.

The web survey questionnaire was distributed to a large number of people involved in ICT research (5.142 contacts), especially to those who use or possess an experimental research facility.

The questionnaire posed questions on technologies involved, proprietary/standard protocols adopted, services/applications offered, testing taxonomy and approaches used, and open questions on services offered, approaches on federation and testbed openness.

The MyFIRE project distributed the survey to representatives from various geographical areas, especially in European and BRIC countries. From a total of 439 returned questionnaires, 301 were considered valid. The profile of respondents included 44% from academic Institutions, 24% from private commercial organizations, 18% from public organizations, and 14% from other origins. Figure 3 presents the geographic distribution of survey respondents. More details are in (Santiago *et al.*, 2011).

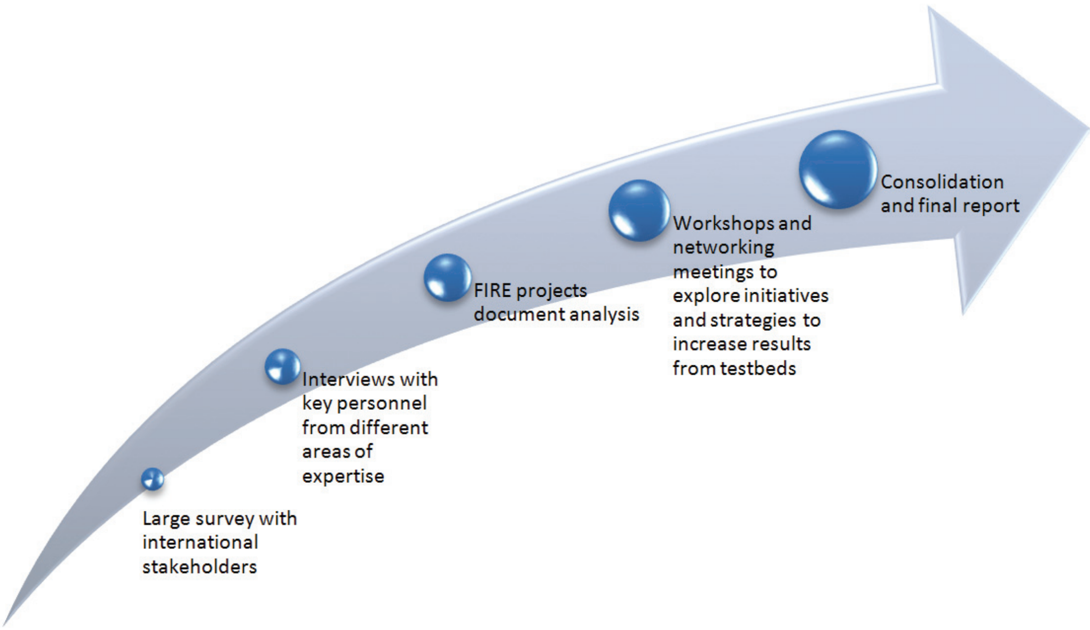

Figure 2. Evaluation Methodology.

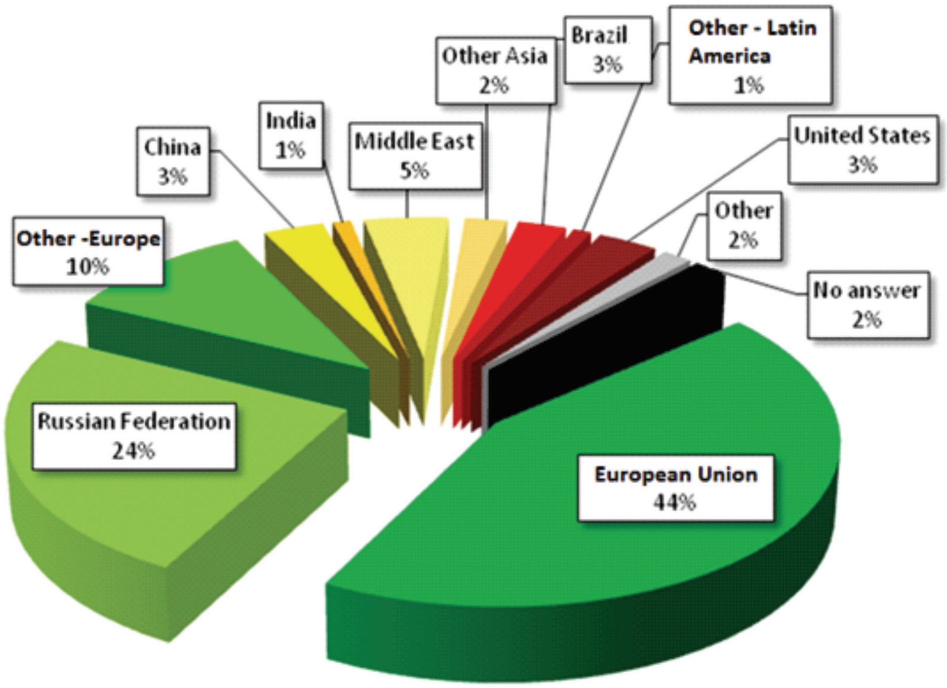

Figure 3. Worldwide distribution of survey respondents.

