FIREWORKS

Future Internet Research and Experimentation

Issues Paper for discussion at the Future Internet Assembly meeting

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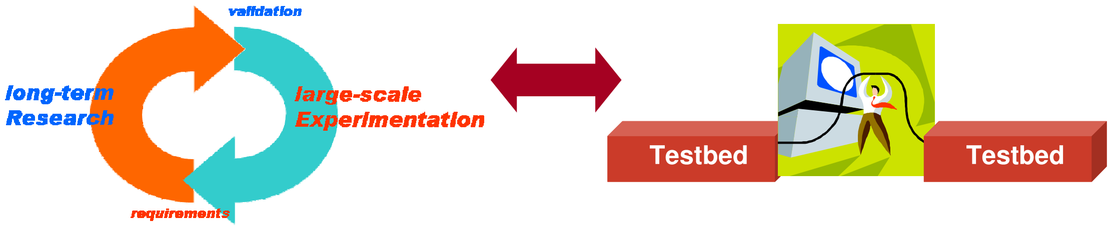
NOTE: this paper is an extended version of the version published before the Bled conference in Future Internet.

Work under the area of experimentally-driven research and experimental facilities, which is also known under the acronym FIRE – "Future Internet Research and Experimentation", has two related dimensions, for which a total of 14 projects has been selected in ICT Call2.

1. Experimentally-driven research on new paradigms and advanced networking approaches for the future internet: many networking researchers around the world have identified emerging limitations of the current Internet architecture and agree that it is time for research to take a long term view and to reconsider the basic architecture of the Internet, to see if any improvement can be identified, even if it does not appear to be backward-compatible at a first glance. To be effective and to produce applicable results, this fundamental research in new paradigms has to be tested, at least as a proof-of-concept, in large scale environments, so as to assess the feasibility of the new concepts, verify their large scale effects (not only at technological level, but also as for their foreseeable implications on users, society and economy) and derive further requirements, orientations and inputs for the research. This kind of experimentally-driven approach avoids that the research efforts will remain at the level of paperwork and will hopefully allow exploring significant improvements over the current Internet.
2. Interconnected testbeds on networks and services: it is envisaged that the interconnected testbeds supported in this area will evolve from gradually federated testbeds towards becoming a sustainable, dynamic, and integrated large scale experimentation facility supporting academia, research centres and industry in their research on networks and services. As opposed to the functionality of individual testbeds, the federation of testbeds will allow testing at larger scale and at system-level. The interconnected testbed activities in this area are open to any relevant European projects within other Objectives of FP7, as well as national, regional or multinational initiatives. These projects will be able to use the facilities or to federate their testbeds within the facility.



The FIRE approach considers the Internet not just as an “interconnection of networks”, in terms of component technologies, but as a complex system, where the introduction of a new technology or protocol, even if confined to a specific layer, may have profound consequences on other layers of the

Internet or implications in terms of the possible services and applications which can be supported, and ultimately on socio-economic aspects, given the increasing role and shaping effect of the Internet on the very fabric of our society.

In their first report published in May 2007, the FIRE expert group has defined FIRE as "a research environment for investigating and experimentally validating highly innovative and revolutionary ideas". Several workshops held in recent months have confirmed the necessity of developing the FIRE experimental facility in close collaboration with experimentally-driven research on new architectures and paradigms for the Future Internet which need large scale testing or proof of concept.

FIRE experimentally-driven research vision

There is an increasing demand from academia and industry to bridge the gap between long-term research and large-scale experimentation, which can be done through *experimentally-driven research* consisting of iterative cycles of research, design and experimentation of new networking and service architectures and paradigms for the Future Internet addressing all levels. FIRE experimentally-driven research in future is suggested to address broad system-level research which views the Future Internet as a complex system and which proves and exploits the full value of the FIRE Facility:

- doing truly multidisciplinary experimental research
- testing new internet architectures and paradigms including at service level
- doing socio-economic impact assessments for future changes to the internet

FIRE research is characterized by its methodology, not only by the scope of the research topics. From the projects submitted and selected for the first call, a number of innovative ideas have emerged, some of which can be considered as paradigms shifts (e.g.: Cross-layer and cooperative design; Multi-hop optimization-based network design; Content and human centric networking; Autonomic, self-configured, and self-managed networking; Minimizing energy footprint and cost; Rethinking the distribution of the intelligence within the network; Integrated and flexible exploitation of heterogeneous resources such as storage, bandwidth, energy, computation, mobility, etc.; Virtualization).

