Next Generation Internet Research and Experimentation

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2

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2.1 Experimentation Facilities in H2020: Strategic Research and Innovation Agenda Contributions

The Internet as we know it today is a critical infrastructure composed by communication services and end-user applications transforming all aspects of our lives. Recent advances in technology and the inexorable shift towards everything connected are creating a data-driven society where productivity, knowledge, and experience are dependent on increasingly open, dynamic, interdependent and complex networked systems. The challenge for the Next Generation Internet (NGI) is to design and build enabling technologies, implement and deploy systems, to create opportunities considering increasing uncertainties and emergent systemic behaviours where humans and machines seamlessly cooperate.

Many initiatives investigated approaches for measuring, exploring and systematically re-designing the Internet, to be more open, efficient, scalable, reliable and trustworthy [FIWARE/FIPPP, CAPS, EINS, FIRE, GENI, US IGNITE, AKARI]. Yet, although no universal methodologies have emerged due to the continuously evolving interplay among technology, society and the economy such initiatives produce a richer awareness of the socio-economic and technological challenges and provide the foundation for new innovative ICT solutions.

The Internet has evolved to the point that today is a vast collection of technologies and systems and has no overall defined design path for its inherent expansion and neither shall the Next Generation Internet. The actual experience is telling us that the Internet evolves through widely adopted experimentation that engages active users and communities rather than through purely technological advances invented in closed laboratories. Individuals and companies use larger experiments as a way to build the knowledge and necessary insights to verify and validate theories and ideas, and as the basis for creating viable, acceptable and innovative solutions driving benefits to Internet ecosystems and their stakeholders. For example *"by the end of 2018, 90% of IT projects will be rooted in the principles of experimentation, speed, and quality"* [Forrester2015].

The actual evidence, based on practical industrial experiences is unambiguous:

- Facebook is a huge and wide ranging social experiment investigating broad topics such as the economics of privacy, appetite for disclosure of personal data, and role of intermediaries in content filtering including emotional effect [14].

- Google's Experiments Challenge and Showcases uses Android as an open platform to engage large participation from OSS communities in the creation of inspirational, distinctive and unique open source mobile applications [5].
- Ericsson uses experimentation to explore opportunities in enterprise ecosystem related to localised applications, global applications along with added value services supporting security, device management and mobile productivity [Ericsson15].
- Smart Cities and underlying programmable network infrastructures uses social experiments with citizens in applications as diverse as transport, energy and environmental management [18].
- Netflix uses an experimentation platform to ensure optimal streaming experience with high-quality video and minimal playback interruption to its customers by testing adaptive streaming and content delivery network algorithms across so called experimental groups involving Netflix engineers and Netflix members [NETFLIX2016].
- Experimentation plays a vital role in business growth at eBay by providing valuable insights and prediction on how users will react to changes made to the eBay website and applications. A/B testing is performed by running more than 5000 experiments per year on the eBay Experimentation Platform [eBay2015].
- Apple used experimentation extensively to explore smart watch ideas initially starting from primitives as simple as an iPhone with a Velcro strap [WIRED14].
- Many industries targeting large online communities (e.g. gaming) use open beta programmes to investigate features and experiences with end user and developer ecosystems, to gain initial market attraction, for example only, the recent Overwatch programme secured 10 million players [17].

These strategies demonstrate that many successful Internet technologies are now developed through experimentation ecosystems allowing creative and entrepreneurial individuals and companies to explore disruptive ideas, freely with large "live" user-driven communities.

Innovation also plays a dynamic role in the process of large experimentation adoption. Experiments are conducted with ecosystems using platforms and infrastructures (e.g. mobile platform, social network, smart spaces and physical wireless spaces) designed to foster innovation by considering value creation through openness, variation and adaptability. These strategies show an increasing need to structure and engage society and communities of users in the co-creation of solutions (one of the multiples forms for innovation) by bridging the gap between vision, experimentation and large-scale validation sufficiently to attain end-user (citizens or industry) investment, either in terms of time or money.

Addressing directly the demand for innovation, Europe must establish large-scale experimental ecosystems aligned with NGI architectures that are sustained beyond individual EU project investments, with full involvement of end-users (i.e. citizens and SMEs), since they provide applicability validation of outcomes. Ecosystems help in anticipating possible migration paths for technological developments, create opportunities for potentially disruptive innovations and discovery of new and emerging behaviours; as well as in assessing the socio/economic implications of new technological solutions at an early stage. In addition, experimentation is an effective way to build evidence for the robustness, reusability and effectiveness of emerging specifications and standards. Note that it is important to recognise that there is no such thing as a “failed experiment”. Even if the findings point to a null hypothesis, learning what doesn’t work is a necessary step to learning what does correctly. Discovering that a technology fails to perform, is not commercially viable or is not accepted by end users is a clear route to future research and innovation challenges for the NGI.

2.1.1 European Ecosystem Experimentation Impacts

Ecosystem experimentation and trials using open platforms are a major contributor to the success of European research and innovation programmes investigating the future of the Internet. Initiatives such as Future Internet Research and Experimentation (FIRE), the Community Awareness Platforms for Sustainability and Social Innovation (CAPS/CAPSSI), the Future Internet-Public Private Partnership (FI-PPP), the 5G-Public Private Partnership (5G-PPP), European Institute of Innovation & Technology (EIT) Digital, and the European Network of Living Labs (ENoLL) have all been delivering platforms and ecosystems that have advanced Internet-based technologies towards markets and society. Each flagship initiative has been designed to fulfil specific complementary socio-economic and technical objectives. For example, CAPS enables societal innovation through open platforms supporting new forms of social interaction, FI-PPP enables innovation through accelerator ecosystems building on the open platform FIWARE, whilst FIRE enables innovation through highly configurable technology infrastructures and services. In particular, selected FIRE examples show that significant long lasting European impacts can be delivered:

- ***SME competitiveness***: experimentation has enhanced 100's of companies' product and service offerings have benefited by validating performance, acceptance and viability using experimental platforms. Examples include: Televic Rail launching their SilverWolf passenger information product on more than 22,000 railcars following complex end-to-end networking performance tests; Evolaris GmbH launching Europe's 1st Smart Ski Goggles service in the Ski Amadé, Austria, Europe's 2nd largest ski area based on user-centric networked media experiments; Incelligent proactive network management products building on cognitive radio experiments, involving realistic conditions and actual testbeds leading to the company being selected as one of the 12 startups awarded to work with Intel, Cisco and Deutsche Telekom, through the next phase of their joint ChallengeUp! Program.
- ***Pioneering concepts***: experimentation has demonstrated ground-breaking results that the world has never seen before. Examples include: Open platforms to transforming the education of the next generation of Internet scientists and engineers through remote experimentation on top of FIRE facilities and open online courses supporting over 1,000s of students and more than 16 courses across several countries (e.g. Belgium, Greece, Ireland, Spain, Brazil and Mexico) by allowing the creation, sharing and re-use of learning resources based on real experiments and data, accessible anytime/anywhere learning [6]; The World's 1st mixed reality ski competition broadcast across European television (BBC, ORF, etc.) radio and online to a global audience of over 700 million [2]; the first generation of networked Internet of Things technologies for pervasively monitoring the underwater environments; validation of HBBTV technology in European broadcast events [10].
- ***Interoperability and standardisation***: experimentation has established evidence and contributed to the development of new international standards, many of those adopted by the market. Examples include: Licensed Shared Access (LSA) technology to maximize mobile network capacity in LTE (4G) communications presented to the ETSI TC Reconfigurable Radio Systems WG1; Transceiver API for a hardware-independent software interface to a Radio Front-Ends developed by Thales Communications and Security SAS standardised in Wireless Innovation Forum (WInnF); Contributions to standardisation fora (Wireless

Innovation Forum, ITU-R, ETSI, IEEE 802, IEEE P1900.6, DySPAN); Simplifying spectrum sensing measurements through a common data collection/storage format, based on the IEEE 1900.6 standard, enabling sharing of experiment descriptions, traces and data processing script for heterogeneous sensing hardware; Establishment of the W3C Federated Infrastructures Community Group to start the standardization of according semantic information models and facilitate collaboration with other groups such as the IEEE P2302 Working Group – Standard for Intercloud Interoperability and Federation (SIIF) – or the OneM2M Group on Management, Abstraction and Semantics (MAS).

