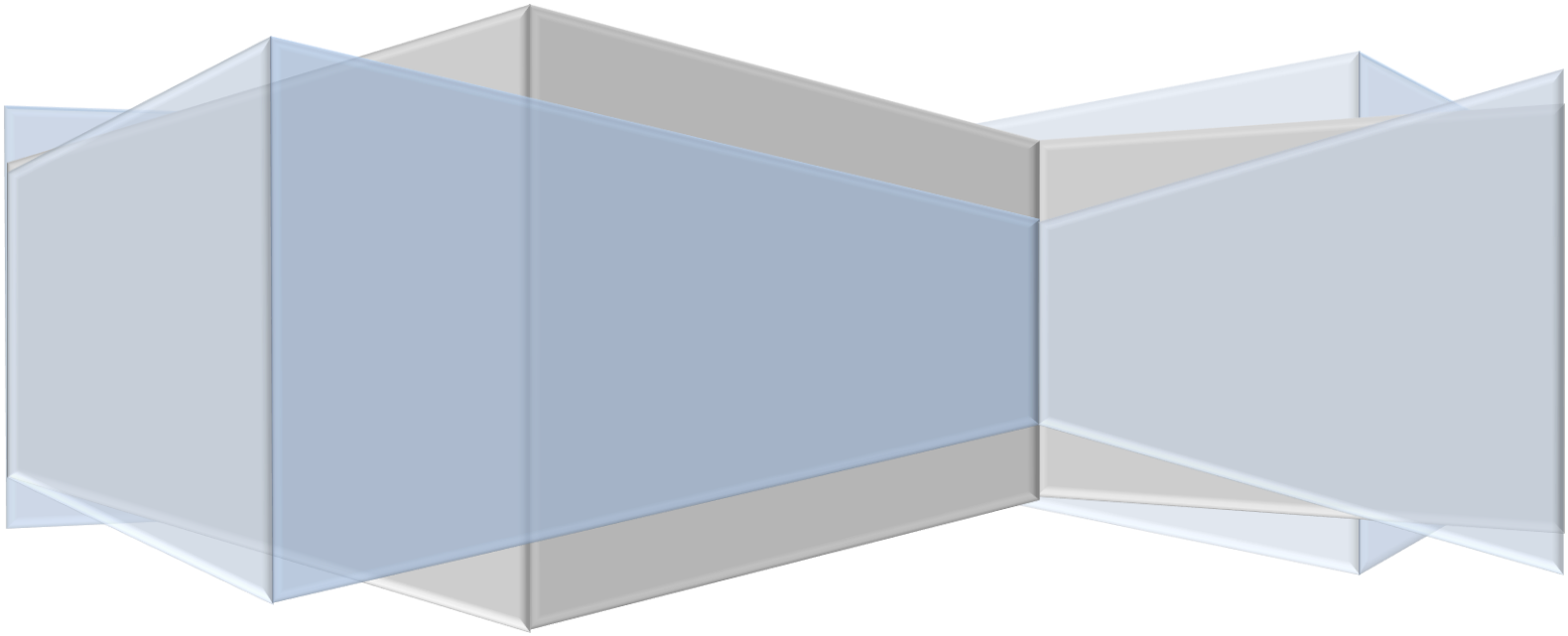
FUTURE INTERNET ASSEMBLY

Future Internet Assembly Research Roadmap

Towards Framework 8: Research Priorities for the Future Internet

FIA Research Roadmap Working Group



Abstract

The Future Internet Assembly Research Roadmap for Framework Programme 8 captures the ideas and contributions of the FIA community on the important research topics that should be addressed for the Framework Programme 8 research programmes broadly grouped around three main concerns; economic and business interests; societal interests and challenges; technical disruptions and capabilities.

The contents of this roadmap originate with the community of researchers working on all aspects of the Future Internet and meet to share and discuss ideas through the Future Internet Assembly through an open consultation of research projects who participate in FIA. This roadmap is primarily concerned with identifying research that can be carried out in the second half of this decade and which will have an impact in 2020 and beyond. By 'impact' we mean will result in products, services, systems, capabilities, that come to market and are available and deployed in that timeframe

The approach adopted in this report is to integrate contributions across the entire space of future Internet research with the aim of bringing out the vision for how and where the Internet will make a significant difference in the future and identifying the broad challenges and gaps, and identifying the solutions and research needs in the future. In this report we have summarised and grouped ideas with the aim of identifying the strong themes and consistent challenges that emerge looking across the whole agenda.

Version: 1.0 (14 May 2011)

Future Internet Assembly Research Roadmap

Framework 8: Towards Research Priorities for the Future Internet

A report of the Future Internet Assembly Research Roadmap Working Group

General Editor: Nick Wainwright (Nick.Wainwright@hp.com)

Editing Team: Markus Fiedler
Anastasius Gavras
Nick Papanikolaou
Hans Schaffers
Nick Wainwright

Document Status: Version 1 for review at FIA Budapest, May 2011

This work is supported by the Effectsplus project (http://www.effectsplus.eu)

Workshop contributions can be found at:

http://www.ami-communities.eu/bscw/bscw.cgi/625664
http://www.ami-communities.eu/bscw/bscw.cgi/639128

Acknowledgements: The editor would like to thank the Future Internet Support Action projects (http://fisa.future-internet.eu) for their support in the organisation and development of this roadmap, our colleagues from the European Commission DG INFSO for their support and guidance, and most importantly to the researchers from the Future Internet Assembly research community for their ideas, workshop presentations and contributions. Special thanks are due to Hans Schaffers, Markus Fiedler, Anastasius Gavras and Nick Papanikolaou for their commitment, enthusiasm and hard work in pulling this report together in a short time.

Contents

1 Summary and Research Priorities

1.1 Scope and Context

This report presents the Future Internet Assembly (FIA) research community's perspective on the priorities for Future Internet research under the EC's Framework Programme 8 (FP8) and was produced by the FIA Research Roadmap Working Group. The scope of this report covers the entire space of Future Internet research interpreted quite broadly, and not limited by current programme scope in FP7.

Research in FP8 aims for impact – in products, services, capabilities, benefits – in a world about ten years from now infused with Internet systems and devices, in which ICT pervades even more of what we do than it does now, and where the fruits of current research will have been borne out in new products and services on the market and in homes, workplaces, cities, and industry.

Thus the context at the start of the next decade, into which FP8 must deliver, is very different from what it was ahead of the previous Framework programme, and as a consequence the FI research community have looked ahead to understand the landscape in which that research must deliver, projecting forward the changes, trends and technologies we see today, describing our vision for the contribution that Future Internet can make, describing the challenges and gaps, and suggesting the research topics that are necessary to make it possible.

This report is the output of a consultation of the Future Internet Assembly research community and covers a very wide range of research areas addressed by challenge one of the ICT Framework Programme Seven and beyond, and was carried out by the support action projects collective known as Future Internet Support Actions (FISA), and includes also the results of open meeting held in March 2011 in Brussels.

By integrating ideas across all the research areas we aim to avoid the 'silo' effect that occurs when research communities, working separately, may identify similar priorities and topics and yet collectively we fail identify these as significant themes and priorities as a whole. In this roadmap we aim to give ourselves a vantage point from which to draw out the big themes that future research should address by altering our perspective, integrating the vision of the research community, linking their conclusions, and suggesting some big research priorities that will shape the future ICT landscape, and to which the FIA research community must respond to, indeed get ahead of, if it is to have a significant impact on the Internet landscape at the start of the next decade and beyond.

1.2 What's Changing? The Context for Future Internet Research in FP8

It is clear that in this timeframe we will have many times more people and devices connected to the Internet than today. We will have gone through a generational shift to attitudes and experience of Internet. We know we will have richer digital experiences delivered through smart devices, ever higher quality digital media, some of it 3D, created both by creative professionals and 'prosumers'. Cities and spaces will be connected and smarter, exploiting the Internet to organise, optimise, compete, and deliver on promises to citizens. The economy of Internet services will have developed,

and the ways in which we interpret and exploit data will underpin how we work, interact, and socialise, notably through contextualised services on smart devices. All sectors of the economy and public life will rely on the Internet to provide services to their customers, to optimise and manage their systems and operations. The Internet will be, even more than now, part of critical infrastructure for business, public sector, and citizens.

But it isn't all rosy - we'll be living in an even more resource-constrained, globally competitive economic landscape, with competition in innovation from high-tech regions outside the EU and USA, and we'll have an aging population with increasing demands for improved quality of life.

The benefits of the digital world will not be uniformly distributed – some areas, sectors or regions will be 'less digital' and some communities will be excluded. Internet services will be delivered from anywhere, but innovation will be clustered around 'hotspots'. Internet technologies will not be fully deployed across the economy – there will be leaders and laggards. Trust, and confidence in the in the Future Internet society may not be as strong, or as high, as we would like – in moving our lives, economies, and spaces online may also move our conflicts, disagreements, and criminals online.

1.3 Vision: What Impact Can We Make Through FI?

The Future Internet research community has a strong vision for how Internet technologies, systems and services can create real value, deliver benefits to citizens, address some of our biggest challenges, and generate new business opportunities in Europe.

In the sphere of the enterprise, the necessary transformation of business into innovative virtual enterprises continues, transforming the roles of customer and employee, providing opportunities to exploiting networked knowledge through open innovation and collaboration. A 'knowledge supply chain' enables high knowledge-content innovation, manufacturing agility, early exploitation of emerging technologies, and collaborative manufacturing, linking networks of specialist high-value manufacturing companies. As enterprises operate in an ever more complex environment, our ability to assess and act on risk and opportunities will be enhanced by sophisticated decision support operating in real time on deep resources of networked information.

A networked innovation ecosystem will pervade the European networked enterprise – a sophisticated, collaborative, knowledge sharing, connected services space in which innovation at the edges of the network, by individuals and SMEs, in cities and spaces can be rapidly exposed to markets and customers. Future Internet Services will be fully inclusive and accessible to everyone, everywhere. Smart cities, citizen centric environments with innovative services and sustainable economies, will be fully connected to the FI.

Underpinning the Future Internet economy is a vast resource of data, information, media and content, and the boundaries have become blurred between these formerly separated categories. This resource, which we call 'networked data' is the means for creating new value –unlocking that value, keeping it open and available as a resource for innovation, exercising sound governance over it, and having the means to exploit it will be a fundamental objective of technology and policy. With a clear framework of rights and obligations with respect to networked data, industry, citizens,

business, and public sector are empowered to exploit it to create new services and to exercise appropriate control over it.

As we look to the future of media, social networks, and smart devices, the future of digital experiences we see that these will become embedded in spaces, places, and buildings, supporting our leisure, work, and social needs. It's clear that we are moving from devices connected to services, towards a future of rich digital environments that support us in what we want to do, augmenting our lives and work and allow us to interact with each other, with cyber world, and with the physical world in rich, rewarding and useful ways.

Thus Future Internet, through networked innovation, networked data, networked interaction, and augmentation provides a foundation for transforming industries and addressing big social challenges. It's beyond the scope of this report to go into detail into all sectors or needs, but it's possible to see how such capabilities can make 'assisted living' something that works at scale, how opening up data about energy usage , can give people and business tools to make choices or create alternatives.

Finally we turn to the Future Internet itself – clearly realise our vision for the impact of Future Internet we rely on increased capacity, reliability, and quality of services. Looking beyond the start of the next decade, infrastructure convergence and cloud has already happened, and looking forward, we view Internet not as network, cloud, storage, or devices, but as the execution environment for smart applications, services, interaction, experience, and data. The future network integrates many different capabilities – sensor nets, Internet, hotspots, wireless, core network, to provide the vastly increased capacity and breadth of services needed. The execution environment operates from data centres, into the network and out into the devices. Networked data is distributed across the FI. We build security into the systems and services and can verify that they are secure. Risk online is not something we can completely eliminate (and perhaps nor should we), end users in businesses, and individuals will have the tools and understanding to manage and make decisions about digital risks. Smart devices have become smart edge systems that link devices we own with embedded devices and systems to create new services and experiences and capabilities.

In this summary we have captured a vision for FI from many and diverse contributors and contributions. Its purpose is to illustrate the potential of Future Internet beyond the current research objectives, and while we have summarised and interpreted, our aim has been to be inclusive and not to leave out any contribution. We don't doubt that omissions and gross oversimplifications have taken place, necessitated by brevity, and intend to address any glaring omissions in future revisions.

1.4 Challenges and Research Priorities

In presenting the research needs in this roadmap we have brought out the 'horizontal challenges' – those that underpin most, if not all, of the applications and use of Future Internet. In developing this roadmap we have had specific inputs in the areas of smart cities, the future of enterprise, digital media, and inclusion. We had little input in areas such as healthcare, energy management, transportation. We don't think that is too much a limitation – our aim has been to bring out the

broad and horizontal research themes that will persist, even grow in scope and opportunity and applicability as we look past the middle of the decade, and particularly those area that address fundamental capabilities, and needs of a networked information society.

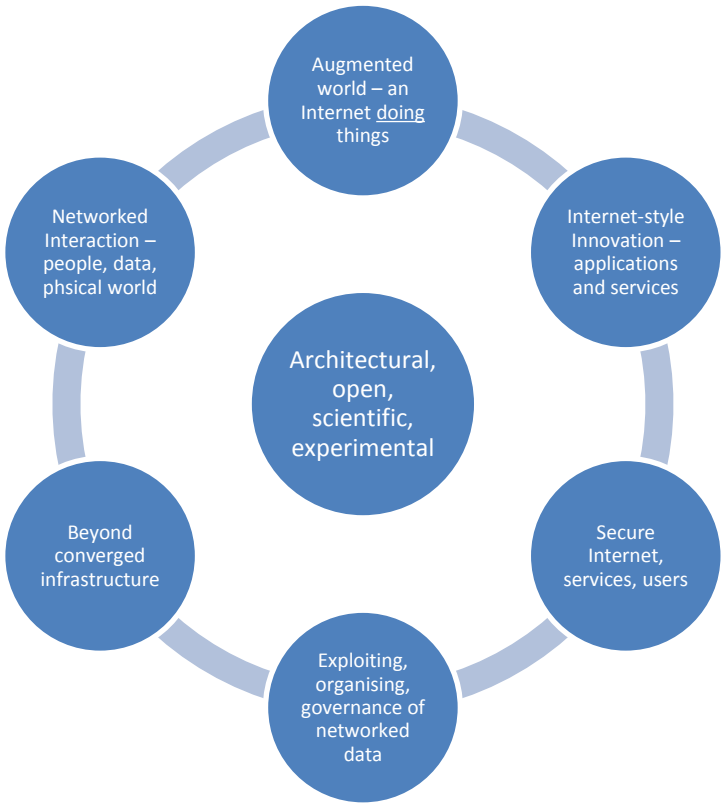
In our research priorities for the Future Internet we see three themes that are foundational and enabling and which support us in *building the Future Internet*. These are:

1. Beyond converged infrastructure – the Internet infrastructure beyond 2020 brings new capabilities and capacities
2. Networked data – exploiting the Internet's natural resource
3. Internet Security - maintaining the security of the Internet and it's users online

Secondly, looking forward towards the research that will transform what we do and how we do it and which are fundamentally integrative, they exploit and use a wide range of networked technologies towards a divers set of objectives, we see three priorities that support us in *using the Future Internet*. These are:

4. Networked interaction – people interacting with each other, with information, and with cyber-physical worlds
5. Networked augmentation – from an Internet of things to an Internet *doing* things
6. Networked innovation –the Internet as an innovation ecosystem, supported by architecture, policy, and invention.

