Future Internet Roadmap

Deliverable 1.1 – Service Web 3.0

Public Roadmap

service WEB 3.0

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Executive Summary	This document provides a roadmap for research and development in the field of the Future Internet, from the perspective of the Service Web 3.0. The roadmap surveys the main challenges to be addressed in the core cross-domain areas identified within the Future Internet Assembly working groups established in 2008 as an initiative of the European Commission. Finding solutions to these challenges is essential if a successful Future Internet is to emerge. Each of these challenges is described in a dedicated section that analyzes the state of the art, proposes solutions on how to overcome the major problems, and elaborates on the role of semantic technologies in the resolution of these problems.
Keywords	Future Internet, Service Web 3.0, semantics, Internet of Services, roadmap, public

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1. INTRODUCTION

Even after four decades of rapid advances, computing is currently subject to revolutionary changes at all levels, including hardware, middleware, network infrastructure, but more importantly intelligent applications. The advent of technologies such as the Semantic Web, Web services or RFID transforms the Internet into an all-encompassing network of knowledge, services and things. Its rapid evolution, both in speed and in capabilities, enables the emergence of innovative markets of services that lead to novel experience to users. The everyday life of citizens and workers of all types is supported by new convergent services of the Future Internet that are available ubiquitously and can sense and react to the physical world. The mission of Service Web 3.0 is to address these impressive developments, to contribute to the implementation of framework programmes and their projects, and to support the preparation of future community research and technological developments in the field of the Future Internet.

This document provides a roadmap for research and development in the field of the Future Internet, from the perspective of the Service Web 3.0. The roadmap surveys the main challenges to be addressed in the core cross-domain areas identified within the Future Internet Assembly working groups established in 2008 as an initiative of the European Commission. The focus thereof is twofold: on the one hand the Internet of Services, as primary area of the Service Web 3.0 support action, and semantic technologies and their potential to support various aspects of the Future Internet, notably the Internet of Services, at every level. Within the underlying network (based on fixed lines, wireless or mobile phone infrastructures) semantics can support the automatic detection of faults and malignant attacks through the matching of data patterns within a network against template descriptions. Additionally, semantics-based reasoning can support automatic repair or network reconfiguration (around a damaged network segment). In the context of the Global Service Delivery Platform semantics enables robust and scalable interoperability. This applies at several levels: i) service interoperability to provide an automated capability to integrate stand-alone services with services which are similar or complementary, for instance from a related business domain; ii) data interoperability, so as to provide the automated understanding of the information exchanged and ensure the overall quality of the service; (iii) interoperability of the service layer with the network and application layers of different providers. In addition to providing unambiguous descriptions, at different levels of abstraction, we can semantically describe mechanisms for solving interoperability supporting their reuse. In addition, semantic descriptions of content, users and devices will be utilized by semantic reasoners to find, adapt and compose relevant provisioned services dynamically. This applies for a wide spectrum of areas, from Internet of the Things to Content Networks or Virtual Worlds.

The remainder of this document provides a general overview of the cross-domain challenges which are currently under investigation in the working groups of the Future Internet Assembly. Finding solutions to these challenges is essential if a successful Future Internet is to emerge. Each of these challenges is described in a dedicated section that analyzes the state of the art, proposes solutions on how to overcome the major problems, and elaborates on the role of semantic technologies in the resolution of these problems.

The roadmap is targeted at scientists and engineers doing cross-domain, interdisciplinary research related to the Future Internet, IT developers, managers and evangelists analyzing the potential of semantic technologies as robust and scalable instrument to realize interoperability at various levels, and finally, at the general public with reasonable technical knowledge interested in the future IT-driven development of life, businesses and society in the 21st century.

The roadmap is accompanied by the Service Web 3.0 movie with the goal of promoting ongoing European efforts and attracting interest and awareness from beyond the academic community for contributing to the definition and realization of the theoretical, technological and socio-economic components of the Future Internet.

2. Roadmapping Methodology

This section explains the methodology followed for the production of this roadmap, as well as of additional specialized roadmaps to be published throughout the course of the Service Web 3.0 project.

The Service Web 3.0 roadmap was created in a three-step process as follows:

- **Identify problem areas and propose realistic solutions** – Our project aims to play a guiding role amongst European research projects that contribute towards the overall Future Internet vision. In order to achieve this ambitious goal, the methodology behind this roadmap focused on compiling a collective perspective on the most prominent problems, and proposed solutions, of the Future Internet. We have invested significant resources in encouraging researchers external to our consortium to take an active role in several working/technical/interest groups co-organized and lead by Service Web 3.0 (e.g. Services and Software Architectures Working Group[1], Future Internet Interest Group[2], Semantic Technology & Ontologies Technical Group[3]). The present document is a reflection of what has been accomplished in these concentrated groups, in addition to reflecting other prioritized problem areas resulting from the discourse lead by European Commission.[4]

- **Identify potential technologies** - Complementarily to this broad range of activities we investigated future directions of research and development of semantic technologies. STI International has hosted a number of workshops[5] with experts affiliated to the Semantic Web and Semantic Web services communities. The

[1] http://services.future-internet.eu/

[2] http://www.serviceweb30.eu/cms/index.php/future-internet

[3] http://wg.sti2.org/semtech-onto/

[4] http://www.future-internet.eu/

[5] The workshops were held 27.9.08 (co-located with ESTC & FIS) and 27.10.08 (collocated with ISWC) - http://roadmap.sti2.org/wiki/

workshops were organized as full-day events in which the participants were asked to share their visions and predictions for the *State of Semantics* within a time frame of 5, 10 and 20 years, respectively. The audience identified the most convincing application areas and technologies addressed which formed the basis for the definition of major topic clusters of prominent themes which deserve further investigation. The compiled results of these workshops were then overlapped with the objectives of the European Commission's envisioned Future Internet and included in this roadmap.

- **Publication of technical roadmap** – The roadmap will be published as a Service Web 3.0 deliverable on the project Web site and will be distributed to the target audiences identified in the previous section through all dissemination channels used in the project. In particular it will be part of a book to be published by Springer in 2009.

- **Evaluation, refinement, customization** - General feedback from this roadmap will effectively improve the creation, maintenance, and publication of additional specified roadmaps as a means of planning and coordinating overall activities oriented towards the realization of the Future Internet and the further progression of semantic technologies. The evaluation and refinement of the roadmap will be undertaken in the context of the working group Future Internet Service Offer of the Future Internet Assembly and at the future roadmapping workshops organized by STI International organized in June, 2009 at the European Semantic Web Conference ESWC2009. In addition, we plan to create three customized roadmaps building upon the current document; one roadmap will focus on the area of services, the remaining two will be adapted to national characteristics in Austria and Poland, respectively. To create these special-targeted roadmaps we will apply the same methodology as described in this section.

3. Content Networks

Content Networks aim to provide location-independent access to various objects. The current Content Networks, however, started to offer something more than only location-independent access to content and focus on supporting the entire chain on interactions i.e. management, creation, distribution, and consumption of content [35].

In addition, we observe the growing importance of multimedia content - video as well as audio and photos. This phenomenon causes a serious concern as multimedia consumes most of the Internet bandwidth. Growing capabilities of the devices and interest of Internet users will only foster the trend.

The following observations (tendency to support the entire chain of interactions and multimedia content becoming ubiquitous) cause many challenges and problems that the Future Internet should tackle in several dimensions. Similarly to [36], we propose a layered architecture for content networks. Creation of effective content networks necessitates work at least in the following areas.

3.1. Metadata and Access

Multimedia data will become a significant constituent of the Future Internet. Individual objects will be related to and interrelated with other content. The Future Internet infrastructure should offer a capability to represent various types of content, in machine-understandable manner, as well as express and maintain connections between various media objects.

Supported by underlying content description and usage metadata, content objects will become dynamically available as needed in user activities or business processes, while their storage and maintenance will be abstracted into the Internet "cloud". This is in line with main idea behind content network where addressing and routing of contents is based on content rather than on their locations ([27], [38]).