Interviews with FI researchers

Interviews served two different purposes:

(i) Contribute to the MyFIRE analysis being made to better understand processes related to Future Internet Experimentation approach, with the perspective of improving the operational and exploitation processes of Experimental Facilities (EF). Particular attention was paid to sustainability issues so as to contribute to the FIRE architecture board working group on sustainability issues.

(ii) MyFIRE coordinated the FISA (Future Internet Support Actions) working group on standardisation and was in charge of the FIRE architecture board working group on standardisation. As such it had to collect the wishes and needs of FIRE projects regarding standardisation and to put in place coordinated actions.

The following profiles were targeted for the persons interviewed:

- **Experimental Facility owners**: persons/organisations managing an experimental facility.
- **Experimental Facility users** (research/academics, industry, projects): they can be representative of organisations or projects making use of experimental facilities.
- **Policy makers (public authorities)**: the ones who define policies related to Future Internet research or regional development.
- **Decision makers (operational level)**: the ones who decide, within an organisation, the set-up of an experimental facility.
- **Funders**: the ones who provide funds supporting the set-up and operation of experimental facilities.

MyFIRE members conducted more than 40 interviews with specialists from Future Internet Research community.

Workshops and FIRE projects documentation analysis

The FIRE projects documentation analysis was used to complement online survey and interviews. After all findings were organized, workshops were conducted in Europe and in BRIC countries to validate them and consolidate the results. The MyFIRE project organized six international workshops: Spain, India, Brazil, China, Poland, and Russia.

Based on findings of the MyFIRE project, it was possible to identify challenges, requirements, and gaps, and, finally, recommendations.

Challenges on Future Internet Testbeds

The Challenges on Future Internet Testbeds are based on requirements from facility providers, users and policy makers. Furthermore, there are gaps EFs have to overcome if they want to enlarge their audience and guarantee their continuity (MyFIRE, 2012a).

Requirements

The requirements analysis was done from the perspective of facility providers, users and policy makers. Furthermore, the Federation and Standardization requirements are presented.

Facility provider perspective

The experimentation infrastructure represents the container in which previously defined experiments will be deployed and executed to assess certain aspects of the technology involved or of an implementation thereof. Some key questions arise whenever someone wishes to use or to extend a given experimentation facility, leading to a corresponding set of requirements.

The testbed should provide technological transparency to the research user community to assess whether the facility is suitable for the quick deployment of the planned experiment, and how to run it, if the facility was found to be appropriate. Information should be provided on technology(ies) targeted by the infrastructure, the kind of experiments supported by the infrastructure, the topology of the infrastructure and its scale, the mechanisms it provides for setting up and controlling experiments, the mechanisms provided by the facility to support interconnectivity with other testbeds (e.g. to create larger scale testbeds) and to what extent interoperability with other facilities is ensured.

Security is another critical requirement regarding confidentiality of the experiments and achieved results. Security aims at ensuring confidentiality, integrity and accessibility (CIA) not just of the testbeds, but also for the data they host. This is particularly relevant for allowing large-scale experiments based on federation of testbeds, potentially involving various vendors.

Interconnectivity and interoperability issues are crucial while offering federated testbeds, so that experiments can be set up by using standard APIs, data exchange formats, protocols etc. In this context, use of standards plays an important role. The glue which allows FIRE projects to interconnect could become the basis of standards by IETF, W3C or ITU, for example (Firestation Group, 2009).

Another issue is the Federation of testbeds, which is a central idea to extend the benefits of FIRE, running experiments using resources provided by different testbeds. The Federation may take the form of a common interface to multiple underlying testbeds. This common interface can consist of a portal for registration and for running experiments. It can also consist of a common Application Programming Interface (API).

User perspective

The FIRE projects cover a varied range of technological and application areas and provide support for experiments at different stages of innovation, from early exploration, feasibility, through development and pre-market testing. This implies that in some cases adherence to established standards is a key requirement – for example, in conformance testing or where co-developing with a telecommunications utility – while in other cases, flexibility and rapid deployment may be more important.

From the point of view of FIRE facilities, "users" are experimenters making use of the infrastructure for research in various ways, rather than end-users of products and services. These users are university research groups, research arms of large companies, and – a particular target group for EU funding – SMEs in need to experiment with innovative ideas. Frequently, FIRE research will be undertaken by consortia which include members from each of these sectors.

From the user community perspective, the requirements are more related to availability, accessibility and usability of experimental facilities at their disposal.

Clear information in terms of technology offered, applications supported and technical support to conduct the experiment efficiently are indispensable, mainly for external users. The experimental requirement may vary from existing capabilities to new challenges in terms of flexibility, scalability, resource discovery and workflow management. In particular, guarantee the reproducibility of experiments through dedicated resources.

Co-operation in terms of expertise/knowledge transfer between researchers and facility provider can lead to innovation in terms of new services, applications, best-practice methodology and standards development.

The FIRE facilities are not only brokers of technical resources but also brokers of knowledge, as they specifically provide a common interface and discovery protocols for disparate or dispersed underlying testbeds which would otherwise be hard for experimenters to find.

Another issue is the Standardization Requirements. Experimental facilities should inform which standardized methods of testing they support. This is essential to minimize test effort and allow repeatability of experiments.