Finally we make some observations as to what it means to be doing Future Internet research, addressing the need to be 'open', experimental, architectural, and scientific in our approaches to the Future Internet research.



Research Priority 1 - Beyond converged infrastructure:

Polymorphic networks, expanding the cloud, building 'smart systems' at the edges

Internet infrastructures – networks, virtualised computing, storage systems, undergoing a period of intense convergence, the boundaries between service platforms and the infrastructure services layer are becoming blurred, and at the same time at the edge of the networks smart mobile devices are becoming pervasive and more capable at the edges of networks.

The future research must look beyond converged infrastructure to the addressing the challenges of meeting the vastly increased demand for bandwidth and services and connectivity and new and different applications and services:

- Polymorphic networks – combining different networks to meet the for capacity and needs of new media, applications, services, infrastructures and networked 'things'
- Expanding the cloud to the edges of the network and beyond, providing the execution environments for new FI applications and services. Real time capabilities will be vital for these new services, data and event processing, interaction processing all demand real time responses, and variability in demand will provide real challenges for the services providers
- Looking beyond 'smart devices' towards 'smart edge systems' – being the execution environments at the edges of the network that link physical and the cyber world, constructed from devices we own, systems in the physical world and Internet services.

Research Priority 2: Networked data

The organisation, exploitation, and governance of the raw material of services and applications

Networked data on a massive scale is the powerhouse of the Internet today and the growth trend looks set to continue as new services and applications are developed, a greater part of the economy and public sector relies on the Internet, and citizens spend increasing parts of their lives online.

Networked data is a horizontal capability of the Future Internet. The organisation, exploitation, and governance of the huge amount of data and information in the Internet will create on-going opportunities and challenges for the next decade. There are underlying tensions between rights of citizens, businesses, and the state over data; the opportunities opened up by integrating data from multiple sources; the need develop new data models to make sense of the myriad of applications and sources (e.g. using the 3d world, augmenting spaces and activities, tacit knowledge in knowledge supply chains are just a few of the many ideas that came up in this consultation), of records of usage, of surveillance data gathered, the list continues to grow.

- Data governance - giving citizens and business tools to be in control of their data, express their rights, and fulfil their obligations and act confidently in cyberspace that is pervaded by data on everything and every aspect life
- How we can build models of spaces, experiences, behaviours, knowledge that can be exploited by new high value services,
- New architectures and systems that underpin data driven services in the Future Internet

Research Priority 3: Security

Securing networks, networked systems and networked citizens

A decade away we will be conducting much more of our lives and economy online than we do now. The scale of Internet use continues to increase relentlessly, and our reliance on the Internet continues to increase. As we do so the potential opportunity, rewards, and impact of cybercrime becomes even more significant. The scale of threats, potential for conflict between individuals, organisations, and states online should not be underestimated. Reliance on Internet for operation of our critical infrastructures means that cyber-defence is even more vital aspect of state security.

Securing the Internet as a socio-technical system is a high priority and continued separate attention is necessary. Internet security can become part of Europe's new defence businesses, and a secure Internet is necessary condition for economic competitive.

Research Priority 4: Networked interaction

New interfaces and modes of interactions with networked systems and devices, with people and communities, with data, through new interfaces, new modalities, new combinations of devices and new perspectives.

Through the Internet we interact with each other, with the physical world, and with the digital world, and indeed, in the future the distinctions my blur even further. Social networks are not the last word on social interaction, web-cams and video conferencing are not the last word on collaboration, games and IPTV are not the last word on entertainment. New interfaces and modalities will create opportunities for richer interaction and for addressing our work, life and emotional needs. New ways of interacting with complex data provide ways to understand complex situation. New interactions with the digital world will provide new media experiences that look beyond 3d. Future networked interaction will not be delivered through one device, in a sit-back, sit-up, or handheld interaction mode, but through collections of devices brought together as smart edge systems, and ideas of ownership, situatedness, virtualisation will create interaction experiences that are effective, engaging, and empowering.

The research theme of interaction, supported by rich interfaces, displays, haptics, and other yet to be developed approaches makes possible to address some of our real concrete needs too – for carbon reduction for example through remote collaboration which can take people off roads, support knowledge business networks, or create valuable social links. Some of the biggest barriers to delivering Internet benefits to excluded groups in Internet are the interfaces. This is just one example, and looking forward the future of networked interaction has real potential to create value given that we are reaching the point where demand and capability come together to make new and valuable networked interactions possible.

Research Priority 5: Augmented worlds

Moving from an Internet of Things towards an Internet Doing Things

The vision of networked services, systems, and devices supporting us in our work and social lives, or in business to control and manage processes and operations has been with us for some time. Hitherto, the Framework Programme Seven has explored Internet of services, reflecting the shift of our economy to a service economy, Internet of things, reflecting the opportunity to measure and manage the physical word using networked systems and these capabilities are beginning to be available.

As we look to the start of the next decade and beyond we can begin explore how we can harness the power of the Internet to 'augment' lives, work, business and spaces in ways that add value. By 'augmentation' we mean 'increasing in intensity' the activities we are doing or the things we need done for us, addressing what we do in our jobs and daily lives, addressing needs of groups and communities, of industry, construction, maintenance, engineering, manufacturing, transport with information, decisions support, risk analysis, options, delivered through interactions and interfaces that are intuitive and un-intrusive. What is currently described as 'augmented reality' has potential to develop into what is fundamentally an integrative, systems, applied approach to addressing problems of industry, people, society and developing techniques and frameworks that harness the scale of the network and networked data onto individual actions, tasks, and activities, transforming what we do and how we do it.

Research Priority 6: Internet-style innovation

Future and Emerging Applications and Services – Internet-style

It is clear that the Internet has been an incredible force for innovation over the past three decades at least. To have created such a platform for innovation, value creation, and benefits to society must rank as one of the outstanding achievements since the industrial revolution. It is our aim that this innovation and value creation should continue, and that Europe should play a big part in it. Every one of the research communities consulted in this programme stressed innovation – both within their field of work and enabling innovative benefits as a consequence of it.

Whether we are discussing topics such future enterprise, cities, or experiences, ideas abound on the kinds of approaches that enable innovative value creation to take off. The network effect, scale, openness, experimentation, software, and pilots, and services, SME and start up participation, application, and real users. This is the 'Internet-style' innovation we aim for. Innovation that happens at the edges of the network, that is stimulated by linkages between sectors, that involves people, where people, communities, business, even public sector, are 'empowered' to take control of opportunities to innovate. Ideas such as making cities into experimental services environments, creating platforms, integrating across industries and sectors, releasing and exploiting data, are enabling factors – they set the conditions for unlocking value and if carried out 'Internet style' they set the conditions for innovation and provide an environment for new applications and services need to be instantiated, built, used, and grow.

Our final theme then is to prioritise innovation, perhaps through a programme that directly focuses on innovation – a Future and Emerging Applications and Services theme that addresses both the need to set the conditions for innovation, and provides opportunities for innovative new applications and services to be built, Internet style, with the direct objective of creating new applications and services, new business, and new benefits for citizens and society.

Research Approaches to Future Internet

Experimental, scientific, architectural, Open

We have highlighted the themes above because they need to be directly addressed and they deal with different aspects of the Future Internet. There are also a number of approaches that are essential to the success of Future Internet initiatives

Scientific and quantitative approaches to understanding the Internet at many levels

The Internet is complex technical and socio-economic system of huge scale and complexity. It exhibits emergent behaviours, complex interactions, and rapid evolution and change. We describe it at many different levels of abstraction. Recognising that the demands on the Future Internet to scale will likely outstrip even the most extreme forecasts, and the trend towards future systems that provide better quality, economy and sustainability, there is a need to improve many aspects of applications, services and networks such as performance, security, risk, usability, and value through models, quantitative approaches and metrics, rather than relying on brute-force engineering or point solutions. The science of the internet – models, behaviours, measurements and experiments – is essential to understanding, managing, scaling, and predicting all aspects of the Future Internet.

Experimental approaches to FI research

Experimental approaches to Future Internet are essential given the scale and complexity of internet systems – and experimental approaches are well embedded within the research community. Experimental infrastructures are complex and difficult to design and sometimes lag behind the state of the art that internet research is aiming to address. The global scale of the Internet suggests international cooperation is necessary for experimental infrastructures for work at scale on Future Internet systems. Experimental environments and test beds involving real users are difficult to create and more difficult to scale. Nevertheless experimental approaches – deployment, use, testing, and measurement at every level should be built into Future Internet research at every level. Looking ahead, recent advances in virtualisation – in networks, storage, computing and applied to infrastructures, devices, and applications, suggest that building in experimental capabilities as 'slices' or operational systems may make it possible to experiment 'live' on the operational Internet.

Taking an architectural approach to Future Internet development

As FI develops support for a wide range of stakeholders seeking to develop, provision, or use a range of networked components and concepts there needs to be an architectural framework that provides on-going guidance, specification and rules of how systems should behave, how everything fits together, how *networked* elements communicate, and how elements are (dynamically) structured

into larger interoperating entities. The architecture needs to present the whole picture, to relate the relevant elements in the picture, and to maintain its own forward plan or roadmap as a consistent part of the overall FIA roadmap. Such architectural coordination has typically been provided by groups such as IETF and with FIA the architecture working group is addressing architecture for Future Internet. As we look forward to research in Future Internet we emphasise the need for the research to take an architectural approach at all levels from infrastructure to services and applications, and to participate in, and where appropriate develop new forums for providing and developing that architectural coordination.

Approaching FI research in an Open way

Finally, we make a plea for Future Internet research, and the Future Internet itself, to be approached with in an "open" way with explicit recognition that the principles that have created immense value at every level in today's internet should be encouraged, promoted, and preserved in tomorrow's Future Internet. Openness and access empowers individuals, SMEs and communities providing them with opportunities to experiment innovate. Open data, open source, open access are all examples of this. The network effect – the increase in value that takes place with scale, as more users, end-points, nodes are connected – drives value creation in an Internet ecosystem of infrastructures, data, devices, services and applications. Individuals – as consumers, bloggers, prosumers, content creators and so forth all have roles to play in the Future Internet. Inclusion – involvement of all communities in the Internet value system creates opportunities. Value creation happens at the edges of the network and the boundaries between sectors. The scale of internet makes small business global scale. Clearly there are many 'tussles' that occur between business, individual, and societal interests and we are not arguing that everything should be "free", but that "openness" should be regarded as a much a fundamental principle for the evolution of Future Internet as it has been for the current internet.

2 Introduction and Scope

A roadmap with a broad perspective on the scope of the Future Internet

The Future Internet Assembly Research Roadmap for Framework Programme 8 captures the ideas and contributions of the FIA community on the important research topics that should be addressed for the Framework Programme 8 research programmes.

In this research roadmap we have deliberately taken a very broad perspective on future Internet. One lesson we have learned from past 20 years is that the expanding scope of Internet, which originated as bits and pipes now is accepted to encompass the vast range of infrastructures and services, technologies and applications that we see today, will continue into the future in ways that we cannot control or predict with any certainty. Therefore this research roadmap includes ideas and challenges that are technology driven, arise from societal challenges, appear as a result of thinking about the future of business and the economy, or are a consequence of individual or collective needs, wants, and desires.

If anything can be said about the scope of this research roadmap it is probably that we haven't addressed anywhere near enough of the space influenced by the Internet or which will be impacted by future Internet developments in the future. However, given the practicalities of constructing a research roadmap based on inputs gathered from the future Internet research community, our roadmap is broadly grouped around three main concerns:

- Economic and business interests
- Societal interests and challenges
- Technical disruptions and capabilities

This roadmap document is a work in progress and in some areas there is scope for further development and opportunities for contribution which are noted in the text.

Current State of the Art

Several key documents are available that provide valuable information and insights for developing our FIA Future Internet Roadmap. Future Internet 2020 (European Commission, 2009) proposes several inspiring future scenarios for example "the personal global network" and "the web-based service economy", and identifies the underlying enabling technologies and barriers.

Future Internet X-ETP Group (2010) proposes a research agenda for the Future Internet focusing on future networking infrastructure. Network related topics include scalable and dynamic routing and addressing;

efficient data and traffic management; adaptability to heterogeneous environments; security, privacy and trust; availability, ubiquity and simplicity; energetic and economic sustainability. Additionally, the research agenda addresses various generic challenges of the Network Society.

FIA Books 2009, 2010 and 2011 identify and elaborate on the following areas of Future Internet research and innovation: Future Internet Research Experimentation, Management and Service-aware Networking, Future Internet Service Offers, Real World Internet, Future Content Networks, Future Internet Socio-Economics, Trust and Identity, Advanced Applications.

FIArch working group (2011) identifies current limitations of the Internet and its architecture for example in processing and handling, storage, transmission and control. A set of design objectives is proposed to respond to the limitations. Such design objectives include accessibility to the communication network but also to heterogeneous data and services, nomadicity and mobility; accountability; manageability, transparency; distribution of processing, storage and control functionality and autonomy.

Various roadmap activities have been carried out in related areas of the Future Internet such as Internet of Things and Future Internet Enterprising. Internet of Things Strategic Roadmap (2009) considers Internet of Things as integrated part of the Future Internet, defined as a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual “things” have identities, physical attributes, virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network. The vision considers the merging of computer networks, Internet of Media, Internet of Services and Internet of Things into a common global IT platform of seamless networks and networked “things”. The Future Internet Enterprise Systems (FInES) roadmap (2010) identifies a number of research challenges related to enterprising open innovation systems. Some of the key themes are federated open application platforms, and interoperability & cooperation infrastructures. One of the main trends identified is interoperability as a service.

Oxford Internet Institute (2011) recently has carried out a study Towards a Future Internet. This study identifies four pervasive forces impacting the future Internet: stakeholder conflicts, changing infrastructure and socio-economic context, governance and regulation, and user focus / inclusion. The study formulates ten key principles to guide the future development of the Internet. According to this study, the future Internet should be

available and accessible, diverse and inclusive, scalable and sustainable.

