Proactive Future Internet: Smart Semantic Middleware for Overlay Architecture

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Abstract

Some initiatives towards Future Internet, e.g., GENI, DARPA’s Active Networks, argue the need for programmability of the network components. Some other initiatives extend this with argumentation for declarative networking, where the behavior of a network component is specified using some high-level declarative language, with a software-based engine implementing the behavior based on that specification. Our Proactive Future Internet (PROFI) vision follows these initiatives targeting also the following two problems: interoperability of the network elements programmed by different organizations, and the need for flexible cooperation among network elements, including coordination, conflict resolution and even negotiation. To tackle these problems, PROFI intends utilization of semantic languages (RDF-based) for declarative specification of network elements' behavior, and application of software agents as engines for executing such specifications. PROFI technological concept is based on the UbiVERSE, a high-level multidisciplinary research vision towards the future global information society which is also described in this paper.

1 Introduction

Global information society plays one of the central roles in modern mankind existence. It is reputed as being of cardinal importance for sustainability of human civilization and being determinant for future evolution of humanity as it lays the foundation for the majority of human’s social and business every-day activities and often defines our contemporary lifestyle. It is long since life in the developed world could be imagined without the benefits that information society and technologies bring to us. Information society has been constantly evolving during few last decades making our existence more opportune, convenient, flexible and generally favorable. Further progress of the human society on a global (perhaps even planetary) scale thus largely and in many aspects depends on appropriate development of the information society as a major driving force of humanity evolution.

The current view of the information society is somewhat twofold. On one hand, surveying how it has changed our lives since its dawn, the information society can be easily named a well developed artificial system, which is very close to maturity. On the other hand, there are still too many crucial challenges and unaddressed issues in this system development, which apparently create barriers and pitfalls hampering continual information society evolution. Although many of these challenges and problems can be solved sooner or later, such solutions will be mainly too specific and proprietary to anticipate and successfully tackle possible future adverse consequences and chain effects, and therefore incapable of forming a solid base for further system evolution, while still being rather effective to achieve local and short-term outcomes. Vast majority of the present-time challenges of the information society proliferation is, however, lying at a higher, conceptual level of the system design and hence requires radical changes to be properly reflected within the design principles. In this way, long-term goals of the information society development can only be achieved and smooth and continual evolution of it can be ensured. The necessity for radical changes in this area is widely recognized on the world-wide scale and is realized throughout many international R&D programs, e.g., EU FP7-ICT. These programs raise important conceptual and technological challenges affecting various parts and aspects of the modern information society and summoned to accelerate its growth, penetration and consolidation on the world-wide scale. The research community looking to solve the identified challenges is not, however, sufficiently consolidated itself. Current snap-shot of the roadmap of R&D activities embracing the entire information society research field looks like archipelago of several major and well-developed research islands: Future Internet, pervasive infrastructures and smart environments, novel service archi-
tectures, Semantic Web information platforms, etc. – with no or poor communication established in between. This problem is reported to have historical roots: in the course of the development of the current version of the information society, research and development activities have also been significantly fragmented amongst major communities focused on the development of different parts and enabling technologies jointly forming the information society base, e.g., the Internet distributed network architecture, the Web information environment, telecommunication technologies and mobile service platforms. Largely due to this divergence (among other factors), the modern information society is still fragmentary as not all its constituent systems and environments are fully connected with one another. Thus, while there is still time to make it at the stage of conceptual design, the gap between different research communities, e.g., network-level (Future Internet) and application-level (Web X.0, SOA) people, should be bridged by envisioning and formulating a comprehensive and coherent vision of the global information society ecosystem, which will encourage and guide research and development of the future ICT solutions and technologies in a converged context and consolidated fashion.

Thus, this research agenda should be seen as an attempt to realize our incentive to create a coherent vision of the global information society ecosystem. Below, the initial, medium detail vision of such an ecosystem is described, including its design principles, enabling technologies, component systems and applicability scenarios.

Future Internet (FI) should be seen as an important asset of the future information society, its major technological and architectural basis, the backbone to many other component systems and technologies to be the part of information society. Thus, appropriate revision of current Internet design and operation principles is of paramount importance for information society evolution.

