Semantics-Driven Interoperability on the Future Internet

Ioan Toma, Elena Simperl
STI Innsbruck, University of Innsbruck
Technikerstrasse 21a, A-6020,
Innsbruck, Austria
firstname.lastname@sti2.at

Agata Filipowska
Department of Information Systems,
Poznan University of Economics
61-875 Poznan, Poland
a.filipowska@kie.ue.poznan.pl

Graham Hench
STI International
Amerlingstrasse 19/35, A-1060
Vienna, Austria
graham.hench@sti2.org

John Domingue
Knowledge Media Institute,
The Open University
Walton Hall Milton Keynes, MK7 6AA, UK
j.b.domingue@open.ac.uk

Abstract

The Internet as we know it today is in an extending success: more than 1,3 billions people are connected to the Web across the globe and more than 700 EB of informations were created or replicated world wide. The development is driven by users, as well as by technology. Web 2.0 changed users to creators of content. Intelligent devices, clothes, fridges, machines and factories are connected and interact automatically without direct human involvement. But since the current Internet consist mostly of unstructured data and resources, most of the data and resources are unusable for the average user. The fact is, the current Internet is broken. We still have not one Web, but a vast variety of different unlinked data. The Future Internet will have to change. This paper proposes a roadmap for research and development in the field of the Future Internet. The roadmap surveys the main challenges to be addressed within the core cross-domain areas of the Future Internet, challenges that need to be solved 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.

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, 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. The Future Internet research has been structured according to five research areas *Networks*, *Internet of Services*, *Internet of Thing*, *3D Internet*, and *Trust and Security* as illustrated in Figure 1. In addition to the five areas, Testbed area for large scale experimental testing are being considered.

For the Future Internet to become a reality we need to understand and resolve convergence challenges in and across the domains areas mentioned above. The following cross-domains were identified: *Content Networks*, *Real World Networks* that includes Internet of Things and Real World & Virtual, *Identity and Trust*, *Internet of Services*, *Management and Governance* and *Socio-economics*. In this paper we provide 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 FIA working groups established in 2008 as an initiative of the European Commission. The focus thereof is on semantic technologies and their potential to support various aspects of the Future Internet, notably the Inter-

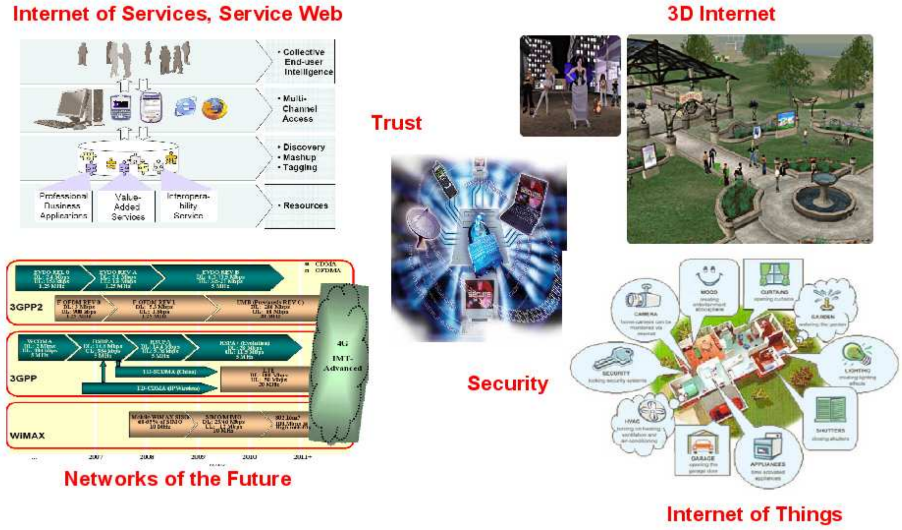

Figure 1. Future Internet - multiple dimensions

net 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. 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 as follows. Section 2 discusses the current challenges and future research directions in the area of Content Networks. In Section 3 and Section 4 we perform a similar investigation for the areas of Internet of Things, Real World and Virtual interfaces as well Identity and Trust. In Section 6 the focus is on Management, Governance in the Future Internet. Finally, Section 7 concludes the paper.

