Final Future Internet Market Assessment and Exploitation Plans
Deliverable D7.4

Autonomic Internet (AutoI) Project
FP7-ICT-2007-Call 1 - 216404

Abstract: The AutoI project envisages a Future Internet of Networks and Service as an optimised network and service solution, which guarantees built-in orchestrated security, reliability, robustness, mobility, context, access, service support and self-management of the communication resources and services. This report outlines Future Internet definitions, challenges, assessment and trends. It describes approaches and technologies in Europe, US, and Japan similar to AutoI. It is also includes the dissemination and exploitation plans of the first year of the AutoI project.

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V2.0	22.10.2010	Alex Galis	Final Edit

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1 Executive Summary

The current Internet has been founded on basic architectural premises and is centred on the network layer being capable of selecting a path from the originating source of a packet to its ultimate destination, with no guarantees of packet delivery or traffic characteristics. The desire for simplicity in the network has pushed complexity into the endpoints, thus allowing the Internet to reach an impressive scale in terms of inter-connected devices. Although the current Internet has been extraordinarily successful, there are many challenges some with fundamental aspects. The very success of the Internet is now creating obstacles to future innovation. In addition, the ossification of the Internet makes the introduction and deployment of new network technologies and services very difficult and very costly. The "Future Internet" research and development threads that seek to solve these issues have recently been gaining momentum.

Next generation network and services require the optimization of multiple types of orchestration mechanisms, enabling network operations (i.e. initialization, dynamic reconfiguration, adaptation, dynamic service deployment support and other tasks) and service tasks to be optimized. In the AutoI project, orchestration refers to the mediation of several Autonomic Management Systems with each other in an attempt to deal with the problem of management domain heterogeneity and integration. The later is a relevant innovation of the Autonomic Internet (AutoI) architecture as it provides the autonomic integration and federation of several autonomic management systems.

Orchestration is seen as the vehicle that will take us from Automated to Autonomic systems in the Management of Future Networks. The ability to tie together a set of automated tasks into a single process that will be executed by machines with minimum human intervention is what orchestration promises. It is not just the final script waiting to be "played" in the sense of BPEL scripts where the concept was introduced. Orchestration of networks, services and resources includes the extended decision making process that will exploit a well-formed knowledge infrastructure in order to compose the orchestration script. Cognitive Control mechanisms that will be fully context-aware with the ability to understand, analyze and extend the existing knowledge are of crucial importance. Technologies to accurately represent specifications and functionality of involved systems are necessary towards dynamic discovery, understanding and interaction. Workflow management techniques are important in the direction of machine interoperability and simplified human intervention. The role of more intelligent negotiations that will be more than an interaction protocol including extended decision making is also stressed in order to solve conflicts among involved systems. Federation as a mechanism to control the union/separation of networks, services and resources in different autonomic management domains is another concept that orchestration has to enable.

Dissemination can be seen in two ways: As an activity external to the AutoI Consortium, addressing other organisations and as an internal process of gaining and knowledge within the AutoI Consortium and within each partner's organisation. External dissemination is focused on target groups, which are companies, organizations or service providers in the mobile networks and telecommunications market. The targeted dissemination was achieved through participation in exhibitions and workshops and through the use of promotional material.

2 Introduction

This deliverable provides an introduction to Future Internet definitions, challenges, assessment and State of the Arch trends along with the exploitation plan of the AutoI project. Approaches and technologies similar to AutoI are also described. The dissemination and exploitation plans of all partners are presented with details including publications in journals and conferences, presentations, standardization activities and future plans for exploiting the knowledge gained.

2.1 Motivation and Objectives of the Document

This report embodies the results of the work performed under Task 7.4 "final market assessment and exploitation". An extended analysis is presented for the Future Internet along with the dissemination and exploitation plans of the consortium and the individual partners are presented.

2.2 Structure of the Document

This deliverable is structured as follows: Chapter 3 deals with the future internet definitions, challenges, assessment and State of the Arch trends. Chapter 4 refers to the dissemination activities for the whole project. Chapter 5 refers to the standardization activities. Chapter 6 concludes this report.

3 Future Internet Definitions, Challenges, Assessment and Trends

3.1 Future Internet Definitions and Challenges

A position statement on the definition of the Future Internet challenges was presented as invited paper at IEEE 2009 Fourth International Conference on Communications and Networking in China (ChinaCom09) 26-28 August 2009, Xi'an, China; http://www.chinacom.org/2009/index.html

This position paper identifies a definition of Future Internet together with the research orientation and the key challenges for the capabilities and the systems in the Management and Service-aware Networking Architectures (MANA) part of the Future Internet. This work was performed as part of the Future Internet Assembly (FIA) activities, with substantial contributions based on the AutoI project work progress. Participants from peer projects (e.g. 4Word, Efipsans, Socrates, SelfNet, Trilogy, Psirf, Reservoir, SLA@SOI, E3) have also contributed.

It was presented and published as part of the following FIA Conferences:

- 12-13 May 2009 FIA Prague - http://www.future-internet.eu/home/future-internet-assembly/prague-may-2009/fia-plenary.html
- 23-24 November 2009 FIA Stockholm - http://www.future-internet.eu/home/future-internet-assembly/prague-may-2009/fia-plenary.html
- 15-16 April 2010 FIA Valencia - http://www.future-internet.eu/home/future-internet-assembly/valencia-april-2010.html

It is also a component of the report on FI Architecture at FIA Valencia - http://www.future-internet.eu/fileadmin/documents/valencia_documents/sessions/Architecture_session_report_v3.1.pdf

3.2 AutoI Architectural Model

3.2.1 AutoI Model Overview

Future Networks are and will be made of interconnections of several heterogeneous and dynamic networks. Networking resources (e.g. separate resources for processing, storage and communication and unified resources) of such new networking infrastructure will have to be combined, across multiple domains, to satisfy on demand applications/services and Consumers' & Users' requests. As such Future Networks are represented by a set of new and self-managed network enabled resource-facing services, providing scalable, QoS guaranteed, normally contextualised, inexpensive connectivity infrastructures on demand. Such unified resource infrastructure can be accessed and used in a simple and pervasive way by consumers/users and by end-users facing services of any complexity.