Consultation of the European Internet research community through the Future Internet Assembly

The contents of this roadmap originate with the community of researchers working on all aspects of the Future Internet and meet to share and discuss ideas through the Future Internet Assembly. The materials for this roadmap were gathered by the FIA research roadmap working group through an open consultation of research projects who participate in FIA, including the support action projects collectively known as the Future Internet Support Action projects (FISA). An open meeting was held on 31st March 2011 and contributions from researchers and projects were presented and discussed by an audience of over 100 researchers. This roadmap is based on the inputs received up to and as part of that workshop and on the comments and suggestions of those present.

Framework Programme 8, research with impact in 2020 and beyond

This roadmap is primarily concerned with identifying research that can be carried out in the second half of this decade and which will have an impact in 2020 and beyond. By 'impact' we mean will result in products, services, systems, capabilities, that come to market and are available and deployed in that timeframe. In doing so we are presented with a conundrum – to describe the future world in which our research will have an impact without being able to predict it with any certainty, in the knowledge that the technologies we develop will shape and change the future in unpredictable ways.

The FIA community is largely a technology research community, and acknowledging that in a technology-led roadmap we aren't doing an exhaustive economic or social analysis of future Internet and as such we ask the reader to allow some latitude and to consider building on and developing the roadmap through additional contributions to a second version to be developed for the Future Internet Assembly in 2012.

Changes - Vision - Challenges – Solutions Framework.

The approach adopted in this report is to integrate contributions across the entire space of future Internet research with the aim of bringing out the vision for how and where the Internet will make a significant difference in the future and identifying the broad challenges and gaps, and identifying the solutions and research needs in the future. To do this we asked for contributors to address the following

- What **changes** will occur? Describe the broader social and other changes that research into the future Internet will need to take into account here. Indicate the timescale of these changes
- What's the **vision**? What positive outcomes can be brought about by the use of technology? Discuss how you imagine the world will be as a result of the changes and advances that will have occurred; what impact will we be able to have? When will we have that

impact?

- Discuss the difficult **challenges and gaps** (broader, technical …) that have to be addressed satisfactorily in order to handle the changes and realise the vision.
- What's the **solution**? Which new approaches/technologies/… will likely be most useful in addressing the gaps and challenges? What research needs will emerge as we try to build such solutions? What are the steps to developing the solutions?

Contributions received are available online. In this report we have summarised and grouped ideas with the aim of identifying the strong themes and consistent challenges that emerge looking across the whole agenda.

Controversial and difficult issues

Finally, there are many difficult and controversial issues and topics to be addressed in the development of the future Internet around which interested parties take differing and often conflicting positions. Issues of privacy, open source, business models, digital rights management, the digital divide, exclusion are just a few. It is not the purpose of this roadmap to take a position on these topics as points of principle, rights, or predictions of the future.

3 What Is Changing? The Internet Shaping the Future

In this section we explore the significant changes that will shape the Internet in the future, through demand for new capabilities and services, opportunities to innovate and address needs, and through disruptive developments that might lead to unforeseeable opportunities.

It is not our aim to describe or predict the future, but simply to identify the broad shifts and changes that are visible now; that we expect to continue, and which believe will drive Internet innovation in the future.

3.1 Shifts In the Economic Landscape Will Shape the Future Internet

Future Internet exists in a complex economic landscape in which globalisation, developing economies, competition, evolution of services economies, changes in technology, and resource competition shape, and are shaped by, the evolving information technologies and Internet. In this section we address some of the key ways in which Internet and economy interact in the future. In this section we discuss globalisation, the service economy, and the future of manufacturing in Europe.

Towards enterprise globalisation, and the emergence of new markets

The process of global organisation and collaboration seen over the last thirty years is still on-going, with implications for both people and technology. At the same time, political, socio-economic and environmental developments will drive economies to more localised modes of operation. Globalization has reorganized the international distribution of labour and production. Globalized markets and production systems call for new ways of doing business, of pushing innovating, of promoting products and services, taking care of customers and clients.

In the decade just started things may change again, significantly. Developing countries are witnessing the progressive emergence of a middle class eager to improve its standard of life. This is causing the domestic market will grow up again shifting the balance of production capacity.

Towards a service economy, where everything is provided as a service

The traditional separation between manufacturing and service industry is progressively fading away, and this trend will probably increase during the current decade. The service economy is currently one of the engines of the current economic recovery. In this respect, we are currently taking part to the so called “servitization of products”. A report of the Organisation For Economic Co-Operation And Development (OECD) in 2000 (*1*) claimed that "Services are transforming OECD economies on a

1 See http://www.oecd.org/dataoecd/10/33/2090561.pdf

massive scale, but are still impeded by regulations and policies that stifle innovation and competition."

Despite many of these impediments are still there (i.e. the lack of a unique European marketplace), they have not jeopardized the potential of the service economy as there are new opportunities for the SMEs (as well as individuals) to enter markets (or to investigate new markets sectors), to compete using the same means (e.g. IaaS) with already existing bigger players competing only on innovations, to increase competitiveness providing a wider choice to the service consumers and to allow developing countries to grow and play an active role in this "globalised" economy. In fact, "services constitute over 50% of GDP in low income countries' and as their economies continue to develop, the importance of services in the economy continue to grow." (cf. Wikipedia Service Economy). In addition to this service economy was also a drive to stimulate new employment opportunities and create a new kind of Internet user, the so called prosumer: individual playing both roles consumers of services as well as creators of added value services based on those consumed.

Trust is a fundamental factor in services

As we shift to an everything-as-a service business model, with increasing scale, federation and composition of services, with more complexity, automation, customisation, and personalisation, the question of whether one can “trust” the service when one doesn’t know who or where it is being provide from, or what other services and service providers it is relying on, becomes significant issue. These services are built on an ever increasing quantity of raw data to provide the customisation and contextual awareness that makes so much of the value, but at the same time the complexity of these systems is vast and the consequences of breach of trust could be disastrous

Towards a high-knowledge specialist manufacturing - developing the Knowledge Supply Chain

In Europe we see that far from disappearing, manufacturing has stabilised as a major proportion of GDP, and is now beginning to grow again. However, developed economies cannot compete for high volume mass production against low wage developing economies. Europe can have competitive advantage in manufacturing by focusing on very low volume or one-off projects requiring high knowledge content innovation. Small Specialist SMEs providing specialised competences to multiple customers will become critical to the economic future of Europe. Knowledge resources are absolutely critical to their success and they are increasingly likely to collaborate with one another to provide functions and services which are beyond their specialist skill sets. We can think of this as a “knowledge supply chain” for specialist high value manufacturing.

3.2 Significant Changes in Society Will Drive Changes in the Internet

The way in which we live our lives, the global challenges to societies, and the increased reliance on the digital world and the Internet are significant changes that Internet will impact, and will shape our approach to technology. In this section we discuss future urban environments, cyber-security issues, and the aging population.

Cities and urban environments will become fully "digital" spaces with joined-up digital services and innovative digital businesses

Cities emerge as Laboratories for the Future Internet, not only for testing technologies but also for exploring new ways of working, enterprising, healthcare and living. Increasingly, digital spaces and advanced ICTs are used to enhance the activities, services and socio-economic development potential of cities. Many cities and also rural areas and regions are still insufficiently connected to electronic highways, but are now pushing the deployment of broadband infrastructure for socio-economic development, and for creating open networks. Cities nowadays widely stimulate broadband pilots in areas such as health care, energy and citizen services. Knowledge-based development and innovation ecosystems are in the heart of the Smart City strategies they are currently developing. This builds on increasing participation and empowerment of citizens in societal issues (environmental, transportation, energy, health, social, art and educational aspects) using social media and open data on a wider scale.

Also, a diversity of technologies for smart city applications is becoming rapidly available: mobile broadband, cloud computing, open data, smart devices, public interfaces, content management systems and web 2.0 social software. Cities' network infrastructure will considerably change to enable mobility and location independent activities. These technologies lay the foundation for urban development and inclusion in 2020 (Institute for the Future, 2010).

These developments also contribute to the role of cities as environments of user driven and open innovation. While most city sectors and economic districts do not yet function as such, and while only few coherent smart city strategies are supporting this development, the concept has become attractive and initiatives come off the ground. For example, crowd sourcing services based on sensor data are in development, and publicly available data can be used to fuel bottom-up innovation. Additionally, public-private partnerships for open innovation will develop to support larger-scale initiatives.

Older people are expected to reach almost one third of the total EU population by

The population of Europe is ageing. Older people are expected to reach almost one third of the total EU population by 2025. This demographic change along with the fact that a significant number of current Internet users will be above 60 in 2025, requires the Future Internet to address

2025

fully the Internet access and usage needs, especially of the older population. If we add also the current number of disabled people which is 10% of the total population, then the number of people that will be directly affected will be almost 40% of the EU population by 2025. (Velasco and O'Flaherty n.d.)

The Future Internet Community that will be ever more mainstream in people's lives, will further isolate these and other excluded groups, especially as the technology becomes highly interactive and participative. Public policy and legislation is placing an increasing emphasis on digital inclusion. The United Nations Convention on the Rights of Persons with Disabilities puts digital accessibility on a par with accessibility of transport and the built environment. The European Commission is now investigating the possibility of introducing a general eAccessibility regulation.

Sustainability continues to drive Internet applications and as a factor in the IT industry through focus on energy consumption and sustainability.

Today we understand that sustainability is a major societal challenge. The focus currently is on energy efficiency in the broader sense and increasingly embraces general issues about the human footprint on the environment and the resource usage in general.

Future Internet technologies will make significant contributions to improve resource use efficiency and impact on the environment; however the ICT sector itself faces the same challenges. This ambivalent relationship between ICT and sustainability must be investigated, focusing on the impacts on each other and identifying the right balance between them.

An agreed measure for evaluating "green ICT" is the CO2 and other GHG emissions of the use and application of ICT. However other factors are not adequately considered in the environmental impact assessment. These factors are related to the use of ultra-pure water and chemicals for the production of ICT equipment and the difficult or impossible recovery of elements that are found in compound materials used in ICT equipment.

Cybercrime and cyber-attacks have the potential to be much more serious than they were ten years earlier

The potential rewards for cybercrime and the potential impact of cyber-attacks will be much greater in the future than it is now. Our reliance on Internet technology in infrastructure, business, daily lives and public services makes them targets for cyber-attack. The shift towards an economic motivation for cybercrime will continue – organised cybercrime could become a big business in the future, and the resources available to carry out attacks – people and clouds – are readily available globally. It could even happen that a major cybercrime or cyber-attack has serious economic or societal impact (a bank collapses, the electricity supply goes down, a power plant is damaged) that confidence in future Internet is damaged.

3.3 What We Use the Internet For Will Become Even Broader By 2020+

Given that the Internet usage has grown so much in the past decade, it is reasonable to expect that Internet usage will grow, not only in number, but also in application, over the next ten years. These changes will shape the Future Internet technology demands and be the foundation for new services and applications in the next decade. In this section we discuss the use of Internet in critical services and utilities, the continued expansion of our individual digital lives into cyberspace, the development of games across new sectors, the evolution of social platforms, the consequences of developments such at the Internet of things, and the changes that will happen around mobile platforms.

We rely on the Internet to manage and control our critical infrastructures

We will face an ever-increasing use networks and networked applications and services in domains such as health services; energy usage and distribution; environmental sensing, monitoring and analysis; logistics and transportation; and personal entertainment. This continuous development may have significant impact on how technology is perceived, but also put specific and sometimes unforeseen demands upon ICT infrastructure.

Our real and our digital lives are ever more intertwined as we rely on Internet services for all aspects of our daily life.

The Internet has advanced from a network for a small community to a support infrastructure for the general public, handling all sorts of information about people, public records, enterprise data, medical data, and things. It became the storage place for information, the infrastructure to where one plugs to and, inevitably, the bottleneck of our communications infrastructure. Moreover, the advances in technology are encouraging us to integrate our digital lives with our real lives.

As the Internet becomes more integral to the way we live our daily lives, end users are becoming increasingly aware of the dangers of making too much information available publicly. People use more devices all the time, and at the same time do more with each device. For example, sensor networks will capture personal information on a daily basis, with or without their knowledge. Certainly there is a trend towards increased privacy awareness, although attitudes towards privacy are changing significantly – for many, the level of privacy concern is decreasing.

Games are a technology driver for future Internet experiences

During last decade, video games became an important part of daily life for many Europeans and are no more a marginal form of culture. The video games industry is a melting pot constantly engendering new business models, creating path-breaking content and germinating unique services that are impelling ground-breaking technological discoveries (e.g. more powerful visual computing, bigger and smaller hard wares and drivers and faster networks). The games industry is a leader in blurring the boundaries of textual, audio-visual and interactive content. Constant and immediate feedback from different kinds of social networks (virtual forums, social network sites) and the users of new virtual services and content have a crucial role in cultivating ground breaking innovations to successfully

virtual products.

"Gameification" will apply game techniques across many economic sectors in which SMS play a big part

"Gameification" is currently introducing both the applied games and the new business models in the fields of education, geriatrics, training, policy making and it is rebuilding them to face the needs and challenges of the digital era. As this model will be mainstreamed to other sectors of society, it is to be expected that content and service producers will have a much more central role in determining the future of the Internet during the next twenty years. In these digital markets, most of the innovative business models, services and content are developed by small entities. The ground breaking viral innovations happen in SME's often lead by university dropouts or citizens without formal higher education.

Social platforms evolve and develop. Applications to business, the growing 'Internet of people', new insights into opinion, attitudes, reputation.

The last few years have of course seen the rise of social networks to where they now are one of the basic pillars of the Internet and increasingly of all of our social relations. One of the next steps in this terrain will be the translation of that into the business sphere. Business relations, inter-enterprise and intra-enterprise, are gradually becoming less hierarchical and both social networking technologies (social graph, social business solutions) and more importantly, the social networking mindset are coming to define the way business interaction takes place.

Social networks raise opportunities for people to share and participate - The Internet of People – a trend that includes Web 2.0, social networks and social computing – promotes the Internet as a fundamental channel for allowing users (individuals, groups, communities) a more and more active role as providers of data, content, and services:.

Social networking platforms reveal new insights as digital footprints left by social networks allow us for the first time to draw a social graph, showing the true connections between people and things. Social media are also important in a commercial context, allowing businesses to mine and exploit new information about their customers and react quickly to safeguard their reputation. Some social networks enable to subscribe to social streams to analyse social opinions as they happen.