Semantics-based technologies will close the "semantic gap" between low-level feature analysis and high-level conceptual annotation, allowing more precise and simultaneously personalized audio, video and image retrieval. An ever-faster moving society with ubiquitous access to the Internet will increasingly expect "on-demand content" [29]. As a result it may happen that delivery time of appropriate content would be preferred over details or completeness of the content.

3.2. Contexts and Discovery

The sheer scale of available content will make finding the right content extremely difficult. This will cause various challenges in terms of dealing with the scale [28].

Classical infrastructures will be extended beyond metadata in order to provide services and content-aware applications that are to support business and end users in their activities and information needs. One of such extensions is content creation and delivery depending on context. Context is understood as a set of easily searchable attributes of contents. The most important is spatial context [39]. Semantics will be also used to describe context of the content objects that will be used for the personalization purposes. In addition, the context will include also characteristics of devices; the context of bandwidth as well as personal preferences of end-consumer. This will allow for more user-tailored interactions.

We also envision a paradigm shift in how companies and users will interact with their media libraries. This paradigm shift will offer new possibilities of dissemination and commercialization by enabling media to be accessed and consumed ubiquitously by any permitted entity on the Future Internet. This will however, require media-based services provided by the Future Internet and acting as mediators of these new interaction possibilities, whether they act as media conglomerates, adapters, composers, editors, deliverers or sellers.

3.3. Transformation and Composition

Not always a content consumer is a final consumer. Popularity of mash-ups proves that the real added value is in content transformation [24]. What people usually need is an aggregation of content, supporting the tendency towards higher inter-connectivity.

In the Future Internet, content and services may be composed freely from those available from other parties, enabling new business models and activities as well as greater efficiency and cost cutting in existing ones. Therefore, standardized definitions and descriptions of media services capabilities are needed as well as their integration into Internet-based activities. In order to support the automated composition along with the discovery, a global Internet service platform which supports multimedia data as possible input to and output from services will be developed.

(Kung, 2002) classifies content networks on the basis of their attributes in two dimensions:

1) Content aggregation: semantic vs. syntactic, and

2) Content placement: content-sensitive vs. content-oblivious.

Therefore, two challenges have to be addressed: to allow to create, modify and manage content, and actively place content at appropriate locations [32].

In addition, some research in the area of: cloud storage and application layers for huge scale media libraries; standards and technologies for intelligent, self-describing media objects; network components for distributed retrieval and dynamic composition of media will be required.

3.4. Delivery Infrastructure

Traditional centralized architecture cannot provide the required scalability properties, as it inherently introduces performance bottlenecks [37]. Increasing mobility of users intensifies their expectations with regard to quick delivery of information. In some cases multimedia systems will need to provide quicker retrieval times with an increasing scale of available media, focusing more on satisfying an information need in time rather than the best results in term of precision and recall.

There will also be a need for seamless end-to-end multi-media communication across a complex combination of network constituents such as personal area networks, body area networks, home networks, fixed access networks, mobile access networks, metro networks and core networks. This communication infrastructure will need to handle high bandwidth data streams and deliver them in high quality and with appropriate quality of service.

Transfer of data across heterogeneous networks will require shared standards and mediator components that can handle high throughput. Consumers will expect ubiquitous media stream access in high quality and without noticeable interruptions. Bottlenecks will need to be avoided through both intelligent adaptation of media data streams to a network and intelligent adaptation of a network to media data streams. As the semantic media characteristics should be available to the network, the network should be able to adapt on that basis, including distributed media delivery and real time network reconfiguration. Quality of service will include near real-time delivery of content and near perfect transmission over wide-area, heterogeneous networks. Media adaptation will include both the adaptation of media type characteristics as well as cross-media type conversion according to user need and context, while retaining the full information content. Therefore, the research work in the following topics is required: network structures for multimedia delivery, including P2P and grid; intelligent routing mechanisms as well as higher levels of compression and decompression, where bandwidth growth is restricted.

To sum up, content networks focus on the data and the ways to best access them; peer-to-peer focus on scalability and churn; grid computing focuses on high-performance execution

[34].

3.5. Consumption

The future network underlying the Internet will not only need to have the bandwidth to handle the sheer scale of content being transferred, but also the technology and infrastructure to handle that transfer as efficiently and securely as possible. The work on trust should be particularly important [30]. Therefore, a Future Internet infrastructure supporting media, or content in general, in its scale and ubiquity will need to offer new types of services and applications to users and enterprises for acquisition and consumption of content according to information or process needs. In fact, the services available in the Future Internet will support the entire content object lifecycle, i.e. creation, packaging, mediation, delivery and consumption, enabling new flexibility in the content marketplace, not just for end consumers but also for the businesses who operate in that marketplace. Such services will ensure for example that the right media is available at the right time using the right channel, and media content itself is closely integrated into end user and business services. In addition, such services will allow also the content lifecycle to become more loosely coupled, with the functionality of different phases being dynamically operated by a large number of service providers, creating new business opportunities and permitting new business models in the growing digital content marketplace.

Licensing and rights will need fail-safe support in this new media landscape as well as new requirements on ensuring trustworthiness and appropriate filtering in media acquisition and access to avoid the new structures being polluted by “media spam” and disruptive players [31]. These aspects would need to be balanced with privacy protections. Research work may concentrate on: policy description languages and rules for use and composition of media; network infrastructure for protecting digital rights and usage policies; methodologies for developing trust and supporting filtering in media acquisition and usage; protection measures again “media spam” and disruptive actors in media networks.

Finally, to support the full media lifecycle, media objects will be packaged with metadata which will be transmitted with them through the network, and will need to be supported in the network infrastructure, including their correct interpretation and modification. Through both available metadata and media analysis support, the network will support the efficient retrieval of media in widely distributed settings, including its dynamic repackaging or composition with other media to meet the retrieval query. This will also include effective payment mechanisms for media access, acquisition, adaptation, composition or delivery.

The content networks will evolve towards self-organizing and self-adaptive networks. Semantic-based technologies support this vision by enabling precise and formal descriptions of data and media content available in the networks as well as other related aspects such as digital rights and usage policies. The semantics will play a major role in addressing this challenge, as well as others mentioned and elaborated within this section, such as:

- capability to represent various types of content, in machine-understandable manner,
- precise and simultaneously personalized audio, video and image retrieval,
- contextualization of content with regard to such contexts as identity, time, location, etc.,
- aggregation of content, supporting the tendency towards higher inter-connectivity,

- dynamic creation, modification and management of content, and active publishing of content at appropriate locations,
- seamless end-to-end multi-media communication across a complex combination of network constituents, by providing conceptual annotations for various content objects using semantic technologies. The functionalities offered by services operating on the content will become automated, more precise and effective.

4. Real World Network

The Future Internet will not be limited to the collection of media and content currently found on the World Wide Web. New develops in virtual reality, user interactivity, and the realization of what is referred to as the Internet of Things, will allow for a Future Internet which both resembles and is completely integrated with our physical realities. The following sections address the challenges in achieving the "Real World Network" aspect of the Future Internet, as well as proposing semantic solutions to some of these challenges.

4.1. Internet of Things

In 2005, the term "Internet of Things" already broke free from the research community with a report from the International Telecommunications Union presented UN Net summit in Tunis, Tunisia.[6] The question is, at this point, how far along have the key enabling technologies developed, what major challenges remain and how does it fit into the grand vision of the Future Internet outlined in this roadmap.

The Internet of Things depends upon technologies such as RFID, wireless communications, real-time localization and sensor networks which are quickly developing, allowing for the Internet of Things to become a topic of discussion and viable (profitable) infrastructure for CIOs and industrial entrepreneurs rather than just academic researchers. Radio Frequency Identification (RFID) technology has evolved from a tool which was originally used to facilitate niche applications, such as electronic toll collection systems, to a general purpose identification technology that is quickly gaining higher expectations from the visionaries behind the Future Internet. Now, RFID tags can be applied to or incorporated into almost any physical object for the purpose of identification and tracking using radio waves; essentially, this lays way for every physical object to be uniquely identifiable. And as RFID tags shrink, even smaller objects can be uniquely identifiable. Finally, ubiquitous sensor networks formed by digitally connecting the RFID tags leads to a massive Internet of Things, far beyond what is currently handled on the Web.[7] With such a network of objects and entities, there will be significant impact on non-ICT domains as well. Everything becomes integrated into sensor networks. Traditional supply-chain models alone will be efficiently redesigned as an increasing amount of necessary processes become automated.