This chapter presents a new autonomic management architectural model developed in the AutoI (http://ist-autoi.eu/autoi/index.php) project.

The AutoI architectural model consists of a number of distributed management systems described with the help of five abstractions - the OSKMV planes: Orchestration Plane (OP), Service Enablers Plane (SP), Knowledge Plane (KP), Management Plane (MP) and Virtualisation Plane (VP). Together these distributed systems form a software-driven network control infrastructure that will run on top of all current networks (i.e. fixed, wireless and mobile networks), servicing physical infrastructures. This provides a means for networked devices or attachments to connect to each other, and through each other to the outside world, providing seamless service provisioning.

The OSKMV planes are new higher-level artefacts to make the Future Internet of Services more intelligent with embedded management functionality. At an abstract level, the OSKMV planes gather observations, constraints and assertions, and may apply rules to these to generate service-aware observations and responses. They are embedded on network hosts, devices, attachments and servers within the network. The main purpose of the OSKMV planes is to make the Future Internet of Services self-knowledgeable, self-diagnosing and ultimately fully self-managing.

The overall AutoI management functionality is designed to meet the following design objectives:

- Embedded (Inside) Network functions: The majority of management functionality should be embedded in the network. As such the Autonomic Management Systems components will run on execution environments on top of virtual networks and systems, which run on top of all current network (i.e. for fixed, wireless and mobile networks) and physical infrastructures.
- Aware and Self-aware functions: They monitor the network and operational context as well as internal operational network state in order to determine whether the network current behaviour serves its service purposes.
- Adaptive and Self-adaptive functions: They trigger changes in network operations (state, configurations, functions) as a result of the changes in network, service or user context.
- Automatic self-functions: They enable self-control such as self- Fault, Configuration, Accounting, Performance, Security (FCAPS) or self-*, of the internal network operations, functions and state. They also bootstrap themselves and operate without manual external intervention except the setting-up of the business goals.
- Extensibility functions: new functions could be added without disturbing the rest of the system (Plug and Play / Unplug and Play / Dynamic programmability of management functions & services)
- Simple functions for minimising life-cycle network operations' costs and energy footprint.

3.2.2 AutoI Architectural Model

The AutoI framework consists of a number of distributed management systems described with the help of five abstractions - the *OSKMV* planes: Virtualisation Plane (VP), Management Plane (MP), Knowledge Plane (KP), Service Enablers Plane (SEP) and Orchestration Plane (OP). Together these distributed systems form a software-driven network control infrastructure that will run on top of all current network (i.e. fixed, wireless and mobile networks) and service physical infrastructures to provide an autonomic virtual resource overlay. Figure 3:1 depicts the network and management resources as distributed in the Virtualisation, Knowledge, Management, Orchestration and Service Enablers planes.