- ***International collaboration***: experimentation has raised the global profile and reputation of European research and innovation initiatives. Examples include: Establishment of the Open-Multinet Forum to facilitate the international collaboration between FIRE and GENI and other members for harmonizing interfaces and information models; Global reconfigurable and software defined networks between Europe, Korea, Brazil, South Africa, Japan and US.
- ***Internet regulation and governance***: experimentation has delivered results driving the evolution of policies regulating networks and services; Examples include: interaction with national regulators (BIPT-Belgium, National Broadband Plan NBP – Ireland, BNetzA – Germany, ANFR – France, ARCEP – France, AKOS – Slovenia, Ofcom – UK); PlanetLab Europe supports the Data Transparency Lab (http://www.datatransparencylab.org/), an initiative of Telefónica I+D, together with Mozilla and MIT, to understand data policies around the world; Internet measurement testbeds are observing the efforts of network regulators around Europe as they implement the European Network Neutrality mandate.
- ***Productivity***: experimental platforms have delivered methodologies, tools and services to accelerate Internet research and innovation. Examples include: evaluation of novel concepts (5G, cognitive radio, optical networks, software-defined networks, terrestrial and underwater IoT, cloud) through pathways from laboratory to real-world settings (i.e. cities, regions and global); Easy access to different individual testbeds through a common portal with a comprehensive description of the and guidelines on how to access and use the federated testbeds; Increasing the reproducibility of experiments through experimentation descriptors linked to provisioning policies supported by benchmarking methodologies and tools to execute experiments, collect and compare results;

2.1.2 Drivers Transforming the Next Generation Internet Experimentation

The drivers expected to transform the NGI can be categorised into advances in intelligent spaces, autonomous cooperative machines and collective user experiences supported by key networking technologies are summarised as follow:

- **Intelligent Spaces**: enabling computers to take part in activities in which they never previously involved and facilitate people to interact with computers more naturally i.e. gesture, voice, movement, and context, etc. Internet of Things (IoT) enrich environments in which ICTs, sensor and actuator systems become embedded into physical objects, infrastructures, the surroundings in which we live and other application areas (e.g. smart cities, industrial/manufacturing plants, homes and buildings, automotive, agrifood, healthcare and entertainment, marine economy, etc.).
- **Autonomous Cooperative Machines**: intelligent self-driven machines (robots) that are able to sense their surrounding environment, reason intelligently about it, and take actions to perform tasks in cooperation with humans and other machines in a wide variety of situations on land, sea and air.
- **Collective User Experience**: human-centric technologies supporting enhanced user experience, participatory action (e.g. crowd sourcing), interaction (e.g. wearables, devices, presentation devices), and broader trends relevant to how socio-economic values (e.g. trust, privacy, agency, etc.) are identified, propagated and managed.
- **Key Networking Technologies**: physical and software-defined infrastructures that combine communications networks (wireless, wired, visible light, etc.), computing and storage (cloud, fog, etc.) technologies in support of different models of distributed computing underpinning applications in media, IoT, big data, commerce and the enterprise.

Within each category listed above, there are trends driving the need for experimentation that leads to the identification of Experimentation Challenge Areas that exhibit high degrees of uncertainty yet offer high potential for Next Generation Internet impact, as presented hereafter in this document.

2.1.2.1 Intelligent spaces

Internet of Things (IoT) is transforming every space in our daily professional and personal lives. IoT is one paradigm, different visions, and multidisciplinary activities [1] that much motivate this change. Today's Internet of Things is the world of everyday devices; 'things' working in collaboration, using mainly the Internet as a communication channel, to serve a specific goal or purpose for improving people' lives in the form of new services. In other words Internet of things has evolved from being simply technology protocols and devices to a multidisciplinary domain where devices, Internet technology, and people (via data and semantics) converge to create a complete ecosystem for business innovation, reusability and interoperability, without leaving aside the security and privacy implications.

The European and Global market for IoT is moving very fast towards industrial solutions, e.g. smart cities, smart citizens, homes, buildings this race is generating that IoT market applications have multiple shapes, from simple smart-x devices to complete ecosystems with a full value chain for devices, applications, toolkits and services. Making a retro-inspection and looking at this evolution and the role that Experimentation has played in this evolution, IoT have covered various phases in the evolution. IoT area has run a consolidation period in the technology, however yet the application side will run a long way to have big business markets and ecosystems deployed [3] and what is most important, the IoT users acceptance that will pay for services.

Wearable devices are the next evolution in the IoT horizon providing clear ways for user acceptance and further user-centric applications development. Wearable technology has been there since early 80's, however the limitation in technology and the high cost on materials and manufacturing caused wearable ecosystem(s) to lose acceptance and stop grow at that early stage. However in todays' technology and economic conditions where technology has evolved and manufacturing cost being reduced, Wearable Technology is the best channel for user acceptance and deployments in large user communities. Demands in technology & platforms (Supply Side) require further work to cope with interoperability, design and arts for user adoption, technology and management and business modelling. On the other hand from User & Community (Demand Side) it is required to pay attention in reliability of devices, cross-domain operation, cost reduction device reusability and anonymity and security of data.

Experimentation Challenges Areas for intelligent spaces may include:

- Engagement of large number of users/communities for co-creation, awareness and design constrains to improve user acceptability.
- Provisioning of large numbers of cooperative devices.
- Scale of data management associated with the scale of devices.
- Interoperability management considering the large array of "standards" that are emerging in the IoT space.

- Energy optimisation for low-powered chips, aligned with intelligence for smart devices and spaces.
- Security, anonymity and privacy because at intelligent spaces the amount of data that is produced is large and most of the time associated to users, by location, usage and ownership.
- Trust management mechanisms and methodologies for ensuring safe human acceptance/participation.

Next Generation Internet impacts are expected to include the:

- Acceptability for new innovative devices and technology that can change aspects of how we perceive aspects at work, live and home.
- Creation of communities for user acceptance and design including user personal identity and reflects the fashion trend of the users.
- Growth and matureness of particular areas, as result of the involvement of users in the process of validation and certification.

2.1.2.2 Cooperative autonomous machines

Autonomous machines operating in open environments on land, sea and air will cooperate to revolutionize applications in transport, agriculture, marine, energy and ecosystems dependent on high fidelity and real-time earth and environment observation and management. Local, regional, national and European initiatives are exploring how autonomous machines can become an integral part of the Internet infrastructure by bridging technical challenges (robotics, cyber physical systems, IoT, Future Internet) and dealing with social challenges of trustworthiness, dependability, security and border control.

Swarm robotics is here allowing collective behaviour by multi-robot systems consisting of boat/aircraft/ground vehicles. Miniaturization will be a continuous trend with nano- and micro-robotics (e.g., robotic implants). This leads to challenges in relation to human-robot coexistence and interaction (e.g., collective human-robot cooperation) along with machine simulation of human behaviour (e.g., reasoning, learning, feelings, and senses). In addition, current machines offer poor interaction with complex dynamic uncertain human-populated and natural environments.

Experimentation Challenges Areas include:

- Mixed human-robot environments (e.g., ITS environment where driverless vehicles can coexist with vehicles having human drivers).
- Heterogeneous mix of autonomous, manual and remotely operated machines.

- Machines operating in natural open and uncertain environments.
- Active security design, monitoring and mitigation in relation to emergent threats from deep learning intelligence machines and systemic dependencies.
- Paradigm shift within the Industrial Internet of Things domains towards Edge Computing, in which programmable, autonomous IoT end-devices can communicate with each other and continue to operate event without connectivity.
- 5G dense network infrastructures with Edge computing capabilities that are complemented with new M2M communications protocols/networks (i.e. NB-IoT).

Next Generation Internet impacts are expected to include:

- Systems that mix humans, machines and all ICT capabilities in ways that are acceptable to society.
- Operational models that optimize the use of distributed intelligence schemes (e.g., distributed AI reasoning, planning etc.).
- Methodologies and knowledge for investigating, developing and operating non-deterministic systems.
- Insights into the trade-offs between autonomy vs. predictability vs. security in cooperative machines.
- Insights into the evolution of legislation and regulatory policies.
- A digitalisation strategy for the industry 4.0 path supported by IoT emergence.

2.1.2.3 Collective human experience

Collective human experience is probably the major driver of Next Generation Internet as it dictates what the Internet is used for and its benefits to both individuals and the overall society. Internet participation is changing due to trends in open data, open and decentralised, shared hardware, knowledge networks, IoT and wearable technologies. Experiences are increasingly driven by participatory actions facilitated by decentralised and peer-to-peer community and open technologies, platforms and initiatives. Concepts such as decentralised network and software architectures, distributed ledger, block chains, open data, open networks, open democracy enable an active role of citizens rather than passive consumption of services and content. Internet participation is reaching, informing and involving communities of citizens, social enterprises, hackers, artists and students in multidisciplinary collaborative environments, as fostered by Internet Science and Digital Social Innovation communities, where creativity, social sciences and technology collide to create innovative solutions mindful of issues of trust, privacy and inclusion.

In addition, human-machine networks are emerging as collective structures where humans and machines interact to produce synergistic and often unique effects. In such networks humans and machines are both actors (Human to Machine – H2M and Machine to Machine – M2M) that raises important issues of "agency", to identify what actors are capable of and permitted to do. This is especially relevant to emerging machine intelligence where machines are capable of evolving intention based on sensing and learning about environments in which they operate. Facebook itself is purely a social machine as it supports Human to Human – H2H interaction whereas for example, precision agriculture with autonomous tractors, survey drones, and instrumented animals self-reporting health would be considered a H2M network.

Collective Awareness Platforms for Sustainability and Social Innovation (CAPSSI) are designing and piloting online platforms creating awareness of sustainability problems and offering collaborative solutions based on networks (of people, of ideas, of sensors), enabling new forms of sustainability and social innovation. These platforms provide strong ecosystems with thousands, or even millions of users, is built by mutual trust that interactive players are providing value to one another. The critical mass in the diffusion of innovations is "the point after which further diffusion becomes self-sustaining". The use of creativity in the innovation process through approaches such as "gamification" is a promising solution for keeping the critical mass of users engaged. The challenge is to identify innovative combinations of existing and emerging network technologies enabling new forms of Digital Social Innovation coming bottom-up from collective awareness, digital hyper-connectivity and collaborative tools.