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[6] Coverage of the summit, particularly highlighting the "Internet of Things" made it into the following media publications: BBC News Online, AFP - Yahoo News, InfoWorld, Trade Arabia, CIO Magazine, IDG Now, International Herald Tribune, News Factor Magazine Online

[7] Other notable technologies supporting the Internet of Things include ONS, EPC, ucode, logical addressing, IPv6, EPCGlobal

However, as Nicholas Negroponte, founder of MIT Media Lab and the One Laptop per Child (OLPC) association, appropriately summarizes "...it's not just putting RFID tags on some dumb thing so we smart people know where that dumb thing is. It's about embedding intelligence so things become smarter and do more than they were proposed to do."[8] In order to achieve a functioning Internet of Things, objects with embedded tags must also contain embedded conceptual descriptions (or reference to). Here again, the technologies behind the Semantic Web will provision "smart" objects with the ability to communicate directly with one another; this could potential allow for the shift from personal computing to community computing based upon shared information about digital and non-digital objects and entities alike, as predicted by Jonathan Murray, World Wide Technology Officer for Public Sector Microsoft Corp.[8] As the Internet of Things creates a core foundational network which supports intelligent systems, new challenges then appear: how will systems attach meaning to objects and entities met while roaming dense sensor networks, and how will they process or compute such information? Semantic technologies are a viable solution, as to the similar challenges found under the mobility and context-awareness domains of the Future Internet; yet semantic technologies offer more than just adding intelligence to the Internet of Things.

Semantic technologies become ever more important when attempting to integrate the foreseen Internet of *intelligent* Things with the Internet of Services (discussed further in Section 6). A core set of services will be required to bridge between the foundational network and service layers. The major challenges in this area directly correlate to the progressive developments in hardware for routing and low-level protocols which support a new standard of communication between the networked objects and entities which make up the Internet of Things; the next requirement is an appropriate set of semantic services that strongly pairs these two foundational layers (Things and Services). The semantic services which sit on top of the Internet of Things should be engineered to handle high speed networking technologies (i.e. to support end-to-end streams in the Gigabit range), dynamic globally identifiable objects and entities (Internet of Things) and to communicate over new symmetrical traffic patterns and simultaneous streams [25].

The assumption of the interconnectivity of physical things and the ability to automatically take advantage of context information and computation to invoke appropriate action naturally highlights issues of security, such as identity and trust concerns discussed in Section 5. The necessity for the management of risks and the enforcement of privacy and security requirements within the Internet of Things & Services Architectures motivates much needed research to respond to such challenges. Other pressing research issues arise from the need for seamless interoperability and reconfigurability of intelligent (semantic) Things & Services for flexible end-to-end solution integration to provide secure service provisioning and bundling and the use of privacy-enhancing technologies within the Internet of Things & Services Architecture.

Conclusively, the Internet of Things should be able to support pervasive ambient intelligence of objects and/or services through context-based computation, resolution and execution of "smart" service-oriented and model-driven systems and services. This requires a framework

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[8] http://www.iht.com/articles/2005/11/20/business/wireless21.php

for semantic-cooperative resolution supported by context management, on-device communications and resources management, as well as context-sensitive privacy policy maintenance and enactment [24]. As noted at this year's conference on the Internet of Things,[9] experts predict an exciting future that closely interlinks the physical world and cyberspace has come to describe a number of technologies and research disciplines that enable the Internet to reach out into the real world of physical objects. However, regardless of how intelligent objects may become, a separate challenge is ensuring that the virtual objects are representing the actual world, thereby allowing the fine line between our virtual and physical worlds to diminish over the next decade. While bridging this gap between our real and virtual worlds is a goal that depends upon the Internet of Things, it extends well beyond into other problem domains inherent to Real World Networks as discussed in the next section.

4.2. Interfaces: Real World & Virtual

As the Future Internet evolves to encapsulate unlimited services, resources, objects, and devices, current user interfaces (e.g. Web browsers & email clients) no longer suffice. In order to provide the user with efficient instruments to handle the abundance and variety of information available on the Future Internet (which includes the Internet of Things), new interfaces must be provided. The solution involves progressive advancements on two major fronts: virtual reality and user interactivity. The goal is to prompt a level of optimal usability for the Future Internet. The Internet of Things comes into play when faced with the challenge of ensuring that the virtual objects are representing the actual world, thereby allowing the fine line between our virtual and physical worlds to diminish over the next decade.

While current research in virtual reality and user interactivity has considerable overlaps, the distinction is notable, as portrayed in Figure 1. On the one hand, developments in virtual reality are quite impressive in their own right. On the other hand, if future interfaces are mere three-dimensional presentations without incorporating user interactivity then communication exchange cannot take place.

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[9] http://www.iot2008.org/

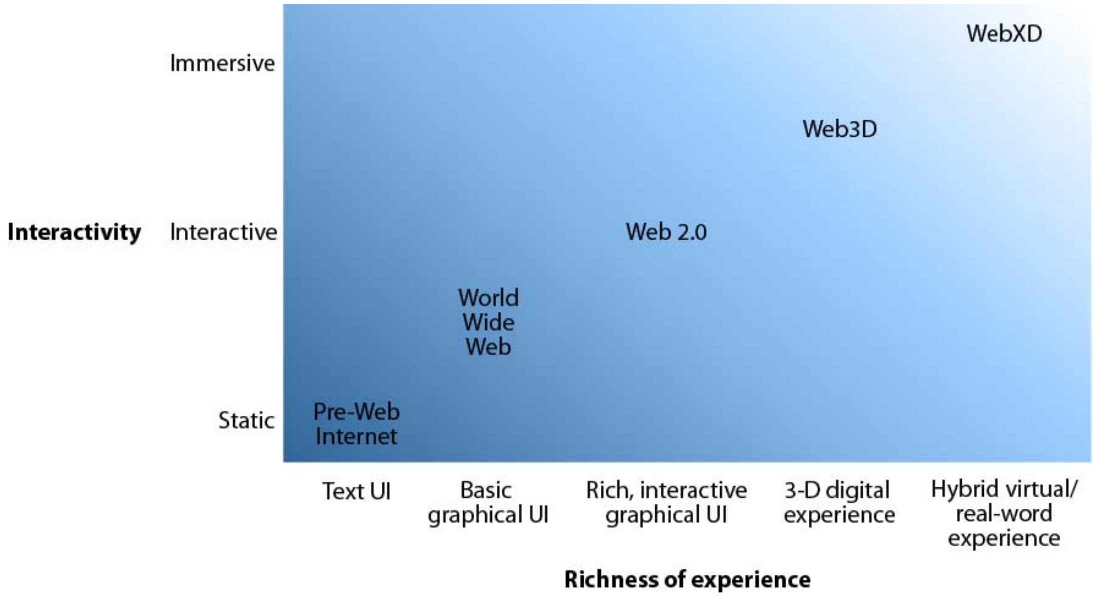

Figure 1 – Forrester: "Web3D: The Next Major Internet Wave" – April 2008

Progressive developments in virtual reality are indeed driven by forces other than the coming demands of the Future Internet (the "offline" gaming and entertainment industry for example), however soon all such industries will be networked so it is appropriate to imagine the coming interfaces of the Internet as virtual. As noted by Forrester's "Web3D: The Next Major Internet Wave" report, "The Internet is on the cusp of its next major evolution: Web3D. Within five to seven years, Web3D will deliver an interactive, immersive experience much richer than the static, text-oriented or even interactive graphical interfaces of today's Web. In the new world of work that Web3D will enable, people will be represented visually by avatars that can move in space, communicate with others, and interact with objects and information - making the digital world seem more like the real world." One of the interesting research projects in this area, 3D4YOU, covers the important aspects of the 3D broadcast chain in order to deliver an end-to-end system for 3D high quality media.[10] Already applications like Second Life are seamlessly integrating virtual world activities with real-world business operations.[11]

