Next Generation Internet Experimentation

Drivers Transforming Next Generation Internet Research and Experimentation

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In a world where competitive economies are increasingly dependent on innovative application of information and communication technologies and where changes in technology and culture are happening rapidly, Europe must remain at the forefront of the Next Generation Internet (NGI). User-driven experimentation is now driving the evolution of the Internet. Europe's public investment policy must foster the creation of vibrant experimentation ecosystems that are supported by the research and development of open experimentation platforms that engage citizens and companies in finding solutions, activating business markets, and addressing important societal challenges.

Editors:

Michael Boniface, IT Innovation Centre, mjb@it-innovation.soton.ac.uk

Monique Calisti, Martel Innovate monique.calisti@martel-innovate.com

Martin Serrano, Insight Centre for Data Analytics, martin.serrano@insight-centre.org

Community Contributors

Alexander Willner (FhG-Fokus), Chiara Petrioli (University of Rome 'La Sapienza'), Federico M. Facca (Martel Innovate), Ingrid Moerman (iMinds), Johann M. Marquez-Barja (Trinity College Dublin), Josep Martrat (Atos), Levent Gurgen (CEA), Sebastien Ziegler (Mandat International), Serafim Kotrotsos (Incelligent), Sergi Figuerola Fernandez (i2CAT), Stathes Hadjiefthymiades (University of Athens), Susanne Kuehrer (EIT Digital), Thanasis Korakis (University of Thessaly), Tim Walters (iMinds), Timur Friedman (LIP6 CNRS Computer Science Lab, UPMC Sorbonne Universités)

European Commission

Nikolaos Isaris, Per Blixt

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Why experimentation is a key element of the Next Generation Internet

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 [FORBES14].
- 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 [Google16].
- 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 [MADRID15]
- 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 [OVERWATCH16].

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.

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 [Jourjon15]; 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 [BBC15]; the first generation of networked Internet of Things technologies for pervasively monitoring the underwater environments; validation of HBBTV technology in European broadcast events [HbbTV]
- ***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;

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.

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 [Atzori10] 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 [Serrano12] 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.

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

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 / intelligence 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.

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) [Marquez-Barja16].
- 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.

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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