In future any innovative idea relevant to future Internet architectures or paradigms would fit into FIRE research, provided that it is based, at least as a proof of concept, on real experimentations, exploiting the FIRE experimental facility or implementing a testbed on its own, to be subsequently made available in the framework of the federated experimental facility. This open approach will allow exploring more traditional as well as alternative paths, which challenge mainstream concepts. This research on alternate paths may appear high-risk but ultimately will reduce the global risk of concentrating all efforts on a promising technology which may eventually prove to be the wrong choice.

FIRE Research is suggested to focus on research which is not limited to specific layers or technologies, but is truly multidisciplinary, cutting across several relevant domains or layers, including physics, human sciences or economics.

Issues which need to be discussed include:

1. Examples of research areas that benefit from this experimentally-driven approach.

2. Which disciplines should be specifically addressed, e.g. networking and communication, service architectures…?
3. How to effectively involve additional disciplines in the research: motivation of researchers, structural problems, etc.?
4. Which kind of socio-economic impact assessments of future changes to the Internet can be effectively forecasted?
5. The time-span of the research, and need for appropriate long-term instruments.

Long term cross domain perspective of the FIRE facility

According to many researchers, the Internet itself has been the largest-scale laboratory for emerging applications and services (skype, youtube, OSN, etc.). However, it is evident that it cannot be considered as a testbed for the basic protocols, architectures and services (see for instance the long deployment time necessary just for an updated version of the Internet Protocol and the need to keep this critical resource operational). The FIRE experimental facility will provide an open playground for this kind of research, being gradually built, based on a federation of existing relevant testbeds, and will grow according to the research needs specified by the related “customer” research projects.

The FIRE experimental facility is planned to be broadly scoped to support research on the Future Internet and its services:

- to include testbeds for different stages of the research and development cycle - from proof-of-concept type testbeds to pre-commercial testbeds
- to support testing the impact of changes to the Internet not only in technical but also in socio-economic terms
- to cover all levels from fast network connectivity to service architectures at different levels
- to be available to academia, research centers and industry including the relevant ETPs
- to allow experimentation with advanced architectures of the Future Internet taking a system view
- to build on the design principle of "open federation of testbeds"
- to allow for access of broad user communities for experimenting on "user experience"
- to become a sustainable research infrastructure for the Future Internet serving both industry and academia in their Future Internet related research and to overcome limited availability of testbeds for the duration of the projects under which they are provided

Issues which need to be discussed include:

1. **Configuration, offering and roadmap of relevant projects** in terms of availability of testbed services to the Future Internet research community as they expect it to be in 2 - 3 years from now.
2. The desired scope of the FIRE facility and the expected added value of federating testbeds by **deriving concrete, visionary, and challenging research scenarios** of experimentally-driven research which the potential users would like **to be supported by the FIRE large-scale experimental facility**.

3. The **most important design principles and characteristics of the FIRE facility**, e.g. federation, virtualisation, auto-configuration, modularisation, security, adherence to open standards, use of open source….
4. How will **fundamental federation principles** be applied, e.g. openness in provisioning and use, excellence of the offering, governance and management of the federation?
5. How can the experimental facility effectively support the research cycle?
   a. Definition of the mechanisms to upgrade the facility to meet future requirements for experimentation by ongoing research
   b. Elaboration on the incentives for both the facility providers and the research projects to engage in a testing relationship as well as definition of the mechanisms that support the planned future inclusion, integration, and use of maturing testbed prototypes in the facility
6. How can the FIRE facility be set-up to **allow for testing a broad range of technologies on the network as well as on the services levels** (protocols, architectures, services, middleware, etc.), considering the internet not just as an interconnection of networks in terms of component technologies but as a complex system cutting across many layers.
7. How to ensure **joint industry commitment and academic involvement** in the FIRE facility? How to promote close collaboration between industry and academia for investigating and experimentally validating highly innovative and revolutionary ideas? How does this collaboration contribute to the sustainability of the facility and its components?
8. How can **end-users be effectively involved** in order to provide real-world feedback? In which cases is this necessary to assess also **usability and socio-economic impact**?

Assessment of terminology

A first attempt to provide more precise definitions of "test" vs. "experimentation" yielded additional issues that need to be addressed. The definition of "experimentation" provided by the American Heritage, Dictionary of the English Language is not helpful in this context since "**Experiment** is a **test** under controlled conditions that is made to demonstrate a known truth, examine the validity of a hypothesis, or determine the efficacy of something previously untried".

Testing is better defined, e.g. at ETSI, where also the distinction between conformance testing and interoperability testing is made:

- Conformance testing gives a high-level of confidence that key components of a device or system are working as they were specified and designed to do. It provides high control and observability but is limited in scope. It tests individual system components but a system is often greater than the sum of its parts, thus conformance testing does not prove interoperability. Conformance testing can be automated.
- Interoperability testing is system testing and is used to demonstrate end-to end functionality. It tests the functionality at a 'high' level and tests the 'whole', not the parts. It shows that a certain function is accomplished (but not how), but does not prove interoperability with other implementations. Interoperability testing is usually executed manually.