Provisioning of open APIs to access the resources, authorization and access control to guarantee security and privacy are also important user requirements. The establishment of a common language between testbeds using standard APIs, services and protocols may facilitate their interoperability and interconnectivity.

Policy makers perspective

FIRE is firstly a European Commission funded program and as such targets a number of high level strategic objectives of the European public authority.

FIRE was initially launched under the 6th Framework programme under the Strategic Objective on Research Networking Testbeds.

The legal basis of the FP6 is given in the Article 163 of the European Commission treaty (EC, 2002) and states that:

> *i. The Community shall have the objective of strengthening the scientific and technological bases of Community industry and encouraging it to* ***become more competitive at international level****, while promoting all the research activities deemed necessary by virtue of other chapters of this Treaty*
> *ii. For this purpose the Community shall, throughout the Community, encourage undertakings, including small and medium-sized undertakings, research centres and universities in their research and technological development activities of high quality; it shall support their efforts to* ***cooperate with one another****, aiming, notably, at enabling undertakings to exploit* ***the internal market potential*** *to the full, in particular through the opening-up of national public contracts, the* ***definition of common standards*** *and the removal of legal and fiscal obstacles to that cooperation.*

These objectives have been reinforced during FP7 and the forthcoming Common Strategic Framework (CSF) where, on the basis of the Innovation Union, innovation is expected to play a central role in the development of the European Union. While innovation is not expected to exclusively rely on Research and Technological Development (RTD), RTD is still considered as one of the key innovation enablers.

Accompanying this initiative and more specifically related to Information and Communication Technologies is the Digital Agenda for Europe 2010-2020 (EC, 2012) which sets a plan for more than 100 actions grouped in 8 pillars: Digital Single Market, Interoperability and Standards, Trust and Security, Very Fast Internet, Research and Innovation, Enhancing e-skills, ICT for Social Challenges and International cooperation.

Both Innovation Union and Digital Agenda for Europe are priorities of the *Smart Growth* Flagship initiative of Europe 2020 (EC, 2012) agenda and demonstrate that beyond research exploitation and innovation to support the European competitiveness, additional benefits are expected from the further development of Internet related technologies.

The benefits of Digital technologies to our everyday lives are recognized. This will rely more especially on the delivery of fast and ultra-fast internet to all EU citizens (EC, 2012) but require applications and services to be developed in relation with the challenges to be addressed.

This encompasses the ICTs capability to reduce energy consumption (target set at 20% in Europe 2020), the support to ageing population, renewing the health services delivery and a better eGovernment offer. Exploration of such scenarios requires the simulation over an infrastructure offering an environment exposing both opportunities and threats that a Future Internet may offer.

The eight pillars in the Digital Agenda all have international dimensions: to attract Europe's best minds to research, world class infrastructure together with international cooperation policies are crucial and are also part of the FIRE objectives.

Finally, the best research ideas must be turned into marketable products and services. While EU investment in ICT research is still less than half of the US levels, FIRE infrastructure is expected to act as a commercialization enabler for any Future Internet innovation, including the socio-economic challenges of the Future Internet.

Another important aspect for policy makers is the path for the EF to become sustainable, at the end of FIRE support, without public funding.

Gap analysis

Figure 4 presents the gap analysis summary developed under the MyFIRE support action project. Gaps were grouped in four main types: Technological, Standardization, Innovation and Sustainability.

Technological gaps

They described the state of the art of technologies used in FIRE testbeds, that were used as input for the gap analysis (Vouffo *et al.*, 2011).

Gaps are presented on aspects related to infrastructure; security and privacy; usability; availability and accessibility:

(a) Infrastructure
Most of the individual testbeds are based on some applications demonstrations and involve functionalities at all layers (from physical to application layers). The network functionalities of individual testbeds are based on the technical requirements of wired/wireless/mobile network aspects that are conventionally known and deployed with add-on software modules for new features. When the future Internet functionalities involving multiple technologies are to be tested, interconnected testbeds are to be used, and hence the interconnectivity and usability requirements from infrastructure play a major role in attracting user communities to the facilities. Also interesting is to note that most of the testbeds relate their activities to software applications for performance improvement and less on hardware acceleration, which explains to some extent the lack of hardware development activities in Europe.

(b) Security and privacy
Future Internet has to be trustworthy with secure transactions and privacy protected. Though security and privacy requirements cover a large spectrum of related issues, there is not a single FIRE testbed project with security or privacy as a major focus in its portfolio. This lack of concern by EFs providers and users, mostly from academia, may face difficulties when applications involving external users from industry are envisaged.