The Real World Network aspect of the Future Internet is not just limited virtualization and the Internet of Things; further emphasis must also be place on the virtualization of users as well in order to bring the two networks together. Future user interactivity should follow the example from the entertainment and gaming communities; computer/social avatars should be used in non-gaming situations. The new virtual world, i.e. the Future Internet, should be met with a new virtual user. Enabling user interactivity remains a focused topic of the Future Internet due to lessons learned from the emergence of Web 2.0 and the overwhelming increase and innovative presentation of user generated. Referring back to Figure 1, in order for the jump from Web 2.0 to Web3D, and the steps to eventually achieving "immersive interacted" will be quite significant. WOWvx is one of the first companies to be making steps

[10] http://www.3d4you.eu/

[11] http://secondlifegrid.net/

in the right direction: a Web 2.0 approach to the generation and sharing of 3D content.[12]

Though once again, without the inclusion of semantic technologies in the innovatively networked virtual reality and user interactivity technologies which comprise the better half of the conceptualized Real World Network aspect of the Future Internet, particular challenges, such as those which also constrain the Content Network domain, will not be overcome. Fortunately, semantic technologies can provide formal descriptions of virtual content and capabilities of user interactivity. Search and retrieval of 3D content or interoperability solutions between conflicting virtual worlds and models could be based upon these formal descriptions. Properly specified semantic descriptions of users and virtual objects (and the Internet of Things) could then bring the Real World Network to integrate with the Internet of Services (as discussed in Section 6), allowing interaction on a level of higher abstraction and increased interoperability and automation throughout the semantically-enabled Future Internet infrastructure.

5. Identity & Trust

In a "Future Internet" related study conducted by RAND Europe for the Dutch Ministry of Economic Affairs [21], *identity*, *privacy* and *trust* have been indicated as highly important by all experts participating in the study. In this section we take a look at existing shortcomings in the current Internet regarding identity (section 5.1) and trust (section 5.2), we propose solutions that address these drawbacks and steps towards these solutions and we show where appropriate how Semantic technologies could and will play a role in these solutions.

5.1. Identity

Identity is a still an open and challenging issue in the context of current Internet. A closer look at the state of the art in identity shows that there is no universally adopted approach on how to represent and how to manage identity data. The continuous growth and change of the Internet from an endpoint communication platform to a connected distributed infrastructure supporting the Web and new contemporary applications like sensor networks, social networks, context-aware computing and others have introduce even more challenges with respect to overall management of identities. To address the general problem of issuing and managing identities for various types of entities, a number of technologies have been proposed including software for authentication, authorization, password management, and so on. More specific there are three categories of technologies aiming to support identity[13]:

- *generic identifiers of electronic objects.*

  The most important approach from this category which became popular in the context of the Web is the mechanism of using URIs/URLs for globally locating resources.

- *"real-world" object identifiers used in electronic applications*

[12] http://www.wowvx.com/

[13] http://www.okkam.org/

This category includes a wide range of approaches such as MAC addresses for network components, generic X.500 and LDAP directory services for hierarchically managed structures, EPC and RFID (the Internet of Things), ISBN for intellectual property resources (e.g. books and publications), LSID for identifying Life Science objects, and many more. Most notable in the context of Future Internet, more precisely Internet of Things are RFIDs.

- *Identification of individuals (persons) in electronic applications*.

  This category includes a set of approaches developed mainly in the context of ECommerce. Some of the most important approaches are X.509[14] for digital certificate and authentication framework and recently OpenID[15], Microsoft CardSpace[16], OAuth[17], etc.

Each of these technologies addresses a specific aspect of identity management but does not provide an overall, full fledged approach for identity problem. Furthermore, identity data is spread out across different enterprises, different applications, different data stores. On top of this the multitude of approaches for identity management is actually increasing the complexity of the problem instead of decreasing it. This leads to what can be called "Identity Anarchy" [1]. The lack of coherent, integrated frameworks and systems for identity management results in identity data being often unsynchronized, duplicated, lost, corrupted, or misused. Given all the factors mentioned before managing identities becomes a costly and complex problem. A centralized control for identities management even though seams easy to realize at first is not really a solution for open, growing environments such as Future Internet. Solutions that follow the principle of decentralize data seam more appropriate. *Virtualization* [1], as proposed by the Grid community is one possible approach to distributed management of identities, supporting on the other hand the idea of a unique identity through different systems and applications. Such a virtual identity should authenticate the user uniquely, should be easily transferred between devices, should maintain the anonymity of its owner, shall be very difficult and/or expensive to replicate.

Additionally to the "Identify Anarchy" other problems and risks must be addressed. This includes identity theft and abuse, disclosure of sensitive information, wrong attribution of charges financial or criminal. Measures need to be in place to prevent, reduce and recover damage to parties. Other identity challenges are generated by the increasing number of devices, sensors, networks and applications. We are already witnessing a rapidly increasing number of mobile devices and mobile applications.

To address these challenges new frameworks and systems for large-scale identity management of users and content are required. The design of such frameworks and systems must take into account virtual identity attributes, identification systems, civil identity systems with strong needs, credential management systems, etc. Good, solid principles of proper naming of entities (natural and legal persons, objects, virtual entities, devices, content, processes, applications, etc) are needed. Furthermore the Future Internet will require infrastructures, protocols and devices for electronic identity of physical people or entities [4]. According to [6] the future research in the area of identity and privacy should focus on:

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14 http://www.itu.int/rec/T-REC-X.509/en

15 http://openid.net/

16 http://msdn.microsoft.com/library/default.asp?url=/library/enus/dnlong/html/introinfocard.asp

17 http://oauth.net/

- new generation device of authentication;
- digital systems for identities, systems of biometrics;
- federation of identities, infrastructures and applications with digital signature;
- tools of trust to protect the chains from associated services: personal medical file, identities cards, e-commerce, e-administration;
- secure modules for computers.

In the context of Internet of Things the following should be better investigated: policy driven (determined) and privacy friendly access control, graceful integration, secure identity carrier beyond the chip card or SIM, careful evaluation of biometric patterns and mechanisms and application areas growing beyond the standard mobile communication domain.

Identity is a hard topic and requires a special attention in the context of Future Internet. Providing a rigid solution to the identity problem even if addresses all issues mentioned above will not work. Other aspects need to be considered even though they might look contradictory to the concept of identity are [21]:

- *anonymity*: people have the right to keep secrets, and possibly even the right to certain anonymity;
- *multiple identities*: peoples identities consist of different elements and they want to retain control over them;
- *control over personal data*: people do not own personal data, yet should be in a position to control it.

Semantic technologies could definitely play a role in realizing part of the identity vision described above. First, one of pillars of current Web and Semantic Web, namely URIs/URLs are a big success story on how identity could be handled in large, open distributed environments. The principles that lead to this success should be consider and apply in a search for the best identity management solution in Future Internet. Second, the ”Identity Anarchy” which is mainly due to heterogeneity of models, devices, applications and languages could benefit from the mediation and interoperability research done as part of Semantic Web. Last but not least Semantic technologies have/will provide ontological model for various identity related aspects such as policies, profiles, networking, etc.

5.2. Trust

Trust is one of the topics of utmost importance in practically any system in use today and will become even more important in a large distributed system such as the Future Internet. The growing number of applications, services, sensors, devices and platforms will make the answer to the question ”whom to trust and whom not to trust” almost impossible to answer. If in the past interaction between unknown people was rather something unusual, nowadays, with the advent of information technology, such interactions are part of many peoples daily life. People sell and buy goods on eBay, play online games and interact on social websites with unknown people. All these kind of interactions and many more require a certain element call ”trust” that people must have as a precondition of their interaction: trust in the systems they are using and trust in the people they interact with.