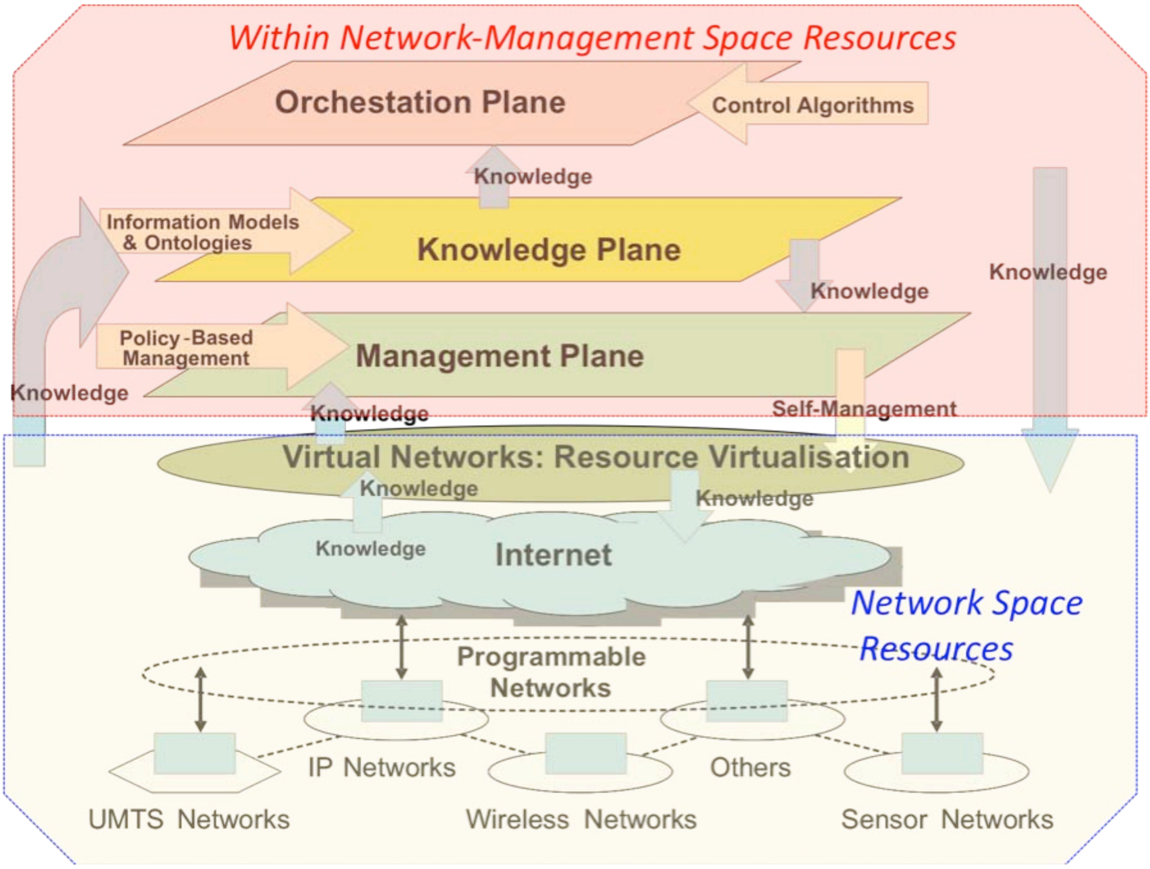

Figure 3:1 - Network and Network Management Resources

The OSKMV planes are new higher-level artefacts to make the Future Internet of Service more intelligent with embedded management functionality. At an abstract level, the OSKMV planes gather observations, constraints and assertions, and apply rules to these to generate observations and responses. At the physical level, they run and as such are embedded on network hosts, devices, attachments and servers within the network. The main purpose of the OSKMV planes is to make the Future Internet of Service self-knowledgeable, self-diagnosing and ultimately fully self-managing.
An overall AutoI autonomic management architectural model is shown in Figure 3.2.

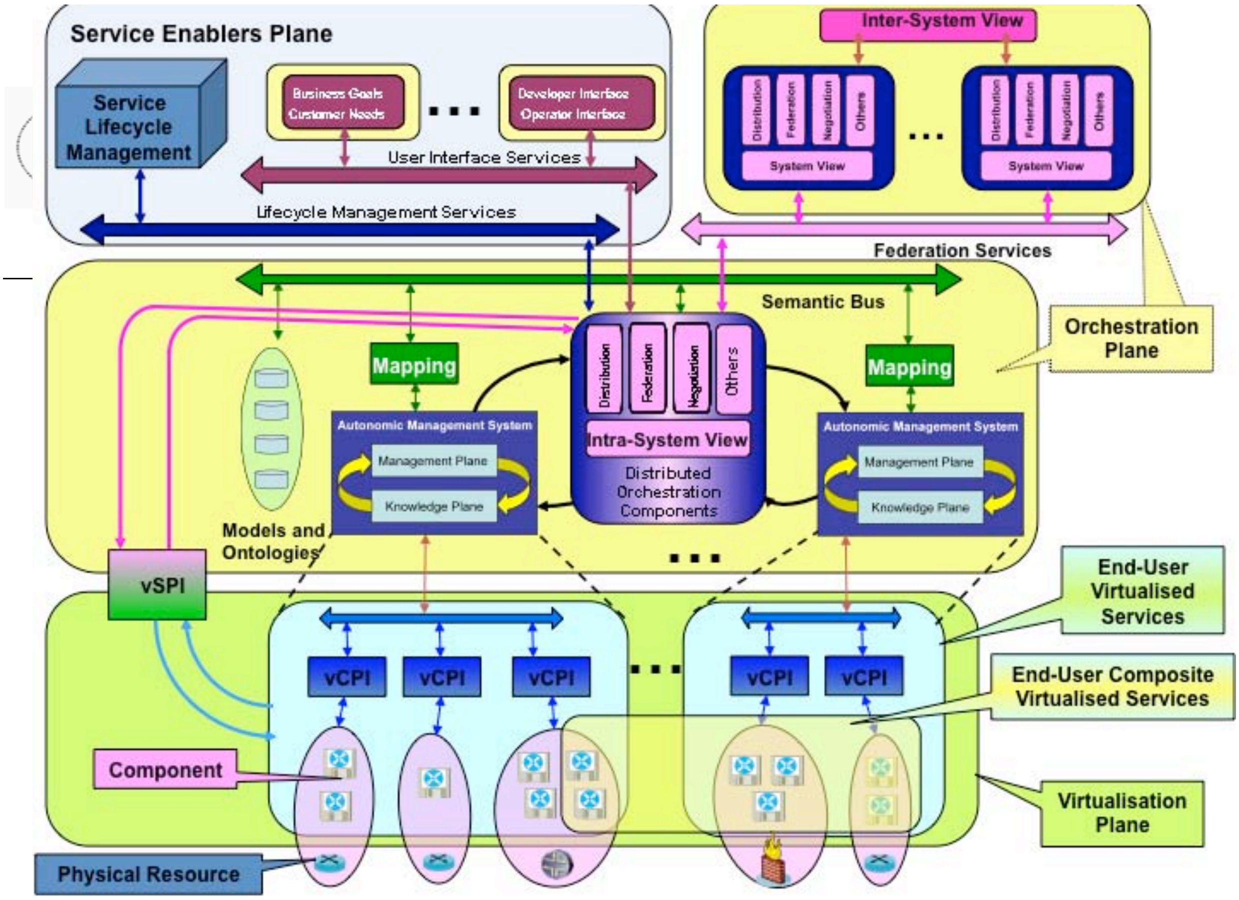

Figure 3:2 - AutoI Architectural Model

3.2.3 Orchestration Plane Overview

The purpose of the Orchestration Plane is to govern the behaviour of the system in response to changing context and in accordance with applicable business goals and policies. It supervises and it integrates all other planes' behaviour ensuring integrity of the Future Internet management operations.