The increasing popularity of social networks and online services (twitter, blogs, forums), is leading users to expect not just Internet connectivity but also social connectivity anytime and anywhere. Increasing penetration of smart devices (see below) allows people to make their (virtual) social participation mobile.

Media and Content is a continues to grow and forms a huge part of

One of the basic realities of today's Internet is that content, especially video content, represents a very large part of the traffic on the Internet. Controlling the use and distribution, while at the same time fostering its

the Future Internet, becoming more pervasive, more complex and more sophisticated

creation, of all this content must be at the centre of any FI strategy. This is made more difficult by the fact that, as the prosumer becomes one of the main drivers for Internet content, the question of authorship is more complicated.

The very first key action the Commission is calling for in the Digital Agenda is to simplify copyright clearance, management and cross-border licensing supporting digital single market. This means that the regulative and legislative framework will be adapted to make this possible: this will shake the industry and content distribution business models opening possibilities to new players and actors to create innovative services and products.

Spaces and places (public, homes, and business) become increasingly pervaded by digital media as display technologies pervade all these spaces.

3D in many different forms becomes a significant part of FI content

A Growing interest in 3D devices, leading to augmented reality and eventually something close to a complete 3D experience. This will not be restricted to social and recreational contexts but also to working environments, leading to services that can overcome spatial boundaries. Already systems of enhanced reality e.g. allow remote surgery with unprecedented precision and success rate. A significant amount of content uploaded to the Internet is 3D content, some professional, some prosumer, some individual content.

Aspects of the 'Internet of things' become widely deployed, machine-machine interaction increases, and massive quantities of data are generated

Widespread deployment of sensor networks and communication devices in cities, roads, homes, , will generate massive flows of data needing to be processed in near real-time.

The Future Internet will not be only for humans but for machines, with many more machines connected than people. M2M communication systems will make it possible to read out sensors and to send commands to actuators, enabling control systems to be built using the Internet. Alongside this is the rise of the web of (linked) data, an extension of the current web. Contrary to the current web, which uses web pages which are mostly being processed (read) by human beings, the web of data is designed for being processed by computer programmes. Hence, the Future Internet needs to be optimised for automation.

The mobile device becomes an interface to the networked things that (physically and virtually) surround you

The mobile phone will sit in the centre of this Web of things. It will help you orchestrate the interactions of the things around you and provide real-time access to all sorts of information, including the people you meet, the places you go and the content that's available there. The phone is the key to authenticating with these connected devices and taking their content with you, wherever you go.

3.4 The Capabilities of the Internet Will Be Significantly Greater and Broader By 2020 And Beyond

Here we consider some of the disruptive technology capabilities that we expect to be widely deployed and used in 2020+. These have the potential to change the game.

Smart applications based on network support

Smart applications will be a major differentiator of the Future Internet from the current Web 2.0 Internet, as they extend significantly beyond today's ways of content mediation and distribution. Smart applications stand out from ordinary applications through abilities of combining data, content, information and services in ways such that new relationships among data and services are exploited. This way, situated services will become the norm, along with new enablers and business models such as federation and micro payments. Smart applications and services are amongst others characterised by highly autonomous operation, e.g. in machine-to-machine scenarios, and will aim at utilising the available network infrastructure as efficiently as possible. Networks are needed to support smart applications in a reliable and scalable way, by handling a plethora of data types and volumes ranging from sporadic sensor data to real-time 3D HDTV. (Fiedler)

Networks are becoming more polymorphic, self-managing and sustainable

We observe an ever-growing number of access and core network technologies, forming the base for real and virtual networks on different layers and in different domains, which we denote as polymorphic networks. Some networks will be integrated, others connect through semantic gateways. Some networks will serve as generic infrastructure (such as the IP-based Internet), others belong to specific applications. Polymorphic networks constitute the basis and provide the resources upon which smart applications and services are built. Their heterogeneity provides new possibilities, but also new challenges for the efficient support of smart applications and services.

Widespread take-up of IPv6

The widespread take-up of IPv6 will enable truly ubiquitous computing, reducing roaming costs and allowing users greater freedom. The increased address range enables a plethora of connected objects, forming a continuum of information and data for the user to navigate.

The future Internet is cloud – blending network, computing, and storage into a seamless service platform

[This section needs a little more discussion– Ed] Previously, the separation between the network, and the data centres, computers meant that we thought of the Internet as a communications infrastructure linking computers (personal, enterprise, hosting). This distinction is blurring and increasingly we think of the Internet as the cloud, a hosting environment for services that integrates computing, storage, and networking. Increasingly as the cloud infrastructure becomes 'utility', software will be independent from the particular flavours of cloud infrastructure on which

it runs.

Like the era before personal computer revolution, cloud computing is increasing the amount of computation on the server side. Service customers benefit by a reduction in costs, less effort for software management and simplified collaboration with other users. Moreover, cloud computing and social networks raise issues with respect to the ownership of private data, with a loss of control by citizens of their personal information and a reduction of freedom with respect to large service providers.

Data and search

[a section is needed on data – this should go in a subsequent version - Ed]

Interaction

How we interact with services and systems and devices will change radically. Now we type, mouse and touch. In the future we will also wave, point, look, gesture, react, or even think! , multimodal, multidevices, haptics, integrated into things, sensing, 3D, displays, systems.

[This section requires further elaboration – Ed].

Sensing / capturing

Ability to capture more of real world

A 3D world

Content uploaded, used and stored in the Internet will be 3D content. This doesn't necessarily mean that all content will be 3d models as in a 3D movie (although some of it may be) but that all the content uploaded and used online will have a 3D aspect to it, e.g. the pictures taken from real world objects uploaded to the Internet can be used for virtual 3-D reconstructions of our real world. 3-D models can be made available to anybody. Digitally-born models will more and more become available through the Internet (Google 3D data warehouse, 3D VIA,) (Behr n.d.)

3.5 Current Research Will Create Technological Opportunities in the 2020+ Timeframe

Current research will be products and services at the start of next decade

Current technology research in the domain of Future Internet will become products, services, capabilities, infrastructures in the 2020+ timeframe on which future research can build and use. Key areas of research and technology development as defined in the Future networks research in FP7 are the following (Work Programme 2011-2012)

Future Networks

Future Networks that support the convergence and interoperability of heterogeneous mobile, wired and wireless broadband network technologies, including notably novel Internet architectures; network management and operation frameworks, wireless and broadband systems and ultra-high capacity all-optical networks.

Cloud Computing	Cloud computing, Internet of Services and advanced software engineering that emphasise technologies specific to the networked, distributed dimension of software and the access to services and data.
Internet connected objects	Architecture and technological foundations for Internet-connected sensors, actuators and other smart devices and objects, enabling person/object and object/object communications
Trustworthy ICT	Trustworthy ICT including security in networked service and computing environments; trust, privacy and claims management infrastructures; and data policy, governance and socio-economic aspects of trustworthy ICT.
Networked Media	Networked media and search systems, including digital media delivery platforms, end-to end immersive and interactive media technologies, and multimedia search technologies.
Experimental Facilities	Experimental facilities (known as FIRE) for experimentally-driven research on the Future Internet; the facilities will provide larger scale and diversity to test and validate the developments at closer to reality conditions.
Future research agenda	Among the concerns from the networking research community for the future research agendas are (see: Future networks, The Way Ahead (2009)

- Among the concerns from the networking research community for the future research agendas are (see: Future networks, The Way Ahead (2009)
- ICT energy consumption and ICT solutions for energy saving
- The concept of “network as a service” which requires closer cooperation between network and service players
- Self-organisation and autonomy to manage the complexity of the networks
- Virtualisation allowing polymorphic networks, network of networks and infrastructure sharing
- Mobile cloud computing requires a more comprehensive research approach

4 What's our Vision?

What impact can the Internet have in the future? What could we achieve with the Internet to address the key challenges and needs of the economy, society, and citizens?

4.1 Future Internet and Business

Our vision is that the Internet penetrates deep into all sectors of the global economy. In this section we highlight the contribution that the Internet in the future can make in each of these sectors (without discussing how!)

Enterprise is 'virtual', transforming roles of customer and employee, and exploiting knowledge through open innovation

Enterprise becomes a virtual "Cloud" enterprise transforming traditional r roles from customers to employees and entrepreneurs. Customers will participate more and more in the definition of products, but also in the production processes (e. g. as "prosumer", i. e. , producer and consumer); employees will work for an enterprise with new legal and working patterns and conditions, moving towards the new figure of "workepreneurs" (a mixed role of employee and entrepreneur).

Another dimension is represented by the evolution of the notion of virtual enterprise and business ecosystem. In short, the total business connectivity, and the fading of enterprise boundaries, will lead to a scenario summarized by the motto: 'the network is the enterprise'.

Open innovation, and a deep rethinking of the rationale underlying current approaches to R&D, leveraging on the 'collective intelligence' that the Internet can support transforms the European industries.

Future Internet enables high knowledge-content innovation,

We will use Internet technology support the application of Europe's highly skilled, knowledge-rich workforce to exploit opportunities for high knowledge-content innovation in both products and processes.

Future Internet technologies drive rapid, disruptive innovation by providing industry with access to knowledge through enhanced, possibly specialized, search services that ensure that even the smallest specialist enterprise has immediate access to advances in the relevant technology. At the other extreme crowd-sourcing technologies supports the rapid specification and design of products which will command a significant, but possibly short-lived, market by providing a needed product.

Supporting manufacturing agility

Future short product and technology life cycles will demand an ability to re-deploy manufacturing assets (equipment and people) rapidly. To exploit short life-cycle opportunities, manufacturing facilities will be able to make rapid changes. Self-configuring manufacturing systems will be capable of responding flexibly to changing demands. The fragmentation of large

plants into outsourced specialist SME manufacture offers flexibility in deployment of assets through enhanced Future Internet services that monitor and control these complex and less homogeneous systems.

Exploiting emerging technologies

Technologies that allow business to exploit emerging and developing technologies whilst monitoring their performance and further development will available through the Future Internet of Things. Risk management services will make initial assessment of risks and potential impacts, and then monitor risks and impacts as the technology and a project to exploit it develop, thus aiding effective decision making.

Supporting collaborative manufacturing

A Future Internet will support manufacturing collaboration by networks of specialist SMEs through services that identify and assemble competences and the necessary resource capacities to exploit an opportunity, and these services will be accessible to non-IT-specialist SMEs. Future Internet services will support operationally very complex and volatile, distributed development and manufacturing virtual organizations.

Services link the real world to the cyber world

The definition and scope of 'services' are being redefined. We have to think of services not just as software entities but as economic and social entities that bridge between two worlds (FP8 Expert Group 2011): 'service platforms' (i.e. the digital world) and 'real life'. New economic and business models, such as having the service provider pay rather than the user; or collaborative/co-operative services offered by many to many are possible. New business markets will arise, scaling with this new ecosystem. More generally, we need to look closely at the whole area of incentives in service provision. Processing data on-the-fly, as it is produced, will be an enabler for new services and business areas. Virtualisation and the cloud will bring opportunities to use remote resources as if they were local.

The Internet of Services will be closely connected to and will interact with the Internet of Things. New services and apps will be able to be composed on top of real-world objects interacting in real time as easily as today's data mash-up compositions. The Internet of Services should be able to process the large amounts of data that will be generated by Internet of Things scenarios. Many of these scenarios require near real-time processing of the data generated from the devices.

New global service delivery infrastructures are required to cope with services and data growth and with the diversity of software and hardware platforms in an economic way. Such infrastructures should offer: universal, resilient network access; seamless integration of networking computing and storage resources; and dynamic and intelligent allocation and distribution of software and data according to context (user needs,

security, and requirements).

We need a user-focused, self-adapting service landscape. Systems should be built in a goal-oriented way by integrating available software and services of which the producer has practical knowledge. We should find innovative new programming models for composite systems (ones combining human and software services); and for distributed secure data cloud applications. The ability to provide maps and objects to deploy (mixed) reality applications should also be investigated.

New, faster, more responsive approaches to software and service development are also required. We have to find easier ways to develop applications that can be distributed and shared across a global infrastructure or resources.

We will have the tools to build secure systems and services and the ability to verify that they are secure

Security is an increasing concern as network systems are involved in even more facets the economy and services provision. Our vision is that these security concerns will not be a barrier to the creation of new and high value applications because there will be good tools for software designers to understand and express security and privacy aspects of systems that they build, and security considerations will automatically be taken into account during software development - we have justifiable evidence (software assurance) that software is secure.

It will be possible to dynamically compose and personalise services in a secure way and customization doesn't come at the cost of security. The services that are available on the open market have well-defined security properties such that it will be possible to make choices about services based on a sound understanding of security and risk. Inter-organisational security analysis and management will be possible.

End user (businesses, and individuals) will have the tools and understanding to manage and make decisions about digital risks

There will be good tools and other support for end users to understand security and privacy implications of services they use. For business, risk assessment will be easy to do and significant amount of the work of risk assessment will be automated and carried out on a regular basis.

End-users will have a better understanding of security and privacy risks, and whilst we will learn to live with insecure world and risks (e.g. In social networking), users will also be more empowered with more control over the level of risk and there will be standard, transparent, interaction with systems and networks so that ordinary people can be assured of privacy and security risks.

Users and businesses will be accountable online, for example through a built-in forensics capability and individuals will be able to enforce rules and

police the net perhaps with less need for centralised policing due to increased awareness and control that users have.

Content, Creative and Media

Barriers to entry for content creation are lowered (and future Internet capabilities such as virtual and augmented realities are used as tools to deliver education and training across a wide range of topics from the classroom to the enterprise to healthcare.

4.2 Future Internet Addressing Societal Challenges

Also in our vision is the way in which the Internet contributes to addressing some of our deepest societal and global challenges. Here we highlight the way in which future Internet makes a difference to these challenges.

Future Internet Services are fully inclusive and accessible to everyone, everywhere and every time they wish to use them

Inclusive access will be built into the Web and all other services by supporting developers in deeply embedding generalised accessibility support within future mainstream ICT products and services based on interactive content and accessed everywhere including the mobile phone and the TV.

Just enhancing the computer that older people and people with disabilities use through Assistive Technology products is not enough for tomorrow's fully interactive web content, we must make accessibility tools available everywhere, all the time. By making these available by default, it will become possible to provide more efficient, inclusive and cost-effective access, to allow productive participation and greater independence. It will also become easier for industry and governments to ensure that new Web technologies and services are accessible to those with few resources.

Accessibility tools will be available everywhere, all the time, without restrictive IPR conditions. The will be used ‘by default’ when future Internet services and systems when are created so that efficient, inclusive and cost-effective access is available to those who might otherwise be excluded from accessing the services and benefits of the Internet in the future, enabling productive participation and greater independence. It will become easier for industry and governments to ensure that new Web technologies and services are accessible to those with few resources.