Providing models, frameworks and methods for trust management have been a research topic in many areas including: human-computer interaction, artificial intelligence, computer mediated communications, internet related technologies, etc. A comprehensive survey on existing frameworks for trust management in the context of Internet-based applications is provided in [10]. Most of the approaches do not address only the trust problem but also security and privacy. Some of the most used standards are: Secure MIME [17], OpenPGP [3], Internet X.509 Public Key Infrastructure [12], XML Digital Signatures (XMLDSIG) [7], Kerberos ticket issuing system [14], Security Assertion Markup Language [11], Platform for Privacy Preferences (P3P) [15], etc. The importance of standards such as SMIME, OpenPGP, X.509, XMLDSIG for trust management is that they allow information to be passed over an untrusted channel with confidence that it will arrive unmodified by third parties, and allows a recipient of such information to be confident of its origin. Some of them, for example PGP are a first step towards realizing a "Web of trust" in which user can express degrees of trust in each other. Other trust models and frameworks were proposed with a focus on on-line interaction in e-commerce (e.g. [5], [8], [18]) or focus on trust as a psychological construct [16].

However, according to [20], most of the developed approaches have the focus on increasing users trust perceptions, rather than allowing users to make correct trust decisions. Despite the abundance of frameworks, models, methods and tools for trust management existing today, it is still possible to fake identities and trust-warranting properties on the Internet. Furthermore, for most users, the trust technologies are novel and complex. As a paradox this makes them harder to be trusted from the beginning. The risk is that these technologies could become part of the problems, rather than the solutions. In [20] the author has identified a set of factors that are decisive to determine a user to trust and engage in an interaction with another party or parties. This includes: the number of parties involved in the interaction, the type of parties (individual, organization, web site), whether the interaction is synchronous or asynchronous, the user's knowledge of the situation, its previous experience, identity and property signal from the other parties, etc. Future technological solutions for trust management need to consider all previous factors when designing scalable solutions for trust. Another open problem with the current technologies is the lack of proper models for describing trust relationships among digital entities, and between humans and digital entities.

As identified in Bled, April 2008[18] trust is a cross domains challenge, requiring a combined research efforts in Future Networks, Service Infrastructures, Networked Media systems, Internet of Things and Experimental Test facilities domains. An interesting set of research questions regarding trust in the Future Internet within and cross the domains mentioned above were identified in [23]. The following questions must be answered at different levels as illustrated in Figure 2.

- At a general level:

  How to provide evidence of trust? By which means can we deliver trustworthiness: measurement, assurance, certification, proof, etc? On which set of languages do we express trust or security policies? How is this implemented across domains and across cultures? How to enable users to make informed decisions on the trustworthiness of the information? (make the concept of trust real, a physical entity, out of the virtual world).

- At network level:

  How to apply the end-to-end principle, allowing for carrying out the functions

[18] http://www.fi-bled.eu/

(accountability, transparency, logging,) at the most effective locations in the network? How to map legal and social requirements from different jurisdictional domains onto policies?

- At software and services level:

  How to design systems that enable information accountability and appropriate use? how to make data usage transparent and accountable in dynamically composed services? Include end-to-end principal here as s/w and services will be key identifier of stakeholder scenarios. Need to integrate trust measures from different systems.

- At test infrastructures level:

  How to test and monitor different policies and accountability mechanisms at a large scale?

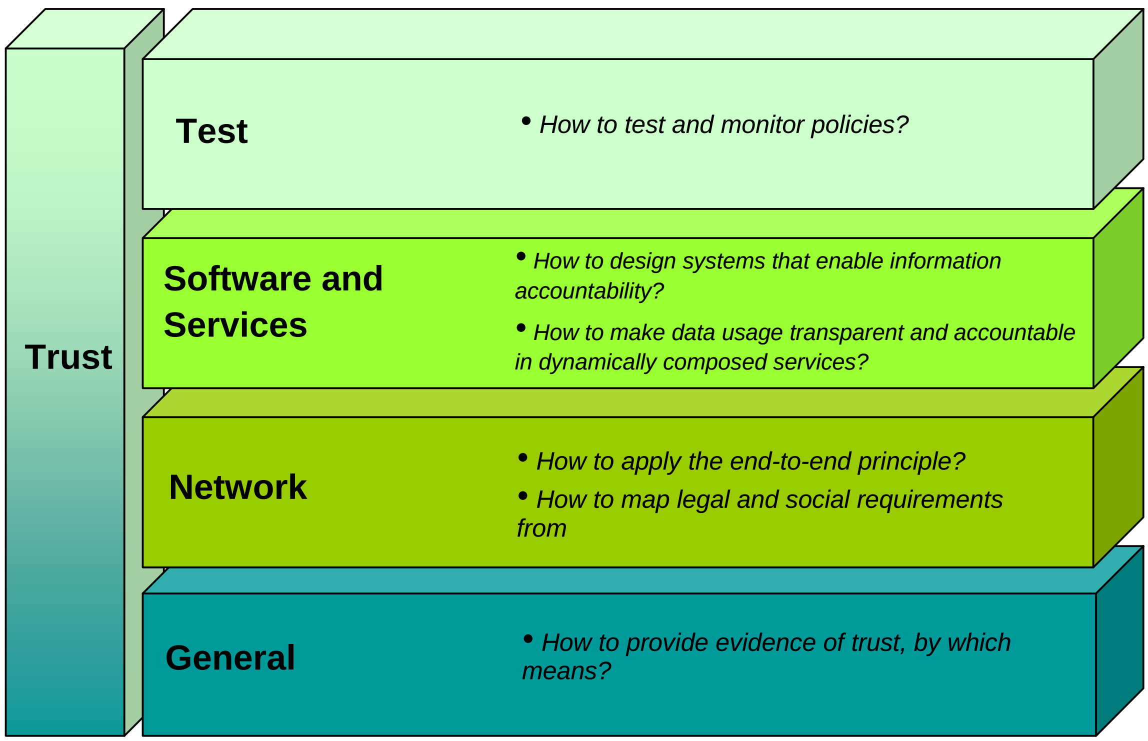

Figure 2 – Trust as a cross domain topic: Research questions to be answer at each level

Trust remains one of the greatest challenges for realizing Future Internet vision. To develop a complete solution for trust one must consider different aspects such as technological, legal, business and social implications of trust. Further research is needed with respect to policy-aware trust architectures and assessment schemes, including identity management. The level of security for applications dealing with user sensitive data needs increase to prevent identity theft and disclosure of unwanted information. Additionally interoperable credential management infrastructures for entities (persons and objects) are required. Schemes for reputations may also be needed in the world of billions of objects, sensors, devices and services. Other challenges that need to be addressed as pointed out in [22], are the development of new models of identity acquisition and behavior control. Relation between trust and other ”non-functional properties” should be further explore. The user perception of trustworthiness of future wireless services is strongly impacted by availability and resilience. Moreover the relation between trust and security is also an important one which should be further explored. The challenge here is then to obtain a greater understanding of partial trust, security-based trust (where trust follows from security), and trust-based security (where security is achieved through a trusted partnership) [6].

Semantic technologies could potentially help in filling the existing and future trust gap. One research question that have been already partially addressed by the semantic community is the modeling of trust and trust relationships. They can provide ways to describe and articulate the level of trust that can be put in knowledge. Semantic technologies will provide intuitive and undemanding ways for expressing, verifying and modifying meta-information that are central to trust, such as policies and preferences of individual and groups. Providing precise and well defined trust metrics as well as mechanisms to monitor and agree on provided metrics is another area where semantic technologies could help. Current research on non-functional properties and Service Level Agreements is just a first step towards this goal.

6. Internet of Services

The rapid development of the Internet, both in speed and in capabilities, will create a whole new and innovative market of services providing a new experience to users. The everyday life of citizens and workers of all types will be supported by new convergent services of the Future Internet that can also sense and react to the physical world[19]. In this section we will examine the research challenges associated with this Internet of Services.

According to the ICTAG report referenced above, the Internet of Services will offer very rich “horizontal services”. These services will foster an interoperability and trust framework for service integration, authentication, privacy and security, which in turn will enable the Web-based service industry to procure, extend and repurpose services for new markets.