The Orchestration Plane can be thought of as a control framework into which any number of components can be plugged into in order to achieve the required functionality. These components could have direct interworking with control algorithms, situated in the control plane of the Internet (i.e. to provide real time reaction), and interworking with other management functions (i.e. to provide near real time reaction).

The context of a managed entity is a collection of measured and inferred knowledge that describe the state and environment in which the managed entity exists or has existed. The Policy Continuum can be used to translate business rules and goals into policies at different abstraction levels (e.g., for network administrators, programmers, and architects). In this respect, the Orchestration Plane is similar to the Inference Plane approach.

However, the AutoI Orchestration Plane differs from the Inference Plane in several essential ways:

- Virtual resources and services are used.
- Service Lifecycle management is introduced.
- The traditional management plane is augmented with a narrow knowledge plane, consisting of models and ontologies, to provide increased analysis and inference capabilities.
- Federation, negotiation, distribution, and other key framework services are packaged in a distributed component that simplifies and directs the application of those framework services to the system.

The Orchestration Plane will also supervise the optimisation and the distribution of knowledge within the Knowledge Plane to ensure that the required knowledge is available in the proper place at the proper time. This implies that the Orchestration Plane may use very local knowledge to deserve a real time control as well as a more global knowledge to manage some long-term processes like planning.

The Orchestration Plane is made up of one or more Autonomic Management Systems (AMS), one or more Distributed Orchestration Components (DOC), and a dynamic knowledge base consisting of a set of models and ontologies and appropriate mapping logic and buses. Each AMS represents an administrative and/or organisational boundary that is responsible for managing a set of devices, subnetworks, or networks using a common set of policies and knowledge. The AMS access a dynamically updateable knowledge base, which consists of a set of models and ontologies. A set of DOC enable AMS to communicate with each other. A set of buses enable the Orchestration Plane to be federated with other Orchestration Planes.

The Orchestration Plane acts as control workflow for all AMS ensuring bootstrapping, initialisation, dynamic reconfiguration, adaptation and contextualisation, optimisation, organisation, closing down of AMS. It also controls the sequence and conditions in which one AMS invokes other AMS in order to realize some useful function (i.e., an orchestration is the pattern of interactions between AMS).

The Orchestration Plane provides assistance for the Service Lifecycle Management, namely during the actual creation, deployment, activation, modification and in general, any operation related to the application services or management services.

3.2.4 Models and Ontologies

In this approach, a single information model is used to define the management data definitions and representations that are used by all system components. This approach is shown in Figure 3.3.

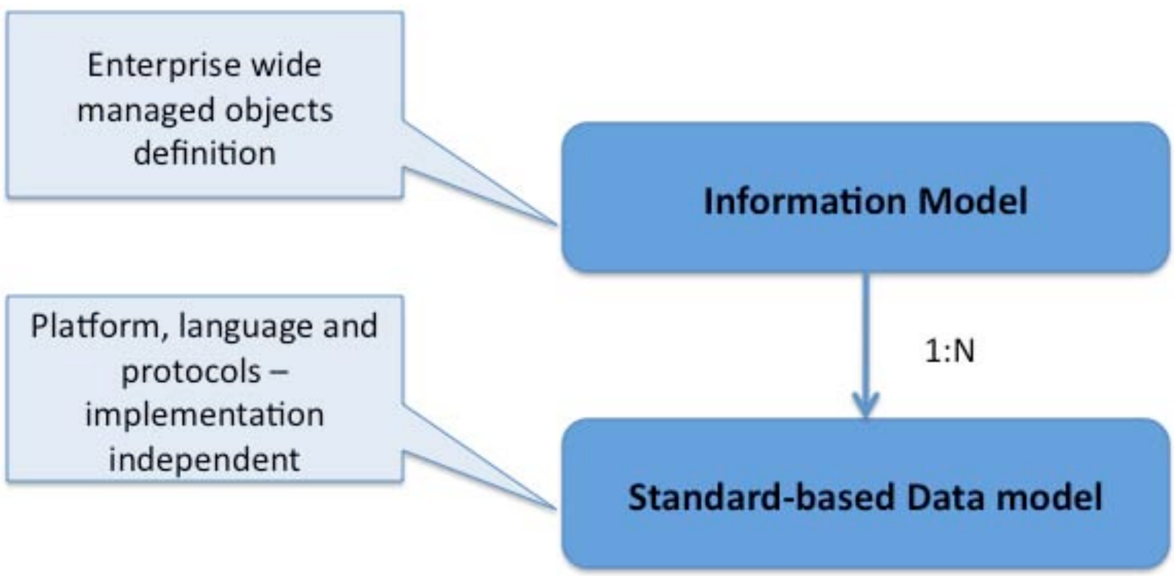

Figure 3:3 - Relationship between Information Models and Data Models

The top layer represents a single, enterprise-wide information model, from which multiple standard-based data models can be derived (e.g., one for relational databases and one for directories). Since most vendors add their specific extensions, the lowest layer provides a second model mapping to build a high-performance vendor-specific implementation (e.g., translate SQL92 standard commands to a vendor proprietary version of SQL). This translation is especially important when an object containing multiple attributes is split up, resulting in some of the object's attributes being located in one repository and the rest of the object's attributes being located in a different repository. Without this set of hierarchical relationships, data consistency and coherency is lost, as there is no way to relate and synchronise the data between these two disparate applications.

Networks consist of diverse devices having different programming models, management data, and functionality. Therefore, the approach used in the AutoI architecture federates different knowledge representation and management technologies and builds a set of mechanisms to extract and fuse knowledge from different data sources into a single representation. Knowledge extracted from information/data models forms facts. Knowledge extracted from ontologies is used to augment the facts, so that they can be reasoned about. Hence, the combination of model and ontology knowledge forms a universal lexicon, which is then used to transform received data into a common form that enables it to be managed. This lexicon enables a common means of communication and cognition to exchange knowledge representation between heterogeneous network elements and domains, and realises the (local) autonomous operation of multiple domains while supporting their (global) interaction.