Smart cities are connected, citizen centric environments with innovative services and

Cities, as well as rural areas and regions will be fully connected by 2020. The Digital Agenda targets the availability of 100 Mbps connections for at least 50% of web users by 2020. FTTH broadband networks and open wifi-lan at public spaces will drive towards full connectedness.

Citizens will act as users and producers of e-services, being involved in the

sustainable economies

creation of online city services related to the environment, transportation, energy, health, social, arts and education. E-spaces, such as for communities and social networks, will be the environments for empowerment and e-participation. The concept of a **Living Lab** will be accepted as innovation ecosystem organisation principle enabling full engagement of citizens and SMEs. Cities will effectively be acting as innovation environments for the Future Internet.

The new economy of cities will mean that cities are global, sustainable and user-driven. City innovation policies target sustainable growth, quality of life and participatory governance. Smart or intelligent cities are addressing the challenges of global competitiveness, reduction of poverty and environmental sustainability. Among the key innovations enabling these goals are ICTs for business lifecycle support and virtual business networking, to support employment and SMEs competitiveness in cities and urban areas. All city districts working as living lab based innovation ecosystems.

Future Internet-based applications in health, security, energy management and business support are key drivers of urban development. Pilots are sustainable and lead to rapid user roll-out and upscaling, and to continuous innovation cycles engaging SMEs for service and technology innovation. A full range of applications becomes available to citizens and citizens are engaged in innovation processes. Future Internet based applications address the major challenges of cities. Advanced ICT-based applications will be available for all: especially in domains such as mobility and transport, business support, health and care, assisted living, energy management, water resources, retail. Availability and access to data e.g. urban flows combined with drives application development and bottom-up innovation by SMEs.

Users are empowered over privacy and personal data

People have basic rights in cyberspace (freedoms, privacy), and will be aware of and understand the privacy issues that affect them. They will have control (be empowered) over personal data and it will be easy for them to choose their level of exposure online through readily available, user-friendly privacy policies to choose from and tailor to one's taste. Sometimes we think of this as the ‘digital delete button’ that will cause digital information to be erased from the Internet wherever it is. On the other hand, we can also think of this as the ability to control what services can be?

From a business perspective, it will be possible to offer services that respect individuals' privacy needs and choices (e.g. for advertising) and at the same time use that personal data to provide high valuable customised

and contextually aware services to them.

Vision for Green ICT

We must develop solutions that mitigate the impacts of first, second and third order effects of ICT. The 1st order effects are related to the mere physical existence of ICT, such as production, use and end-of-life treatment. The 2nd order effects are related to the application of ICT which leads to optimisation of processes in other sectors (e.g. traffic optimisation); substitution (e.g. e-processes replace traffic) and induction (e.g. create more demand in other sectors). The 3rd order effects are related to the societal changes that ICT brings along, such as deep structural change towards a dematerialised economy, increased dependency on a critical infrastructure, and rebound effects. Examples of rebound effects are the stimulation of increased demand due to time-saving optimisation (e.g. increased leisure time traffic), software-induced hardware obsolescence or the miniaturisation paradox, which indicates that hardware, is getting cheaper faster than it is getting smaller. The Jevons Paradox applies to the current situation, that is the proposition that technological progress that increases the efficiency with which a resource is used tends to increase (rather than decrease) the rate of consumption of that resource.

Finally we must consider that Europe has a critical dependency on rare earths for the production of advanced ICT equipment. Some materials are very sparse on earth, such as indium (In), a rare chemical element with soft, malleable and easily fusible properties. Indium is currently consumed at a rate that will exhaust the world-wide reserve base of economically-viable indium in only about 10 years from now.

The critical dependency on such materials means that Europe must invest in e-waste management in addition to the fact that in environmental terms, due to the materials recovered, we save energy otherwise used for their primary production.

Our meetings, interaction, remotely really works

Telepresence becomes a really valuable way to meet, collaborate, and interact with people at a distance, making interaction more immediate and effective. In a world where the knowledge supply chain is critical to business success, energy costs are high, telepresence becomes a business success factor, and contributes to sustainability by creating an effective alternative to carbon-based transport, taking cars off roads, people off planes, carbon out of economy

Presence in space and time

The advances in display and other interface technologies, ranging from 3D, haptics, other senses up to augmented cognition will enable applications that shift the perception of the users' presence in space and time. This capability is called situation awareness and has many practical

applications. The simplest applications are replacement of physical travel, experiencing future situations, education/learning or perceiving gaming landscapes. However a broader range of benefits and opportunities are likely. Perception of the environment is critical to decision taking in complex and dynamic areas such as emergency response situations (fire, police), aviation, air traffic control, power plant and complex factory operations.

Gameification is mainstream

The best practices of interactive services (e.g. community management) and digital business models (e.g. micro transactions) developed in games industry will be mainstreamed to the other sectors of society. In practice this means that e.g. in the area geriatrics revolutionary health games will be introduced, in the area of education and lifelong learning different kinds of educational games will become the norm, city planning will be based on technology developed for games using mixed reality, decision making processes in political parties will be based on virtual community management methods (Behrmann n.d.)

A User-Centric Internet Fostering Innovation and Collaboration

Innovative businesses will rely on the custom service compositions that they meet their goals and needs.

There will be powerful new paradigms that enable businesses to handle the vast amounts of data generated and to manage digital assets throughout their lifecycle, so as to bring instant value to end-users.

The Internet of Services for the Internet of Things

We envisage the use of web technology to make a 'Web of Things' which is accessible and programmable by developers that are not necessarily experts in the field.

We expect there will be services to support and manage a vast majority of non-human Internet users (i.e. M2M services), reflecting the potential growth in connected devices.

A Future Internet Based on Privacy, Security and Trust

Security, privacy and trust are the foundations for service capabilities and user experience, especially for accessing services and data on shared and exposed resources. Systems will be able to query, aggregate and correlate sensitive data in ways that preserve privacy.

Future architectures will make it easy to develop fully-decentralised secure services offering the necessary levels of security and trust. The new service platforms will be inherently dependable, i.e. dependability will be an inherent attribute rather than an intrusive 'add-on' as in most current infrastructures.

In the Future Internet, the boundaries between correctness, safety and security will slowly disappear. This decentralised paradigm presents a major challenge for verification, which currently relies on a global view of system behaviour. Furthermore, analysis performed at design time can

only be partial, since Future Internet services will be open and dynamic by nature: verification at runtime will also be required.

New Service Environments and Infrastructures

We predict the emergence of a global scale service platform with new business/revenue models that reflect the shift towards very large service providers. Of course the large-scale virtualised platforms and associated tools and services will be manageable due to advances in user interfaces and information presentation.

Applications, services as well as platforms/infrastructures will be optimised for virtualisation; the issues of availability, dependability and security for virtualised infrastructures will have been addressed to a significant extent.

Infrastructures will be scalable, where scalability leads to a non-linear increase in costs. Scalability is especially significant in view of the growing number of devices, the exponential increase in data, the increasing need for processing data on-the-fly, and the pervasive need for security.

Smart energy management is an issue that spans from data centres to mobile devices. Services will communicate better with the infrastructure to have them energy-aware with self-adaptive energy efficient networks and computing resource management.

Autonomic systems will enable large-scale infrastructures to cope with failures and improve maintenance while preserving services to the users.

New Ways of Developing Software

Development time meets runtime: The development of Future Internet services will be characterized by the disappearance of the boundary between design time and runtime. This has a deep impact on software engineering activities such as, evolution, maintenance, testing and verification that, until now, leveraged models produced at design time. It is thus necessary to offer effective means to retrieve and maintain models at runtime in order to drive all these activities online.

4.3 Future Internet Technology

We acknowledge that the Internet is not just led by problems and applications, what's our vision for what the Internet itself might be able to do?

Polymorphic networks support smart applications and services

Well-performing, secure, reliable, economical and sustainable polymorphic networks constitute the basis for smart applications and services. Networks, services and applications will be interwoven, and application-specific networks will be the norm. Future networks will be highly scalable and operate in highly autonomous, cognitive and cooperative manners, providing controllable service quality and security far beyond best effort. Future provisioning will happen in a holistic, multi-disciplinary way. Being a true commodity for everyone, the combination of smart applications, services and networks will enable new and previously unavailable benefits

for multiple stakeholders, such as users, enterprises, industry and society.

The deep embedding of future smart applications and situated services in essential parts of daily usages provides a true basis for reinforced social, economic and ecological stability on a global scale. (Fiedler n.d.)

Internet of things

Some content expected on this? - Ed

Web clients

We envision an Internet where the final users will have more control on their local or remote data and where the Internet clients will maintain more control of the computation, and the distribution of resources between client and server. Third party services will be able to execute also on the client side, while server side computation will be used when local resources are not sufficient. A new user interaction model will emerge, less application oriented, and more information and service oriented. Final users will install on their computers, not monolithic applications, but more fine grained local services and functionalities. They will interact, not with applications, but with aggregate (local or remote) services, building a unique, integrated and personalised environment to satisfy their own, individual information management needs. Final users will work, not with traditional documents, but with views on interrelated, structured data, built by aggregating local and remote information. They will manage diverse information types, such as text, audio & video, without being aware of the underlying data formats (such as 'doc' or 'html' for text). In the long term, the service-oriented web will become the common model of computation and there will no longer be any distinction between the computer desktop and the browser, or between the modality of interaction with locally stored information and with Internet, "cloud" content

3D assets are seamlessly integrated into a complete 'mixed reality'

Virtual 3D reconstructions of the real world will complement the current image and video data on the Future Internet.

Based on collected, distributed and filtered information a cognitive meta-model serves as information carrier for applications and should provide the templates for object classification that can be used to create and recognise new types and forms of objects. These objects are referred to as evolutionary 3D objects.

Evolutionary 3D objects must be based on presentation independent object descriptions. The Future Internet architecture must take account of evolutions of new knowledge carriers within independent ecosystems creating and establishing adequate communication channels.

The seamless integration of 3D assets and concrete relations to image

analysis and synthesis are enablers for implementing simulated mixed reality environments and provide augmented capabilities for many types of services (Behr).

Nano communications

Nanotechnologies emerge as a means for constructing components at the sub-microscopic scale of a nanometer and allowing the fabrication of simple devices ranging in size from 0.1-10 µm. Although largely in the research phase, practical applications have been experimentally demonstrated. Useful applications of nanomachines could be in medicine e.g. to identify and destroy cancer cells, or in the environment for detecting chemicals and their concentration.

Recent progress in nanotechnology and nanoscience has facilitated the study of molecular electronics. At the experimental level the advances have facilitated the manipulation of single-molecule electronics. While these artefacts are mostly operating in the quantum realm of less than 100 nm (a scale where quantum mechanical effects become relevant) their collective behaviour can manifest in the macro scale.

Research must be performed on the interfaces from the macro world to the nano and molecular worlds, in order to usefully interact, observe, control, organize, and exploit the behaviour of nanomachines and molecular building blocks, as well as retrieve useful information from the sub-microscopic world. The research can extend to the programmability of their properties and behaviour.

Generally the problem of interfacing is challenging research for the next years, since the known means of communication at this scale differs from the communication means in the macro scale.

Important fields of research are securing the macro/nano interfaces in particular in applications which have a direct impact on species and the environment in general. The possible programmability of their properties is enhancing this requirement.

The starting point is that it has been demonstrated that electromagnetic waves generated by electromechanically resonating nano-materials can be produced and processed at this scale.

Augmented Living

Advances at the borderline of ICT and human cognition provide grounds for the development of services that until recently could have easily be pushed in the science fiction corner. However advances in interfacing technologies with human senses in general will improve the reality feeling considerably leading to virtual environments that might not be distinguishable any more from real environments. In addition advances in

all areas of medicine have provided humans with many restorative technologies that can also be used to enhance or optimise human mental or physical performance.

Neuroscience begins to understand the human brain, cognition and human behaviour in complex dynamic environments. Technology and engineering have started to develop and implement the concept of a brain-computer interface, and starts to deliver wireless and wearable interfaces. Although all applications are still in the experimental phase, the area has made significant leaps forward. In particular progress in made in both directions namely (i) control or communicate with a machine via brain commands, and (ii) augment the brain's cognition with information from outside.

Starting from simple augmented reality applications, and perhaps ending at augmented cognition, many services and applications are possible. Most of them will be based on human cognition supporting technologies that will be available on the market and usually will require communicating in some way or other via a body area network to some back end service pool via wide area networks.

With the assumption that in 10-15 years from now the number of communicating human cognition supporting technologies will not be negligible and will have a profound impact on the networks. Such technologies may or may not be distinguishable from the emerging Internet of Things.

What will be the required capabilities of networks to deal with a fairly large number of human cognition supporting technologies? How can the different networks be efficiently combined to deliver the infrastructure to support this vision? What are the enabling platform services that must be in place to support the efficient and secure delivery of such services? Research must answer questions about the technical, societal, and last but not least ethical impacts of such a vision.

5 What Are The Challenges That Need To Be Addressed?

In bringing out the broad challenges for the Future Internet we attempt to approach this from the perspective of each of the different stakeholders

- People: What are the challenges to making the Internet work for people, as users, citizens, individuals, family members, carrying out our daily lives, bringing up families, working, living
- Business: What are the challenges to making the Internet work for business, growing, innovating, being efficient, across different sectors,
- Society: What are the challenges to making the Internet work for society, i. e. collectively, thinking about some of the big shifts and how the

Finally, as we look at the broad technical challenges across the future Internet

- Technology: What are the big technical challenges to creating the future Internet

5.1 Business, Economy

Future Manufacturing challenges Interoperable Enterprise environments

To support future manufacturing innovation, low cost, distributed, adaptive, interoperable, secure Internet environments are essential. Specialist SMEs may be involved in several different projects or collaborations simultaneously, all of which may require different enterprise environments. Future Internet services must be able to adapt to provide new Internet based working environments at minimal effort cost. Future Internet environments must therefore be extremely flexible and adaptive rather than requiring the user to change their working practises to fit in with the operational requirements of multiple different working environments.

Extensive Monitoring, Evaluation, Risk Management and Forecasting

Creating and maintaining an efficient collaborative network throughout its lifecycle and achieving optimum performance throughout its operation is very challenging. All supply chains and virtual organisations face risks from competitors, changes in customer or market requirements, partner failure and disruptions such as resource failure, bad weather, staff illness, disasters, Potential risks exist for individual partners and for the network as a whole. Partners within a collaborative environment therefore need constant support to be made aware of both potential problems and emerging opportunities in order to maintain and improve the operational effectiveness of their network or supply chain. Future Internet systems therefore need to provide services for extensive monitoring, evaluation and forecasting of network performance and potential operational breakdown or failure.