The major underlying trends in this area include:

- Increasing self- and observer quantification and participation driving post broadcast networks with end user engagement in creative wide ranging processes.
- Increasing machine agency shifting beyond automation systems to situations post automata networks where autonomous machines increasingly evolve their own intentions and goals driven by increasingly high level

human defined policy constructs necessary to deal with the complexity of interaction.
- Increasing geographically localized interaction moving towards situations post "mega" mediator networks (interaction purely supported by Internet giants such as Google and Facebook).

Experimentation Challenges Areas include:

- Hyperlocal infrastructure, service and platform models.
- Deep "Me-as-a-Service" provisioning, orchestration and choreographies.
- Distribution of agency in networks, machines and people.
- Intention independent and transparent networking.
- Decentralized and distributed social networks, wikis, sensors, block chains value networks, driven by real-time human monitoring and observation sensor data streams.
- Accounting for the context through changing conditions.
- Experimenters' participatory involvement in collective awareness/intelli gence production.

Next Generation Internet impacts are expected to include:

- Operational models fostering localised ownership and control building on international standards.
- Multi-actor protocol/system design principles and methodologies for cooperating machines and people.
- Networking protocols robust to and adaptable to variations of outcomes and with transparent constraints.
- Participatory innovation and interaction models supporting collective intelligence production.
- Insights into the disruption of new value systems supported by emerging technologies such as block chains.
- Definition of new legislation to accommodate the entrance, and reduce barriers, of new technology, service and applications into daily lives of European citizens.
- Democratisation of the internet across new open and innovative services.
- Technology drivers that facilitate the emergence of new business models that may also operate under a collaborative economy based model. Thus, citizens and social impact is considered as a key driver for technology evolution.

2.1.2.4 Key networking technologies

Major initiatives such as the 5G-PPP are transforming wireless networking technologies and software defined infrastructures. 5G standardization is driving the activities for designing new protocols addressing diverse aspects of wireless networks and services.

Experimentation Challenges Areas include:

- Wireless investigations closer to real world ecosystems providing ways to demonstrate the applicability of experimental evidence to real-life application scenarios and to explore realistic coexistence/interference scenarios.
- Involve end devices: more flexible, compact, energy efficient radio platforms.
- End-to-end experimentation integrating radio – network – application/services through co-design in early phases through multi-disciplinary research, development and innovation.
- Low-end vs. high-end flexible radio platforms considering new high end spectrum bands (e.g. cm and mmWave) in contrast to mobility scenarios with (very) large-scale experimentation standardisation of low-cost SDR.
- Massive (cooperative) MIMO aiming to reduce complexity & cost, and involve distributed, heterogeneous devices forming virtual antenna arrays.
- Multi-channel radio supporting multiple virtual Radio Access Technologies (RATs) running simultaneously in a single wireless node, supporting simultaneous operation of new-innovate (RATs) and traditional RATs.
- Over the air downloading of new RATs, live reprogramming of wireless device & synchronous instantiation of new RATs (adding/updating RATs) on a set of co-located wireless devices.
- SDR 'record-and-replay' building real world wireless environment (background scenarios), E.g. out-of-band transmissions (satellite, TV, aviation, etc.) to instantiate real-life scenario emulating many concurrent systems in real world.
- Co-design of the wireless access and the optical backhaul and backbone in an integrated manner, researching at the convergence point between optical and wireless networks (FUTEBOL) [15].
- NFV/VNF applications over the platforms employed by the testbeds can assist in building modular testbeds.

- New protocols based on existing technologies (e.g. beyond LTE for cellular communications, WiGig, etc.).
- New management architectures moving towards the orchestration of functionalities towards the extreme edges of the network to reduce latency, enhance reliability and ensure data sovereignty (Edge Computing).
- Complete slicing of network-topologies including available frontend and backend services such as EPC to setup separate management domains for various use cases that require partly orthogonal QoS parameters, such as IoT/M2M or CDN networks.
- Convergence of new 5G scenarios with new IoT capabilities and technologies.
- Architectures that reduce the limitations that TCP-IP have towards the expansion of Internet (i.e. mobility, addressing, etc.).

NGI impacts are expected to include:

- Evidence for performance, viability and acceptability of approaches and technologies for 5G. Proof of scalability of 5G able to cope with increasing network traffic demand, viability to migrate from legacy to 5G, coexistent of 5G and legacy.
- Evidence for robustness of networking standards.
- Homogeneous services across networks, information technologies, IoT devices and people.

2.2 Policy Recommendations for Next Generation Internet Experimentation

The drivers for the Next Generation Internet presented in this document i.e. Intelligent Spaces, Autonomous Cooperative Machines, Collective User Experience, Key Networking Technologies act as study areas that requires a dedicated consideration in policy support and European agenda reorganisation. The clear view in how the drivers are a priority for Europe, likewise the increasing convergence of Internet technologies and more involvement of the society drive the need to reconsider the design and scope of future initiatives. The following recommendations are designed to maximise the potential for Europe to create technological breakthroughs and deliver truly global impact towards Next Generation Internet Experimentation.

More Than Just Technology Networks: Successful Internet platforms deliver technology-enhanced ecosystems supporting large-scale efficient interactions between platform users. A technologically advanced platform without users will deliver no impact. Europe must focus on developing where networks of users and technology can coexist in ways that support sustainable growth of real life network and as a consequence drive demand for emerging information and communications network architectures.

Transparent and Accelerated Innovation Pathways: Industry and SMEs need clear routes to market for research and innovation activities. Platforms that deliver insight that cannot be adopted within applicable investment cycles are not relevant to business. Europe must establish experimental platforms with clear innovation pathways that deliver commercial opportunities whilst addressing contemporary/legacy constraints, market-driven interoperability/standardisation, and regulation.

Programmatic Consideration of Business and Technology Maturity: Large industry and SMEs have different capacity to invest, appetites for risk and rates of return. Europe must design and nurture current initiatives with a business and technical strategy that optimally aligns technology lifecycle phases with appropriate business engagement models for different stakeholders (Industry vs SMEs vs Research).

Quantifiably Large and Dynamic: Ecosystems must be sufficiently large and interactive to understand performance, acceptance and viability of platform technologies in real-world scenarios. Large-scale is often cited but rarely quantified. Europe must establish measurable criteria and tools for Next Generation Internet ecosystems (e.g. infrastructure, platforms, data, users, etc.) necessary to support research and pre-commercial activities ecosystems (i.e. up to city-scale), and mechanisms to rapidly scale networks towards market entry.

Nondeterministic Behaviour vs Replicability: Insights gained in one specific physical or virtual situation need to be applied in many global situations to maximise the return on investment. Computer science wants to deliver replicable experimentation however this is looking increasingly unachievable considering that networks are inherently non-deterministic and that open systems and real-life experiments only exacerbate uncertainties. Europe must foster the development of methods and tools supporting investigation into non-deterministic systems incorporating human and machine interaction in open environments that allow for insights to be replicated across the globe.

Next Generation Internet Technology and Investment Education: Learning about the potential of NGI technologies and business implications is essential for the next generation of entrepreneurs and SMEs in Europe and beyond. Unless innovators understand the ecosystem and technology potential sufficiently to convince investors (e.g. business units, venture capitalists, consumers, etc.) of the value proposition continuation funding and consequent impact will not be delivered. Europe must support platforms that educate the next generation entrepreneurs and technologists whilst supporting SMEs in the development of NGI business plans and provide ways to test the viability of solutions with potential investors.

Multidisciplinary Action: The interconnectedness of Next Generation Internet Experimentation systems means that multidisciplinary teams must work together through common objectives. Europe must support end-to-end experimentation driven by multidisciplinary teams from different technology domains (e.g. wireless networks, optical networks, cloud computing, IoT, data science) in relation to vertical sectors (healthcare, creative media, smart transport, marine industry, etc.) and horizontal social disciplines (e.g. psychology, law, sociology, arts).

Efficient and Usable Federations: Collaboration is often the most cost effective way to acquire capability, scale or reach necessary to achieve an objective. Yet the benefits of collaboration through federated platforms are limited by the barriers of interoperability, multi-stakeholder control, trust concerns and policy incompatibilities. Europe must support federated Experimentation-as-a-Service approaches where there are clear benefits to users of the federation and where techniques lower the barrier to experimentation and cost of maintaining federations through increased interoperability, usability, trustworthiness, and dynamics by contributing to or leading market accepted standardisation efforts.

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2.4 Experimentation Facilities Evolution towards Ecosystems for Open Innovation in the Internet of Future

2.4.1 Changes in the FIRE Portfolio

The FIRE **demand side** is changing as well, with changes in experimenter demands and requirements, and higher expectations as regards how FIRE should anticipate the needs and requirements from SMEs, industry, Smart Cities, and from other initiatives in the scope of Future Internet such as Internet of Things and 5G. Within FIRE this is also anticipated by **new types of service concepts**, for example Experimentation-as-a-Service. These new concepts affect the methods and tools, the channels for offering services to new categories of users, and the collaborations to be established with infrastructure and service partners to deliver the services.