(c) Usability
It is clear that if one has to be successful with an experimental facility, there should

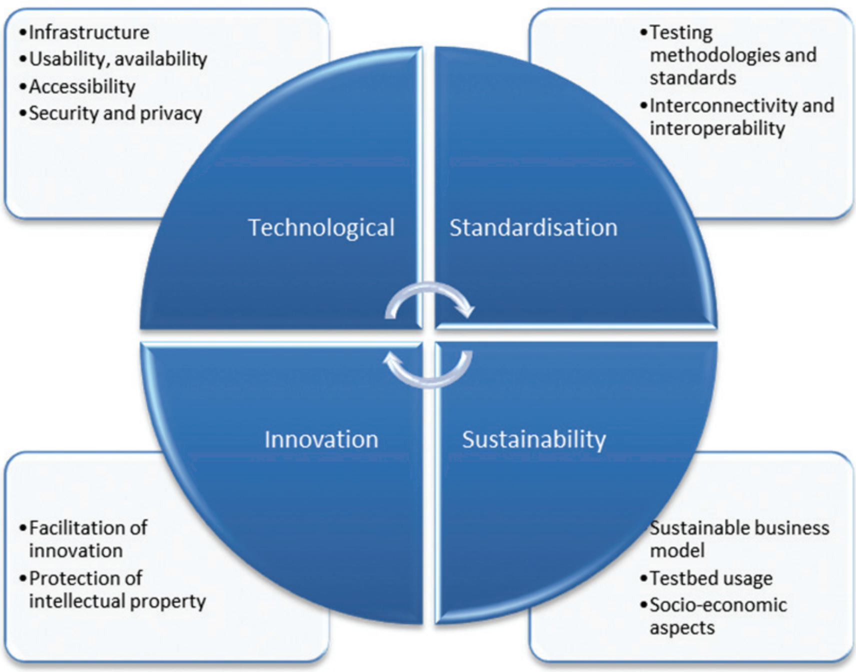

Figure 4. Gaps coverage.

be a good match between what is available and what is required.

We saw previously that there are many varied technical requirements, but nevertheless there are common needs for scale and variety in test facilities, and for the reproducibility and monitoring of experiments. This should relate to some type of training offered by the experimental facility providers. They would appreciate if the experimental facility providers could pass test for standards conformity, which will help to promote the innovation towards a commercial perspective. In addition to this, the ease of use of the facility plays a major role in attracting users.

(d) Availability, accessibility:

Availability and accessibility of experimental facility on demand is another important criterion from the users' perspective.

The cost involved is another important issue. It should be more efficient than inhouse costs with additional expertise from the facility providers. Lack of organized approaches and methodologies inhibit optimized usage and hence cost reductions.

FIRE experimental facilities are not well known to researchers outside the internal user community and awareness of capabilities of facilities must be improved to attract industrial users, based on the business model for sustainability. It is good news that, as long as the research is funded by the European community, the access is free to the research user community. However, the support and expertise needed for setting up the experiments are not generally available for free (or even at reasonable costs).

Enabling potential users to locate correct and timely knowledge about the available resources is a key requirement. The Infinity Project, which is funded through FI-PPP rather than as a part of FIRE, is shortly to launch a web-based repository of available infrastructures; this seems to be a promising approach, but there is still a need for greater usability and greater support if the testbeds, once located, are actually to be used by their target communities.

Standardization gaps

Standardization is not a popular topic within the FIRE communities, which comprise researchers who do not want to be involved with standards.

However, there are many misunderstandings on the importance of standardization (as a collective process involving all stakeholders) and on related standardized methods which can improve the exploitation of Experimental Facilities, leading also to help on sustainability.

The following gaps were identified:

- Lack of use of standards or standardized solutions to operate the facility (access, test methods, benchmark, federation, etc.);
- Passive behavior towards standards and standardization process. Researchers acknowledge the importance of standards but do not want to be involved;
- Gaps between researchers interests to get more involved in standardization activities but no structured support is offered to them;
- Lack of understanding on how EF can be better used to support standardization and, in particular, on standards validation and support to certification.

Some aspects are much relevant: testing methodologies and standards; interconnectivity and interoperability**.**

(a) Testing methodologies and standards

In the early stages of experimental facilities development, users are restricted to the project participants more concerned with testbed federation technical activities.

Mature facilities seeking sustainability have to attract new users from the research community and enterprises to test new developments and solutions that can be supported by the facilities.

The experimental facilities announce the available features for testing, in general terms, but do not identify the testing methodologies supported or standards to be followed. The limited information provided about the experimental facilities will not attract external users to improve the test facility and hence there is a need to create a match between the important "customers" requirements with the test facility providers' offer.

Furthermore, researchers are mostly "unprepared" when coming and using the EFs. They should be better prepared on what they can expect from the experiment and, ideally, on using some methodologies to capture and validate their requirements.

In such scenario, it is very difficult to expect external users from business organizations and the broad research community to choose these research facilities for their experimentation, since it is not easy to outsource testing and experimentation and, in particular, to get some kind of conformance testing for commercial introduction.

(b) Interconnectivity and interoperability

ICT technologies follow different standards in their implementation. However, standards do exist to improve interconnectivity and interoperability across different vendor/standards for a given type of system.

Generally, testbeds do not support such interoperability criteria and do not specify standards needed to interface with their experimental facilities.

It is also observed that the researchers are not exposed to standards development work, but are only aware of existing and commercially supported standards in their work. Thus, the European research is not moving towards commercial exploitation, since complying with adopted standards is one of the key criteria for commercial success.

It seems that researchers are not aware of the potential use of EF to improve interoperability and standard validation, in particular when new technologies result in emerging (and not validated) standards (for example 6LowPan, OpenFlow).

