FP7 ICT ADVISORY GROUP

Working Group on "Future Internet Infrastructure"

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1. Introduction

The face of the Internet is continually changing, as new services and applications emerge and become globally significant at an increasing pace. Recent developments include –

- Social networking interactivity and communications
- User generated content – wikis, blogs, podcasts and video
- Shift of broadcast content to the internet – internet radio, downloads & IPTV
- Emergence of a rich set of web based services and applications – resources, service building blocks and applications
- Migration of the internet from the desktop into the world, through wireless connectivity and mobile computing devices
- Increasing potential for the integration of the ”physical world” with the digital world of the internet, through identification labels (RFID), sensors and embedded systems and actuators
- New business and operating models for provisioning of software and hardware (Software-as-a-Service, Cloud Computing)
- Better access to knowledge for humans and machine agents through standardized semantic mark-up languages (RDF, OWL)

The infrastructure of the Internet has and will continually evolve to support and enable new services, trends and businesses. This is best exemplified by the growth (in this first phase of the Web) of the businesses of Google, Amazon, eBay and others AND the computing infrastructures and services that are needed to support them. Each of them, along with other global service providers, are operating network and service infrastructures of increasing scale and diversity of services, with very large numbers of users.

Over the next decade, developments and innovations in the network and service infrastructure will continue, with significant investment on a global scale. For example, the multi-billion Euro investments that leading communications service providers are making in IP based Next Generation Networks will simplify network infrastructure, but the greater impact will come from the much richer and more flexible service capability.

Though the infrastructure of the internet has evolved, its underlying architecture has not. This was not created to function in the role that it currently undertakes, as the global critical infrastructure, and it has a number of fundamental limitations. Moreover, the piecemeal growth and addition of functionality has created a set of structural anomalies. It has proved to be very successful as a unique platform for global innovation, but this success tends to obscure some of the problems, and to make them harder to fix. Some believe that we are very close to crisis, and this has motivated research initiatives across the world, exploring approaches for a successor to, or evolution of, the current network architecture.

In Europe, the EIFFEL Think-Tank report (http://www.future-internet.eu), was released in December 2006, and identifies a number of drivers for the next generation Internet. Amongst the technological drivers are much more emphasis on mobility, the anticipated changes in scale from millions to billions of connected devices, increases in bandwidth, increase in digitised media, increasing importance of security and evolution of services to more adaptability, and awareness of user context and preferences. The report also identifies a number of socio-economic drivers; these include the effect of ICT on socio-economic development, the need for privacy, security, the concept of an online identity implemented with credentials such as credit cards, but also avatars and the desire for end-user empowerment. The report identifies technical challenges to be overcome; the main one being to understand the architectural foundations and design of the Future Internet.

The aspiration that we describe here is that the Future Internet will be a global, open platform that will fix the shortcomings of the current architecture, and also support a set of emerging Visions for the future impact of the Internet. Each of these Visions take different perspectives on the underlying infrastructure, and one of the key research challenges is to derive a robust technical design for the future network and service infrastructure that supports these. This will probably replace the current layering paradigm with a more general model.

Europe is well-placed to take a leading role in defining and developing the network and service infrastructures for the future.

In the following, we first look at some of the emerging trends and services that are likely to drive the evolution of these infrastructures, focussing on two aspects that we believe are the most significant and potentially disruptive, and where there is the potential for European value:

- Internet of Services – the service infrastructure
- Internet of Things – the integration of the physical and the digital world

A third vision addresses some major enhancements in the user experience by the introduction of an Internet of 3D Worlds.

We also discuss the trends, requirements and challenges for the underlying network and service infrastructure, since this is a critical underlying resource for the services and applications of the Future Internet. It is currently the focus of major regional research initiatives, and it is imperative that Europe carefully considers the scope and objectives of its research programme in relation to this global activity.

Finally, we examine the major research challenges in realising these visions, and in designing the network and service infrastructure that is required to support it. We close with some specific recommendations.

2. Emerging Visions for the Internet

In this section, we describe three of the Visions for the Future Internet that will drive the requirements for its network and service infrastructure. Some of the developments and innovation in these Visions can take place within existing architectures and business structures, and along well sign-posted trajectories (e.g. Service Oriented Architectures). In other cases, change may require architectural revolution, or may result in business disruptions.

The Vision for the Internet of Services.

Low entry barriers for provisioning, brokering and consumption of services are crucial for large and in particular small enterprises acting as service providers and trying to access a worldwide market of potential service users.

In the last few years, Service Delivery Platforms (SDP) have emerged in the telecommunications sector to manage delivery of communications, media and entertainment services from communications service providers to mobiles, PDAs and IPTV. SDPs integrate class-carrier platforms, conventional middleware and enterprise services for service delivery (CRM, billing, master data management), and now form a critical part in the technology stack of major vendors. With substantial growth in a short time since inception and with massive forecasts of hand-held communications devices, analysts predict a revenue surge as SDPs engage on data services as value-added consumables.