Knowledge management across the supply chain

Knowledge Management in supply chains or virtual organisations is more complex and challenging than for a single organization due to differences in business and cultural environments of the partners within the collaboration and the overall structure of the network.

Explicit knowledge, such as details of resources, designs, can be captured and disseminated between partners in a virtual organisation fairly easily with careful use of existing technologies. However the major challenge remains of capturing and exploiting the tacit knowledge (e.g. expertise and experience of staff and management). Yet such tacit knowledge is the most valuable resource of an innovation-centric SME as it represents their competitive edge. Failure to capture and use tacit knowledge within the enterprises and from the external environment (e.g. market) generates intensified risks for a collaborative network, such as out dated products, inventory problems, forecasting mismatches, high manufacturing and other costs. New innovative business and management models and methods are therefore needed to enable the effective and efficient acquisition of tacit knowledge as these will result in enriched business intelligence.

Enterprise

Social knowledge media. Internet is inducing deep changes in the socio-economic scenario. People will be increasingly empowered, thanks to the increasing facilities to discover, connect, exchange information and knowledge, and allow its advanced use work and invent together, remotely. Such an empowerment will be deployed in their role of citizens and workepreneurs (see above). The new power will be unleashed by the possibility of gathering and putting together action and knowledge, in new social and production settings.

Knowledge Clouds. Internet will be asked to connect all possible resources: data, knowledge, people: real and virtual (e.g., avatars), real world resources: physical (e.g., smart objects) and virtual (abstract entities, e.g., a marketing strategy). Knowledge and data will be mainly managed where they are generated, but progressive layers of 'context and pragmatic' knowledge will be created and maintained. The Knowledge-Cloud will expand beyond the enterprise boundaries and will boost also the capacity of continuous innovation (a knowledge-intensive activity).

New forms of enterprise and organization will progressively emerge, characterized by high flexibility and innovation capability. They will be structured with a systematic, engineering approach, adopting also large levels of decentralization and self-organization for some parts and components. Here the notion of Enterprise Resource is central, conceived in its broadest import, and positioned in a totally connected cooperation

environment.

Digital Commoditization. This challenge refers to the marked growth of standard (though flexible) business services largely available, easily accessible, and flexibly usable on the Internet. The transformation of business services into commodities is a guarantee of easy adoption for enterprises and the inclusion in their business processes.

Interoperability Service Utility. The large variety of actors operating and cooperating on the Internet require ubiquitous and easily accessible mechanisms to allow different entities (e.g., people, enterprises, objects, systems) to connect each other and to exchange information, objectives, tasks. The Future Internet, among its intrinsic facilities, will be able to provide powerful services to achieve the needed levels of interoperability (in terms of performance, costs, QoS,).

We can't make all the risks disappear - Business must be able understand and make decisions about risk, based holistic view of threats and security situation

Business trade and operate in challenging environments all the time and they need to understand the risks they are exposed to and take decisions about how to respond to those risks. As businesses continue to deeply embed and rely on the Internet in the very broadest sense, they need to assess and make decisions about their 'Internet risk exposure' and the consequences for the business in general. Indeed, Internet risks and business risks are as intertwined as the business and Internet have become inseparable.

In this context, some of the challenges that business face are in achieving risk awareness and situation awareness in a user-friendly way, delivering quantitative risk assessment in real time, having predictive analysis of security problems so that they can take preventative steps, and performing anticipatory impact analysis for decision support.

This has to take place in a cross layer, cross domain approach, using models that deal with security and risk in a holistic manner, make risk-sharing between cooperating parties possible, and not treating these as silos and independent problems or risks.

Turning security management from an art into a science; metrics, assurance and policy.

It is an oft-quoted maxim that what you can't measure you can't manage. Whilst we can observe security breaches, count threats, and monitor incidents, there are not adequate metrics for security, particularly those that address impact, cost, and threat. Developing suitable security metrics and risk assessment techniques for future Internet security is challenging, and when developed these must be tested in real scenarios in real time.

Likewise, security assurance – the ability to demonstrate and provide proof that systems are secure through audit, certification, and testing

needs to be developed to work in a future Internet world where multiple parties are involved in complex interacting systems of service provision and where competition frequently results in unwillingness to disclose and share information about security and risks.

In a complex multi-party environment it's vital to be able to express security policies in ways that all parties can understand and implement and enforce. There will be challenges in capturing and expressing socio-technical contexts in machine readable form, resolving policies at run time in multi-party service contexts, making policies from different sources interoperable, and enforcing policies on the service and at the end user sides.

5.2 People, Users, Societal Challenges

Cities

Cities nowadays are addressing a complex set of socio-economic policy challenges: competitiveness, inclusion, innovation and skills, employment and entrepreneurship. Creation of a sustained innovation economy and innovation ecosystem is a key concern of smart city policies. To support that goal, they work on creating the digital as well as immaterial (knowledge) infrastructure of smart cities and on establishing public-private partnerships for sustainability. To support that sustainability innovations should address societal and urban challenges such as energy efficiency, environmental quality, mobility, healthcare and business support. A challenge is also to create end-user driven and participatory innovation environments on city-wide scale to experiment on cloud computing, open data, media technologies and Internet of Things applications. Other specific gaps and challenges include:

- Create innovative financial models of broadband investment and address current economic uncertainty
- Enhance the digital skills of citizens and SMEs
- Ensure business and city stakeholders support for smart city strategies
- Identify real demands for ICT-based applications and clarify socio-economic benefits
- Integrate the envisaged digital services to the overall working of cities, strengthen launching customer role of local governments.
- Encourage direct citizen and SMEs participation in service innovation
- Establish social spaces for open creation (e.g. innovation pavilion)
- Experiment on interconnected devices in the city spaces (sensors, actuators, smart devices,);

Make cloud services and software components available to build networked applications.

Challenges for

Neither the average end-user nor Web developers, managers or

***accessibility**: familiarity with accessibility requirements, implementing design for accessibility, and making interactive multimedia applications accessible.*

commissioners are familiar with the complexity of user requirements resulting from personal characteristics and preferences (e.g., for people with disabilities and older people), together with the variety of devices they might use.

While user-cantered design (UCD) is now a commonly used process for designing mainstream hardware, software, and web interfaces, design for accessibility is relatively uncommon in education and practice. As a result, the scope of users and the situations in which they operate products is not as inclusive as it could be. By integrating accessibility into the design process, designers can efficiently create products that work effectively for more people in more situations. In fact, costs for accessibility can be justified in the same way as those for usability, which is now commonly regarded as a mandatory requirement. Designing for accessibility will yield greater usability for all, not just for people with disabilities.

The rapid increase in the multimedia and interactivity of the Web makes the issue of accessibility for users with disabilities and older users much more complex and difficult to solve. As happened with the introduction of graphical user interfaces for personal computers and with the original introduction of the World Wide Web, people with disabilities and older people face the possibility of being unable to use these exciting new applications and participate in the developing information society.

Finally, Internet Protocol Television (IPTV) has the potential to fundamentally change the way people interact with their television sets. Whereas previously television was largely a passive experience, with IPTV there is the opportunity to deliver a wide variety of interactive television (iTV) applications to the user. The former television "viewer" is rapidly becoming a television "user", who interacts with different aspects of the programming that is delivered to them

People must understand and be in control of their exposure to Internet risks

It is a huge challenge to enable end users – both ordinary people who want to use services and systems, and people who have to manage Internet systems for business or service operators – to understand and manage future Internet security.

Making security and privacy management 'user friendly', for example by representing security contexts in an understandable way, is challenging. There is a balance to be struck between security and usability and it is highly likely that this balance will shift over the coming decades, but it is not clear in which direction. User interface design for security presents many challenges – reducing cognitive complexity and providing means for 'intuitive' configuration of security and privacy for people who don't want or need to wrestle with complex computer systems. It is not even clear

what globally accepted and intuitive 'trust anchors' exist on which to hang the whole framework from.

Identity and privacy capabilities in the future Internet must respond to changing policy, services, and individuals needs and requirements

Future Internet challenges around privacy and identity online will continue to arise as a consequence of developments in public policy, dramatic increase in the power of data analysis, increasing amounts of data captured directly and indirectly, new and valuable service offerings based on personal information and context, differences in approaches between different countries, national security interests, and last but not least, attitudes of individuals and communities towards privacy and identity online.

New forms of digital content, evolving business models, whither DRM?

Given that media and content has been one of the first and arguably the most impacted and transformed sectors, the question of what challenges arise as we create the next networked digital media world is particularly interesting, if difficult, to address.

Clearly there are many challenges that arise from the tussles that occur around rights, use (licenced, fair, or otherwise), mash-up and reuse, protection, theft, distribution digital materials. It is not the role of this roadmap document to come down on one or other side of the "DRM is good/bad" debate, nevertheless it is clear that online digital content (in the broadest sense) will evolve and change as much over the next decade as it has in the past and that the management of digital rights must evolve along with it.

The quantity and variety of digital content is set to increase, covering professional, prosumer, consumer generated stuff and including social media, blogs, tweets. Perhaps the challenge is to develop a forward looking rights management model for emerging media that gives all participants a range of ways to licence content and to derive revenues and recognition from it that makes it possible for all parties involved in the business to participate in the business model and in revenues that derive from it. The challenges that will arise then will arise from

- The fine grained content abounding in the future Internet
- Contextual content, and rights of the owner of the context
- Going beyond payment for attention, to payment for effect
- Situated media and simulated reality

5.3 Technological Challenges

Developing Correct Software

The abstraction level currently used in programming languages needs to be improved; model-driven development has proven successful in abstracting complexity in larger systems, but for systems-of-systems hierarchical modelling is needed. It is also easy to see that the global optimum for the full system might be suboptimal for its parts and vice versa. Thus, there is a need to enable model-based continuous optimisation and adaptation at various levels and in real-time. The weak part in model-driven engineering has always been the code generation, and research should be invested into making the platform-specific mapping fully automatic for different platforms. Software today runs in clouds on parallel hardware and grids. The change from sequential software to multiple entities running in parallel will bring new challenges for code development that may be handled by clever code generation and automated support for deployment on parallel platforms. Finally, research should be invested into formal methods for correctness proofs of mission-critical models.

The challenge of capacity and resource management in the network (limits of capacity and performance)

One of the major challenges is to find and bypass the bottlenecks in the network system. In practice this means efficient solutions for management and better utilization of autonomic management features. The work conducted in research of autonomic networks and autonomic network management has mainly focused on different small scale ad hoc networks, sensor networks and optimizing the data transmission capabilities. The big challenge in future is still to apply the found solutions globally and also to optimize the network infrastructure and services towards the energy-efficient solutions. The work is still needed also for cutting down the operational expenses in the management systems.

Due to the increasing volume of the information and data, the intelligent arrangement of storage capacity, data reserves and caches are also one of the key challenges for future networks. This includes not only the well-defined and clear business models for providing content in large scale, but also arranging load balancing, improving user access and providing secure and trusted operations for content (and not only for users but also for content and service providers).

In addition to aforementioned challenges on trusted and secure content access and content centric networking, autonomic network management, and energy/resource aware computing and communications, the “real world Internet” challenges will also become immediate in media and information delivery in future Internet. The small devices and sensors/actuators can be also seen as a part of the media and information sources, which makes the future networking landscape more polymorphic and complex. Since the resources for such devices are very limited,

building up a robust and efficiently controlled system is challenging.

Networks that support smart applications embedded in everything from infrastructure to cities to services will be challenging to develop

Smart Applications will have complex and challenging requirements for the networks:

- use of application-specific networks with own topologies, naming schemes, and routing and resource management techniques;
- use of very different transmission modes even in parallel (yet any mix of intermittent and delay tolerant, multi-hop mesh, packet- and circuit-switched transmission modes is permitted);
- smart provider and connectivity selection (e.g. based on economic competition and ecological considerations); or
- being agnostic whether wireless, mobile or wired connections are used.

Smart services require a holistic approach for design and engineering under which goes beyond the “one-size-fits-all” approach to the current Internet.

One of these boundary conditions is the need for immediate follow-up of emerging trends. We are facing a high speed of application development, combined with quick (and potentially dirty) deployment. A consequence of this “rush” is that some parts of the systems involved in service delivery cannot keep track and turn into bottlenecks (such as the mobile networks when the smartphone avalanche happened).

Furthermore, future arenas for smart applications extend beyond the “western world” to all parts of the globe with specific demands, potential and economic boundary conditions.

The challenge “legacy versus clean sheet” will prevail. Issues of social, economic and ecological sustainability need to be addressed. The boundary conditions demand for an improvement of the still quite limited understanding of relationships between users, technology and business.

Developing and operating secure future Internet systems necessitates taking a systems approach and having the tools to address

One of the greatest challenges in developing and operating secure future Internet systems is recognising that we are dealing with complex cyber-physical-human systems and taking a holistic approach to systems security.

This means having the ability to make and maintain models of complete systems, understanding the coupling between system, dealing with systems that change, adapt, and interconnect over time, when components are reused in other systems. It is often difficult to determine where the system boundaries are, and the interaction between different layers of abstraction (e.g. Internet layers) cannot be ignored.

In many cases very high levels of security and availability will be required, such as when supporting critical infrastructures. Resilience and failure tolerance are real challenges. In other cases the scale of the number of systems involved, such as in large scale sensor systems and applications or in the interaction between mobile and situated computing systems will be vast. It may be that systems (e.g. sensors) do not have the capacity to implement strong security measures and in such a situation a systems approach must be taken to ensure that the systems are robust and secure.

Services

From a cloud point of view, all existing software can be considered as legacy software, a major barrier to the widespread take-up of SaaS. Such legacy systems need to be evolved and adopted according to a model-driven approach in order to be executed as a service.

Interoperability and pervasiveness of services remains a key challenge which is far from being solved. Efficient and practical methods for describing the interfaces of services, usable by machines, are required.

There is a need for new metrics to assess costs, risks, values and dependability of software-based services, including human-provided services.

Software engineering for web applications needs to be further developed as a discipline in order to simplify the delivery of properly internationalised, accessible and device-neutral applications.

It will be necessary to bootstrap the Internet of Services by populating it with a critical mass of services, thus creating new business opportunities and research ideas.

There will have to be more public test suites for web specifications, so as to encourage interoperability of diverse implementations.

Broader participation in web standardisation, beyond the ICT industry to include European sectors such as automotive, consumer electronics, health and medical.

Special attention has to be paid to building an composing services, looking at how to quantify and control information sharing in service composition, risk reduction capabilities when recruiting services for compositions, secure dynamic creation/adaptation of services, and developing a new notion of security testing for services, suitable for producing evidence of security properties.

Cloud

Something on cloud here- Ed.