The current scenario of interconnectivity at the physical layer is basically through public Internet for application level experimentation (e.g. PANLAB, OPENLAB,).

For high performance experimental work across academic research communities, the GEANT network is used, since most of the research community is connected to this network. However, applications testing can be done using commercial Internet, which is another reason why the software application testing is most popular among the user community, but other uses of EF must be promoted to fully exploit their potential for other types of testing. Only FEDERICA (VPN, network slice) provides another type of access addressed in the FIRE projects, to access the resources of experimental facilities, using NREN facilities.

Innovation gaps

In considering pathways from the highly experimental research carried out on FIRE to innovation, it is necessary to look, not only at the short and medium-term exploitation of the testbeds, but also at the outcomes that may arise from longer-term innovation dependent on research carried forward from FIRE.

Recognizing that the pathways to innovation are rarely linear and involve many social, as well as technical factors, requires understanding, as far as possible, of the entire ecosystem in which FIRE is situated.

In terms of costs and benefits, the costs of FIRE are relatively easy to identify (although probably hard to itemize in detail), but the benefits are long-term, hard to define, and may not become apparent for many years, especially considering the highly innovative environments investigated in FIRE.

It is positive to note that experiences from earlier phases of FIRE are reflected in changes such as the setting-up of the FIRE Architecture Board and the FIRESTATION project. However, in terms of maximizing impact, there is still a lack of co-ordination among FIRE and with non-FIRE projects. Outside the funded Open Call experiments, usage is low, apart from the inheritance from earlier projects and some open access usage.

As routes to innovation, we have considered aspects specific to the Future Internet, including “clean slate” and “evolutionary” approaches, virtualization, and “tussles” between stakeholders. There are commonalities with innovation in other technological realms, including user-led and open innovation and, in particular, the importance of standards as both outcomes and enablers of innovation.

There is the over-arching imperative for FIRE and its successor projects to remain open and generative, enabling support and experimentation of new, ground-breaking ideas.

In this section, we discuss some specific roadblocks as well as opportunities which need to be addressed on the paths to Innovation in FIRE, if its long-term impact is to be maximized.

(a) Facilitation of innovation

The FIRE facility projects offer strong added value in terms of scale and variety of federated technologies and international links, that can be configured for research needs in a controlled environment, “close-to-real life" or in laboratory conditions, and hence able to give reproducible results, with close links between the highly experienced staff at the testbed operators and the experimenters, which can facilitate innovation towards new services and products.2

(b) Protection of intellectual property

The intellectual property and confidentiality of test results is another major hurdle to attract users to the experimental facility. There is no general guideline in this respect, which should be developed to make the FIRE experimental facility a successful initiative.

Thus, the IPR has to be protected to provide value to the work of researchers, to stimulate the innovation and creativity of research community. There are many ways identified, but not documented, on how they are done by the user community or facility providers:

- Patents: Experimental results can lead to the patent on behalf of innovators. However, in Europe, patents are taken by the companies, with minimum benefits to the researchers. Patents should be attributed to persons rather than to companies, with clear guidelines on how the commercialization benefits of innovation should be shared between the researcher and the affiliated company to promote innovation.
- Open source: Open source release of research work is the fastest path for innovation, since the results are available to the large community of researchers. This may provide pride and personal career benefits to the researchers in their professional career. Experiments using testbeds should be documented and disseminated as case studies to the research community and other prospective users.
- Standardisation: Work carried out in research projects can lead to the development of new standards which will facilitate early commercialization initiatives.
- New Spin-off or sale of ideas: New entrepreneurships should be promoted with some guarantees/subsidies for the commercialization of proven ideas to improve the competitiveness of Europe.

Sustainability gaps

Sustainability is the weakest link of all testbeds in the European research framework. We have seen, over the years and under the My-FIRE analysis, the testbeds being open during the last few months of the project for any experimentation by external users. Generally, they are not supported after the project conclusion, with some exceptions in NRENs being part of GEANT.

Though most of the testbed projects claim to address sustainability, there is hardly any testbed to be cited, which is available for longer time with stability and new features for experimentation. In a scenario contemplating federation of all FIRE projects, the existing IP testbeds should have a sustainable future as part of that.

(a) Sustainable business model

Thus, there is a recognised need for experimental facilities projects and experimental facilities federations to plan their exit strategy through the creation of a relevant business model.

The objective of an experimental facility is to develop innovation with high potential for economic benefits, thus the business model of an experimental facility has to describe how to create, deliver and capture financial, economic, social, and technological value.

The first question is the balance sheet among the technological, the economic and the financial value. In other words, has an experimental facility to be financially sustainable? Or if it provides technological value, can the financial losses be offset? In this case, how to evaluate technological value? And at the end of the project, is it more efficient to close the testbed built or to adapt it to the needs of other users projects?

Currently, FIRE federated experimental facilities are funded through projects under the FIRE initiative, dedicated to specific research for a consortium. If the experimental facilities are open to external users, their providers are not necessarily interested in attracting these users as they would need to adapt services for them, set up rules for access, negotiate IPR etc. Thus many experimental facilities are underused.

