FIA Session “Linked Data in the Future Internet” - Position Paper
FIA Assembly, Ghent, 16 December 2010

Enabling Information Interoperability in the Future Internet

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Abstract. The Future Internet is currently seen as an opportunity to improve the network infrastructure addressing service-oriented, social trends and economic commitments. Future Internet and next generation communications systems challenges mainly demand end user requirements, personalized provisioning, service-oriented performance, service-awareness networking, information interoperability and data models integration. This paper focuses on information interoperability and cross domain information managing Internet systems. Research activity and results about semantic enrichment tasks for management information contained in both enterprise and networking information and data models respectively is described. Ontologies are used to support reusable, common and manageable service and network information for service composition and management operations in the inference plane in Future internet systems. An introductory application scenario on current service agnostic Internet is depicted.

Keywords. Interoperability, Cross-domain, Future Internet, Knowledge Engineering, Semantics, Ontologies, Networks and Services, Management.

1. Introduction

Convergence towards Internet technologies for communications networks and services has been a clear trend in the Information and Communications Technology (ICT) domain in the past few years. Although widely discussed, this trend has not fully run its course in terms of implementation, due to many complex issues involving deployment as result of non-interoperable aspects where social, economic and political dimensions take place, all these issues a matter of end-user demands and requirements.

The Future Internet (FI) is currently seen as an opportunity to improve the network infrastructure addressing service-oriented, social trends and economic commitments. So challenges in the future communications systems mainly Internet-based systems demand, in terms of end user requirements, personalized provisioning, service-oriented performance, and service-awareness networking. To support these demands information interoperability and data model integration are crucial.

A visionary perspective for what the Future Internet looks like has been described in previous works [1][2][3]. The intention in this paper is not to define what the Future Internet is, but rather to view the Future Internet in a service-oriented manner, coming through a revision about the role knowledge engineering can play to satisfy part of the mentioned challenges. In Future Internet, services and networks follow a common guideline; provide solutions in form of implemented interoperable mechanisms.

Communications networks have undergone a radical shift from a traditional circuit-switched environment with heavy/complex signalling focused on applications-oriented perspective, towards a converged service-oriented architecture space (SOA), mostly Internet interaction by customer as end-user and network operators as service providers. The business benefits of this shift significantly reflects cost reduction and increase systems flexibility to react to user demands more efficiently and by replacing, in a best practice case, a plethora of proprietary hardware and software platforms with generic solutions supporting standardised development and deployment stacks. As an example of this shift, the emergence and wide-scale deployment of wireless access network technologies calls into question about the viability of basing the future Internet on IP and TCP – protocols that were never intended for use across highly unreliable and volatile wireless interfaces (information and data exchange).

Research initiatives addressing this SOA requirement argue that the future lies in layers of overlay networks that can meet various requirements whilst keeping a very simplistic, almost unmanaged, IP for the underlying Internet, GENI NSF-funded initiative to rebuild the Internet [4]. Others argue that the importance of wireless access networks requires a more fundamental redesign of the core Internet Protocols themselves [5][6]. Whilst this debate races nothing is a clear outcome in terms of information interoperability or data models sharing.

We follow the idea that service agnostic design are not anymore a way to achieve interactive solutions in terms of service composition and information sharing capabilities for heterogeneous infrastructure support. A narrow focus on designing optimal networking protocols in isolation is too limited. Instead, a more holistic and long-term view is required, in which networking issues are addressed in a manner various protocols delivering communications services can be supported, meeting rapidly changing communities of users needs. This new holistic view increasingly stops to become a matter of critical infrastructure. Network operators are today coming to realise lack in the promise of simpler all-IP networks, where new integrated Internet services are easier and quicker to design, develop, deploy and manage.

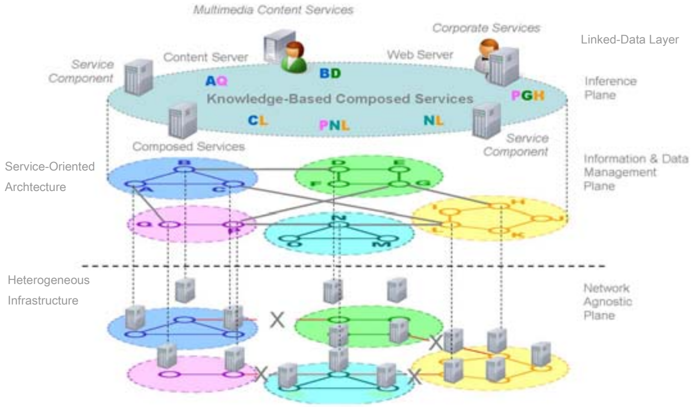

Figure 1. Knowledge-Based Service Composition View – Information Interoperability.