In Section 2, we sketch the UbiVERSE concept of the future information society, and in Section 3 we specifically focus on the enhancements we particularly envisage within the FI sector. Section 4 describes some significant, from our viewpoint, related approaches in the FI field. Finally, Section 5 concludes the paper.

2 UbiVERSE: Ubiquitous Virtual Ecosystem for Resource-oriented Smart Environments

Traditionally, the Internet network architecture and the Web information environment built on top of it have been the backbone of the information society due to their high availability, persistence and global coverage. However, as new challenges of integration of Telecommunication systems with IT systems, mobility, ubiquity, and trust appeared and have been growing more and more crucial, this backbone has been getting more and more obsolete raising the need for serious revision. In recent years and till today, active research and development work towards the revisited vision of the Internet, Web, and Telecommunication technologies has been performed. Unfortunately, in spite of remarkable advances on the revision path in these technology areas and even mutual acknowledgement of correlation among the developments in these areas, the research efforts are largely independent and very little attention is paid to the coherent vision of the universal information society.

UbiVERSE is an attempt to set out such a universal coherent vision of the future global information society that will be based on the recent developments in the research and technology areas of future Internet, Web, ubiquitous smart environments, and flexible service architectures. UbiVERSE will, however, not only outline conceptual framework of the future information society, but also provide a concrete technological solution for incorporation of the achievements from different technological areas into a single information system.

Our vision of the UbiVERSE future information society targets creation of a single global and unified distributed information environment which is based on the concepts of (information) resource and seamless internetworking, interoperability and integration amongst ubiquitous resources. Architectural and functional organization of such an environment should be based on the principles of openness, extensibility, configurability, flexibility and sustainability.

Methodologically, UbiVERSE will entail meta-level architectural approach and will utilize a semantics-based agent-driven inter-middleware platform that employs declarative programmability, personalization, proactivity and semantic technologies to step up as a universal and efficient superstructure over future Web/Internet and other ICT systems and environments, and to act as intelligent glue seamlessly interconnecting all constituent technologies and components of the future information society. We refer to such a middleware as UBIWARE; the work towards it has started in the research project with the same name [11].

Specifically, the spectrum of technologies that are envisioned to form the backbone of the future information society is rather wide and shall at least include the following: Future Internet network architecture; Web X.0 information environment; various Service Oriented Computing (SOC) technologies and architectures (SOA); ubiquitous smart systems and environments (including various wireless access technologies and service interfaces); telecommunication systems and mobile service platforms; other legacy systems; individual isolated resources.

The principal layout of the UbiVERSE environment is illustrated in Figure 1. The role of agent-based resource mediation between various component systems is particu-
larly highlighted. In the figure, the agents are marked with "A" and resources – with "R".

UBIWARE is the dedicated middleware solution to be the core element of the UbiVERSE information environment. Its major goal is to make various UbiVERSE resources interoperable. Resources within UbiVERSE can be roughly presented on three conceptual layers: hardware (devices, embedded electronics, sensors, etc.), information and software (data repositories, services, applications, etc.), and human. It is assumed that in general case every resource is connected to the UbiVERSE environment through one of its own environments and using some specific middleware platform deployed within the corresponding environment. Conceptually, UBIWARE should be seen as intelligent interface that allows linking together diverse middleware solutions, which differ not only by implementation but also by their intended use. So, UBIWARE is a middleware architecture that aims at providing interoperability between distinct middleware platforms and at providing communication transport between resources on these platforms. UBIWARE is technologically based on utilization of rich data semantics, multi-agent coordination and intelligent algorithms. Two major applications scenarios for UBIWARE can be identified:

1. Intra-layer interoperability. UBIWARE links resources residing on the same layer, but on top of technologically different middleware platforms. UBIWARE establishes an interface between originally non-interoperable platforms or enhances (via utilization of semantics and pro-activity) the existing interface in case the middleware platforms are interoperable. In this way, UBIWARE can, e.g., manage the interoperability of resources connected though an RFID middleware and resources connected through another middleware for embedded electronics, such as e.g. the one developed in the FP6 RUNES project (http://www.ist-runes.org/).