Thus, one important issue raised by our analyses is the lack of external users for most testbeds, although recent Fire projects have launched calls for proposals destined to experiments by external users. However, although many proposals are normally received by the call, only few funded users will be selected. This finding confirms that sustainability without partial funding is a difficult proposition. Most of the testbeds have been developed in an "one-shot" mode to satisfy internal users, the researchers in their short-term research agenda.

In sufficiently mature testbeds, Private Public Partnership-PPP model can be a solution, if the proper business model for longer term is well defined, with some kind of subsidies to the user group rather than to the facility providers. However, for this to be a realistic possibility, discovery and usability of the testbeds need to be a priority.

(b)Testbed usage

The FIRE Projects cover many areas of Future Internet experimentation for real hands-on experience with new developments from the research community. It is to be noted that though the FIRE initiative is one of the key objectives within the 'future Internet' challenge 1 of the FP7, cross-communities interaction with outside testbeds are limited.

(c) Socio-economic aspects

The FIRE initiative has adopted open calls for well-defined experiments and use case definition. These open calls have adopted a relatively easy-to-access application and evaluation process in keeping the FP7 rules and good practices with evaluators independent from the testbed operators. They lead to a large number of applications, demonstrating the researchers' interest to interact with these testbeds.

The criteria for proposals selection include the development of the project as well as assessment of project results impact, and applicants are required to explain how their proposed experiments would contribute to the overall impact of the facility project. The Open Call process is an important part of developing the FIRE testbeds into mature facilities, in addition to the direct benefits they are expected to bring in terms of experimental results.

FIRE testbeds are mostly internal research oriented, having few or no real external users. In this sense, the social aspects are not regarded as a priority in these projects. Living labs, which make use of some FIRE testbeds, shows higher concern for users' social aspects and has developed methodologies to interact with and manage users.

Recommendations and way forward

Based on these analyses, this section leads to some recommendations on 3 major topics: standardization, innovation, and sustainability (MyFIRE, 2012a).

Standards

From the standards perspective, three activities are important to be considered: validation of standards from the experimental facility; contribution to standards by active standardization activity; improving facilities following standardized methods of testing, provisioning open API to access the resources, authorization and access control to guarantee security and privacy.

Table 1 presents a summary of recommendation on standards.

Innovation

From the innovation perspective, two main gaps have been identified:

- Facilitation of innovation - FIRE should consider the provision of a scale and a variety of technologies through federation and international links; yet retain the values of their member nodes in being able to offer a controlled environment, close to real life or in laboratory conditions; and hence being able to give reproducible, justifiable, and empirically validated results with close links between the highly experienced staff at the testbed operators and the experimenters;
- Protection of intellectual property: using patent, open source, standardization or spin-off.

Table 2 presents recommendations for innovation.

Sustainability

From the sustainability perspective, the main gap is how to guarantee sustainability of experimental facilities and create different business models that can be considered viable solutions.

Based on the analysis done by MyFIRE, the business model should be able to adapt, depending on the position in the lifecycle of the EF, the status of the EF, the source of funding of the EF, the distance to market of

Table 1. Recommendation for standardization (summary).

Recommendations
a) Consider offering FIRE facilities for validating standards in coordination with active standardization working groups;
b) Increase researchers' awareness of the importance of a proactive involvement in standardization activities also as a tool to secure and validate research activities;
c) Increase the use of standard and/or standardized methods within FIRE facilities to improve and optimize the use of facilities. Contribute to common standards for the whole FIRE facilities if those are not available;
d) Researchers should have a method to define their requirements (what they want to check before using the EFs) and to verify compliance of their requirements using the EFs;
e) Researches should check whether appropriate methods which suit their needs exist and whether there are some best practices already;
f) A benchmarking approach should be encouraged for EFs as well as contributions to define a common approach over all EFs;
g) It will be very useful if the standardization process is based around facilities that are open for everyone to experiment with. An open approach to standardization should help.

Table 2. Recommendation for innovation (summary).

Recommendations
a) Federation should continue and be strengthened, not only as a means to sustainability, but also to maximize the benefits of FIRE and ensure co-ordination between projects;
b) The Open Call process is likely to strengthen testbeds to meet the needs of their target communities. However, it will be necessary to monitor this process to ensure that the benefits are maintained;
c) Usability of facilities must become a priority if the community of users is to be widened beyond those who are already experts or who can be directly supported by testbed operators;
d) Liaise with the Infinity Project and others to strengthen resource discovery;
e) Develop clear pathways to innovation; this includes pathways to commercialization, but also processes of standardization and dissemination among the research community.

services provided, the Future Internet layers targeted by the EF, and the technologies covered by the EF.

If innovation and research advancement is the value expected from the EF, the technologies and services provided by an EF would be used more efficiently if they could benefit more users, increasing exploitation of produced innovation and research advancement; a necessary condition is to raise the capacity of the EF to adapt to the needs of external users.

Based on this analysis, Table 3 shows some recommendations for sustainability.

Brazilian perspective

Testbed facilities for experimental research in Brazil are conceived, implemented and managed by universities and research institutions and funded by official bodies like CNPq, FAPESP, Ministry of Science, Technology and Innovation. Even in academic circles, the users of the few existing testbeds - GIGA (Rossi *et al*., 2005) are limited to partners of the project leading to very low utilization of the facilities. Participation of private and public enterprises is limited in the application side. Transfer of knowledge from universities to enterprises is not usual as the latter prefer buying commercial solutions already proved elsewhere.