This approach enables the AutoI architecture to treat network devices and attachments, people, and other entities of interest as addressable "objects" that can be made up of other addressable objects and have relationships, such as dependencies, with other addressable objects. Hence, in AutoI, packets and streams can be sent to people or places, as opposed to a device interface. This abstraction is critical, as it seamlessly enables different types of connections to the receiving object, instead of in current networks, where the sender has to make an explicit choice in how to connect to the object.

3.2.5 Autonomic Management System

In the current Internet, the data, control, and management, planes are bound together and often use the same links. For example, TCP connection setup control messages and SNMP management messages use the same links as the data messages. This has at least three drawbacks:

- the data plane is limited to packet-oriented data,
- the design of each of the three planes is unduly complicated, and
- inherent security risks exist, since it is relatively easy to get at control and management data by simply attacking the data plane path.

While some efforts, such as Generalized Multiprotocol Label Switching (GMPLS), attempt to separate control and data planes, they are still closely integrated with the existing Internet.

Another advantage of separating the control and data planes is to provide increased isolation for an application or set of applications. In particular, the performance and security of isolated applications should not be affected by other applications sharing the same resources. A key advantage of the AutoI architecture is that it can provide a programmable mix of isolation and sharing of network resources.

Each AMS consists of a management plane and a knowledge plane, as well as interfaces to a dedicated set of models and ontologies and interfaces to one or more Distributed Orchestration Components. Mapping logic enables the data stored in models to be transformed into knowledge and combined with knowledge stored in ontologies to provide a context-sensitive assessment of the operation of one or more virtual resources. Another set of interfaces enables framework services, such as directory services, naming, federation, and others, to be used by the AMS.

The AMS is designed to be federated, enabling different AMS that are dedicated to governing different types of devices, resources, and services to be combined. In order to support this, each AMS uses the models and ontologies to provide a standard set of capabilities that can be advertised and used by other AMS. The capabilities of an AMS define functionality that can be used by other AMS; such functionality can be negotiated (e.g., through pre-defined agreements, auctioning, and other mechanisms).

An AMS collects appropriate monitoring information from the virtual and non-virtual devices and services that it is managing, and makes appropriate decisions for the resources and services that it governs, either by itself (if its governance mode is individual) or in collaboration with other AMS (if its governance mode is distributed or collaborative), as explained in the next section.

The Distributed Orchestration Component (DOC) provides a set of framework network services. Framework services provide a common infrastructure that enables all components in the system managed by the Orchestration Plane to have plug-and-play and unplug-and-play behaviour. Applications compliant with these framework services share common security, metadata, administration, and management services. The DOC enables the following functions across the orchestration plane:

- Federation: each AMS is responsible for its own set of virtual and non-virtual resources and management services that it governs. This can be thought of as a domain. Federation enables a set of domains to be combined into a larger domain, where selected functionality of each constituent domain contributes to the overall functionality of the larger domain.

- Negotiation: each AMS advertises a set of capabilities (i.e., services and/or resources) that it offers for use by other components in the Orchestration Plane. The negotiation component enables the specific functionality of selected capabilities to be agreed upon between AMS. Examples include using a particular capability from a range of capabilities (e.g., a particular encryption strength when multiple strengths are offered), being granted exclusive use of a particular service when multiple AMS are competing for the sole use of that service, and agreeing on a particular protocol, resource, and/or service to use.

- Distribution: the DOC provides communication and control services that enable tasks to be split into parts that run concurrently on multiple AMS within an Orchestration Plane, or even across multiple Orchestration Planes. This function ensures that AMS that have different implementations and functionality can collaborate. Note that an AMS is self-governing, in that it can decide when to collaborate, and what percentage of its resources and management services to provide for collaboration. If an AMS does not collaborate, then it provides status messages to the Orchestration Plane.

- Governance: each AMS can operate in an individual, distributed, or collaborative mode. In each case, it collects appropriate monitoring data in order to determine if the virtual and non-virtual resources and management services that it governs need to be reconfigured. Business goals, service requirements, context, capabilities and constraints are all considered as part of the decision making process.
- An AMS is aware of both its needs as well as those of other AMS in its federation. Consequently, it can decide which set of other AMS it collaborates with. This collaboration can be different depending on the types of functionality and services that are the subject of the collaboration.
- AMS acting as individual entities are responsible for managing their resources and management services, and send status messages to other AMS in the Orchestration Plane that they are located in.
- Distributed AMS are AMS that are specifically designed to work with other AMS. They need not be located in the same Orchestration Plane. Tasks are accomplished by coordinating the activities of each distributed AMS through a set of well-defined contract interfaces (similar to DCOM or CORBA in concept, with the addition of contract interfaces).
- AMS that act as collaborative entities can act as either a local or a global collaborator. A local collaborator is responsible for coordinating the functionality of all other AMS in a given Orchestration Plane, while a global collaborator coordinates the functionality of AMS across multiple Orchestration Planes. This enables emulation of client-server, n-tier, clustered and peer-to-peer architectures.
- Intra - Future Internet System View: this provides an overall, composite view of the system as seen by the components within a given Orchestration Plane.
- Inter - Future Internet System View: this provides an overall, composite view of Orchestration Planes that are collaborating, as in a multiple domain system. Note that DOC can be distributed as well. For example, a single organisation could be made up of three different groups – engineering, marketing and sales. Each group is likely to have its own set of AMS, since each group will in general have multiple administrative domains. Hence, each group would in general have at least one DOC to enable the different AMS in that group to communicate with each other, and a separate DOC to enable each group to communicate with the other groups.