Experimentation can be defined as the orderly or methodical observation of the variation of facts resulting from artificial stimuli in a reproducible environment that confirms a hypothesis (verification) or rejects it (falsification). In an experiment we manipulate at least one system parameter (variable) according to a pre-defined plan and observe its impact on other (dependent) parameters under controlled conditions. The validity of the hypothesis, is only shown if we can reproduce the experiment under the same conditions and obtain the same result. During experimentation we aim to minimise or eliminate "uncontrollable" environmental effects. A controlled condition usually means a laboratory environment.

In summary testing has a known list of stimuli and observation points which are checked off, whereas experimentation is the search for the „right" stimuli and observation points that are useful for a reasonable assessment of a system.

Furthermore a large scale environment, as envisioned by FIRE, has too many parameters that cannot be under a single control, thus rendering the environment "uncontrollable". The logical consequence is that an uncontrollable environment is not reproducible, which is does not contribute to the postulation that the validity of a hypothesis, is only shown if we can reproduce the experiment under the same conditions and obtain the same result. This is especially true if an experimental environment includes users and user groups, since human behavioural patterns cannot be reproduced.

Proceed by focusing on concrete projects' collaborations

To progress the concrete use of the Future Internet Research and Experimentation facility by its potential customers – the collaborative projects – a well defined relationship between the provider and the customer is necessary. This section is distinguishing collaboration as a process. In a collaborative process, the goal is not only to achieve a desired outcome, but to achieve that desired outcome in the most efficient and effective way possible for the stakeholders and all interested parties involved.

Agreement to Collaborate: Before agreeing to collaborate, the collaborating parties must understand the key elements of this process:

- Collaboration requires parity among participants
- Collaboration is based on mutual goals
- Collaboration depends on shared responsibility for participation and decision making
- Collaboration means shared resources
- Collaboration requires shared accountability for outcomes
- Collaboration relies on mutual trust

These key elements distinguish collaboration as a highly interdependent process that requires an upfront commitment to work within these elements from all participating entities before going forward.

Collaborative Guidelines: The list below summarises steps in the process to engage in collaboration between FIREworks/FIRE projects and their "customers":

- Identify and bring project/collaborative parties together. This step is basically covered by the call for use scenarios and the responses provided by customer projects and FIA clusters.

- Provide understanding of scope of the collaboration and the expectations. This step is currently ongoing and is partly addressed by an analysis of the feedback received by customer projects and FIA clusters. The results of this analysis will be shared and discussed in the FIRE session at the FIA in Madrid. Furthermore this step will include one or more feedback loops to clarify requirements by customer projects.
- Define success/desired results. This steps as well as the following steps must be executed case by case for each customer project that wishes to collaborate.
- Define and discuss concrete elements of a collaboration within a customer project, specifically: a) Leadership, b) Roles, responsibilities and ownership issues, c) Communication, d) Decision-making, e) Time management and priorities, f) Disagreements, g) Accountability, h) Outside resources, i) Milestones, j) Reward and recognition, k) Evaluation plan.
- Identify possible barriers and how to remove them.
- Obtain a commitment to collaborate from each member to move forward under the agreed upon collaborative guidelines.

Analysis of FIRE use scenarios – Offering vs. need

Table 1: Offerings

PII	• Procuring testing facilities from user applications and services to network components, protocols and whole network settings
	• Class 1 – Outsourced Testing and Testbeds - covering generic outsourced testing applications, including business economic view of savings and combined synergies instead of self-contained testbeds.
	  ○ Outsourcing of testbed environments.
	• Class 2 – Test of Services and Applications - containing the main technical cases of testing technologies, services, networks, protocols and other new-state-of-the-art user driven innovations
	  ○ Concurrent testing.
	  ○ User driven innovation.
	• Class 3 – Interoperability, Conformance and Certification – addressing a three-step workflow to guarantee quality of testing and results.
	  ○ Service continuity in fixed mobile access networks.
	  ○ Re-use of test suites.
	  ○ Reuse of Testing Tools.
	  ○ Certification Process.