Trust in the cloud – add something from Security and Trust- maybe data

processing in the cloud? Could merge IoT trust into this cloudy world – IoT clouds of sensors?

The framework for capturing, storing, and managing sophisticated multidimensional objects that could support real augmented realities does not exist

The infrastructure will need to address simulated mixed reality and augmented reality as key technology which requires online capturing, processing, simulation and registration technologies for multi-dimensional data (3D/4D/nD). The Future Internet has to provide new ways of accessing and retrieving 3D documents.

Declarative 3D documents serve as the information carrier for applications. New processing techniques and tools are required for authoring 3D documents. The process steps for scanning, transporting and matching of object must be interpreted and implemented for the 3D case.

A significant shift and increase of community driven 2D/3D life and real-time information exchange, transmission, processing and storage will require a changes in the connectedness of entities, e.g. requiring symmetric network access and balanced processing in the network vs. at the edge.

Future Internet clients will be sophisticated collections of smart devices, situated computing, and services. Today's programming paradigms for web-clients do not support this model well at all.

The clients of the future Internet will be a more diverse set of clients than those we see today and looking at the convergence between the smartphone and pc as 'smart devices'. Yet future web clients will play a role in sophisticated interfaces which may involve collections of smart devices, situated devices, sensors, which may be owned by the user, run services on behalf of the user, or be some third party involved in the interaction in some other way.

The challenge of programming future Internet clients is that current and incoming web standards, including HTML5, are not enough to transform the browser into a complete execution environment. For example, the characteristics of JavaScript, the most common language for client side computing on the web, are not suitable for programming in the large. Fully fledged programming languages, such as Java, have only limited access to DOM and browser features, while workarounds such as compilation to JavaScript complicates the development.

Current web browsers adopt a model of extension based on plug-ins. A third party plug-in may add the support for new data formats such as PDF or DOC. The weakness of this approach is that any plugin may re-implement the same functionalities on a different data format, causing inconsistencies in the user interaction. More in general, plug-in technologies for web browsers do not distinguish between new functionalities support for existing functionalities applied to a new data format, and new modalities of interaction for existing functionalities. This

in turn requires the user to be aware and knowledgeable of data formats and tools.

The management of local data versus remote data is also distinct, with limited control by the final users (not technicians) over remote data and remote execution. There is no standard supporting the client-side integration of data and services directly by such users. No common standard exists for the client-side management and execution of third party services in a web client.

The challenge of data

Networked data is a horizontal capability of the Future Internet. The organisation, exploitation, and governance of the huge amount of data and information in the Internet will create on-going opportunities and challenges for the next decade. There are underlying tensions between rights of citizens, businesses, and the state over data; the opportunities opened up by integrating data from multiple sources; the need develop new data models to make sense of the myriad of applications and sources (e.g. the 3d world for augmenting spaces, of tacit knowledge in knowledge supply chains), of records of usage, of surveillance data gathered, the list continues to grow.

- Data governance - giving citizens and business tools to be in control of their data, express their rights, and fulfil their obligations and act confidently in cyberspace that is pervaded by data on everything and every aspect life
- How we can build models of spaces, experiences, behaviours, knowledge that can be exploited by new high value services,
- New architectures and systems that underpin data driven services in the Future Internet

6 What Are The Solutions/Research Needs?

6.1 Business

Overview of research areas to be addressed

Future Internet functionalities will enable novel ways of working and doing business in many ways. Key developments are towards smart, agile enterprises and collaborative enterprise networks. Enterprises of the future are envisioned to be ever more open, creative and sustainable; they will become "smart enterprises". Innovation lies at the core of smart enterprises and includes not only products, services and processes but also the organisational models and relations that comprise the enterprise's value network. The Future Internet aims to provide enterprises a new set of capabilities, enabling them to innovate through flexibility and diversity in experimenting with new business values, models, structures and arrangements. Combinations of different technologies will be needed to deliver maximum value and these combinations require the federation and integration of appropriate software building blocks. A new generation of enterprise systems comprising applications and services are expected to emerge, fine-tuned to the needs of enterprise users by leveraging a basic infrastructure of utility-like software services.

These challenges give rise to the following areas of research and innovation in the Future Internet and Business domain, including

- Beyond cloud computing and software as a service to support component-based enterprising in ad-hoc business networks
- Information integration from heterogeneous sources, information governance
- Secure and trusted transaction environments in temporary and virtual business networks
- Contextual services respecting data privacy rights/expectations

The Future Internet supports the operation of business in complex, high-value, networked business ecosystems.

In the context of globalisation of work, business and innovation, the Future Internet provides promising opportunities for renewal of the European industrial system and enterprising. Key concepts underlying the future enterprise include the knowledge cloud, business servitization, and open innovation. New forms of enterprise and organization will progressively emerge, characterized by high flexibility and innovation capability. They will be structured with a systematic, engineering approach, enabling decentralization and self-organization for some parts and components

Future Internet enables innovative manufacturing ecosystems

The Future Internet offers a range of options to support Europe's highly skilled, knowledge-rich workforce to exploit opportunities for innovation in products and processes. Such opportunities include the support of flexible high-knowledge-content innovation; of agile manufacturing processes; and

of collaborative manufacturing in networks. In order to realize this vision, R&D should address the development of distributed, adaptive, interoperable and networked enterprise environments to support manufacturing innovation. Such environments constitute novel management paradigms to support virtual factories and enterprises and also provide extensive capabilities for monitoring, evaluation, risk management and forecasting. Essential strategic research objectives include:

Supporting decision making and coordinating in the networked enterprise

New Knowledge Management environments need to provide the right blend of knowledge and functionality to empower [manufacturing] managers to make their decisions from a position of informed strength and particularly to help them to adapt or modify their priorities and operational decisions quickly and efficiently in the face of changing customer conditions or operational disruptions. Tacit knowledge forms a considerable part of what constitutes organisational knowledge management, including organisational memory, and learning.

Self-managing networks of business and computing entities will support the necessary levels of decentralization of decisions and coordination to be achieved in vast areas of the enterprise. Smart objects will have the capacity of directly interact and cooperatively evolve to achieve the business objectives, able to proactively adapt to unexpected changes, while hiding their intrinsic complexity.

Interacting and understanding complex situations and information

In the business environment, business users have to deal with complex situations and analysis complex data. New kinds of interfaces and ways of interacting with data will provide ways for people to understand and engage with complex situations, harnessing the power of computing, new devices and systems.

Business focused services (using knowledge from complementary ontologies) may be adopted to serve the individual needs of particular industries or cross functional domains. Intelligent / adaptive interfaces are required to filter, combine and present information stored in the multiple models depending on the context of the problem and user preferences.

Self-organising resource management, finding and matching resources

Software systems that support the operations and management or enterprises (e.g., ERP, CRM, SCM) will be capable of significant degrees of autonomic computing, self-organization, and independent evolutionary behaviour. Automatic 'reasoners' will play a central role in smart, approximate search engines, operating over the net to find and match complementary resources.

Linking Knowledge in a

The Internet will be able to manage Linked Data in a fast and effective

'knowledge cloud'

way. Knowledge representation, management, consistency validation, different forms of reasoning (from inductive to abductive, form deterministic to probabilistic, form taxonomic to similarity reasoning) will be available over the net as service utilities. Ontologies of various types may be used to provide flexible interoperable semantic knowledge models.

Risk Management and Mitigation in Collaborative Networks

Uncertainty can often be reduced and risks managed and mitigated by experience and learning. However, acquiring, disseminating and maintaining the knowledge from past experience and learning from previous projects or collaborations are complex. Both individual partners and collaborative networks as a whole require fast, predictive feedback from risk assessment techniques so that adaptive risk mitigation strategies can be better targeted to enable the design and implementation of improved more resilient supply chains and virtual organisations which can be speedily configured to address new business opportunities.

6.2 People / Social

Interaction

Through the Internet we interact with each other, with the physical world, and with the digital world, and indeed, in the future the distinctions my blur even further. Social networks are not the last word on social interaction, web-cams and video conferencing are not the last word on collaboration, games and IPTV are not the last word on entertainment. New interfaces and modalities will create opportunities for richer interaction and for addressing our work, life and emotional needs. New ways of interacting with complex data provide ways to understand complex situation. New interactions with the digital world will provide new media experiences that look beyond 3d. Future networked interaction will not be delivered through one device, in a sit-back, sit-up, or handheld interaction mode, but through collections of devices brought together as smart edge systems, and ideas of ownership, situatedness, virtualisation will create interaction experiences that are effective, engaging, and empowering.

The research theme of interaction, supported by rich interfaces, displays, haptics, and other yet to be developed approaches makes possible to address some of our real concrete needs too – for carbon reduction for example through remote collaboration which can take people off roads, support knowledge business networks, or create valuable social links. Some of the biggest barriers to delivering Internet benefits to excluded groups in Internet are the interfaces. This is just one example, and looking forward the future of networked interaction has real potential to create value given that we are reaching the point where demand and capability

come together to make new and valuable networked interactions possible.

Cities

Some of the research needs for the creation of smart cities are:

- Innovation ecosystems based on integrating policies for urban development, revitalisation and digitisation, smart environments harnessing collective intelligence and user driven innovation, and experimentally driven Future Internet research.
- Ubiquitous smart city broadband infrastructures: smart city open network infrastructures and services, wireless sensor networks enabling smart systems, smart personal devices, open data infrastructures, cloud computing, public ambient interfaces, Internet of Things (see: Institute for the Future, 2010)
- Open city platforms (`i-phone cities`) enabling the creation of products / services by citizens, including marketing and delivery
- Technologies and components: Content management tools; Collaboration tools; Cloud services and software components to build networked applications; Smart systems based on Internet of Things; semantic web and M2M communication
- Enable the access and sharing to common assets: open data repositories, experimentation facilities, and testbeds, user communities for validating new services, technology platforms and experimental know-how, IPR for open data
- Simplification of programming languages, enabling user-generated services and harnessing mass IT literacy.

Privacy

Some of the research topics in Privacy in the future include

- Developing socially robust on-line privacy models that reflect the many and diverse attitudes towards privacy online that will prevail in a future Internet society which relies on advanced personalised and contextual services
- Providing business and service providers with the means to implement complex and challenging data management, including the ‘delete’ button for personal data
- Dealing with personal data (for example gathered as a consequence of other services, for example energy management or in mobile scenarios) so that it can be used as a basis for services by third parties whilst preserving privacy
- Maintaining the option for people to have anonymity / pseudonymity online and conversely, linking digital identifies to real persons

Inclusiveness

Older people are expected to reach almost one third of the total EU population by 2025. The current number of disabled people is 10% of the total population. The number of people that will be directly affected [by inclusivity issues] will be almost 40% of the EU population by 2025. Our vision is Future Internet Services that are fully inclusive and accessible to everyone, everywhere, every time they wish to use them. This is challenging for future highly interactive, multimedia, content. To achieve this we will have to integrate 'design for accessibility' into all design processes.

Within the context of user requirements and capabilities, the Future Internet Research must bridge the gap between the world of guidelines and standards and the world of software development.

There is a need to support the integration of accessibility in the software engineering process by providing a set of semantic models (User/Interaction, Device and Application Models) and a set of tools for developers that facilitate the analysis and improvement of accessibility and adaptability compliance for ubiquitous Future Internet applications, without the complexity of reinventing ad-hoc approaches and solutions to implement accessibility. Models of users, devices and applications should support transparent, dynamic and context aware adaptations, providing applications with a self-configuring capability to provide accessible interfaces.

DfA platform components hosted in a services-enabling automatic service description, discovery, composition, and negotiation with a multiplicity of reusable inclusive services, which may be mobile or nomadic, multi-device, multimodal and multi-context.

To provide industry and the public sector with tools and frameworks that support seamless accessibility integration in distributed development environments. Going beyond simple preferences for presentations, the user models for interactive TV should go further in describing the personalization of interactive content, creating interaction models for each individual user type. For users with disabilities, older user or mainstream users, it should be possible to transform the content of interactive applications so that they are optimized to the user's preferences. This combination of models, representing a virtual user, goes beyond the types of personalization and provides a rich R&D area for true adaptation to both the person and their choice of devices.

While the modelling of devices has been always an industry-driven effort from mobile device manufacturers, there is a need to develop

standardised generic device profiles that can respond not only to everyday scenarios today, but also can be flexible enough to cope with future scenarios coming from the ubiquitous Web 2.0. There is a clear gap in application modelling in Mobile/Ubiquitous Web 2.0 and Cloud Computing to cope with assistive devices and the Web of Things, Services and Content. Not only that, but context/location-awareness, seamless roaming and portability, privacy and trust problems should all be addressed in the Future Internet Roadmap.

Finally, all of these areas require the research and development of Web Compliance Engineering and Accessibility Evaluation Tools that can deal with the increasing complexity of Web applications, the challenges of a wide variety of mobile devices, the richer user interfaces coming out of Web 2.0 and the non-uniform policy environments worldwide.

6.3 Technical

The aim of future network design is to build a systematic network system that enables smart applications to become a reality, i.e. a commodity for people, thus reinforcing the social, economic and ecological sustainability of the society. We call this approach the weaving of the technological fabric, which consists of the various hardware and software elements of network and the enablers that permit applications to become smart. The interweaving is materialized by enablers, which are physical entities and mechanisms or intellectual methods and algorithms, the operation of future networks, and future smart applications.

Performance of Future Networks

In order to properly support user-perceived quality of smart applications, the performance of the underlying and enabling polymorphic networks needs to be addressed. This implies optimal deployment and use of resources, i.e. efficient hardware and software building blocks, and corresponding smart management approaches that are bridging applications, services and networks.

In particular, performance of future networks demands for research work amongst others on (a) architectures, such as network structures and placement of resources such as links and caches; (b) well-dimensioning and right-provisioning of resources; (c) proactive and reactive management strategies;

Making IT Greener (reducing energy consumption, lifecycle, resources,)

As energy efficiency and awareness are key challenges for the future Internet and network environments, future ~~media ne~~tworks will have to consider new solutions for management and load balancing in local and global network and service domains, tackling the bottlenecks and use of resources and energy of ICT in different environments such as data centres, cloud computing systems and data repositories, potentially in

autonomic, cognitive and distributed ways.

Internet of Things

In the "Internet of Things (IoT)" and "Real-world Internet", optimization of resource utilization of the high number of sensor and actuator devices; their distributed management; new solutions for control and data plane signalling to merge the systems to Internet backbone; energy harvesting; and intelligent actuator devices are expected to provide additional value both for energy issues and to integrate the "IoT" into the generic Internet environment.