2 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 [9]. Moreover, the observed tendencies cause many challenges and problems that the Future Internet should tackle including metadata, discovery, composition. They are shortly elaborated in the following sections.

2.1 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 to assure technical and organizational interoperability. 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"([4]).

2.2 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 [5]. Classical search 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. The semantics will be also to describe context of content objects that will be used for the personalization purposes. In addition, the context will include also characteristics of devices (technical interoperability); the context of bandwidth as well as personal preferences of end-consumer.

2.3 Transformation and Composition

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.

2.4 Delivery Infrastructure

Transfer of data across heterogeneous networks will require assuring interoperability via usage of 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.

The content networks in the Future Internet 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: (1) capability to represent various types of content, (2) precise and simultaneously personalized audio, video and image retrieval, contextualization of content, (3) aggregation of content, supporting the tendency towards higher inter-connectivity, (4) dynamic creation, modification management and publishing of content, (5) seamless end-to-end multi-media communication across a complex combination of network constituents.

3 Real World Networks

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.

3.1 Internet of Things

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 reality. Radio Frequency Identification (RFID) technology has evolved to a general purpose identification technology. Now, RFID tags can be applied to or incorporated into almost any physical object for the purpose of identification and tracking using radio waves. 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[1]. 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.

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

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

that dumb thing is. It's about embedding intelligence so things become smarter and do more than they were proposed to do."[2] 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. 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 5). A core set of services will be required to bridge between the foundational network and service layers. 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.

3.2 Interfaces: Real World & Virtual

As the Future Internet evolves to encapsulate unlimited services, resources, 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, 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. Future interfaces could benefit from the developments in virtual reality which are quite impressive. These developments are 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 Forresters "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 this 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[3]. Already applications like Second Life are seamlessly integrating virtual world activities with real-world business operations[4]. 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. 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.

4 Identity and Trust

In a "Future Internet" related study conducted by RAND Europe for the Dutch Ministry of Economic Affairs [3], 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 4.1) and trust (section 4.2), we propose solutions that address these drawbacks and we show how Semantic technologies could and will play a role in these solutions.

4.1 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. To address the general problem of issuing and managing identities for various types of entities three categories of technologies aiming to support identity[5] have been proposed: (1) *generic identifiers of electronic objects*, popular examples in the context of the Web is the mechanism

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

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

[4] http://secondlifegrid.net/

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

of using URIs/URLs for globally locating resources, (2) *real-world object identifiers used in electronic applications*, that includes a wide range of approaches such as MAC addresses for network components, EPC and RFID (the Internet of Things), ISBN for intellectual property resources (e.g. books and publications), and many more and (3)*identification of individuals (persons) in electronic applications*, that includes a set of approaches developed mainly in the context of ECommerce such as X.509[6] for digital certificate and authentication framework and recently OpenID[7], OAuth[8], 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. This leads to what can be called "Identity Anarchy" [1]. For this problem, solutions that embrace the principle of decentralize data seam more appropriate for identity management systems of the future. 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. 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. Other identity challenges are generated by the increasing number of devices, sensors, networks and 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.

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.

[6]http://www.itu.int/rec/T-REC-X.509/en
[7]http://openid.net/
[8]http://oauth.net/

4.2 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 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".

Providing models, frameworks and methods for trust management have been a research topic in many areas. A comprehensive survey on existing frameworks for trust management in the context of Internet-based applications is provided in [8]. 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[9], OpenPGP[10], Internet X.509 Public Key Infrastructure[11], Kerberos ticket issuing system[12], Security Assertion Markup Language [6], Platform for Privacy Preferences (P3P)[13], etc. For most users, the trust technologies are novel and complex. The risk is that these technologies could become part of the problems, rather than the solutions.