2.4.2 Technological Innovation and Demand Pull

In response to the envisaged changes in the FIRE landscape, AmpliFIRE has identified new research directions based on interviews, literature surveys and leading conferences, and highlighted what the FIRE research, facilities and community may look like in the future [1]. We found that funded Open Calls and STREPs, and unfunded Open Access opportunities, which are increasingly aligned with the main FIRE experimental facilities, are influencing FIRE's evolution from the demand side, by showing customer "pull" supplementing and even replacing technology "push." Thus it is expected that FIRE, which has been technology-driven, will increasingly be shaped by demand-pull factors in the period 2015–2020. These user demands will be based on four main trends:

- The Internet of Things: a global, connected network of product tags, sensors, actuators, and mobile devices that interact to form complex pervasive systems that autonomously pursue shared goals without direct user input. A typical application of this trend is automated retail stock control systems.
- The Internet of Services: internet/scaled service-oriented computing, such as cloud software (Software as a Service) or platforms (Platform as a Service).
- The Internet of Information: sharing all types of media, data and content across the Internet in ever increasing amounts and combining data to generate new content.

- The Internet of People: people to people networking, where users will become the centre of Internet technology—indeed the boundaries between systems and users will become increasingly blurred.

In order to contribute to these four fast moving areas, the FIRE ecosystem must grow in its technical capabilities. New networking protocols must be introduced and managed, both at the physical layer where every higher wireless bandwidth technologies are being offered, and in the software interfaces, which SDN is opening up. Handling data at medium (giga to tera) to large (petabyte) scale is becoming a critical part of the applications that impact people's lives. Mining such data, combining information from separated archives, filtering and transmitting efficiently are key steps in modern applications, and the Internet testbeds of this decade will be used to develop and explore these tools.

Future Internet systems will integrate a broad range of systems (cloud services, sensor networks, content platforms, etc.) in large-scale heterogeneous systems-of-systems. There is a growing need for integration e.g. integration of multi-purpose multi-application wireless sensor networks with large-scale data-processing, analysis, modelling and visualisation along with the integration of next generation human-computer interaction methods. This will lead to complex large-scale systems that integrate the four pillars: things, people, content and services. Common research themes include scalability solutions, interoperability, new software engineering methods, optimisation, energy-awareness, and security, privacy and trust. To validate the research themes, federated experimented facilities are required that are large-scale and highly heterogeneous. Testbeds that bridge the gap between infrastructure, applications and users and allow exploring the potential of large-scale systems which are built upon advanced networks, with real users and in realistic environments will be of considerable value. This will also require the development of new methodological perspectives for FIRE [8].

As we emphasize focusing on "smart systems of networked applications" within the FIRE programme, the unique and most valuable contribution of FIRE should be to "bridge" and "accelerate": create the testing, experimenting and innovation environment which enables linking networking research to business and societal impact. FIRE's testbeds and experiments are tools to address research and innovation in "complex smart systems", in different environments such as cities, manufacturing industry and data-intensive services sectors [9]. In this way, FIRE widens its primary focus from testing and experimenting, building the facilities, tools and environments towards closing the gap from experiment to innovation for users and markets.

2.4.3 Positioning of FIRE

This leads to the issue of how to **position FIRE in relation to other initiatives** in the Future Internet landscape. FIRE is one among a number of initiatives in the Future Internet research and innovation ecosystem. FIRE seeks a synergetic and value adding relationship with other initiatives and players such as GÉANT/NRENs and the FI-PPP initiatives related to Internet of Things and Smart Cities, EIT Digital, the new 5G-PPP and Big Data PPP initiatives, the evolving area of Cyber-Physical Systems, and other. For the future, we foresee a **layered Future Internet infrastructural and service provision** model, where a diversity of actors gather together and ensure interoperability for their resources and services such as provision of connectivity, access to testbed and experimentation facilities, offering of research and experimentation services, business support services and more. Bottom-up experimentation resources are part of this, such as crowd sourced or citizen- or community-provided resources. Each layer is transparent and offers interoperability. Research networks (NRENs) and GÉANT are providing the backbone networks and connectivity to be used by FIRE facilities and facilities offered by other providers.

In this setting, FIRE's core activity is to provide and maintain sustainable, common facilities for Future Internet research and experimentation, and to provide customized experimentation and research services. However, given the **relevance of experimentation resources for innovation**, and given the potential value and synergies which FIRE offers to other initiatives, FIRE should assume a role in supporting experimentally-driven **research and innovation of technological systems**. For this to become reality FIRE and other initiatives should ensure cooperation and FIRE should also consider opening up to (other) public and private networks, providing customized facilities and services to a wide range of users and initiatives in both public and private spheres. FIRE's core activity and longer term orientation requires the ability to modernize and innovate the experimental infrastructure and service orientation for today's and tomorrow's innovation demands.

2.4.4 Bridging the Gaps between Demands and Service Offer

The gaps between the technologies presently offered in FIRE as testbeds, and the gaps between the layers in which its communities have formed are large. For example, the gaps between wired and wireless networking, between networking researchers and cloud application developers, and between both sorts of developers and end user input all require bridges that exist today only as research efforts (an example is the Fed4FIRE project). Developing future scenarios and identifying prospective user requirements are useful tools to shape and drive those bridging activities and chart the most direct paths from the present fragmented FIRE portfolio of testbeds, which are either hardware or user-oriented, to the goals of Horizon 2020. This requires a sustained effort to articulate how the technical goals of the present FIRE activities can be lifted, channelled and amplified to support the societal goals represented in Horizon 2020. This places requirements on the FIRE community which, as engineering teams with an often academic focus, will need to collaborate with different types of communities and actors. The FIRE community needs to clarify and justify such requirements and identify new instruments and relationships with business and SMEs that can draw upon FIRE's strengths. For this, we must expose the gaps and identify the communities that need to be engaged or created. This helps to create the "pull" that can make FIRE effective as 2020 approaches, and assist the individual projects as they provide the "push."

2.4.5 Testbed-as-a-Service

Increasingly, experimenters, developers and innovators expect to find the tools and services they need and the infrastructure in which they will do measurements and develop applications packaged in groups that allow easier access and more rapid development. The catch phrase "X as a service" (XaaS) captures these expectations. Today's infrastructures, even with the strides made towards federation and provision of powerful standard enablers, are still far from the desired shape presented in Figure 2.1. The Testbed as a Service concept (all of Figure 2.1) consists of as many as three connected layers and two value-added offerings, each of which needs to offer standard APIs and be easily adapted to multiple purposes over both long and short term.

Infrastructure available as a service benefits from the federation accomplishments of Fed4FIRE and GENI using the model of slices, and the technologies around SFA and OMF or NEPI for access to infrastructure, acquisition of reservations for resources, dispatch of experiments and capture of their results. But there is much more to be done to make these tools available to a broader audience, reduce the training requirement and learning curve. There are common elements now standardized in the OpenFlow community to make the interface to more flexible and powerful networking infrastructures itself more flexible, but these only begin to explore the ways in which the communications infrastructure can be more responsive to application

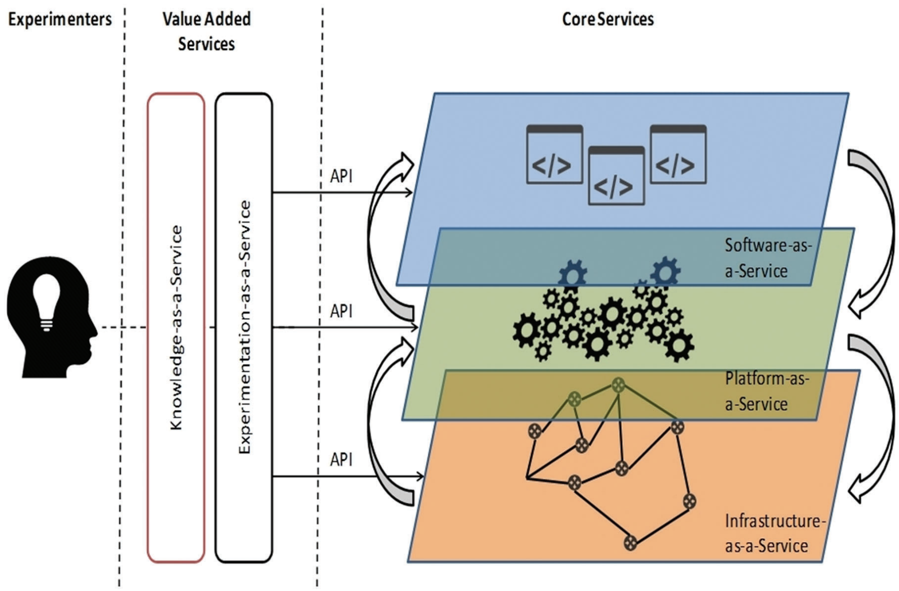

Figure 2.1 X as a Service [7].

requirements. While standard building blocks such as OpenStack exist, there are strong pressures to enhance these. FIRE can make a critical difference in evaluating the platform components proposed for extending this service concept and understanding their value. Also needed are studies of the possible options at the interfaces and their codification into APIs between the layers, and to implement services to support new demands from users more interested in the results of an experiment rather than performing their experiments themselves.

Data curation, archiving, and tools for access of experimental data, learning from experimental data, and extracting useful information using sparse sampling and other complexity techniques will be key components of Knowledge-as-a-Service. While much research in these "big data" areas is being done already in academia and in industry, FIRE with its rich trove of experimental data from Smart Cities projects, can make a contribution. Focusing on the environmental data that sensor-rich cities collect might be a good strategy, avoiding the sensitivities around healthcare data and the proprietary nature of most commercial and market activity data. Also, "big data" studies do not as a rule involve truly vast amounts of data, or require access to data centers on the largest commercial scales.