Security

There will be security mechanisms which do not reduce the usability of the overall FI infrastructure. In particular, in FI there will be transparent authentication (identification and authorisation) mechanisms, which are federated to enable single sign-on for multiple diverse services. A particular security feature of FI will be the establishment of several different trust areas or trust domains - these are portions of network infrastructure in which the participating users and devices are mutually trusting of one another.

Better situational awareness for users will be made possible by richer and more powerful SIEM platforms and tools. Although SIEM today is done only within the confines of a corporate infrastructure, in FI it will be necessary for SIEM platforms to be deployed across multiple clouds and different providers.

Security by policy is a key element of the FI and research into mutually interoperable, consistent policy languages, models and access control mechanisms will be essential. For security in the Future Internet it will also be necessary to conduct risk assessments across infrastructures and clouds, and this will require the development of new, and refinement of existing, risk assessment methodologies. Furthermore, due to the complexity and diversity inherent in large clouds, much of the risk assessment will need to be automated, and methods developed for the visualisation of risk.

- Better Languages And Tools For Specifying and Developing Secure Software
- Improved Assurance Methods
- Privacy-Aware Software Development
- Cooperation On Issues Of National Security
- Development Of Universally Acceptable Digital Identifiers
- Development Of Rich And Expressive Security Models
- Development Of Tools For Tracking Data
- Enhancement Of Legislation To Accommodate Technological

Developments

- Education Of Citizens
- Research And Investment In Security Tools And Technology
- Consideration Of Novel, Radical Approaches

Augmentation

The vision of networked services, systems, and devices supporting us in our work and social lives, or in business to control and manage processes and operations has been with us for some time. Hitherto, the Framework Programme Seven has explored Internet of services, reflecting the shift of our economy to a service economy, Internet of things, reflecting the opportunity to measure and manage the physical word using networked systems and these capabilities are beginning to be available.

As we look to the start of the next decade and beyond we can begin explore how we can harness the power of the Internet to 'augment' lives, work, business and spaces in ways that add value. By 'augmentation' we mean 'increasing in intensity' the activities we are doing or the things we need done for us, addressing what we do in our jobs and daily lives, addressing needs of groups and communities, of industry, construction, maintenance, engineering, manufacturing, transport with information, decisions support, risk analysis, options, delivered through interactions and interfaces that are intuitive and un-intrusive. What is currently described as 'augmented reality' has potential to develop into what is fundamentally an integrative, systems, applied approach to addressing problems of industry, people, society and developing techniques and frameworks that harness the scale of the network and networked data onto individual actions, tasks, and activities, transforming what we do and how we do it.

3D

Virtual 3D reconstructions of the real world will complement the current image and video data on the Future Internet.

The infrastructure will need to address simulated mixed reality as key technology which requires online capturing, processing, simulation and registration technologies for multi-dimensional data (3D/4D/ND). The Future Internet has to provide new ways of accessing and retrieving 3D documents.

Based on collected, distributed and filtered information a cognitive meta-model serves as information carrier for applications and should provide the templates for object classification that can be used to create and recognise new types and forms of objects. These objects are referred to as evolutionary 3D objects.

Evolutionary 3D objects must be based on presentation independent object descriptions. The future Internet architecture must take account of evolutions of new knowledge carriers within independent ecosystems creating and establishing adequate communication channels.

Declarative 3D documents serve as the information carrier for applications. New processing techniques and tools are required for authoring 3D documents. The process steps for scanning, transporting and matching of object must be interpreted and implemented for the 3D case.

A significant shift and increase of community driven 2D/3D life and real-time information exchange, transmission, processing and storage will require a changes in the connectedness of entities, e.g. requiring symmetric network access and balanced processing in the network vs. at the edge.

6.4 Approaches and Methodologies

Cross disciplinary research

The Future Internet is not just a technological, but a socio-technical system. The Future Internet will meet society's needs so it is closely related to societal trends and demands. In areas such as healthcare, smart cities and enterprising, behavioral, economic, organizational and societal issues are of high importance besides technology issues. Additionally, analogies can be exploited with biological and social systems. All this implies a high level of relevance of multi-disciplinary oriented research into the socio-technical nature of the Internet, which is seen as a socio-technical *system.* Taking system characteristics into account in research and design, such as complexity, scalability, heterogeneity, trustworthiness and change, requires systems oriented approaches to research and innovation.

Open to different cultures and excluded/ disadvantaged groups

Future Internet research advance an "Open Development Model" that allows researchers, disadvantaged groups, & industry to participate, combine their efforts & benefit.

- Consider various IPR models, allowing use by everyone
- Open up access in all countries & languages
- By localisation-friendly & culturally open user, device & application models

Innovation, Involving, benefiting, stimulating start-up business and SMEs

There is an imperative to stimulate and encourage the participation of SMEs and the creation of start-up businesses from the Future Internet research in Europe. A strong case was made in the input regarding the European Games industry that SMEs are the innovators in this space.

Contributions in the area of Enterprise stressed the evolution of enterprise towards virtual networked enterprise with specialist SME playing large and pivotal role. Likewise, smart city and spaces can be hotbeds of innovation and SME participation

Whether we are discussing topics such future enterprise, cities, or experiences, ideas abound on the kinds of approaches that enable innovative value creation to take off. The network effect, scale, openness, experimentation, software, and pilots, and services, SME and start up participation, application, and real users. This is the 'Internet-style' innovation we aim for. Ideas such as making cities into experimental services environments, creating platforms, integrating across industries and sectors, releasing and exploiting data, are enabling factors – they set the conditions for unlocking value and if carried out 'Internet style' they set the conditions for innovation. At the same time, new applications and services need to be instantiated, built, used, and grow.

Evaluation methodologies

Smart services require a holistic approach for design and engineering under specific boundary conditions. A holistic approach consists of a close interweaving of user, society and technology offerings and requirements; functions and methodologies in design and engineering; and smart applications and networks through enablers. In particular, the concepts of how to interweave, i.e. achieve smart combinations of future technologies and methodologies for supporting smart applications are at the core of our vision to future RTD. The metaphor of fabric can be transferred to relationship of the above outlined new areas of concerns.

Correspondingly, two sets of design methods can be identified. The first focuses on application and technology areas: future smart applications, smart mediation techniques, and smart connectivity. The second addresses foundations and methods for (a) design of smart network architectures and protocols; (b) quantitative performance evaluation of smart network and applications through measurement, modelling, analysis and simulations; (c) design of smart algorithms for the control and the operation of smart networks and applications; and (d) improved methodological concept for addressing socio-economic issues in the design of future smart networks for smart applications.

In the past, problem solving typically consisted of "throwing resources onto the problem". Recognising that the demands on the Future Internet to scale will likely outstrip even the most extreme forecasts, and the trend towards future systems that provide better quality, economy and sustainability, there is a need to improve many aspects of applications, services and networks such as performance, security, risk, usability, and

value through realistic modelling rather than relying on brute-force engineering or point solutions. In particular, the parameters of interest need to be measurable and comparable within quantitative studies that will have to be essential parts of design and deployment of future networked systems.

Experimental approaches

The objectives for experimentation and experimentally driven research originate in the ambition to create a multi-disciplinary, long term research environment for investigating and experimentally validating new networking architectures and service paradigms. This environment must promote experimentally-driven yet long-term research, joining the two ends of academy driven visionary research and industry-driven testing and experimentation, in a multidisciplinary approach. Finally we must be able to engineer such forward looking systems at scale that are used as research environments for investigating and experimentally validating a thesis.

Experimentally-driven research, as a visionary multidisciplinary research methodology, defines the challenges for and takes advantage of experimental facilities. It is realized by means of iterative cycles of research, oriented towards the design and large-scale experimentation of new architectures and paradigms for the Future Internet - modelled as a complex distributed system. The refinement of the research directions must consider the data and observations gathered from experimentation in previous iteration steps which requires the specification of relevant metrics and measurement tools.

The rationale thus is to create a dynamic between elaboration, realization, and validation by means of iterative cycles of experimentation. Nevertheless the "validation by experimentation" objective opens a broad spectrum of experimentation tools (in the broader sense) ranging from simulation to real system experimentation. The selection of the experimental tool selection depends among others on the cost function which depends on complexity, experimental and running conditions and level of realism. Adding "realism" to the experimental environment means to construct systems that mimic as far as possible our anticipation of how the future Internet environment will look like.

Such experimental environments are forerunners of the future Internet, which means that they may evolve to become live operational parts of it. Due to the high cost of such systems we must be able to create and use a "slice" of current advanced real systems for experimentation without the worry to "break" the real system if something goes wrong.

Virtualisation is a technology that could be used to "slice" the real world

system and is applied today in networks, computing resources and storage. In the future we must be able to apply the same concept to complex and aggregate environments such as complete laboratories or even cities.

A scientifically sound research methodology requires better tools for the management of experimentation, among others common experiment description methods, resource models, lifecycle management, and management of experimental data as a persistent shared asset.

Experimentation at scale requires our ability to integrate and federate existing experimental facilities into larger aggregates. International collaboration on integration and federation of experimental environments can largely contribute to satisfying the requirements for experimentation at scale and adds more "realism".

Architecture

As FI develops support for a wide range of stakeholders seeking to develop, provision, or use a range of networked components and concepts there needs to be an architectural framework that provides ongoing guidance, specification and rules of how everything fits together, how *networked* elements communicate, and how elements are (dynamically) structured into larger interoperating entities (services, say).

A second need is for the means to coordinate research and development to wards such a framework. There are already parallel activities, e.g.

- to extend and supplement the architecture, structure, and functionality of the current Internet
- to exploit the current Internet, building interoperable services within current constraints, possibly with standardisation of common concerns
- theoretical studies towards new network/inter-network architectures and their fall-out (like, does trust and security become easier?)
- practical investigation and experimentation of alternative networking

The architecture needs to present the whole picture, to relate the relevant elements in the picture, and to maintain its own forward plan or roadmap as a consistent part of the overall FIA roadmap. It should cover

- a common perspective and approach to shared issues for elements connected across and interworking via the Internet;
- a guide or frame of reference for further technical development of

the architectural framework and elements.

Some suggested baseline design goals for the architecture include support for:

- service composition/federation
- interoperability of services and entities
- dynamics and mobility
- heterogeneity
- gateway(ing) services
- cross-layer needs
- modularity – reusable/replaceable (service-, -) components
- boundaries, compartmentalisation and domains
- simplicity and understandability – allowing manageability
- inherent trust and security

7 Conclusions and Next Steps

In this report we have documented in detail the outcomes of the FIA's consultation with Future Internet project managers and participants. As discussed at the start, the material presented here is primarily based on short papers and presentations given at the Future Internet Research Roadmapping Workshop held in March 2011. The summary at the beginning of this report has outlined a number of emergent common themes, including:

- Going beyond converged infrastructure
- Exploiting networked data
- Achieving Internet security
- Taking advantage of networked interaction
- Improving quality of life through networked augmentation
- Creating new products and services through networked innovation

We also observed that Future Internet research needs approaches that are open, experimental, architectural and scientific. We have concluded that traces of all these themes are evident in all the contributions we have received so far, and hereby declare the consultation effective and an overall success.

We note here some important research themes that have been omitted. In particular the themes of sustainability, cloud computing, and data, have not been borne out in sufficient detail in this version of the research roadmap due to a lack of suitable contributions - inputs. We expect that subsequent versions will address these themes better, as they are certainly relevant and significant dimensions of much Future Internet research.

This first version (V1) of the FIA research roadmap was produced through a consultation that started at FIA Ghent in December 2010 and will be made available for review and comment at FIA Budapest in May 2011. A web-based consultation will be opened to allow opportunity for comment and feedback from June through to the end of August. Comments and contributions will be integrated into a second version which will be released shortly before FIA Poznan in October 2011. We intend to hold an open discussion at the time of FIA Poznan to present and discuss the roadmap with the Future Internet research community.

8 Bibliography

Ahola, Jari, and Jyrki Huusko. “Future Internet Replacing Current Content Delivery Architecture and Business Models.” n.d.

Behr, Johannes. “3D Internet Whitepaper.” n.d.

Behrmann, Malte. “European video games industry as forerunner of digital revolution.” n.d.

Fiedler, Markus. “Weaving the network for the smart applications of the future.” n.d.

FP8 Expert Group. “Software Consultation - Workshop Report.” 2011.

Gavras, Anastasius. “FIA Community Input to FP8 - Eurescom Contribution.” n.d.

Kantola, Raimo. “From E2E to TtT and E2C / Trust and Cloud.” n.d.

Missikoff, Michele. “The Future of Enterprises and the Future Internet Enterprise Systems.” n.d.

Moore Olmstead, Paul. “Content and Media / Future Media Internet.” n.d.

Papanikolaou, Nick, and Nick Wainwright. *Trust and Security Research Roadmap.* n.d.

Pu, Dana. *Mosaic of the Cloudy Future.* n.d.

Popplewell, Keith. “Future Internet Enterprise Systems for Manufacturing.” n.d.

Schaffers, Hans, Nikos Komninos, and Marc Pallot. “Future Internet for Smart Cities Initial Roadmap.” n.d.

Setian, Lucy. *Internet of Things: The wireless generation of digital empowerment.* n.d.

Skarmeta, Antonio. *Identity-based, Secure Communications for Future Internet.* n.d.

Torrelli, Francesco. *Next generation web clients.* n.d.

Velasco, Carlos, and John O'Flaherty. “Roadmap for research into the Future Internet – eAccessibility.” n.d.

Wilander, Jerker, and Jacques Magen. *FIRE topics for FP8 discussions.* n.d.

Additional References

ERCIM News (2009): Special Theme: Future Internet Technology. Nr. 77.

European Commission DG INFSO (2009): Future Networks, the Way Ahead.

European Commission (2009): Future Internet 2020. Call for Action by a High-Level Visionary Panel.

European Commission (2009): Internet of Things Strategic Research Roadmap.

EC FIArch Group (2011): Fundamental Limitations of Current Internet and the Path to Future Internet.

Gavras, A. (Ed.) (2010): Experimentally Driven Research White Paper, ICT FIREWORK project.

ITU (2009): The Future Internet. ITU-T Technology Watch Report 10.

Oxford Internet Institute (2011): Towards a Future Internet. Interrelation between Technological, Social and Economic Trends. Final Report for DG INFSO and Media.

Tselentis, G. et al. (Eds.) (2009): Towards the Future Internet. IOS Press.

Tselentis, G. et al. (2010): Towards the Future Internet. Emerging Trends from European Research. IOS Press (2010).

Domingue, J. et al. (Eds.) (2011): The Future Internet. Future Internet Assembly 2011: Achievements and Technological Promises.

Institute for the Future (2010): A Planet of Civic Laboratories. The Future of Cities, Information and Inclusion.

Future Internet X-ETP Group (2010): Future Internet Strategic Research Agenda.