OneLab2	• Provide infrastructural support for large-scale data-centric networking research (CDN, Pub-Sub, Routing in a slice)
	• Integrate Opportunistic Networking and DTN platforms through the SAC Gateway
	• Establish methodology to compare networking experiments in non controllable environments
	• Customers (users and research targets)
	    ○ Liaison with "pilot" projects (Haggle & ANA (SAC), PSIRP (Content), 4WARD (Future Internet)
	• Examples:
	    ○ Autonomic Network Architecture develops a monitoring infrastructure for self-managing autonomic networks that can be validated and experimented in real-world like environment in OL2
	    ○ To test whether pulse coupled oscillators can be used e.g. for time synchronisation in Ad-Hoc networks and thus applied to congestion control in IP based networks
	    ○ The impact of different inter-AS peering configurations on the performance and scalability, therefore the impact of different economic conditions on the viability of various proposed internetworking solutions.

FEDERICA	• European scale network and system agnostic e-infrastructure • Virtualization infrastructure to provide "slices" to researchers in FI, where a slice is a mix of network circuits and computing elements
VITAL++	• Testbed federation dedicated to IMS research • Combining P2P technology and implementing IMS elements in control plane for federation

WISEBED	• Deploy large numbers of heterogeneous sensor nodes into one federated testbed interconnected with Internet
	    ○ Different types of sensors, topologies and environments
	    ○ Evaluate and test algorithms and protocols at large scale
	    ○ Derive models of real-life situations and scenarios for simulations
	    ○ Develop a software library ("WISELIB")

UNITE	• API for connecting geographically distributed testbeds over internet -> VDT (Virtual Distributed Testbed) • Enabling sharing of hardware and software components ○ 3G, WiMax/WLAN, DVB-H

Table 2 Needs and matching

Project	Description	Need for testing	Potentially matching environment
C-CAST	C-CAST studies context aware information 'push' for consumers	Context sensing (sensors, network footprints)	OneLab2, WISEBED?
		Aggregation and reasoning for content matching algorithms based on user/group situation	
		User groups -> PII	PII
Self-NET	Congestion management techniques for BS-ATA in WiMax network	Traffic loads	OneLab2
		Recovery times	
SEA	Studies seamless content delivery across broadband networks, varying from broadband broadcasting to P2P topologies	TV and IPTV streaming (SVC, MVC, MDC Videos and selected combinations)	PII
		Using fixed / Wireless / Mobile Networks and P2P Networks	PII and OneLab2 (plans include PlanetLab US)
		While adapting & protecting the stream on the fly	PII
SOA4ALL	Delivers a comprehensive framework and infrastructure that integrates complementary and evolutionary advances (i.e., SOA, context management, Web principles, Web 2.0 and Semantic Web) into a coherent and domain independent service delivery platform. Among others it addresses:	Deploys an own infrastructure which is available to third parties that want to conduct experiments in an environment hosting a large set of services and tools to support test generation, automation and test case ranking and selection. The environment includes semantic spaces and an Enterprise Service Bus (ESB) with deployment and monitoring components as the	The environment is network technology agnostic

	• Scalability • Discovery • Dynamic composition • Robustness • Context-Awareness	main supporting functions. The infrastructure includes service engines for Execution, Reasoning, Ranking and Selection as well as Discovery	
NEXOF-RA	NESSI Open Framework – Reference Architecture – Use scenarios • Service procurement • Service lifecycle support • Management services for grid and service platforms • PhiMas: personal health information monitor and alert service • Collaborative e-learning scenario • Deployment and configuration of a generic platform (e.g. an e-Learning) • e-Health: complex diagnostic workflow • e-Health: assisted living • Traffic management: large scale emergency handling • Crisis management system of systems • Effective and efficient collaborative decision making • e-Commerce information sharing	NESSI Open Framework – Reference Architecture – Requirements • Uniform service representation • Service discovery mechanisms • Decentralised architecture • Service description • Service deployment • Service decommissioning • Interoperability and flexible communication standards • Federated (temporal) identity management • Location based routing • Services integration by semantic mash-up • Harmonization of several heterogeneous information sources • Unified communication • Integration of an application with legacy applications, ERP, etc. Critical and	The NEXOF-RA use scenarios need further in depth analysis

	• Mobile office for an owner of a micro-enterprise • Safety at work in the construction sector • e-Government online application submission service • e-Government online fee visualization and payment Service • Assisted Industrial Maintenance (using 3D virtual environments) (S17)	foremost for the client • Adaptive deployment • Workflow management and integration • Aided configuration • Modelling capabilities • Technical interoperability • Device integration / vertical integration • Distributed workflow • Stateful, device adaptive service transfer • Adaptability • Rapid reconfiguration • Integrity (self-diagnosing and self-healing) • Dependability for device integration • Compliance to privacy, and security policies • Collaborative business process acquisition, modelling and effective management • Distributed architecture • Integration of services • Monitoring and reliability • Orchestration • Trust and confidence	

		• Service discovery • Information as a service • Execution of human-based process steps • Information integration • Distributed transaction support • Non repudiability of data transfer • Cross-certification • Resilience & Continuity of service	