The figure 1 depicts the mentioned service-aware Future Internet holistic view and its implementation relies on the inference plane [7], a plane where the exchange of information facilitates knowledge-driven support and generation of composed services with operations by enabling interoperable management information. So the move towards converged IP-based communications networks increases providing solutions to a number of significant technical issues by using more standard information exchange promoting information interoperability and allowing the networks can be managed effectively and most important offering open opportunities for a user knowledge-based service-oriented support can have a fundamental impact on future communications networks and services.

This paper focuses on information interoperability and cross domain information sharing controlling communication systems for Future Internet network and services approach. The extensible, reusable, common and manageable information inference plane is critical for this deployment [7].

The novelty aspect of this approach relies on the fact that high level infrastructure representations do not use resources when they are not being required to support or deploy services. We optimize resources using this approach by classifying and identifying, by semantic descriptions in a knowledge-based fashion way what resources need to be used. Thus dynamically the service composition is executed and service deployed by result of knowledge–based analysis.

Organization of this paper is as follows: Section II presents challenges for a knowledge–based future Internet where information exchange occurs to support composed service creation and delivery. Section III introduces our knowledge engineering approach in a form of meta-ontologies facilitating information interoperability and a demonstrator supporting the inference approach. Section IV presents the summary and outlook and finally some relevant references used in this paper are listed.

2. Challenges in a Knowledge-Based Future Internet

Taking a broad view of state of the art and current development of data link interactions and converging communications networks as reference studied in this paper, many of the problems present in current Internet interoperability are generated by interoperability problems, we identify three persistent problems:

1. Users are offered relatively small numbers of Internet services, which they can not *personalise* to meet their *evolving needs*; communities of users can not tailor *services* to help *create, improve and sustain* their *social interactions*;
2. The Internet *services* that are offered are typically *technology-driven* and static, designed to maximise usage of capabilities of underlying network technologies and not to satisfy user requirements *per se*, and thus cannot be *readily adapted* to their changing *operational context;*
3. Network operators cannot *configure* their networks to *operate effectively* in the face of changing *service usage patterns* and rapid networking technology deployment; networks can only be *optimised*, on an *individual basis*, to meet

specific low-level objectives, often resulting in sub-optimal operation in comparison to the more important *business and service user objectives*.

As the move towards convergence of communications networks and a more extended service-oriented architecture design gains momentum worldwide facilitated mainly by pervasive deployment of Internet protocol suites, VoIP is a clear example of this, the academic research community is increasingly focussing on how to evolve networking technologies to enable the “Future Internet”. In this sense we believe that addressing evolution of networking technologies in isolation is not enough; instead, it is necessary to take a holistic view of the evolution of communications services, their societal drivers and the requirements they will place on the heterogeneous communications infrastructure over which they are delivered [8][9].

By addressing information interoperability challenge issues, Internet systems must be able to exchange information and customize their services. So Future Internet can reflect changing individual and societal preferences in network and services and can be effectively managed to ensure delivery of critical services in a services-aware design view with general infrastructure challenges.

3. Knowledge Engineering Approach – Semantic Annotation

An activity running currently is the composition of data models for enabling information management control. It focuses in the semantic enrichment task of the management information described in both enterprise and networking data models with ontological data to provide an extensible, reusable, common and manageable inference plane in the Future Internet systems.

The proposed knowledge-based approach provides tools to integrate user data with the management service operations, and offers a more complete understanding of user’s contents based on their social relationships and hence, a more inclusive governance of the management of resources, devices, networks, systems and services for promoting the integrated management with formal information models including social aspects. This approach is to use ontologies as the mechanism to generate a formal description, which represents the collection and formal representation for network management data models and endow such models with the necessary semantic richness and formalisms to represent different types of information needed to be integrated in network management operations. Using a formal methodology the user’s contents represent values used in various service management operations, thus the knowledge-based approach over the inference plane [7] aims to be a solution that uses ontologies to support interoperability and extensibility required in the systems handling end-user contents for pervasive applications [10].