3.2.6 User Interface Services

These services enable different types of users to interact with different functions AutoI. The Policy Continuum can be used to provide appropriate interface abstractions for each class of user, in terms of grammar, type and sophistication of interface, and other factors. For example, business users will be presented customised interfaces, primarily of a graphical nature, that enable them to manage and manipulate business objects, such as Service Level Agreements; lower-level technical details will be abstracted and normally hidden from view. In contrast, network administrators will be presented customised interfaces, primarily of a script-driven nature, that enable them to understand and change the operation of network resources and services. In both cases, the customisation is done using the distributed knowledge base (i.e., the models and ontologies, and appropriate mapping logic) to construct appropriate terminology for each specific constituency. Policies are used to control access to functionality, along the lines of role-based access control.

3.2.7 Service Enablers Plane Overview - Lifecycle Management Services

The AutoI architecture defines an innovative lifecycle that provides a common framework for the identification and specification of a business problem, along with the specification and development of a deployable solution, which enables products to be built and deployed. This is necessary due to the changing conditions in which a service is provisioned; hence, the service and in particular management service must be lifecycle managed as it evolves and responds to these changes.

The Service Enablers Plane (SEP) consists of functions for the automatic (re) deployment of new management services, protocols as well as resource - facing and end-user facing service. It includes the enablers to allow code to be executed on the network entities. The safe and controlled deployment of new code enables new services to be activated on demand.

This approach has the following advantages for AutoI:

- Service deployment is taking place automatically and allows a significant number of new services to be offered on demand.
- It offers new flexible ways to configure network entities that are not based on strict configuration sets.
- Special management functions and services can be easily enabled locally for testing purposes before they are automatically deployed network-wide.
- Services that are not used can be automatically disabled. These services can be enabled again on demand, in case it is needed to.
- It eases the deployment of network-wide protocol stacks and management services.
- It enables secure but controlled execution environments.
- Different functionalities are supported from the various vendors. This makes it difficult to introduce a generic execution environment that is not vendor-specific.
- It allows an infrastructure that is aware of the impact on the existing services of a new deployment.
- It allows an automatic decision making infrastructure that guides the deployment of new tested network services.
- It allows optimal resource utilization for the new services and the system.

3.2.8 Knowledge Plane Overview

The Knowledge Plane was proposed by Clark et al. [44] as a new dimension to a network architecture, contrasting with the data and control planes; its purpose is to provide knowledge and expertise to enable the network to be self-monitoring, self-analyzing, self-diagnosing and self- maintaining or self-improving.

AutoI introduces a narrow functionality knowledge plane (KP), consisting of models and ontologies, to provide increased analysis and inference capabilities. AutoI's KP brings together widely distributed data collection, wide availability of that data, and sophisticated and adaptive processing or KP functions, within a unifying structure. This brings order, meets the policy, scaling and functional requirements of a global network, and, ideally, creates synergy and exploits commonality of design patterns between the many possible KP functions. The main KP components are an information and context service plus models and ontologies, which enable the analysis and inferencing capabilities. Knowledge extracted from information/data models forms *facts*. Knowledge extracted from ontologies is used to *augment* the facts, so that they can be reasoned about. Hence, the combination of model and ontology knowledge forms a *universal lexicon,* which is then used to transform received data into a common form that enables it to be managed. The information and context service provides:

- information-life cycle management (storage, aggregation, transformations, updates, distribution) all information and context in the network and addresses the size and scope of the Internet;
- responsiveness to requests made by the AMS;
- triggers for the purpose of contextualisation of AMS (supported by the context model of the information model);
- support for robustness enabling the KP to continue to function as best possible, even under incorrect or incomplete behaviour of the network itself;
- support of virtual networks and virtual system resources in their needs for privacy and other forms of local control, while enabling them to cooperate for mutual benefit in more effective network management.

3.2.9 Management Plane Overview

The Management Plane consists of AMS, which are designed to meet the following design objectives and functionality:

- Embedded (Inside) Network functions: The majority of management functionality should be embedded in the network and it is abstracted from the human activities. As such the AMS will run on execution environments on top of virtual networks and systems, which run on top of all current network (i.e. for fixed, wireless and mobile networks) and service physical infrastructures.
- Aware and Self-aware functions: It monitors the network and operational context as well as internal operational network state in order to assess if the network current behaviour serve its service purposes.
- Adaptive and Self-adaptive functions: It triggers changes in network operations (state, configurations, functions) function as a result of the changes in network and service context.
- Automatic self-functions: It enables self-control (i.e. self-FCAPS, self-*) of its internal network operations, functions and state. It also bootstraps itself and it operates without manual external intervention. Only manual/external input is provided in the setting-up of the business goals.
- Extensibility functions: It adds new functions without disturbing the rest of the system (Plug_and_Play / Unplug_and_Play / Dynamic programmability of management functions & services).

- Simple functions: Minimise life-cycle network operations' costs and minimise energy footprint.

In addition the Management Plane, as it governs all virtual resources, is responsible for the optimal placement and continuous migration of virtual routers into hosts (i.e. physical nodes and servers) subject to constraints determined by the Orchestration Plane.
The AMS are design to follow the autonomic control loops depicted in the following figure.