A broadened concept of global and open Service Delivery Platform is proposed for the Internet of Services. It will go beyond the client-server model of service delivery to support rich mechanisms of global service supply, where third parties have the capability to aggregate services, act as intermediaries for service delivery and provide innovative new channels for consuming services. This reflects the future requirements of the mainstream enterprise service communities and the globalization of these enterprise services.

To realize this vision, an open platform for tradable, composable, value-added services on the internet is required. Such a platform will need to build upon and extend: Web 2.0 concepts to allow for community-driven service innovation and engineering on a large scale; global repositories for value-added services; and, semantic support to enhance enable automatic composition of value-added services. This will enhance reusability of services, and allow for reasoning to derive further knowledge. Legal, security, logistics, business and technical aspects must be simultaneously addressed for an integrated approach to the Internet of Services, where the service consumer will get customized services within Business Webs. This is why EDA (Event Driven Architecture) will complement SOA in customize complex services either for creating added-value mash-up services or for sensing and reacting to (possibly unexpected) situations typical of compliance, logistics or finance services.

The Vision for the Internet of Things

“The Internet of Things” is going to include information about objects of the real world and their respective surroundings. This information will be provided by the things, as they obtain and reveal the information through a huge variety of sensors and wireless communication devices mounted in different environments, embedded in systems, worn by users, or even swallowed or injected under the skin. The increasing computing capabilities of such devices will also allow the implementation of completely novel processes.

Physical objects include not only sensors to detect a variety of information *from* the physical world as well as local data storage and devices to help process the data, but also (mechatronic/robotic) machines that can act *on* the physical world. The Internet of Things can then integrate many different sensors, actuators, microsystems, mechatronic systems, and robots at its ends, thus allowing the Internet not only to exchange and process *information* but also to control *actions* in the real world.

When connected to the Internet of Things, mechatronics, smart products, and robotics technology are becoming increasingly pervasive in our daily environments

In Japan and South Korea, scenarios where the Internet connects smart environments, objects, and robots have been clearly envisaged, and strategic lines of research and development along this direction are given high priority.

“The Internet of Things” can help integrate *pervasive computing* with *pervasive robotics*, truly filling the gap between the ICT world and the physical world.

From a strategic point of view, this vision of “The Internet of Things” has many potential advantages:

- it adds an enormous range of new industrial opportunities to ICT market, makers and providers;

- it offers new opportunities for a strategic alliance between ICT and non-ICT industry in Europe. Huge markets, such as automation, energy generation and management, medical, environment, and so forth, can be better catered for;

- it increases the perceived and real usefulness of the Internet to the majority of EU citizens, who are interested not only in navigating and retrieving information, but also in getting physical support to their daily needs (for all citizens, and particularly for citizens with special needs, such as disabled and elderly);

- it involves not only the Internet geeks, but virtually all citizens;

This vision is in full synergy with the vision of improving ICT opportunities by advancing the Internet infrastructure and services.

A Vision of an Internet of 3D Worlds

The advent of 3D environments has been pioneered through games and is rapidly gaining momentum. This technology places stretching requirements on the Internet infrastructures. Second life is a typical example, but more complex applications are expected to emerge which will open new classes of issues such as including high-availability and realtime requirements. Increased technological capabilities (see Justin Ratner's speech at last Intel's developers forum or http://www.meshverse.com/2007/10/09/review-%E2%80%9Cthe-rise-of-the-3d-internet%E2%80%9D-part-3/) are probably needed, whilst issues such as interaction between virtual and real world, interoperability across multiple virtual environments, multiple identities or standards are still open. In addition, such environments are expected to put additional requirements on search (and find) technologies which will have to cope not only with text based information, but with unstructured and structured multimedia representation of objects, with or without semantics built in.

Grand Challenges

In preparation for FP7, a previous incarnation of ISTAG produced the report "Grand Challenges in the Evolution of the Information Society" (September, 2004).

The report goes on to identify 11 grand challenges. Of these, the 100% Safe Car, the Internet Police Agent, the Pervasive Communication Jacket and the Intelligent Retail Store are the most pertinent to the Future Internet theme. Common themes which run through the grand challenges include:

- The need for robust design principles for dependable systems.
- The issues of trust, privacy and security.
- The challenges created by dramatic changes in scale (from millions of wired components to billions of wireless components).

The user experience

From the user perspective, there are a number of ways in which the Future Internet must support or deliver richer capabilities:

Intelligence

To the user, the Future Internet will present Itself as an intelligent infrastructure which supports humans as well as machine agents and allows for seamless interaction of both of them It will need to understand the semantics of content and to deliver knowledge rather than information to the user, in a pro-active manner. With the increased coupling between the digital and physical worlds, it will provide effect and action as well as information.