Benefiting from these opportunities requires a foundation of adaptable infrastructure, wired and wireless, software-defined, more open than ever before. The FIRE projects have made great strides in federating different kinds of facilities and exposing their novel capabilities to experimenters and end users. To meet the new demands and support the expansion to become an Internet of Things, Services, Information and People, FIRE will provide testing facilities and research environments richer than the commercial world or individual research laboratories can provide.

2.4.6 Future Scenarios for FIRE

For setting out a transition path from the current FIRE facilities towards such a "FIRE Ecosystem", AmpliFIRE identifies two key uncertainty dimensions and in that space of outcomes proposes four alternative future development patterns for FIRE (illustrated in Figure 2.2):

1. ***Competitive Testbed as a Service***: FIRE as a set of individually competing testbeds offering their facilities as a pay-per-use service.
2. ***Industrial cooperative***: FIRE becomes a resource where experimental infrastructures (testbeds) and Future Internet services are offered by co-operating commercial and non-commercial stakeholders.
3. ***Social Innovation ecosystem***: FIRE as a collection of heterogeneous, dynamic and flexible resources offering a broad range of facilities e.g. service-based infrastructures, network infrastructure, Smart City testbeds, support to user centred living labs, and other.
4. ***Resource sharing collaboration***: federated infrastructures provide the next generation of testbeds, integrating different types of infrastructures within a common architecture.

These scenarios are aimed at stretching our thinking, but FIRE must choose its operating points and **desired evolution** along these two axes. The vertical axis ranges from a coherent, integrated portfolio of FIRE activities at bottom (a natural foundation) up to individual independent projects (the traditional situation), selected solely for their scientific and engineering excellence. The horizontal line reflects both the scale of the funded projects and the size of the customer or end-user set that future FIRE projects will reach out to and be visible to. Clearly FIRE must be open to good ideas at multiple points along the scale of size. For the larger efforts, which need to engage a broad cross-section of the engineering community or the end users, the impact can be enormous.

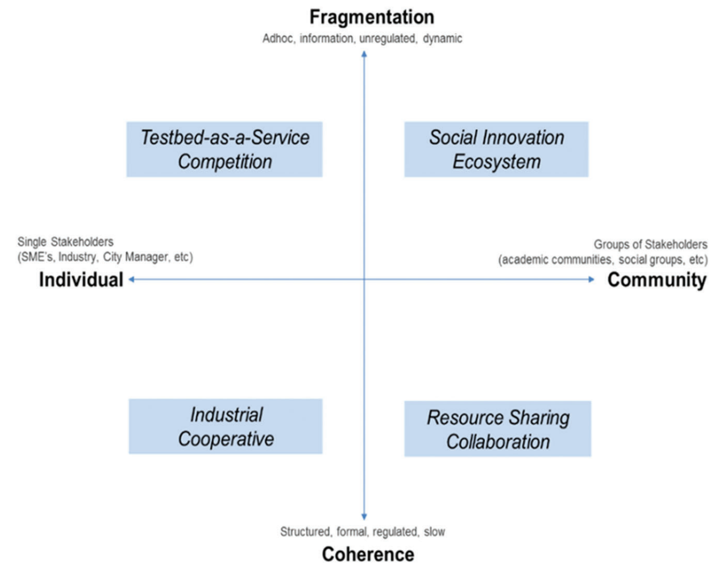

Figure 2.2 FIRE scenarios for 2020 [1].

Really innovative contributions may come from smaller, more aggressive, riskier projects. Large-scale EC initiatives such as FI-PPP, 5G-PPP, Big Data PPP and around Internet of Things (AIOTI) should have an influence on their selection and justification. Early engagement is essential to accomplish this.

2.5 FIRE Vision and Mission in H2020

FIRE's current mission and unique value is to offer an efficient and effective federated platform of core facilities as a common research and experimentation infrastructure related to the Future Internet; this delivers innovative and customized experimentation capabilities and services not achievable in the commercial market. FIRE should expand its facility offers to a wider spectrum of technological innovations in EC programmes e.g. in relation to smart cyber-physical systems, smart networks and Internet architectures, advanced cloud infrastructure and services, 5G network infrastructure for the Future Internet, Internet of Things and platforms for connected smart objects. In this role, FIRE delivers experimental testing facilities and services at low cost, based upon federation, expertise and tool sharing, and offers all necessary expertise and services for experimentation on the Future Internet part of Horizon 2020. For the **medium term**, FIRE's mission and added value is to support the Future

Internet ecosystem in building, expanding and continuously innovating the testing and experimenting facilities and tools for Future Internet technological innovation. FIRE continuously includes novel cutting-edge facilities into this federation to expand its service portfolio targeting a range of customer needs in areas of technological innovation based on the Future Internet. FIRE assumes a key role in offering facilities and services for 5G. In addition FIRE deepens its role in experimentally-driven research and innovation for smart cyber-physical systems, cloud-based systems, and Big Data. This way FIRE could also support technological innovation in key sectors such as smart manufacturing and Smart Cities. FIRE will also include "opportunistic" experimentation resources, e.g., crowd sourced or citizen- or community- provided resources.

For the **longer term**, our expectation is that Internet infrastructures, services and applications form the backbone of connected regional and urban innovation ecosystems. People, SMEs and organisations collaborate seamlessly across borders to experiment on novel technologies, services and business models to boost entrepreneurship and new ways of value creation. In this context, FIRE's mission is to become the research, development and innovation environment, or "accelerator", within Europe's Future Internet innovation ecosystem, providing the facilities for research, early testing and experimentation for technological innovation based on the Future Internet. FIRE in cooperation with other initiatives drives research and innovation cycles for advanced Internet technologies that enable business and societal innovations and the creation of new business helping entrepreneurs to take novel ideas closer to market.

> In 2020, FIRE is Europe's open lab for Future Internet research, development and innovation. FIRE is the technology accelerator within Europe's Future Internet innovation ecosystem. FIRE is sustainable, part of a thriving platform ecosystem, and creates substantial business and societal impact through driving technological innovation addressing business and societal challenges.

2.6 From Vision to Strategic Objectives

The role of the FIRE vision and mission statement is to inspire for the future, answering the question "Why FIRE?" and "Where to go?" Within the context of uncertainties surrounding FIRE's longer term future, the actual evolution of FIRE is shaped by the range of scenarios and by the planning and implementation decisions that are being taken within the EC and within FIRE and related initiatives. For example, the Fed4FIRE project to create a high-level framework is driving coherence in technology, operations and governance across many of the FIRE facilities. There are also interesting implications regarding collaboration of FIRE facilities with related programs such as Future Internet PPP and possibly the Big Data PPP which are more oriented towards business innovation than FIRE. Testbeds participating in these initiatives may have to operate in more than one scenario, requiring them to adapt new operational models, legal contexts and technical implementations.

To structure the process of identifying future directions, FIRE should agree on strategic objectives for its mid- and longer term evolution. Technical objectives oriented towards FIRE's core activity are a necessity but they are not sufficient on their own as FIRE also needs strategic positioning in terms of how it achieves sustainable value creation activity and how it positions and interacts with other major initiatives.

2.6.1 Strategic Objectives

We identified the overall strategic objective for FIRE as to become a sustainable environment for research, development and innovation in the Future Internet, supporting researchers and the community to tackle important problems, and acting as an accelerator for industry and entrepreneurs to take novel ideas closer to market. Figure 2.3 visualises the potential strategies that could be employed to achieve these objectives in a high-level roadmap.

The key strategic objectives for FIRE will be:

- For 2016: to increase its relevance and impact primarily for European wide technology research, but will also increase its global relevance.
- For 2018: to create substantial business and societal impact through addressing technological innovations related to societal challenges.
- For 2018: to become a sustainable and open federation that allows experimentation on highly integrated Future Internet technologies; supporting networking and cloud pillars of the Net Futures community.
- For 2020: to become the RDI environment space that is attractive to both academic researchers, SME technology developers, and industrial R&D companies with emphasis on key European initiatives such as 5G, Big Data, IoT and Cyber-Physical Systems domains.

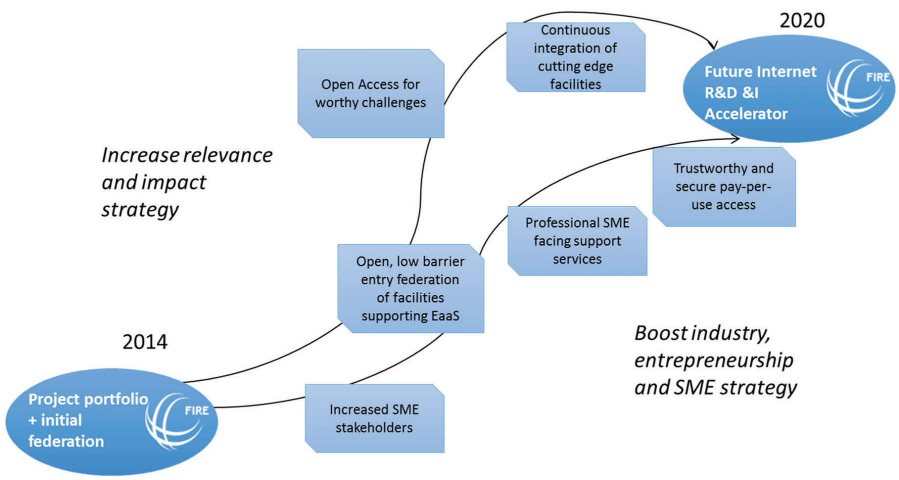

Figure 2.3 Overall strategic direction of FIRE [2].