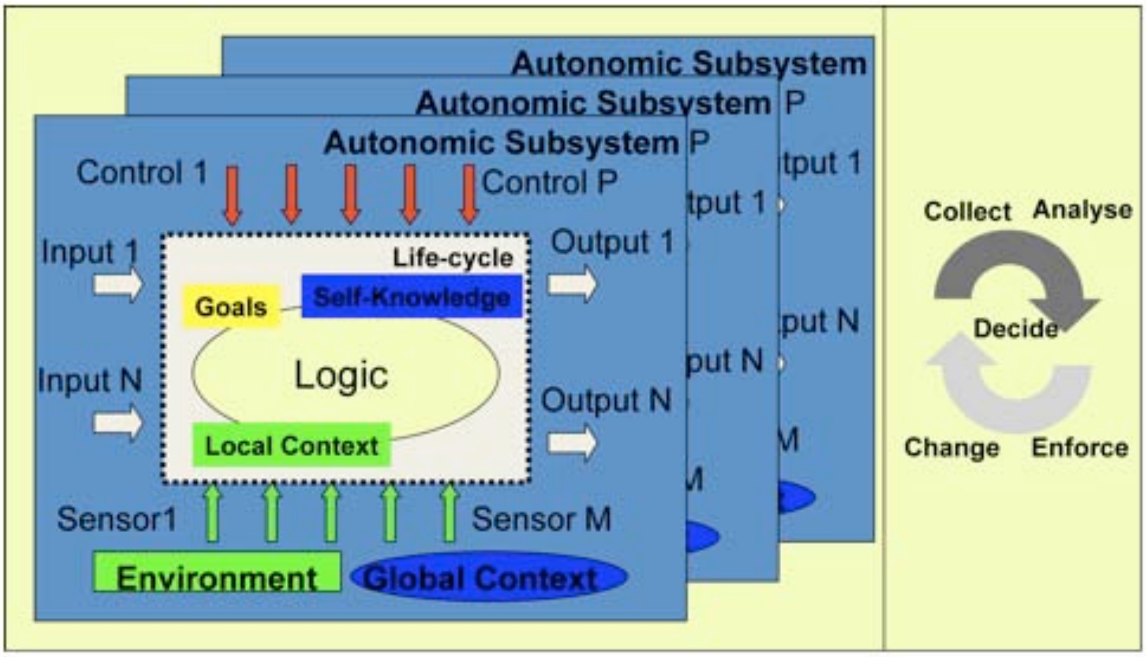

Figure 3:4 - Autonomic Control Loops

3.2.10 Virtualisation Plane Overview

One of the key requirements that differentiates AutoI from other systems is its emphasis on virtualisation (i.e., the abstraction) of resources and services.
Virtualisation hides the physical characteristics of the computing resources being used from its applications and users. AutoI uses platform virtualisation to provide virtual services and resources. Platform virtualisation separates an operating system from its underlying platform resources; resource virtualisation abstracts physical resources into manageable units of functionality. For example, a single physical resource can appear as multiple virtual resources (e.g., the concept of a virtual router, where a single physical router can support multiple independent routing processes by assigning different internal resources to each routing process); alternatively, multiple physical resources can appear as a single physical resource (e.g., when multiple switches are "stacked" so that the number of switch ports increases, but the set of stacked switches appears as a single virtual switch that is managed as a single unit).
Virtualisation enables optimisation of resource utilisation. However, this optimisation is confined to inflexible configurations within a single administrative domain. AutoI extends contemporary virtualisation approaches and aims at building

an infrastructure in which virtual machines can be dynamically relocated to any physical node or server regardless of location, network and storage configurations and administrative domain.

The virtualisation plane consists of software mechanisms to treat selected physical resources as a programmable pool of virtual resources that can be organised by the Orchestration Plane into appropriate sets of virtual resources to form components (e.g., increased storage or memory), devices (e.g., a switch with more ports), or even networks. The organisation is done in order to realise a certain business goal or service requirement. Two special interfaces, called the vSPI and the vCPI (Virtualisation System Programming Interface and Virtualisation Component Programming Interface, respectively). A set of control loops is formed using the vSPI and the vCPI, as shown in Figure 3:5.

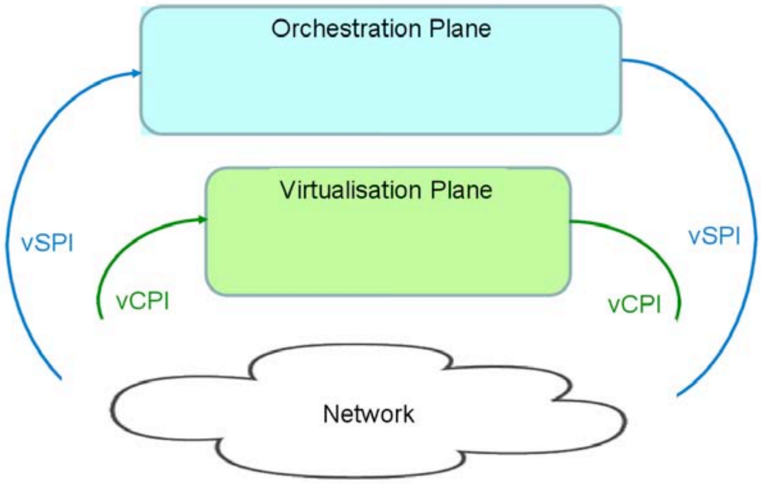

Figure 3:5- Virtualisation Control Loop

3.2.11 vSPI (Virtualisation System Programmability Interface)

The vSPI is used to enable the Orchestration Plane (and implicitly the AMS and DOC that are part of a given Orchestration Plane) to govern virtual resources, and to construct virtual services and networks that meet stated business goals having specified service requirements. The vSPI contains the "macro-view" of the virtual resources that a particular Orchestration Plane governs, and is responsible for orchestrating groups of virtual resources in response to changing user needs, business requirements, and environmental conditions. The low-level configuration (i.e., the "micro-view") of a virtual resource is provided by the vCPI, as explained in the next section.