Nevertheless, there is an acute sense of urgency in developing mechanisms to stimulate novel applications in several areas crucial to economic development of the country in the next decades:

- ICT technologies may play an important role to produce applications in different fields but the challenges they face are formidable.
- Experimental research and extensive testing are necessary to build innovative applications before implementation.
- Cooperation with the EU, the United States and other developed countries are well established in academic programs. Participation in research projects is also increasing but is restricted to the academic environment.

Table 3. Recommendation for Sustainability (summary).

Recommendations
a) The EF must be well-documented and advertised, as a key point to attract users. The objective is to ease the use of the EF. Providing standardized testing approaches would also help in providing comprehensible offers.
b) The EF must set up a proactive marketing policy, by identifying the relevant target of potential users. The EF must conduct a market research analysis to identify the potential users among the research community together with their specific needs. The EF must develop appropriate communication, by targeting known potential users in particular through collaborative projects and unknown potential users dedicating specific human resources to watch potential users, understand and anticipate their needs, and develop specific communication with them. Federation of testbeds can permit sharing communication on specific domains.
c) The EF must formulate a commercial strategy, by making a non-concurrence analysis with the public or private sector; by paying particular attention to Federation, where the competition risk can be within the federation; by designing appropriate offers (services); by understanding the market of potential users and their needs (market research analysis) and by evaluating the real cost of testing taking into account money, time and human resources consumed, and distinguishing OPEX to CAPEX.
d) Besides running experiments, the EF should develop new services based on the facility uniqueness and its staff expertise. This includes the organization of interoperability events, the use of FIRE facilities to establish an overall certification scheme, the offering of test as a service and consulting and training services.

Recently, the joint Call between Brazil and the EU was instrumental to establish more cooperation on Research and Development. This call selected proposals for financial support to projects that can significantly contribute to the scientific and technological development of the countries involved in the area of Information and Communications Technologies in order to create a significant R&D infrastructure with impact on the different sectors of Brazil. In its first wave, this initiative chose five thematic areas: Microelectronics/Microsystems; Networking Monitoring and Control; Future Internet experimental facilities; Future Internet security; e-Infrastructures. Specifically in FIRE, in this first wave, there is the project FIBRE - Future Internet testbeds/experimentation between Brazil and EU (Sallent *et al.*, 2012) involving 9 Brazilian partners covering almost all regions from Brazil. This initiative could become a reference to cooperative projects in the future, with Brazil and EU funding participants on their side.

Conclusions

Experimental facilities (EF) rely mostly on public grant for a specific project, and more often than not have a limited group of users at the end of project. If innovation and research advancement are the values, the technologies and services provided by an EF would be better used if they could benefit more users, so as to permit increased exploitation of produced innovation and research advancement. A necessary condition is to raise the capacity of the EF to adapt to the needs of external users with special attention to end-users from enterprises.

In order to guarantee sustainability of experimental facilities, it is fundamental to develop a suitable business model. Demonstrating sustainability has been the weakest achievement of all experimental facilities in the European research framework.

From the Brazilian side, it is important to recognize the best practices and learn from errors from mature environments. Thus, the Brazilian experimental facilities could be more efficient with this knowledge.

After 2 years of work, the proposed recommendations by the MyFIRE project are synthesized in Figure 5.

Acknowledgements

The research leading to these results has received funding from the European Community seventh framework programme (FP7/2009-2012) under the Coordination and the support action project: MyFIRE (grant agreement nº 258348). The project is part of THEME [ICT-2009.1.6] - Future Internet experimental facility and experimentally-driven research.

All the public deliverables from MyFIRE are available at (MyFIRE, 2012b).