2.6.2 FIRE's Enablers

AmpliFIRE's report on FIRE Strategy [2] provides a detailed elaboration of strategic directions for FIRE's "enablers": the domains of service offering, facilities and federation, EC programme relations, ecosystem development, and collaboration. Below we concisely address some of the main points.

Service offering. On the shorter term, FIRE's service offer strategy must ensure that FIRE remains relevant and meet current and future experimenter demands and be driven by demand [5, 7]. FIRE should also promote common tools and methodologies to perform experiments. FIRE's offer in the next years will transform towards a service-oriented framework where the concept of Experimentation as a Service is central. The model presented in Figure 2.1 depicts how facilities or federations can offer a service to experimenters. The lowest layer is the infrastructure, the actual physical machines. In the middle is the platform layer, able to control the infrastructures in a more organized manner, making use of predefined APIs, such as software-defined networks. On the topmost layer, software can be run as a service, giving experimenters access to applications. Crossing these layers, two services can be defines. One is experimentation as a service, where experimentation is offered in a customized approach with less or no concern about the infrastructure, platform or services behind the scene; just knowing that it is available and can be accessed is in most cases enough. The Fed4FIRE project serves as an example. Additionally a final step could be knowledge as a service, where experimenters are helped in order to set up experimentation, but also that lessons can be learned from the different experiments (what worked, what didn't work) and can be disseminated.

User and community ecosystem strategy. This will become a more and more important aspect of FIRE strategy and future business model. The concept of platform ecosystem and multi-sided platforms is potentially relevant for FIRE and opens new opportunities. Unlike a value chain or supply chain, a (multi-sided) platform-based activity brings together and enables direct interactions within a value network of customers, suppliers, developers and other actors. The range of FIRE facilities and services can be seen as constituting a platform ecosystem facilitating multi-sided interactions. For example, developer communities may use the FIRE facilities to directly work with business customers on technology and product development, whereas the current FIRE service model focuses on giving researchers and experimenters access to FIRE facilities[1]. The issue is then to what extent the current FIRE ecosystem realizes its opportunities and what the strategic options are to extend the current FIRE model to a platform-based ecosystem model.

Collaboration strategy. Given FIRE's positioning in the wider Future Internet ecosystem collaboration in the shorter and longer term is essential and must be grounded in clear value propositions [10]. To reach the next phase FIRE should target both strong ties and loose ties collaboration. By strong ties we refer to relationships that have developed throughout many years, while loose ties collaboration is represented by more dynamic relationships. Both are of equal importance. By close collaboration between different actors within the FIRE value-network we can capitalize on sharing of testbed resources, and foster FIRE to become more dynamic and user-driven to attract and serve a wider base of partners. This also includes a complex prosumer exchange value-network structure where providers of testbed assets also can be users and vice versa. In existing FIRE collaborations these prosumer structures can be found as strong elements for sustainability beyond the lifetime of a project and foster long-term relationships. Also the framework for cooperation must support flexible forms and easier entry into collaborations as well as to sustain beyond the lifetime of a project.

As FIRE is positioned in an environment of continuous change also FIRE collaboration relations will evolve and new relationships and partners

[1]In [3], AmpliFIRE discusses broadening the Future Internet user base by providing experimenter solutions, offering APIs that match community practices (BonFIRE, Experimedia).

will emerge finding new opportunities for win–win by collaboration but also defining new demands for being part of the FIRE value-network. In this context FIRE needs evolution in several domains and even to reflect on its position in being a “research and experimentation environment” as this is being more attractive for research partners than other actors. How can FIRE also serve stakeholders with specific interest in the development of new services and products for the Future Internet with a commercial purpose? These stakeholders are mainly representatives from industry and their requirements on collaboration models might differ from the existing more research oriented. To increase their attraction for FIRE collaboration the FIRE value-network should be extended by complementary partners to the traditional ICT actors, e.g. customers and users. But can FIRE really fit all? FIRE will remain interested to cooperate with core initiatives within the landscape of Future Internet research, innovation and experimentation, like 5G-PPP, FI-PPP, Internet of Things, Smart Cities, Big Data, which requires FIRE to show a clear position on its offerings and uniqueness. Some examples:

- **5G-PPP**: FIRE experimental facilities could potentially be of use for the 5G-PPP. Fed4FIRE offers a large number of federated facilities across Europe of which most are potentially important for 5G testing (including cellular networks, WiFi and sensor based networks, cognitive radio networks, but also SDN and cloud facilities). CREW offers open access to wireless testbed islands and advanced cognitive radio components as well as support services.
- **FI-PPP**: integration of relevant FIRE facilities in XiFi’s federated nodes infrastructure, especially physical computing/storage facilities and back-end infrastructures such as sensor/IoT networks used by applications and services to run experiments on top of them.
- **GÉANT/NRENS**: cooperation in terms of connectivity is ongoing in several FIRE projects. Other opportunities could include extending GÉANT service offerings to include testbed as a service. Some related activities are going on in federation of testbeds, and experiment management towards Experimentation-as-a-Service (Fed4FIRE), and resource control and experiment orchestration and monitoring (OpenLab, FLEX, CREW). FIRE projects might extend their use of GÉANT/NREN resources and FIRE and GÉANT may cooperate in services and resources. FIRE may leverage GÉANT facilities and improve GÉANT services adding services such as testbed access. FIRE and GÉANT can also collaborate on SDN/Networking Protocols & Management.

- In relation to **Smart Cities**, and technological innovations in the domain of **Internet of Things** and **cloud computing** of high relevance for city innovation, FIRE moves further into this direction in projects such as OrganiCity and FIESTA. Next steps would be to establish project-oriented discussions and explore opportunities for common calls with key organisations in this area.

In order to develop FIRE collaboration opportunities for the future the ability in realization and implementation of concrete collaboration models will be essential. To do so collaborating partners must be able to define what is the goal of collaboration, what is the win-win and what are the assets used to enable collaboration and to establish an exchange structure for the collaboration as well as models for governance. Therefore we should ask ourselves *Who* is the formal body to interact with and to formalize collaboration? Finally, realizing the FIRE collaboration vision beyond 2020 requires to be linked with and to influence what FIRE partners today and in the future define as the strategic directions of FIRE and what partners want it to be to be attractive for collaboration.

Portfolio management. There is an inevitable problem of getting coherence with a selection of projects chosen individually for their excellence by mostly academic referees. Incentives added in the past include asking projects to present evidence of a relationship with existing FIRE projects (easy to do towards the end of a Framework Programme, not so easy at the outset of one, but FIRE's continuity may alleviate this). This results in project groupings which allow more varied approaches still focused on a single infrastructure technology or bringing a single technology closer to end users.

One suggestion that has been raised in recent years is finding ways in which the FIRE programme can provide some of the assistance and even direction that is offered to start-up companies. This may involve management attention and involvement in changing project directions that were difficult to achieve under FP7 and may have become impossible in Horizon 2020. Nonetheless, we present in this review the suggestion that a support action focused on achieving earlier and better exploitation might be considered and describe how it could work, and what problems it would solve.

Managing innovation and exploitation needs attention and could be addressed more systematically. Today, many projects end after the first demonstrations are presented. Exploitation may be planned, but it lies in the future, if it happens at all. Project structures, as specified in future calls could, by the middle period of 2016–2018, require that some projects have their capabilities demonstrated and external interfaces ready for the first full review.

These projects could then report progress on external utilization and exploitation by the end of the project. Although not all projects will, or should, achieve this, we can imagine seeing identification of partners and a pathway to commercialization by the end of a FIRE project.

Future sustainability. Sustainability of the FIRE ecosystem has been raised as a concern in many of the interviews we conducted after issuing the draft FIRE radar vision document. Users want to see one or a few components of a FIRE testbed sustained (or successfully evolving) and the ultimate responsibility lies with the institutions in which these components reside. If only one institution is involved, as is the case with iMinds in Belgium, a member of OpenLab, Fed4FIRE and CREW, then sustainability of the several component testbeds that iMinds supports (the Virtual Wall, the W.iLab.t and others) is addressed through the institution pursuing multiple means of support. In the case of iMinds, all modes seem to be open – EC funding, regional support and industrial partnerships have all contributed. For testbeds whose components are distributed over multiple institutions, projects like BonFIRE and OFELIA have created informal consortia which continue beyond any single EC integrated project, and link only the key partners. Typically these consortia intend to offer something like Open Access or similar lightweight short-term involvement in their testbed's use, and will explore multiple sources of funding to make this happen. Accounting systems to allow fairly precise allocation of costs to the different uses that result are being created as they will be needed downstream in this model. Finally, the OneLab Foundation is an actual legal entity that has been created to manage the activities of the PlanetLab Europe, NITOS, and FIT-IoT Lille testbeds using the network operating center (NOC) and federation toolkit that has been created under OpenLab and Fed4FIRE.