ICTAG also describes the concept of a global and open Service Delivery Platform to be part of the Internet of Services[20]. This platform will go beyond the client-server model of service delivery and will 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.

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, providing global repositories for value-added services and, semantic support to enable the automatic on-the-fly composition of value-added services. The above will enhance the reusability of services and also allow for reasoning to derive further knowledge.

Figure 3 below, from Lutz Heusers presentation[21] during Bled conference[22] shows the two

[19] ftp://ftp.cordis.europa.eu/pub/ist/docs/web-based-service-industry-istag_en.pdf

[20] ftp://ftp.cordis.europa.eu/pub/ist/docs/future-internet-istag_en.pdf

[21] ftp://ftp.cordis.europa.eu/pub/fp7/ict/docs/ch1-g940-280-future-internet-ld_en.pdf

[22] http://www.fi-bled.eu/

layers of the Internet of Services.

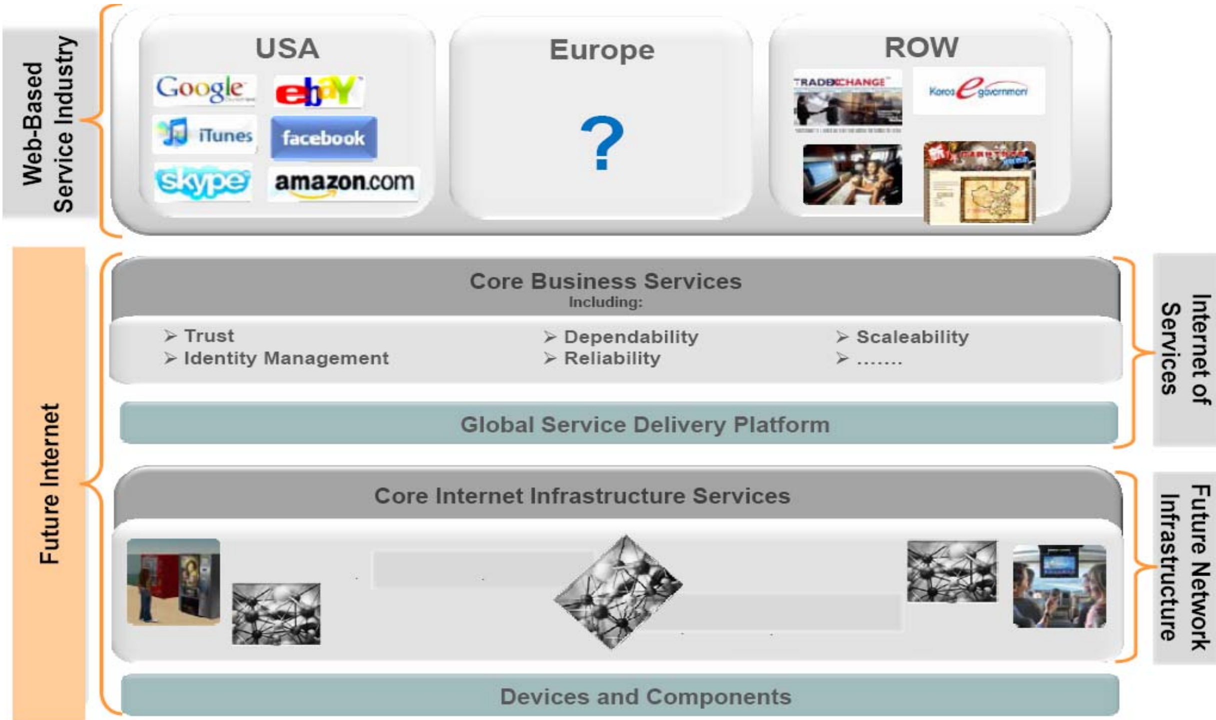

Figure 3 – A Global Service Delivery Platform[21].

In order to realize the Internet of Services able to offer services to consumers at the right time and place it is necessary to understand and be fully aligned with other technical domains which are as well developing concepts and technology for the Future Internet. In the following, we outline the core dependencies of the Internet of Services with other aspects of the Future Internet to illustrate the impact of a service-oriented view on Internet technologies.

1. **The Internet of Services and the Internet of Things.** The Internet of Services leverages on the capabilities offered by the Internet of Things (see also Section 4.1) that can sense and react to physical objects. And vice versa, service technology is utilised to transform the basic information provided by RFID tags into useful and manageable services.
2. **Social networking and user-generated content:** The Internet of Services is leveraging on individuals and virtual communities to develop content and services. The largest source of data on the Internet is now user generated. For example, Facebook's[23] 41 million active users (with 10^5 new users every day) have uploaded 1.8 billion photos and created 1,800 applications. Additionally, user generated content will grow as the world's 4+ billion applications - such as cameras, phones or PCs - increase by 50% by 2010. Newer types of devices are also coming onto the market such as the iPhone, Amazon Kindle and road navigation devices which will be able to digest and produce richer Internet content. It is expected that user generated services will follow the same trends and patterns as seen around user generated content. Several challenges arise from this development. It is necessary to identify the requirements to facilitate the exchange of user-generated content/services (whether

[23] http://www.facebook.com

for payment or not). Besides, additional dedicated standards are needed, in particular metadata standards, to ensure searchability and interoperability. The notion of trust will need to be supported what also requires, that the origin of user-generated content/services needs to be verifiable. Since notions of trust change within a dynamic user-generated service and content context, the Internet of Services has to support dynamic and flexible context-awareness. Apart from that, the Internet of Services needs to support dedicated permission and privilege management. Particularly in the area of content on demand, secure transactions and payments have to be facilitated through dedicated services.

3. **Cloud computing.** This still vaguely described term tends to cover the ability to provide computing resources (power, storage and communication) as a service. Companies like Amazon[24] are already providing such services. If more and more companies rely on cloud computing instead of relying on their own in-house services, the impact of an Internet of Services increases dramatically and, moreover, it has to be able to deal with service delivery on a web-scale. As another challenge, it needs to be clarified, which parties will influence and control the potential "Global Service Deliver Platform (GSDP)" and the "horizontal services" which are provided. Besides, new business models will continuously arise from such developments and need to be identified and supported accordingly.
4. **Global service delivery platform (GSDP) for the Future Internet.** As fundamental challenge, the scope and actual definition of the GSDP needs to be clarified as well as how GSDP might contribute to and facilitate innovation? Within the ICTAG vision, this global platform plays a prominent role. In defining this term following aspects need to be addressed:
    a. Scope of GSDP: Potential options would be, instance, a single platform, a single point of access, a federation or network of interoperable platforms. Moreover the extent of centralization and decentralization is of importance. The basic functionality of the GSDP needs to be defined from a European perspective. As important aspect here, the question arises, if the platform will be solely concerned with service delivery or if it will support service development as such.
    b. Distinct notions of "Service": The term service is determined by distinct visions, each having certain implications on the GSDP:
        i. The vision of billions of services (then the platform would be mostly a search/discovery/composition tool),
        ii. The vision of IT Service Parks (then the platform would be mostly a QoS-preserving secure integration platform), the vision of Telco companies (then the platform is mostly a well-controlled secure platform on which services can be accessed by authenticated paying customers),
        iii. The vision of Future Media (then the platform is mostly a distribution platform of content with digital rights management),
        iv. The vision of Business Services – enterprise, government, healthcare, banking, consultancy, services - (then the platform is mostly an intelligent reasoner, able also to configure - i.e. annotate ontologies, tune input parameters -, test or simulate the execution of services).
    c. Ownership and impact factors: As another field of research, ownership of GSDP would need to be defined and further impact factors need to be identified. This includes the potential market and business models for the GSDP and whether and how these would be independent from the actual services provided.