3.1 Service and Network Management meta-Ontology Modelling

The meta-ontology approach introduced in this section integrates concepts from the IETF policy standards [11][12] as well as the TM Forum SID model [13][14]. In this paper important classes that were originally defined in the IETF, SIM and DEN-ng models will be cited and implemented as such, some other extended or adapted for communication services adaptability, for more details see [15]. The meta-model defines a set of interactions between the Context Data, Pervasive Management, and Communications Systems Domains in order to define relationships and interactions between the classes from the information models on these three different domains. The meta-Ontology construction process, which is a four-phase methodology is result of formal study to build up ontologies contained and studied from [16][17].

The formal language used to build the set of ontologies is the web ontology language (OWL) [18][19], which has been extended in order to apply to pervasive computing environments; these additional formal definitions act as complementary parts of the lexicon. The formal descriptions about the terminology related with management domain are included to build and enrich the proposal for integrating network and other management data with context information to more completely define the appropriate management operations using formal descriptions. The proposed meta-Ontology model integrates concepts from policy-based management systems [20][21] to define a context-aware system that is managed by policies, which is an innovative aspect of our research work. Figure 2 shows the Ontology high level representation. The image represents the integration of the entity information classes related to the management operation class through the event class. The Event class interacts with other classes from different domains in order to represent context information. Note that only the InfoEntity class from the context information model domain and the Event class from the service management domain are shown.

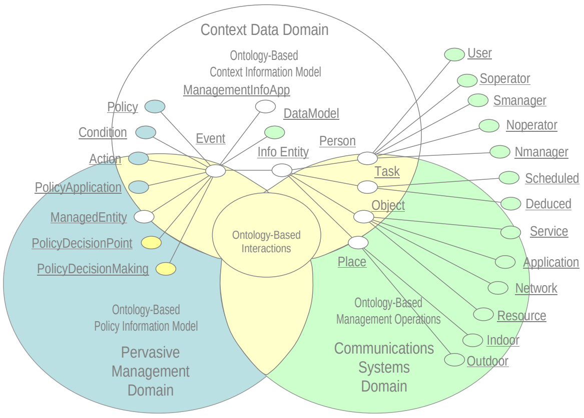

Figure 2. View of InfoEntity Integration in Service-Oriented Management Systems - by Domains.

This representation simplifies the identification of interactions between the information models. These entity concepts, and their mutual relationships, are represented as lines in the figure. The InfoEntity class forms part of an Event class, and then the Event govern the policy functionality of a Managed Entity by taking into account context information contained in Events. This functionality to enables context to change the operation requested from a pervasive service or application, and is represented as interaction between Event and InfoEntity.

The meta-Ontology model is driven by a set of pervasive service management use cases that each requires service lifecycle policy-based management architecture as represented in figure 3. The service composition and its model representation contains the service lifecycle operations, as depicted in figure 3. In this figure, service management operations, as well as the relationships involved in the management service lifecycle process, are represented as classes. These classes will then be used, in conjunction with ontologies, to build a language that allows a *restricted* form of English to be used to describe its policies. To do so context information is underlayed in such relationships, which a correspondence with activities called “*events*” could be so related to context information.

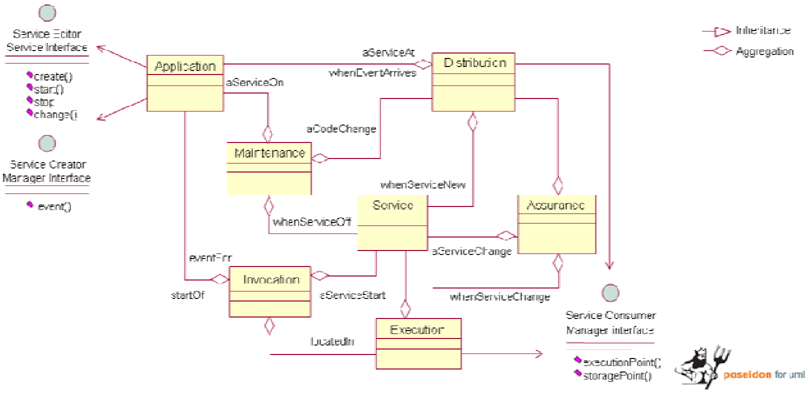

Figure 3. Control and Representation of Service Lifecycle Interactions - UML model.

The meta-model is founded on information models principles for context information and policy management promoting an integrated management, which is required by both pervasive as well as autonomic management applications. The combination of context-awareness, ontologies and policy-driven services motivates the definition of a new, extensible, and scalable semantic framework for the integration of these three diverse sources of knowledge to realize a scalable management platform.