As identified in Bled, April 2008[14] trust is a cross domains challenge. An interesting set of research questions regarding trust in the Future Internet within and cross the domains mentioned above were identified in [2]. The following questions must be answered at different levels:

- 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?
- At network level:
  How to apply the end-to-end principle, allowing for carrying out the functions (accountability, transparency, logging, etc.) at the most effective locations

[9]ftp://ftp.isi.edu/in-notes/rfc2633.txt
[10]ftp://ftp.isi.edu/innotes/rfc2440.txt
[11]ftp://ftp.isi.edu/innotes/rfc3280.txt
[12]ftp://ftp.isi.edu/innotes/rfc1510.txt
[13]http://www.w3.org/TR/P3P/
[14]http://www.fi-bled.eu/

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?
- At test infrastructures level:
  How to test and monitor different policies and accountability mechanisms at a large scale?

Trust remains one of the greatest challenges for realizing Future Internet vision. Relation between trust and other "non-functional properties" should be further explore. 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.

5 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[15] . 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[16]. 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. 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.

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 3) that can sense and react to physical objects. And vice versa, service technology is utilized 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. User generated content will grow as the worlds 4+ billion applications. Newer types of devices are also coming onto the market. Several challenges arise from this development. It is necessary to identify the requirements to facilitate the exchange of user-generated content/services. Additional dedicated standards are needed, in particular metadata standards, to ensure searchability and interoperability. The Internet of Services has to support dynamic and flexible context-awareness, dedicated permission and privilege management.
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[17] 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. As another challenge, it needs to be clarified, which parties will influence and control the potential "Global Service Deliver Platform

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

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

[17] www.amazon.com

(GSDP)" and the "horizontal services" which are provided.

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: (1) *Scope of GSDP*: a single platform, a single point of access, a federation or network of interoperable platforms? (2) *Distinct notions of "Service"*: The term service is determined by distinct visions, such as the vision of billions of services, of IT Service Parks, of Telco companies and Business Services, etc., (3) *Ownership and impact factors*: ownership of GSDP would need to be defined and further impact factors need to be identified.

5. **Semantics.** The increasing impact of Semantic Web standards such as OWL[18] and RDF-S[19] 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. In that, so-called Semantic Web Services (SWS) technologies aim at the automatic discovery and orchestration of services on the Web. Despite first results - in the form of reference models such as WSMO [10] and OWL-S[20]. 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.

6 Management and Governance

In this section we take a look at existing shortcomings in the current Internet regarding management (section 6.1) and governance (section 6.2), 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.

[18]http://www.w3.org/OWL/
[19]http://www.w3.org/RDFS/
[20]http://www.daml.org/services/owl-s/

6.1 Management

Different networking technologies, new and growing number of mobile and ad-hoc networks, cellular phones networks and many more make current centralized 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 [7]. 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.

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 include: (1) Management of Ubiquitous Virtual Resources, (2) Cross-domain Self Management functions and cross-layer cooperative Future Internet systems design providing integrated management functionality, (3) Embedding management functionality in all Future Internet systems, (4) 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), (5) 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. Non-functional 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.

6.2 Governance

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”. 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)[21]. 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. Traditional governance approaches become less and less flexible and hard to enforce in the current and future Internet. Current 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 [3]. 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 all levels the principles of good governance should be followed. 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.

7 Conclusions

The Future Internet is an ambitious European initiative which involves extensive collaboration across multiple scientific and industrial domains. In this paper we have 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. Finding solutions to the challenges identified in the paper is essential if a successful Future Internet is to emerge. In this paper we have identified the major challenges for each Future Internet area and we have proposed solutions on how to overcome the major problems. Furthermore we have elaborated on the role of semantic technologies in the resolution of these problems, showing the real potential and benefits of using these technologies.

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