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[24] http://www.amazon.com

5. **Semantics**. The increasing impact of Semantic Web [40] standards such as OWL[25] and RDF-S[26] to enable interoperability between distinct resources on the Web also applies to the Internet of Services. Particularly the highly diverse and complex capabilities of Web services demand for semantically rich annotations allowing for rather automated interoperability [43]. In that, so-called Semantic Web Services (SWS) technologies [44] aim at the automatic discovery and orchestration of services on the Web. Despite first results - in the form of reference models such as WSMO [41] and OWL-S [42] – SWS are a field of ongoing research with an continuously increasing impact on the Future Internet. Challenges SWS technologies have to cope with include, for instance, to provide formal service semantics which on the one hand are expressive enough to effectively reason and automate discovery of heterogeneous services but still are manageable in a way that allows for web-scale deployment and provisioning of SWS.

7. Management and Governance

In this section we take a look at existing shortcomings in the current Internet regarding management (section 7.1) and governance (section 7.2), we propose solutions that address these drawbacks and steps towards these solutions. Furthermore, where appropriate we show how Semantic technologies could help realizing the identified solutions.

7.1. Management

Administration and supervision of various entities is often refer as management. If in the early state of information systems management was done in a centralized and manual fashion involving simple control and monitor activities. A major characteristic of existing and future networks, applications, services, sensors and devices is the increasing heterogeneity. Different networking technologies, new and growing number of mobile and ad-hoc networks, cellular phones networks and many more make current management approaches difficult, time-consuming and error-prone. This growing complexity and heterogeneity demands new forms of management. One intuitive approach to reduce the complexity of managing large scale systems is to push the management functionality towards the edge of the system and as well to develop intelligent management solutions that will allow parts of the system to manage themselves. The concept of *Self-Management* refers to the ability of a system to manage its own activities without human intervention. The most prominent initiative with respect to Self-Management is the Autonomic Computing Initiative (ACI) started by IBM [13]. The ACI defined a set of features that a Self-Management system should have, which are grouped under the name of *Self-**. This includes: (1) *Self-Configuration* - automatic configuration of components, (2) *Self-Healing* - automatic discovery, and correction of faults, (3) *Self-Optimization*: automatic monitoring and control of resources to ensure the optimal functioning with respect to the defined requirements and (4) *Self-Protection*: proactive identification and protection from arbitrary attacks. As identified in [2], with self-managing components, several requirements for the Future Internet can be satisfied. Self-healing functions can improve resilience, Self-configuration reduces operational cost, increases scalability and helps dealing with highly dynamic changes, for example with mobile networks. The Future Internet will be composed of autonomic components with each of them containing functions to manage themselves. Other management challenges that involve cross domain research activities have been identified in [9]. This includes:

- Management of Ubiquitous Virtual Resources - including the integrated and flexible

[25] http://www.w3.org/OWL/

[26] http://www.w3.org/RDFS/

usage of heterogeneous and assumable virtual resources for energy, networking, computation, storage, content, mobility, etc;

- Cross-domain Self Management functions and cross-layer cooperative Future Internet systems design providing integrated management functionality, including: system lifecycles, monitoring, (re)configuration, optimization, organization, performance, adaptation, context, semantics, security, composition, assurance, negotiation, repository, SLA, QoS, billing, functions management; minimizing life-cycle Future Internet system costs, minimizing the energy footprint;

- Embedding management functionality in all Future Internet systems (i.e. InNetworks management, InServices management, InContent management);

- Dynamic deployment of (new) management functionality with no interruption of Future Internet systems and services operation (i.e. Plug-and-Play, UnPlug-and-Play, programmability);

- Orchestration and integration of management functionalities.

Further research is needed in the areas of modeling and specifying policies and nonfunctional properties. More precisely better solutions for end-user policies, policy combination need to be delivered. Nonfunctional properties models are needed for management related NFPs such as: security, reliability, robustness, mobility. With respect to these challenges, semantic technologies, more precisely ontology based model could be very useful. Self-management and the self-* characteristics that are connected to self-management implies a higher degree of automation. Semantic technologies are known as potential solution for the automation problem ant thus they could help realizing the automatic computing vision.

7.2. Governance

Governance is a relatively new concept which has been used in various contexts, including state governance, corporate governance, networks, self-organizing networks. In general terms governance refers to ”rules, processes and procedures, and specific actions that impact the way in which power is exercised on a specific area of concern”[19]. The terms *governance*, *policy* and *policy implementation* are fundamental to the overall governance process. *Governance* is about ”who” has the rights to take decisions, to be exercise power on the area of concern. *Policy* is about the ”what” question, namely what policies and rules are to be put in effect. Finally *policy implementation* is about ”how” to implement and enforce the policy. Governance decisions for current Internet are taken/coordinated by the Internet Corporation for Assigned Names and Numbers (ICANN)[27]. The core responsibilities of ICANN are the assignment of domain names and IP addresses. With the growth of the Internet i.e. number of devices, number of users, Internet governance becomes a challenging task. Rapid changes in the Internet are challenging its governance structure and its self-regulating nature. Traditional governance approaches become less and less flexible and hard to enforce in the current and future Internet.

To bring more flexibility, adaptability and scalability into to the governance process, current

[27] www.icann.org/

research trends around governance are focusing on self- and co- schemes. Such approaches are a first step towards accepting the global, multi-faceted nature of the Internet and dealing with failing jurisdictions and poor enforcement [21]. Other aspects that are relevant to governance are self-regulation as well as international and multi-stakeholder Internet governance. Self-governance and self-regulation are the basis for a decentralize governance solution. Self-* schemes need to be operated in a regulated space and supported by co-regulations. On top of these islands of self-governance the Future Internet will need a global governance structure. At this level and not only here the principles of good governance as identified in [21] should be followed. This includes: transparency, accountability, targeting, proportionality, consistency, wide participation and exchanges of good practice. Governance is challenging topic that in the context of Future Internet requires a cross domain approach. This involves not only technical aspects at the level of networks and services but also legal and social aspects.

8. Socio-economics

Socio-economics is the study of the interplay of society and economics. The Internet has achieved enormous importance in both economics and society, a role that was not anticipated at its inception, and which has not received sufficient attention in the technology-driven developments since. The socio-economics of networks have been investigated for over 30 years. The technical community has to recognise the growing social implications of the internet, acquaint itself with existing research results in this area, as well as increase dialogue with the researchers behind it. Without this, we cannot develop the necessary new insights into how to structure the architecture and services of the Future Internet.

Society will rely on the Future Internet as much as it does today on electricity, because the Future Internet will underpin and improve daily life in both developed and developing countries. Commerce, government services, socializing, entertainment and medicine are all dependent on the Internet, and this dependence will become deeper and wider. Broadband telecommunications and services must be available "anytime, anywhere". Particularly in the developing world, network connectivity will likely be achieved through very different technologies to those in the West — such as wide area wireless meshes or satellites. Bandwidth will be more limited there, and the network will need to be smarter w.r.t. caching, routing, and traffic flow management. In the next few years, around three billion new Internet users will join the one billion existing ones, but they will do so from mobile phones or other cheap devices. Most will not know English, and have very limited technical knowledge, but they too must have access to information, be able to conduct commerce, socialize, and contribute content from their very different perspectives.

As the dynamicity and configurability of the network increases, the implications of users' choices become more complex. How do we ensure that the Future Internet remains accessible to those outside the technology-afffine circles? Technological education can play some part, but we should not require most users to understand deep technical issues. Security must, at some level, be understood and controlled by the user, because it is ultimately the user who determines what can be done in their name, and how that might be delegated. Most people are unaware of how their personal information is already used for data mining and profiling. The network must be accountable to humans: able to advise on privacy decisions, and explain adverse consequences when they inevitably arise. Better managed personal information could be used much more constructively. The current financial crisis can be attributed to lack of information: derivatives based on mortgage and other debts became detached from knowledge of the underlying assets and debtors. With pervasive semantics, these would have been transparent, and bad risks could have been identified earlier and more clearly.