From the Figure 3, the Service Editor Service Interface acts as the application that creates the new service. Assume that the service for deploying and updating the service code in certain network nodes has been created. This result in the creation of an event named “*aServiceOn*”, which instantiates a relationship between the Application and Maintenance classes. This in turn causes the appropriate policies and service code to be distributed via the Distribution class as defined by the “*aServiceAt*” aggregation. The service distribution phase finds the nearest and/or most appropriate servers or nodes to store the service code and policies, and then deploys them when the task associated with the “*eventFor*” aggregation is instantiated. When a service invocation arrives, as signalled in the form of one or more application events, the invocation phase detects these events as indication of a context variation, and then instantiates the service by instantiating the association “*aServiceStart*”. The next phase to be performed is the execution of the service. Any location-specific parameters are defined by the *“locatedIn”* aggregation. The execution phase implies the deployment of service code, as well as the possible evaluation of new policies to monitor and manage the newly instantiated service.

Monitoring is done using the service consumer manager interface, as it is the result of associations with execution. If maintenance operations are required, then these operations are performed using the appropriate applications, as defined by the*“aServiceOn”* aggregation, and completed when the set of events corresponding to the association “whenServiceOff” is received. Any changes required to the service code and/or polices for controlling the service lifecycle are defined by the events that are associated with the*“whenServiceNew”* and *“aServiceChange”* associations.

The service management operations are related to each other, and provide the necessary infrastructure to guarantee the monitoring and management of the services over time. The UML design shown in figure 3 captures these relationships, thus the pervasive service provisioning and deployment is on certain manner assured to provide service code and policies supporting such services to the service consumers. The coding process for formalizing the ontology follows the definitions and specifically the description contained in the filed “relation” from the definitions provided in this chapter. It is very important to understand the real sense of the “relation” field, as this represents how the descriptions and concepts are used to build and enhance the proposed ontology.

The base or this ontology code is included in [10]. However this section contains partial description about some of the concepts more relevant when ontology is created, descriptions, definitions and integration of concepts are also included and described.

Figure 4 shows the OWL grammar section of the ontology that describes the InfoEntity and its corresponding domain elements. It is a description of an object class for representing an InfoEntity, and represents the simplest definition and relationships in sense of disjointness to the Application, Place, Person, DataBaseIM and Task classes. The disjoints represent a semantic tool for filtering the seek of information, thus the objects classes including disjoints can be easily identified to be considered or not as part of the knowledge that is being seek.

```
<owl:Class rdf:ID="Event">
    <rdfs:subClassOf rdf:resource="#Policy"/>
        <owl:Restriction>
            <owl:onProperty rdf:resource="#isPartOf"/>
            <owl:someValuesFrom rdf:resource="#DomainConceptPolicy"/>
        </owl:Restriction>
</owl:Class>
    <owl:Class rdf:ID="Condition">
        <rdfs:subClassOf rdf:resource="#DomainConceptPolicy"/>
        <rdfs:label rdf:datatype="&xsd;string">Condition Class</rdfs:label>
        <rdfs:subClassOf rdf:resource="#PolicyModel"/>
        <owl:disjointWith rdf:resource="#PolicySet"/>
        <owl:disjointWith rdf:resource="#PolicyRule"/>
        <owl:disjointWith rdf:resource="#PolicyGroup"/>
        <owl:disjointWith rdf:resource="#Event"/>
        <owl:disjointWith rdf:resource="#Action"/>
        <owl:disjointWith rdf:resource="#PolicyModel"/>
    </owl:Class>
<owl:Class rdf:ID="Action">
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty rdf:resource="#isPartOf"/>
                <owl:someValuesFrom rdf:resource="#DomainConceptPolicy"/>
            </owl:Restriction>
        </rdfs:subClassOf>
        <rdfs:subClassOf rdf:resource="#PolicyModel"/>
        <owl:disjointWith rdf:resource="#PolicySet"/>
        <owl:disjointWith rdf:resource="#PolicyRule"/>
        <owl:disjointWith rdf:resource="#PolicyGroup"/>
        <owl:disjointWith rdf:resource="#Event"/>
        <owl:disjointWith rdf:resource="#Condition"/>
        <owl:disjointWith rdf:resource="#PolicyModel"/>
    </owl:Class>
<owl:Class rdf:ID="ManagedEntity">
     <rdfs:subClassOf rdf:resource="#Policy"/>
</owl:Class>
<owl:Class rdf:ID="Obligation">
     <rdfs:subClassOf rdf:resource="#Policy"/>
</owl:Class>
<owl:Class rdf:ID="Authorization">
     <rdfs:subClassOf rdf:resource="#Policy"/>
</owl:Class>
```

Figure 4. Event InfoEntity Description using OWL Grammar Representation.