2.7 FIRE Roadmap towards 2020

2.7.1 Milestones

The FIRE Roadmap of milestones is shown in Table 2.1 [3]. It essentially pinpoints milestones for FIRE to deliver within the framework of roadmap solutions. For example, "before 2016, open access will be a requirement of a FIRE testbed". The table is split into three phases: i) 2014–16, ii) 2016–2018, iii) 2018–2020 that identify the milestones and decision points of the roadmap. These phases are then broken down into a common template of solutions within layers of the FIRE ecosystem:

Table 2.1 FIRE Roadmap Milestones 2014–2020

	2014–2016	2016–2018	2018–2020
FIRE Resources Solutions	Testbeds will be established in the domain of software services (2016) Gradual implementation of converged federation (2016)	Cutting-edge FIRE testbeds are established in key areas such as 5G, IoT, Big Data (2016–2017) A converged set of resources is aligned with 5G architectures (2017–2018)	Continuing to establish cutting-edge FIRE testbeds in key areas such as 5G, IoT, Big Data (2018–2020) A converged set of resources is aligned with 5G architectures (2018–2020)
FIRE Services and Access Solutions	Open Access is implemented as a requirement (2015–2016) Projects are funded that develop services supporting reproducibility (M16) EaaS solutions will get harmonized and interoperable (2016–2017) All FIRE Open Access projects get integrated into one single portal for offering coherent package of services (2015–2016)	Mechanisms are set in place that support cross-facility experimentation through a central experimentation facility (2016) A FIRE Broker initiative is implemented providing broker services across the FIRE portfolio (2017)	Implementation of a new financing model to ensure sustainability of resources (2019) FIRE legal entity enables pay-per-use services (2018–2019) FIRE facilities implement secure and trustworthy resources capabilities (2019)
FIRE Experimenters Solutions	Alignment of EC units leads to cross-domain access to facilities and services (2016–2017) FIRE is made accessible to wider communities by offering community APIs (2015–2016)	Alignment of FIRE and 5G in terms of facilities, services and experimentation actions (2016–2017) Introduction of accelerator functionality for "technology accelerator"	SMEs are key target group of FIRE, with Open Calls specifically dedicated to SMEs (2018) Professionalisation of FIRE services marketing Introduction of startup funding as part of "full-service accelerator"
FIRE Framing conditions solutions	Professionalization of FIRE's internal organization (2015) Collaboration agreements in place between FIRE and large initiatives such as 5G PPP (2015)	A Network of Future Internet Initiatives is established (2016–2017) Cross-initiative collaboration in the Future Internet domain is implemented to enable seamless interconnection	FIRE, within NFII, is operating as legal entity to ensure sustainability and professionalisation

- The FIRE *resources* layer considers the role of the testbeds made available through FIRE i.e. whose development is funded in part by the FIRE programme. These represent an important element in achieving objectives through making the right experimental facilities available, sustaining facilities, and ensuring provision meets user demands.
- The FIRE *service and access* layer considers the services provided to the user to allow them to perform experiments; these can be experimental services to perform and monitor experiments (set up experiment, report on results, etc.), services to utilise facilities directly (SLA management, security, resource management), and central services managing the FIRE offering (e.g. a FIRE portal). Also the mechanisms employed to allow users to access and make use of the testbed are considered e.g. fully open access, open calls, policy based access, etc.
- The FIRE *Experimenter* layer considers the consumer, i.e. the overall FIRE user base who utilise the available FIRE testbed resources. Solutions in this layer will implement changes in the user base, e.g. changing from a traditional academic community in Europe, to a more global community, and/or more industry and SME users.
- FIRE *framing conditions* solutions address the activities concerning the ecosystem conditions and the activities carried out to operate FIRE, and also integrate FIRE with wider initiatives.

Phase I: 2014–2016

In this period, partly covering the new Work Programme 2016–2017, we expect continued and intensified attention to funding facilities that increase impact and relevance by balancing Future Internet pillars. Testbeds in the domain of software and services are prioritized. Cutting-edge testbeds should be added in key areas 5G, IoT, Big Data and Cyber-Physical systems. Loosely-coupled FIRE federation will be continued in order to simplify cross-domain experimentation. In order to increase the experimental use of facilities, FIRE-funded facilities will be required to offer open access Also, ease of use and repeatability and reproducibility of experiments must be improved by promoting Experimentation-as-a-Service concepts. Both actions aim at simplifying cross-domain experimentation. The main priority regarding experimenter solutions is to increase the user base and actual use of facilities, by making FIRE accessible to the larger Future Internet community, by offering community APIs and establishing interoperability. The FI-PPP and GENI are prominent initiatives in this time period. Also, common experimentation standards across initiatives will be required, such as cloud and IoT APIs. Strategic alignment and collaboration between FIRE and other EC programmes (DG CONNECT and wider) needs to be pursued, e.g. preparing for joint calls and stimulating interactions among the Unit priority areas. FIRE as a community needs to start working towards a credible level of organisation to prepare for sustainability and professional service offers.

Phase II: 2016–2018

In this period, FIRE establishes cutting-edge Big Data facilities relevant to research and technology demands to support industry and support the solving of societal challenges. Federation activities to support the operation of cross-facility experimentation are continued. A follow-up activity of Fed4FIRE is needed which also facilitates coordinated open calls for cross-FIRE experimentation using multiple testbeds. Additionally, a broker service is provided to attract new experimenters and support SMEs. This period ensures that openly accessible FIRE federations are aligned with 5G architectures that simplify cross-domain experimentation. Second, via the increased amount of resources dedicated to Open Calls, FIRE will create an Accelerator functionality to support product and service innovation of start-ups and SMEs. For this, FIRE will establish a cooperation with regional players and other initiatives. FIRE continues to implement professional practices and establishes a legal entity which can engage in contracts with other players and supports pay per use usage of testbeds.

Phase III: 2018–2020

FIRE continues to add new resources that match advanced experimenter demands (5G, large-scale data oriented testbeds, large-scale IoT testbeds, cyber-physical systems) and offers services based on Experimentation-as-a-service. The services evolve towards experiment-driven innovation. More and more FIRE focuses on the application domain of innovative large-scale smart systems. Implementing secure and trustworthy services becomes a key priority, also to attract industrial users. Responsive SME-tailored open calls are implemented, to attract SMEs. FIRE continues the Accelerator activity by providing dedicated start-up accelerator funding. FIRE takes new steps towards (partial) sustainability by experimenting with new funding models. Sustainable facilities are supported with continued minimum funding after project lifetime. FIRE community has achieved a high level of professional operation. FIRE contributes to establishing a network of Future Internet initiatives which works towards sharing resources, services, tools and knowledge and which is supported by the involved Commission Units.

2.7.2 Towards Implementation – Resolving the Gaps

Setting out a vision, strategy and roadmap must go hand in hand with being aware about the gaps that need to be resolved. Two categories can be distinguished: 1) gaps with respect to the current FIRE offerings, and 2) gaps with respect to the FIRE vision. The current FIRE offering has evolved from individual projects, many of which had specific project objectives to build testbeds on which to make experiments, but were not expected to federate with others, be open for researchers outside of the project consortium, or continue after the end of the project contract timeframe. The fact that these features are now increasingly being offered is a result of earlier gap analyses by FIRE stakeholders and actions taken by the EC to address the issues incrementally in successive Calls for Proposals. The assessment of FIRE's relevance for Future Internet experimenters is, however, a continuous process; new technologies, devices and protocols emerge and new ways of improving the experience for both experimenters and testbed providers are identified. AmpliFIRE's Portfolio Capability Analysis [4] lists some of the main gaps with respect to the current FIRE offering that have been identified by experimenters (or potential experimenters). In many cases, these gaps reflect the increasing interest being shown in the FIRE facilities by SMEs and industry organisations, as opposed to the traditional users, who are largely from the academic community.

Many of the gaps, in particular those associated with the usage of FIRE testbeds by a higher number of SMEs and industrial organisations, are common to the needs for FIRE testbeds identified by the reports on FIRE Vision [1] and FIRE Future Structure and Evolution [2]. However, we have identified additional requirements, related to 1) the concept of FIRE becoming the common European Experimentation Infrastructure incorporating FIRE testbeds with ESFRI, FI-PPP, CIP ICT-PSP, GEANT; and 2) the transitioning of the more mature FIRE facilities towards business innovation and education platforms within (for example) the EIT Digital context. In general terms – whilst FIRE has been strong, historically on networking topics – more effort needs to be placed now on service aspects and extending expertise into the commercial area. Testbed-as-a-Service, Experimentation-as-a-Service, Knowledge-as-a-Service, and all of the functions and tools that underpin these concepts become increasingly important. We propose the following actions to address the identified gaps:

- Common FIRE tools should be built for TaaS, EaaS and KaaS, rather than each project developing their own.

- One FIRE portal should exist, through which the resources of all FIRE projects can be accessed by experimenters as a single entity.
- There should be a more coordinated approach to FIRE collaboration (e.g. with respect to support for the FI-PPP, 5G-PPP, Big Data PPP etc.), rather than the ad-hoc mechanisms applied today.
- For addressing the sustainability issue, an independent stakeholder alliance funding mechanism to manage the European common platform should be considered.

2.8 Main Conclusions and Recommendations

FIRE has evolved into a diverse portfolio of experimental facilities, increasingly federated and supported by tools, and responding to the needs and demands of a large scientific experimenter community. Issues that require attention include the sustainability of facilities after projects' termination, the engagement of industry and SMEs, and the further development of FIRE's ecosystem. A more strategic issue is to develop a full service approach addressing the gaps between ecosystem layers and addressing integration issues that are only now coming up in other Future Internet-funded projects. A related challenge is to expand the nature of FIRE's ecosystem from an offering of experimental facilities towards the creation of an ecosystem platform capable to attract market parties from different sides that benefit from mutual and complementary interests. Additionally, FIRE should anticipate the shifting focus of Future Internet innovation areas towards connecting users, sensor networks and heterogeneous systems, where data, heterogeneity and scale will determine future research and innovation in areas such as Big Data, and 5G and IoT [9]. Such demands lead to the need for FIRE to focus on testbeds, experimentation and innovation support in the area of "***smart systems of networked infrastructures and applications***".