2. Cross-layer interoperability. UBIWARE helps resources residing on different layers to interoperate despite of serious (conceptual) heterogeneity of their respective middleware platforms.

Apparently the second type of scenario is much more challenging and sophisticated. In order to make this scenario possible UbiVERSE must act as a sort of intelligent wrap over all its constituent technology platforms, i.e., Internet, Web, telecom systems, etc., which not only improves their interoperability noticeably, but also enhances their own operation in many ways.

Below, we consider possible enhancements of the Future Internet vision inspired by and sprung from the UbiVERSE concept.

3 PROFI: Proactive Future Internet

Big industrial players involved in the Future Internet technology area are interested in seeing Future Internet platform self-manageable, in particular, in the aspects of optimization, maintenance, performance management, and re-configuration. The PROFI technological concept (as further elaboration of the SmartResource [10], and UBIWARE [11] concepts developed by the Industrial Ontologies Group) is seen as a promising approach to cope with self-manageability problem in its versatility. As systems (inter alia networking) become increasingly complex, traditional solutions to manage and control them reach their limits and pose a need for bringing self-configuration and self-management aboard. Also, heterogeneity of the ubiquitous components, communication standards, data formats, networking protocols, etc., creates significant hassles for interoperability in such complex systems. The promising technologies to tackle these problems are the Semantic Web for interoperability, and Software Agents for management of complex systems.

The major PROFI objective is to provide the basis for such future Internet overlay architecture that will integrate autonomous (self-managed) proactive programmable Internet components. To achieve that, a specialized agent-driven middleware platform [6] is to be designed. It is envisioned that each future Internet programmable component, e.g., host, router, edge cluster, edge node, etc. (terms are taken from the GENI vision [4]) will be assigned a representative agent within PROFI. The resulting multi-agent system will be the core of the targeted future Internet overlay architecture for enabling flexibility, adaptability, self-
configurability and self-management of the future Internet infrastructure. Utilization of semantic technologies in PROFI will ensure efficient and autonomous coordination among PROFI agents and will thus bring another dimension to interoperability of future Internet components and entities.

Also, Future Internet Upper Ontology will be designed as an important asset contributing to interoperability realization within Future Internet platform. FI Upper Ontology will be used not only for the benefit of PROFI middleware architecture, but also and importantly for facilitation of interoperability and integration of existing and new future components and solutions. This implies that FI Ontology will also be used to cope with problems other than specific PROFI issues, such as naming and addressing, interoperability and integration, security, privacy and trust on the scale of the entire future Internet architecture. The PROFI will enable various information and networking components to automatically discover each other and to configure a complex system functionally composed of the individual components’ functionalities.

PROFI can be considered as an engine for declarative networking. PROFI will enhance available declarative networking languages (e.g., Snlog [8, 1]) by adding to them explicit semantics (according to the W3C standards) specified in the ontological format. Our Semantic Agent Programming Language (S-APL) [7], which is an RDF-based language for declarative programming of proactive components, can be utilized within the PROFI platform. S-APL is suitable for semantic description/annotation of various physical (e.g., network components, devices, etc.) and virtual (e.g., informational facts, rules, policies, commitments, individual and collaborative behaviors, etc.) resources [9]. In S-APL, there is no strict separation between the data (descriptive knowledge) and program code (behavioral knowledge). S-APL is assumed to be used both as the programming language (for specification of network components behavior) and a communication content language (among architectural components). The syntax for RDF used in S-APL is one of Notation3 (N3), which is more compact than RDF/XML. S-APL is a hybrid of semantic rule-based reasoning engines such as CWM (http://www.w3.org/2000/10/swap/doc/cwm) and agent programming languages (APLs). From the semantic reasoning point of view, S-APL is CWM extended with common APL features such as the Beliefs-Desires-Intentions architecture, which implies an ability to describe goals and commitments among the overlay architectural components – data items presence of which leads to some executable behavior, and an ability to link to sensors and actuators implemented in a procedural language. From the APL point of view, S-APL is a language that has all the features (and more) of a common APL, while being RDF-based and thus providing advantages of semantic data model and reasoning. S-APL introduces the semantic cognitive agent architecture, which has three layers: the top-level Behavior Engine, the middle-level S-APL storage, and the bottom-level Reusable Atomic Behaviors (RABs) and the blackboard (for non-semantic data). The architecture also enables agents to access both S-APL programs/data and RABs from remote repositories.