The use of XML, and the resulting use of RDF extensions, aimed to improve the expressiveness of ontology languages. The RDF-Schema (RDFS) [22] language emerged as a set of extensions to provide increased semantics of RDF by providing basic ontological modelling primitives, like classes, properties, ranges and domains.

One of the advantages of using OWL to express the ontology is to provide a number of tools for parser and text editors. This enables new adopters to use a tool or set of tools that is best suited to their needs. OWL is used to define the set of concepts and constraints imposed by the information model over which it defines instances.

3.2 Functional Architecture Approach

A functional diagram for functional architecture supporting the meta-Ontology with its functional components as initial approach is depicted in Figure 5. This diagram shows the interactions between the main components. The architecture controls with a certain high level domain-based view, how service composition is performed, thus the control of the behavior is considering like added value functionalities using high level and formal representations expanding operations in other service application domains.

The architecture presented is using information to manage service operation and instructions with ontology-based information models using semantic mechanism. Based on previous implementation experience [23][24] this architecture allows adaptability and dynamism to current and future Internet services with the advantages of incorporating context from users and applications in form of events.

This functional approach offer more functionality than standard service-aware management approaches, as they cannot orchestrate system behaviour using knowledge from business, network, and other constituencies. By representing these data in a formal manner, data can be integrated, and the power of machine-based learning and reasoning can be more fully exploited. In this approach we translate data from a device-specific form to a device- and technology-neutral form to facilitate its integration with other types of information. The key difference in this architecture, compared with a non ontology-based enabled, is the use of *semantic* information to guide the decision-making process.

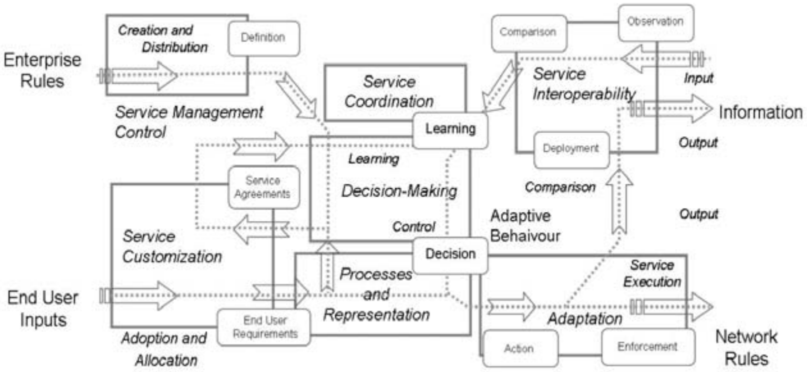

Figure 5. Semantic-Based Service Control Engine - Functional Architecture.

Observation is translated to events to be co-related with the system’s behaviour and its activity and then learned to make the system react when the same event occurs in the future. Co-related events trigger and control each set of independent related events thus certain level of autonomy is achieved. The service composition process involves analyzing the triggering events expressed in an appropriate interoperable language via service coordination and decision-making integration, and matches them to service management and control level available [25] with the difference of this component using semantic descriptions to co-relate events with particular kind of conflicts that must be identified and evaluated. A detailed Semantic-Based Service Control Engine (2SCE) and its components as part of Functional Architecture is out of the scope of this paper, however implementation results are being analyzed and interaction between different domain events tested successfully.

4. Conclusions

In the future Internet high demands of information interoperability to satisfy service composition requirements being controlled by diverse, heterogeneous systems make more complex perform system management operations. Thus the approach introduced in this paper emerges as an alternative to solve part of those information interoperability complex requirements in the Future Internet of networks and services.

We have studied and demonstrated how formal representation of service and networks information facilitates information interoperability in service composition and management processes. Remaining research challenges regarding information model extensibility and information dissemination exist and would be conducted to conclude implementations, experiments composing services.

This paper makes references to formal and theoretical foundations for the development of interoperability of information by using knowledge engineering techniques, semantic aggregation. Information interoperability is a crucial requirement in Future Internet. Their implications for networks and services is still and open issue for research and interoperability and information exchange must be validated via direct industrial investment, and roll out real integrated test beds to trial new network infrastructures (potentially overlay networks or new inference plane infrastructures) for services.

Acknowledgements

This research activity is partially funded by Science Foundation Ireland (SFI), grant 08/SRC/I1403 FAME-SRC (Federated, Autonomic Management of End-to-End Communications Services - Scientific Research Cluster). Project partners participate actively in EU Projects and FIA Initiative.

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