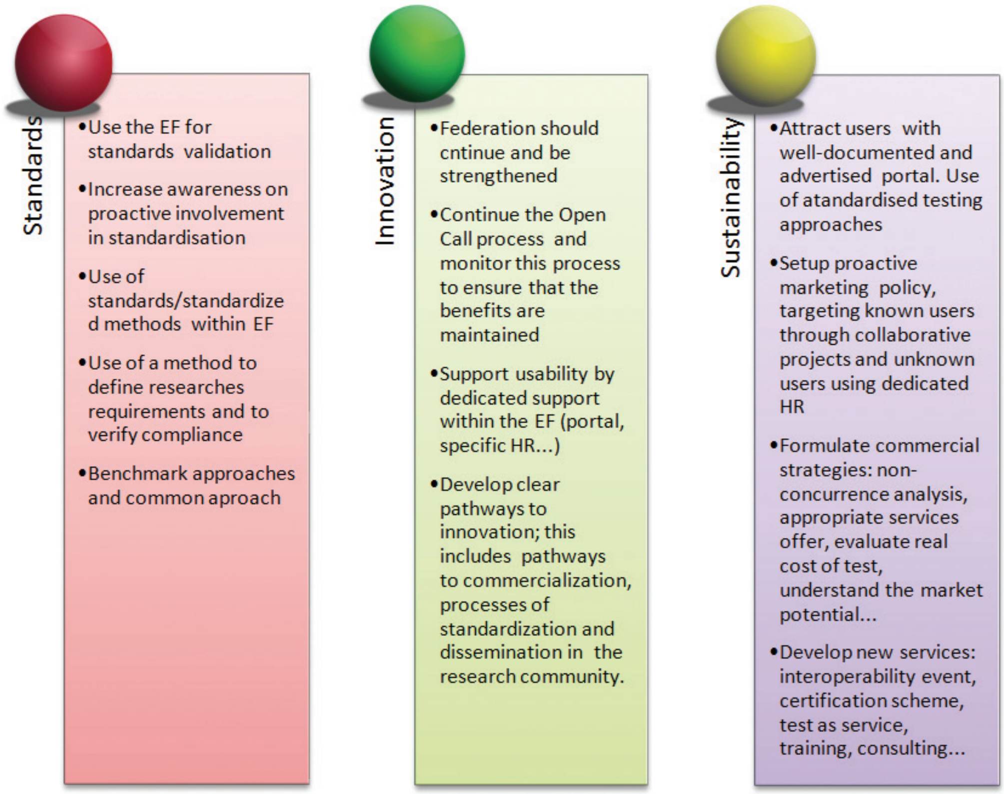

Figure 5. Recommendations Summary.

References

CORDIS. 2014. Future internet research & experimentation – fire. Available at: http://cordis.europa.eu/fp7/ict/fire/. Accessed on: April 24, 2014.

EC. 2002. Consolidated Version of the Treaty Establishing the European Community. Available at: http://www.ictregulationtoolkit.org/en/toolkit/docs/Document/2364. Accessed on: April 24, 2014.

EC. 2012. Digital agenda for Europe 2010-2020. Available at: http://ec.europa.eu/digitalagenda/. Accessed on: December 01, 2013.

FIRESTATION GROUP. 2009. Fire: Future internet research and experimentation fire white paper. Technical report, Fireworks project, 51 p. Available at: http://www.ict-fireworks.eu/fileadmin/documents/FIRE_White_Paper_2009_v3.1.pdf. Accessed on: April 24, 2014.

MYFIRE. 2010. The project – MyFIRE – from experiment to future internet. Available at: http://www.my-fire.eu/. Accessed on: December 01, 2013.

MYFIRE. 2012a. Contribution to FIRE roadmap v4. Available at http://www.my-fire.eu/. Accessed on: December 01, 2013.

MYFIRE. 2012b. Public deliverables. Available at: http://www.my-fire.eu/. Accessed on: December 01, 2013.

ROSSI, S.M.; SCARABUCCI, R.R.; STANTON, M.A.; DE BARROS, M.R.X.; SALVADOR, M.R.; SIMOES, F.D.; ROCHA, M.L.; DA SILVA NETO, I.L.; ROSOLEM, J.B.; FUDOLI, T.R.T.; MENDES, J.M.D.; CASTRO, N.F.; MACHADO, I.; REGGIANI, A.E.; PARADISI, A.; MARTINS, L.; 2005. Project GIGA-high-speed experimental IP/WDM network. *In*: International Conference on Testbeds and Research Infrastructures for the Development of Networks and Communities, 1st, Trento, 2005. *Proceedings…* IEEE, p. 242-251.

SANTIAGO, A.; MIYAKE, M.; SATHYA, R.; LE GALL. F.; BAUMBERGER, M. 2011. A survey with owners and users of experimental facilities aimed at applications on future internet. *In:* Workshop de Pesquisa Experimental da Internet do Futuro, II, Campo Grande, 2011. *Proceedings...* Campo Grande, **1**:3.

SALLENT, S.; ABELEM, A.; MACHADO, I.; BERGESIO, L.; FDIDA, S.; REZENDE, J.; AZODOLMOLKY, S.; SALVADOR, M.; CIUFFO, L.; TASSIULAS, L. 2012. Fibre project: Brazil and Europe unite forces and testbeds for the internet of the future. *In*: International Conference on Testbeds and Research Infrastructures for the Development of Networks and Communities, 8th, Thessaloniki, 2012. *Proceedings…* **44**:372-380. http://dx.doi.org/10.1007/978-3-642-35576-9_33

STANTON, M. 2011. Mensagens dos coordenadores do wpeif. *In:* Workshop de Pesquisa Experimental da Internet do Futuro, II, Campo Grande, 2011. *Proceedings...* Campo Grande, **1**:IX.

VOUFFO, A.; PAVENTHAN, A.; IVANOV. A; YHUANGF.; SANTIAGO,A. 2011. D1.1: Report on Technologies, protocols, services and applications in FIRE testbeds and experimental facilities-MyFIRE Consortium. Available at: http://www.my-fire.eu/. Accessed on: December 01, 2013.

ZAHARIADIS, T.; PAPADIMITRIOU D.; TSCHOFENIG, H.; HALLER, S.; DARAS, P.; STAMOULIS, G.D.; HAUSWIRTH, M. 2011. Towards a future internet architecture: The Future Internet. *Lecture notes in computer science*, **6656**:7-18. http://dx.doi.org/10.1007/978-3-642-20898-0_1

Submitted on January 6, 2014
Accepted on May 21, 2014