The principal outcomes, the PROFI approach focuses on, include the following:

Resource-oriented networking: PROFI builds upon the information networking paradigm of the Future Internet and extends it via unifying the treatment of all types of communication actors (devices, network nodes, information objects, applications and services, etc.). In addition to changing from physical to logical binding of communication actors, this paradigm unifies principles (logical naming and addressing, metadata-based search and discovery) of communication among groups of various resources, should they be hardware components or high-level service artifacts. This type of communication framework will in consequence allow easy establishment of cross-layer communication links (e.g., between a network node and an informational object).

Interoperability: as technical interoperability will be laid as fundamental principle of the Future Internet design, this type of interoperability must be largely provided by the future Internet itself. PROFI’s major concern is semantic interoperability amongst future Internet resources. Semantic interoperability is a prerequisite for seamless information inter-networking and integration, and for smooth autonomous communication between various FI resources. What is more, semantic interoperability framework is an absolute must for successful mediation between FI and Web/SA resources. Semantic interoperability can be achieved by exploitation of rich metadata describing informational objects and semantic resource descriptions written in compliance with well-established semantic standards and on the base of predefined domain ontologies and FI upper ontology.

Self-manageability: self-manageability is another important dimension of the future Internet, where the PROFI approach can bring significant value. PROFI brings self-management aboard via presenting totally distributed agent-driven proactive management system. PROFI agents monitor various components, resources and properties within the system architecture and react to changes occurred by reconfiguring the architecture in certain way with respect to the predefined configuration plan. Configuration plans basically represent enhanced business models which are adhered to during accomplished communication procedures between different parties. Due to purely distributed layout of the agent system and outstanding agents’ programmabil-
ity, merely all existing and new business models can be formalized and enacted by the PROFI management platform. In addition to this, PROFI agents are capable of learning via utilizing available data mining algorithms and further dynamically reconfiguring the managed architecture on the basis of acquired knowledge. PROFI can be deployed on top of any architectural model due to benefits of agent technologies and open resource interfaces. Also, PROFI platform can make use of contextual information derived from the managed networking environment.

**Trust and reputation:** Trust is identified as one of the major and most crucial challenges of the future Internet. We envisage a semantic ontology-based approach to building a universal trust management system. To make trust descriptions interpretable and processable by autonomous trust management procedures and modules, trust data should be given explicit meaning via semantic annotation. Semantic trust concepts and properties will be utilized and interpreted using common trust ontologies. This approach to trust modeling is especially flexible because it allows for various trust models to be utilized throughout the system seamlessly at the same time. Trust information can be incorporated as part of semantic resource descriptions and stored in dedicated places within the PROFI platform. Communication and retrieval of trust information will be accomplished through corresponding agent-to-agent communication. Agents representing communicating resources must be configured appropriately to handle all necessary trust management activities between the corresponding communication parties. Trust management procedures can be realized as a set of specific business scenarios in the form of agent configuration plans.

### 4 Related Work

GENI (Global Environment for Network Innovations) [4], is a continental-scale, programmable, heterogeneous, networked system driving "clean-slate" FI research. It will consist of a collection of physical networking components, including links, forwarders, storage and processor clusters, and wireless subnets. These resources are collectively called the GENI substrate. The substrate components will be programmable. This will make it possible to embed any network experiment in GENI, including clean-slate designs that are radically different from today’s Internet architectures and protocols. GENI will not be a static artifact, but rather a dynamic infrastructure that is continually renewed. GENI is equally likely to result in alternative protocols and architectures running inside the network.