The greater part of this intelligent action will be provided by the intelligent services and applications running on the infrastructure, but the Future Internet Infrastructure must provide the appropriate support

Quality of Service

Quality of service will be measured in a deeper way, relating to the quality of the information provided, or the user experience

Service Repository

The Future Internet should offer like the Naming service (DNS/ICAN) also a Web Services repository and governance service (UDDI/???).

Trust

In the Future Internet, Trust will be critical.

- Can we trust the people we meet, or the organisations and companies that we deal with?

Understanding trust in its multiple facets and manifestations: trust between people, between people and the cyber-infrastructure, among people using the cyber-infrastructure, in a society of human and software entities, finally in more complex value network and ecosystem settings.

- Can we trust the data or the knowledge?

Trusting data or knowledge passes through engineering trust management, access control and policy systems. They should be flexible enough to understand and accommodate the dynamic nature of trust. They should integrate seamlessly with existing and future security systems, for example detection of fraud, intrusion attacks, other malicious behaviour, trust and risk assessments and relationship and access control policies. Moreover considering the huge number of data and knowledge circulating in the “Internet of the Future”, certify the provenance of data or knowledge will become a critical issue.

3. Requirements for the Future Internet Infrastructure

The visions briefly sketched out above begin to define some of the characteristics of the network and service infrastructure in this Future Internet. We expect an infrastructure that will provide:

- Connectivity services
- “horizontal services” such as identity, ttrust, location, brokering
- Computing resources as services

These will need to be provided in an intelligent manner, personalised to the needs and context of the user, and at the desired quality level.

And support the “vertical services”:

- Information & knowledge services
- Business and applications services
- Sense and action on the real world

Also, the infrastructure must support dynamic business relationships and value chains. Service providers need an infrastructure where they are able to manage and balance revenue, costs and risk. The “vertical” services will also need the support of a rich set of “horizontal” enabling services such as identity, trust, location, brokering etc.

We can glimpse some of the first signs of this future infrastructure today, in advanced SOA implementations within enterprises, in the NGN implementations of leading telecommunications providers, and with the emergence of web services and utility computing services on the Internet. However, there are formidable challenges in scaling up to a global open and dynamic infrastructure,

These lead implementations are built on top of the current Internet architecture, and would seem to offer evidence that a new service infrastructure “could” be built on top of the current network architecture, in the small at least. However, this obscures some very significant issues:

- The current Internet architecture has some very significant shortcomings, and can be convincingly described as operating on the edge.
- The current architecture does not have the hooks to support flexible business models that will reward investment in the infrastructure which will be required to support the type of capabilities envisaged in the earlier visions.

- There is also a strong desire to virtualise connectivity, and provide this as a smart and dynamic converged service. This would require radical architectural changes, including embedding some key horizontal enabling services in the network infrastructure.

Fixing these issues with radically different network architecture could open up connectivity to the same kind of dynamic innovation that we are expecting to see in other virtualised services. It also ensures that we are not constructing a new service industry on the sandy foundations of the current architecture.

There is a large programme within the Framework programme on the Future Internet (at the level of the network infrastructure), and one opportunity for this paper is to provide some guidance to that programme.

4. Research Challenges

Internet of Services

Overall, we see as main challenges:

- Enablement of Business Webs where services are tradable goods on the internet by developing a next generation service infrastructure for engineering, discovery, brokerage, composition and execution of value-added services. Key ingredients are Web 2.0, Semantic Technologies, Service-Oriented Architectures (SOA) and their integration with Event Driven Architectures (EDA).

- Harmonization of system architectures (SOA),service infrastructure architectures (SOI), and networking architectures to advance the structure of multi-tier, federated and Internet scale architectures, support all kinds of business models, applications and emerging hardware and networking environments and provide transparent and integrated access for all relevant stakeholders

- Advanced system lifecycle approaches including engineering, deployment, composition, provisioning, management and decommissioning phases that support transparent knowledge tracking, feedback loops, prediction and simulation, allow for a clear separation of concerns between different stakeholders and support the full variety of business scenarios while adhering to overarching sustainability requirements.

- Advanced infrastructure technologies in terms of hardware, middleware and related programming models that meet the required flexibility of the networked economy.

- Repository service and governance (UDDI/???)

Internet of Things

Technical research challenges to turn the vision of Internet of Things into reality have to be addressed at multiple layers of the entire technological framework and infrastructure (discussed bottom-up):

- Further research on and development of basic enabling or so called **edge technologies**, such as sensors and actuators, passive/active identification tags, embedded systems etc. that are attached to real world objects and making objects “smart” enough to participate in novel Internet of Things application scenarios. Are there missing standards?