Assuming the technical infrastructure can be provided, how do we ensure that the activities enacted upon it do not skew further the socio-economic balance of power? A Future Internet could level the playing field of global economics more quickly and profoundly than any other single system: the offshoring of call centres, software development, and education make it much easier for poor countries to catch up than in capital intensive industries. There is a dark side: virtual worlds have had spill over into the real world: divorces and suicides have already been caused by online behaviour. Virtual currencies have led to real-world prosecutions for theft, and 'gold farming', a bizarre cottage industry strong in China, has driven the Korean government consider legislating on trading in virtual currencies.

Users have come to expect Internet content to be free at the point of use. Much of it is genuinely free, being the product of individuals' ego or altruism: scientific papers, open source code, forums, and blogs are all freely available in a way that is difficult to reproduce without the Internet. Commercial content is mostly supported by advertising, and content aggregators like YouTube and MySpace represent a cross-over category, extracting value from others' content. What are the implications for a society that chooses to be taxed in an unaccountable way through advertising? Down the road, it seems implausible that advertising can support ever growing services and content. Advertising revenues will fall as more content providers compete for advertiser's attention, and services seen and used only by machines cannot be monetised via advertising at all. Besides, how will copyright be managed? Music companies appear to be retreating from digital rights management, instead defending copyright through the courts. Can or should the Future Internet provide for the kind of lock down present in the latest digital video formats? Lifecycle engineering for content, storage, and distribution must be considered.

Strengthening collaboration between technology experts and policy makers

By its nature, the socio-economics of the Future Internet are not especially amendable to technical solutions, but technologists must play a role. First, they must understand the scale and centrality of their work to the lives of billions, and appreciate the needs of people, most of whom do not have access to the latest technologies. That knowledge must lead to action: greater engagement and collaboration of technologists with policy makers, who often do not have the necessary background to fully comprehend the technology, let alone its opportunities and risks. Mishandling issues like software patents, copyright, and laws on censorship and government wiretapping could strangle much of the Future Internet's potential and can only be avoided by involving well-informed experts into the decision-making process.

Efficient and understandable security mechanisms

Problems with security in Bluetooth, WiFi, and misplaced physical devices prove that even in focused areas, security falls short. As more information and capital moves online, we need to trust the global network fabric. In that, the following needs can be observed:

1. Security must be applied everywhere, in every device, at a deep level.
2. Formal verification of security protocols will become more common, and the resulting properties and proofs made visible via semantics.

Many security breaches are achieved through social engineering. Examples are phishing, spam, scams, unprotected data, lost memory devices. Users need to understand the threats, and the implications of their behaviour. Hence, requirements are:

1. Policy languages that can be understood by end users.
2. Reasoners that can communicate implications of choices, and explain what went wrong when, inevitably, the user encounters undesired behaviour.
3. User interfaces that tie them together

Well-managed anonymity and privacy

Users should be able to participate in content use and create, communicate, socialise and spend money while revealing as little or as much about themselves as they wish. When crime does occur, law enforcement must be possible.

1. Allowing users to determine how much knowledge applications, organisations and the network itself know about them, and varying this.
2. Payment systems that guarantee anonymity and traceability in the event of criminal activity. If micropayments become common, their management must be integrated with user's banking providers and their own security policies.

To cope with the all the above challenges, formal semantics - as foreseen by Tim Berners Lee [40] – will play a pivotal role since by its very nature the Semantic Web facilitates transparency and interoperability. This applies at a technological level, i.e. interoperability between machines, as well as to the communication between humans which could be significantly facilitated and improved through formal semantics.

9. Conclusion

The Future Internet is an ambitious European initiative which involves extensive collaboration across multiple scientific and industrial domains. This roadmap has analyzed 6 significant problem areas addressed by the European Commission in order to establish the major challenges and potential solutions where semantic technologies can provide important contributions.

Content Networks – the major challenges for current content and media networks to evolve into self-organizing and self-adaptive networks of the Future Internet are: effective addressing and routing of contents based on content rather than on their locations; efficient representation of various types of content; precise and simultaneously personalized audio, video and image retrieval; contextualization of content with regard to such contexts as identity, time, and location; aggregation of content, supporting the tendency towards higher inter-connectivity; dynamic creation, modification and management of content; actively publishing content at appropriate locations, and seamless end-to-end multi-media communication across a complex combination of network constituents. By providing conceptual annotations for various content objects and enabling precise and formal descriptions of data and media content available in the networks as well as other related aspects such as digital rights and usage policies using semantic technologies, the functionalities offered by services operating on these content networks will become automated, more precise and effective.

Real World Networks – as our physical world becomes digitally represented through sensor networks and the Internet of Things, collectively with the complementing progressive developments in virtual reality and user interactivity, we face the following challenges in realizing the Real World networks: pervasive ambient intelligent objects linked together via RFID tags and sensor networks; virtual worlds and entities integrating with the service-oriented and model-driven systems and services; enabled on-device communications and resources management; re-invent new semi-automated supply-chain systems and non-ICT process models; search and retrieval of 3D content; and resolving interoperability problems between conflicting virtual worlds and models. Properly specified semantic descriptions of users and virtual objects (and the Internet of Things) could then bring the Real World Network to integrate with the Internet of Services allowing for interaction on a level of higher abstraction and increased interoperability and automation throughout the semantically-enabled Future Internet infrastructure.

Identity and Trust – the major challenges within the Identity and Trust domain of the Future Internet include: efficient systems and devices for widespread authentication and authorization; digital systems for identities, such as biometric systems; coherent, integrated frameworks and systems for identity management and service level agreements; elimination of abundance of unsynchronized, duplicated, lost, corrupted, or misused identity data; federation of identities, infrastructures and applications with digital signature; tools of trust to protect the chains from associated services: personal medical file, identities cards, e-commerce, e-administration; secure modules for computers; trust management; trust relationships among digital entities, and between humans and digital entities. Semantic technologies adopt the principles behind the Web and the Semantic Web in respect to the URI in order to provide an identity system which could be handled in large, open distributed environments; several of the identity and trust problems bound to result from future heterogeneous models, devices, applications and languages could benefit from the mediation and interoperability research currently active in the Semantic Web community.

Internet of Services – as the future society will be supported by new convergent services of the Future Internet that can also sense and react to the physical world, challenges in realizing the Internet of Services will include: leveraging on the capabilities offered by the Internet of Things in order to sense and react to physical objects; utilizing service technology to transform the basic information provided by RFID tags into useful and manageable services; leveraging on global users and virtual communities which develop services; provide computing resources (power, storage and communication) as services (i.e. cloud computing); and defining and provisioning global service delivery platform. These challenges can be confronted with formal semantic services which are both expressive enough to effectively reason and automate discovery of heterogeneous globally distributed services but are still manageable in a way that allows for large scale deployment and provisioning of semantic services over the Future Internet.

Management and Governance – the Future Internet needs a global management and governance structure, which should respond to the existing challenges such as: transparency, accountability, targeting, proportionality, consistency, wide participation and exchanges of good practice; Semantic solutions for management and governance include ontological models which include non-functional properties such as: security, reliability, robustness, mobility, as well as precise descriptions of governance policies and parameters of management. Semantic technologies can provide intuitive ways for expressing, verifying and modifying meta information, providing precise and well defined governing metrics as well as mechanisms to monitor and managed networked activity.

Socio-economics – the Future Internet will have a tremendous socio-economic impact unlike any preceding communication instrument or infrastructure: commerce, government services, social sciences, health sciences, entertainment, communication norms, general societal interactions, etc., will all become dependent upon the Future Internet. Challenges to be overcome in this domain include: incorporating scalability into all networked solutions; closing the gap between technology experts and policy makers; ensuring security in all networked activities; and allowing necessary anonymity and privacy. A semantic model of our socio-economic world dependent upon the Future Internet facilitates transparency and interoperability; i.e. interoperability between machines, as well as to the communication between humans, while maintaining security, anonymity, and privacy policies, could be facilitated and significantly improved through formal semantics.

This roadmap is a public document to be freely distributed in order to gain widespread and diverse feedback as the Service Web 3.0 project continues. This roadmap will be the basis for several specialized roadmaps that will focus on the progressive realization of the Internet of Services and provide concrete national plans for further research and development focused on the application of semantic technologies to the relevant problem domains of the Future Internet.

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