According to Larry Peterson (one of GENI architects, Princeton University, USA), Future Internet should and will support programmability, virtualization, federation support and instrumentation deep in the network. GENI management framework will overlay network experiments on the substrate, where each experiment is said to run in a slice of the substrate. Overlay networks will also improve Internet routing and enable routing messages to destinations not specified by an IP address. An important attribute of the management framework is its support for decentralized control. Individual building blocks will be largely autonomous and self-managing, but can be included in a slice by invoking a well-defined interface on each. Collections of building blocks (e.g., complete or regional subsets of edge sites, composition of backbone components) can be considered as aggregates and managed independently of each other. The management infrastructure will include a set of services that will be used to embed a slice in a particular set of resources; monitor the behavior of slices and components; collect, aggregate, and archive measurement data; and so on.

Much progress has been achieved to introduce programmability on the network level according to Active Networks [2] concept introduced by DARPA. Active networks allow embedding programs into the network nodes, which increases the complexity and customization of the computation within the network and between the communicating endpoints. This technology not only simplify designing of new flexible services but also to deploy them rapidly, making active networks much more self-configurable than legacy ones.

According to Intel research challenges [5], any widely-distributed system needs to track its participating nodes, and be able to exchange messages among them. Such facility is called an overlay network, since it provides an application with customized networking functionality (naming, topology, routing) that runs as a layer over traditional IP networking. Overlays are in wide use, including in commercial mail/calendar servers, application-level multicast systems, and distributed hash tables. It is tricky to design, build, and deploy an overlay suited to a particular application and environment. To ease the process of management of overlay architectures, it is reasonable to use a high-level declarative language to describe overlay networks in a compact and reusable form. EECS UC Berkeley uses so called P2 system [3] to specify and execute working, detailed overlays in over 100x less code than is used in traditional implementations. It automatically compiles high-level specifications to a dataflow-oriented runtime system, which can itself be used by expert programmers to specify efficient overlays. P2 is part of a more general effort to consider the networking technology in the context of database query processing. P2 approach provides not only simpler, safer specifications for network protocols, but also - within the same framework – the ability to query, monitor and control all aspects of the network’s distributed state. Declarative languages are known to encourage programmers to focus on program outcomes (what a program should achieve)
rather than implementation (how the program works). Of particular interest is recent work on declarative networking, which presents declarative approaches for protocol specification and overlay network implementation (e.g., activities by Intel Research lab and EECS UC Berkeley). Declarative logic languages (e.g., Snlog) have been promoted for their clean and compact specifications, which can lead to code that is significantly easier to specify, adapt, debug, and analyze than traditional procedural code, see e.g. [8, 1]. Expectations from Declarative Networking include: topology by specification, routing by constraints, addressing by content, rapid prototyping, customizability, synthesis of multiple layers, and distributed machine learning.

![Figure 2. PROFI overlay architecture](image)

Figure 2. PROFI overlay architecture

Figure 2 shows one possible interpretation of PROFI concept in the context of overlay networks and declarative networking. The configuration of the network can be controlled by a multi-agent system in which each of the agents is taking care of a particular programmable component of the network. Agents are able to run declaratively described behavior, they can communicate, negotiate and collaborate among each other when appropriate; they are aware of broader context, able to share it with each other and are able to utilize the functionality of the components in a more flexible way making individual or even collaborative decisions about needed reconfiguration depending on the situation.

5 Conclusions

As demonstrated above, the PROFI concept entails a vision of a multifaceted, multi-purpose and multipronged middleware platform applying multidisciplinary approach to extension and enhancement of the Future Internet vision. Further, the PROFI platform should be also seen as intelligent stratum between the FI (networking) architecture and the future Web and other service oriented environments. Realization of the PROFI platform is expected to make a significant contribution to major features of the future Internet and other ICT ecosystems including future networked ICT service architectures and smart ubiquitous environments. The principles laid in the PROFI foundation follow the recent trends of programmability and declarative networking in modern FI research and are based on the major achievements in the field.

The primary elements of innovation within the PROFI approach are declarative networking overlay architecture comprising programmable network components and associated agent-based semantic management system. This particular middleware solution adds to overall network system flexibility, openness, and manageability.

The principal outcomes the PROFI approach focuses on include: resource-oriented networking, interoperability, trust and reputation, and self-manageability. Finally, PROFI contributes to realization of a larger and more comprehensive vision of the future information society and outlines the principles of its re-organization and consolidation at a variety of scopes and scales.

References