To address the viewpoints identified by the FIRE community, the FIRE initiative should support actions that keep pace with the changing state-of-the-art in terms of technologies and services, able to deal with current and evolving experimenter demands. Such actions must be based upon a co-creation strategy, interacting directly with the experimenters, collecting their requirements and uncovering potential for extensions. FIRE must also collaborate globally with other experimental testbed initiatives to align with trends and share expertise and new facilities. Where major new technologies emerge, these should be funded as early as possible as new experimental facilities in the FIRE ecosystem.

This analysis leads to conclusions and recommendations regarding the future direction of FIRE. The following is a concise summary of conclusions and recommendations, grouped in three areas: (1) the vision and positioning of FIRE, (2) the strategic challenges, and (3) the action plans. These conclusions and recommendations have been elaborated in more detail in the AmpliFIRE D1.2 report [11].

2.8.1 FIRE Vision and Positioning

- FIRE's strategic vision for 2020 is to be the Research, Development and Innovation (RDI) environment for the Future Internet, creating business and societal impact and addressing societal challenges. Adding to FIRE's traditional core in networking technologies is shift of focus in moving upwards to experimenting and innovating on connected smart systems which are enabled by advanced networking technologies.
- FIRE must forcefully position the concept of experimental testbeds driving innovation at the core of the experimental large-scale trials of other Future Internet initiatives and of selected thematic domains of Horizon 2020. Relevant initiatives suitable for co-developing and exploiting testbed resources include the 5G-PPP, Internet of Things large-scale pilots, and e-Infrastructures.

2.8.2 Strategic Challenges for Evolution of FIRE

- FIRE should help establish a network of open, shared experimental facilities and platforms in co-operation with other Future Internet initiatives. Experimental facilities should become easily accessible for any party or initiative developing innovative technologies, products and services.
- FIRE should establish a "technology accelerator" functionality, by itself or in co-operation with other Future Internet initiatives, to boost SME research and innovation and start-up creation. A brokering initiative should provide broker services across the FIRE portfolio or via exploitation partnerships. Community APIs should be offered to make FIRE resources more widely available.
- FIRE's core expertise and know-how must evolve: from offering facilities for testing networking technologies towards offering and co-developing the methodologies, tools and processes for research, experimentation and proof-of-concept testing of complex systems. FIRE should establish a

lively knowledge community to innovate methodologies and learn from practice.

- FIRE should ensure longer term sustainability building upon diversification, federation and professionalization. FIRE should support the transition from research and experimentation to innovation and adoption, and evolve from singe area research and experiment facilities towards cross-technology, cross-area facilities which can support the combined effects and benefits of novel infrastructure technologies used together with emerging new service platforms enabling new classes of applications.
- FIRE should develop and implement a service provisioning approach aimed at customized fulfilment of a diverse range of user needs. Moving from offering tools and technologies FIRE should offer a portfolio of customized services to address industry needs. FIRE should establish clear channels enabling interaction among providers, users and service exploitation by collaboration partners.
- FIRE should become part of a broad Future Internet value network, by pursuing co-operation strategies at multiple levels. Cooperation covers different levels: federation and sharing of testbed facilities, access to and interconnection of resources, joint provision of service offerings, and partnering with actors in specific sectoral domains. In this FIRE should target both strong ties and loose ties opportunistic collaboration. Based on specific cases in joint projects, cooperation with 5G and IoT domains could be strengthened [10].
- FIRE should evolve towards an open access platform ecosystem. Platform ecosystem building is now seen critical to many networked industries as parties are brought together who establish mutually beneficial relations. Platforms bring together and enable direct interactions within a value network of customers, technology suppliers, developers, facility providers and others. Developer communities may use the FIRE facilities to directly work with business customers and facility providers. Orchestration of the FIRE platform ecosystem is an essential condition.

2.8.3 Action Plans to Realize the Strategic Directions

- The ongoing development towards federation of testbeds should be strongly supported; it is a key requirement now and in the future. We have proposed several actions to accomplish this goal, which is taken up in the Work Programme 2016–2017.

- FIRE should strengthen the activities aimed at wider exploitation of its testbed resources by increasing the scope and number of experiments and experimenters using FIRE facilities.
- FIRE should increase the number of projects and experiments that lead to resolving societal challenges. Bring end user communities to the FIRE community to stimulate innovation for the social good. Promote open source community building methods such as hackhatons and open source code.
- FIRE should initiate actions to leverage its resources to start-ups and SMEs.
- FIRE should initiate activities aimed at decreasing the time to market for experimenters.
- FIRE should maintain and strengthen its relevance for the researcher community.
- The potential capability of FIRE facilities and resources for regional development, to support technology development and product and service innovation, should be exploited.
- FIRE should expand its range of facilities to also address research and innovations in sectors where "networked, smart systems" are crucial for innovation.
- FIRE facilities are to be exploited for standardisation activities (proof-of-concept).
- FIRE should selectively engage in international co-operation, based on reciprocal and result oriented actions.
- Create co-operation across Future Internet related initiatives and stimulate alignment of EC units.
- FIRE should establish a professionally coordinated community to lead its development toward 2020.

2.9 Final Remarks

As explained in Section 2.2's vision and mission statement for FIRE and detailed in Sections 2.3–2.4, we foresee a further development of FIRE's mission and value offer. One particular challenge is to expand the nature of the FIRE's ecosystem, from offering facilities to mostly experimenters in academic research institutes towards a **wider spectrum of actors** in a growing FIRE ecosystem, including large businesses and SMEs, developer communities, and other initiatives or programmes. FIRE will continue to offer an efficient and effective federated platform of core facilities as a common research and experimentation infrastructure related to the Future

Internet; this delivers innovative and customized experimentation capabilities and services not achievable in the commercial market. FIRE will expand its facility offers to a wider range of technological developments in EC programmes e.g. in relation to smart cyber-physical systems, smart networks and Internet architectures advanced cloud infrastructure and services, 5G network infrastructure for the Future Internet, Internet of Things and platforms for connected smart objects. FIRE delivers experimental testing facilities at low costs based upon federation, expertise and tool sharing, offering all necessary expertise and services for experimentation on the Future Internet part of H2020. In the longer term, FIRE's mission is to be the research, development and innovation environment, or "accelerator" within Europe's Future Internet innovation ecosystem, providing the facilities for research, early testing and experimentation of innovative technologies and solutions, by accelerating Future Internet technology-induced innovation cycles resulting in advanced applications and business support leading to the creation of new market opportunities. The overall strategic objective for FIRE is to become a sustainable 'R&D&I lab'-like facility for research in the Future Internet; supporting researchers and the community to tackle important problems, and acting as an accelerator for industry and entrepreneurs to take novel ideas closer to market.

The strategy to realize this future role is multidimensional and AmpliFIRE jointly with the FIRE community and the Commission have been working towards the definition of a set of strategic objectives aimed at 2020, and a range of activities to realize the 2020 objectives.

The strategy includes the following key recommendations:

- Establish an easily accessible network of open and shared experimental facilities and platforms and create partnerships with other Future Internet initiatives to realize this.
- Target industry and SME innovators by establishing an "accelerator" functionality, starting with creating a market interface aimed at aligning demands and offers.
- Increase the number of experiments and experimenters using FIRE, attracting new user/stakeholder groups such as large ICT companies, developer companies, SME innovators, Smart Cities and regions, and other EC programmes.
- Target business innovator needs related to accelerating product and service innovation and go-to-market, addressing the needs and demands of companies in different stages of their development lifecycle. Work together with innovation intermediaries.

References to AmpliFIRE Reports and White Papers

[1] AmpliFIRE D1.1: FIRE Vision and Scenarios 2020. Final report, May 2015.
[2] AmpliFIRE D1.2: FIRE Future Structure and Evolution. Interim report, June 2014.
[3] AmpliFIRE D1.3: FIRE Ecosystem Progress Report. FIRE Roadmap towards 2020. Final report, June 2015.
[4] AmpliFIRE D2.1: FIRE Portfolio Capability Analysis. Final report, June 2015.
[5] AmpliFIRE D2.2: Overview of Experimenter Requirements. Final report, February 2015.
[6] AmpliFIRE D3.1: FIRE Collaboration Models. Final report, April 2015.
[7] AmpliFIRE D3.2: FIRE Service Offer Portfolio. Final report, March 2015.
[8] AmpliFIRE White Paper: Experimental Methodology Challenges. June 2015.
[9] AmpliFIRE White Paper: Potential of FIRE as Accelerator for New Areas of Technological Innovation. June, 2015.
[10] AmpliFIRE White Paper: FIRE Value Proposition. September 2014.
[11] AmpliFIRE D1.2: FIRE Future Structure and Evolution. Conclusions and Recommendations for FIRE's Future. Final report, February 2015.

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For more information, see AmpliFIRE's website http://www.ict-fire.eu/home/amplifire.html
AmpliFIRE reports and White Papers are available for downloading at this website.