- Research must also concentrate **networking technologies**, such as fixed, mobile, wired and wireless networks allowing the highly available bidirectional communication on different levels, i.e. between real world objects, applications and services that offer functionality specific to Internet of Things.

- Scalable, secure and semantically enriched **middleware systems** (low level SOAs) play a key role putting real world data into the context of various Internet applications. Research will have to concentrate on how to bridge gaps that occur due to the usage of heterogeneous device, network, sensors and other technologies.

- **Platform services** that run in the background have to support a superior management of all involved technical components (i.e. trillions of loosely coupled devices!) in an integrated way ensuring scalability, high availability, and the safe and secure execution of the requested functionality.

- Further to the above technical questions, intensive research has to be conducted in order to accelerate the adoption of Internet of Things in various applications domains. This covers the analysis of current and future demands and trend in various industries, public and governmental organizations, etc. to find and justify the economic and societal impact. Some economic benefits that may motivate the implementation of the Internet of Things are: improved process performance, visibility, and scalability, higher level of automation, increased cost efficiency through real-time, high-resolution data, enhanced process, product or service performance management, better transparency of physical flows and detailed status information, etc.

Converged Infrastructure challenges across the visions

There are a set of challenges from the two visions that should be brought together, but addressed in different ways in different timescales. In the nearer term, in the context of the current network architecture (IP and the end-to-end architecture), the following issues need to be considered:

- Converge the visions of the Internet of Services and the Internet of Things into a seamless single concept. Especially the Internet of Things layers of platform service structures and semantically enriched middleware components might profit from sophisticated service provisioning methods described in the respective sections above.

- Horizontal and vertical Interoperability of Trust, Security Dependability attributes in environments where the boundaries between the network and service providers are no longer clear and multi-service interactions among service providers can span a poly-infrastructure consisting of varied unrelated network providers. This makes not feasible at the moment delivery of services with run-time agreements of trust security and dependability attributes over these environments.

Then, these converged visions can be used as a common scenario to drive the design of next generation network architecture. The major challenges in this are:

- Developing an architecture that fixes the shortcomings of the current Internet, which include:
    - Security, Privacy, Trust, Identity Management
    - Hooks for business and incentive models

    - Support for Semantics
    - Support for mobility
    - Adequate resilience (e.g. DDOS)

- Creating an architecture that is flexible enough to support a range of application Visions and business models in a dynamic way.
- Replacing the traditional layering paradigm with a more general model (which may have impact on wider system architectures)
- Ensuring convergence between technology, business and regulatory concerns

There is a further general challenge, which is hard to assess at this stage. This relates to the operation of service ecosystems at massive scale, as is envisaged in the Visions.

5. Recommendations

Future Internet Infrastructure

- The vision from the previous ISTAG (and from the companion paper on Web services) is that a European focus will be in utilizing ICT to solve societal challenges. This creates an asset that can be sold in European and global markets. This is greatly facilitated by common global standards in the network and service infrastructure, which would encourage a collaborative approach to working with the "Future Internet" research initiatives in other major regions.
- The visions for the Future Internet presented here, and others, all foresee an environment where what the user receives is the result of a composition of a number of elements. It is essential that the architecture developed is capable of sharing the reward from providing the end service down the value chain to the contributors of those elements used. In order to avoid creating new "stove-pipes," such a mechanism must be capable of stretching beyond the elements envisaged by any particular vision. They also need to include the return for the contribution of the infrastructure upon which all the capabilities will.
- In developing a new network architecture (as well as with converging between and amongst vertical scenarios), the Internet experience has been that there are problems with working on too narrow a scenario ("internet of services" or "internet of things") AND there are well known limitations with horizontal layers. Many of these problems stem from the approach that tries to identify the full set of requirements up front and to embed the resolution of all resource conflicts in the design phase. The one thing that is clear from the history of the current Internet is that we cannot predict how it will be used in the future. We therefore recommend that there needs to be a focus on programmable / run time defined approaches to resolving resource conflicts.
- We are suspicious of the value of large scale and generic test-beds early in the research life cycle. Test-beds should be to "test"

- In parallel with the technology research, it is important to create forums and dialogues with all the stakeholders in the Future Internet, on technology, business and regulation (vendors, service providers – old and new, users, developers and regulators). This needs to be encouraged at as early a stage as possible.

- Compared to the US programme on the Future Internet, or Korea, or China, the EU are perhaps too constrained by the instruments of Framework, They are able to provide support for a portfolio of research projects, but it is difficult to provide real direction, leadership or focus. In the Future Internet, Europe is in danger of being left behind through this. It is an area where industry could have more ability to create an atmosphere conducive to leadership, but (again) the current instruments don't lend themselves to an obvious way forward.