The governance is done by the set of AMS that are responsible for managing each component or set of components; each AMS uses the vSPI to express its needs and usage of the set of virtual resources to which it has access.

The vSPI is responsible for determining what portion of a component (i.e., set of virtual resources) is allocated to a given task. This means that all or part of a virtual resource can be used for each task, providing an optimised partitioning of virtual resources according to business need, priority and other requirements. Composite virtual services can thus be constructed using all or part of the virtual resources provided by each physical resource, as shown in Figure 3:5.

The vSPI monitors “macro-level” status of the virtual resources that it governs. This is different than the vCPI, which monitors “micro-level” status of the virtual resources that it configures. For example, the vSPI is responsible for informing the AMS that a particular virtual resource is ready for use, whereas the vCPI is responsible for informing the AMS that a particular virtual resource has been successfully reconfigured.

vCPI (Virtualisation Component Programming Interface)

Each physical resource has an associated and distinct vCPI. This enables the AMS to manage the physical resource, and to request virtual resources to be constructed from that physical resource by the vCPI of the Virtualisation Plane. The AMS sends abstract (i.e., device-independent) commands via the vCPI, which are translated into device- and vendor-specific commands that reconfigure the physical resource (if necessary) and manage the virtual resources provided by that physical resource. The vCPI also provides monitoring information from the virtual resources back to the AMS that controls that physical resource. Note that the AMS is responsible for obtaining management data describing the physical resource.

The vCPI is responsible for providing dynamic management data to its governing AMS that states how many virtual resources are currently instantiated, and how many additional virtual resources of what type can be supported.

3.3 State of the Art Review and trends

3.3.1 Architectures and Management Frameworks

Table 1 summarizes the state of the art with respect to established and ongoing network and service management frameworks as applicable to existing telecom and Internet networks technologies.

Forum	Main Results
ACF - Autonomic Communications Forum [1]	DEN-ng Directory Enabled Networks
ITU-T International Telecommunications Union – Telecommunications Sector [2]	TMN – Telecommunication Management Network OSI - Open Systems Interconnection Management
TMF - TeleManagement Forum [3]	SID – Shared Information and Data Model NGOSS – Next Generation OSS e-TOM – Enhanced Telecom Operation Map TNS – Technology Neutral Architecture
DMTF- Distributed Management Telecommunication Forum [4]	CIM – Common Information Model DEN- Directory Enabled Networks
3GPP – 3rd Generation Partnership Project [5]	IMS – IP Multimedia Subsystems OSA Parley – Open Service Architecture Parley Group
OMG – Object Management Group [6]	MDA – Model Driven Architecture CORBA – Common Object Request Broker Architecture
IETF – Internet Engineering Task Force [7]	SNMP – Simple Network Management Protocol NMRG – Network Management Resources Group DISMAN – Distributed Management
ETSI European Telecommunications Standardisation Institute [8]	TISPAN – Telecoms & Internet converged Services & Protocols for Advanced Networks

Table 1 – State-of-the-art on management frameworks

The above standardisation or forum results are not easily applicable to the emerging Future Networks and the Next Generation Internet.

3.3.2 Autonomic Management Frameworks

Following table is an illustrative collection of significant, project related or independent, activities in the area of autonomic architectures for future networks:

Name	Main Results
Autonomic Computing (IBM Study)	[10, 11] propose and explore a holistic vision for autonomic computing in which the system as a whole would attain a higher degree of automation than simply the sum of its self-managed parts. Various research initiatives have been based on this motivation.
Network Self Management and Organization – NESTOR (Colombia University - Sponsored by DARPA – USA)	[17] emphasizes the role of a uniform object-relationship model of network resource, in order to allow any kind of manager (human or software) to configure and control the network behaviour.
Complexity Oblivious Network Management – CONMan (Cornell University - Sponsored by NSF – USA)	[16] is based on the concept of "Network Managers (NM)", which are software agents, distributed in the network devices. It introduces the Module Abstraction that allows the NMs to generically manage all the network entities with the same simple primitives, and allows the managed entities to translate these primitives.
The 4D Architecture – 4D (Carnegie Mellon University - Sponsored by NSF – USA)	[13] is based on four planes: a "brainless" data plane, a decision plane that controls and manages the network, a discovery plane and a dissemination plane that links the network elements to their managers.
FOCALE (Motorola Study)	[14] is based on a dynamic knowledge base with learning and reasoning mechanisms; the Information Model (DEN-ng) is a prerequisite for relevant knowledge dissemination. It makes use of distributed agent driven by a policy manager through business objectives.
Autonomic Network Architecture - ANA (ANA FP6 Project - Sponsored by EU)	[15] proposes a meta-architecture to host and inter-connect scenario specific networks. It incorporates a distributed cross-layer monitoring framework to allow for functional composition and re-

	composition.
Generic Autonomic Network Architecture –GANA (EFIPSANS FP7 Project - Sponsored by EU)	[16] is based on the 4D architectural principles. The decision plane is composed of distributed agents. It aims at solving scalability deficiencies by inducing 4 hierarchical levels: networks, nodes, protocols and functions.
In-Network Management INM (4WARD FP7 Project - Sponsored by EU)	[9] introduces a new paradigm for network management, where management functions are embedded capabilities of the devices. It promotes an iterative approach to shift from the actual situation to a clean slate architectural design.
Washington University Survey	[18] presents a survey on Architectures for the Future Networks and the Next Generation Internet.

Table 2 – A sample of proposed autonomic architectures for future networks.

Despite their technical soundness and promising concepts, none of these architectures has been adopted by the operators and vendors, nor emerged as a standard.

3.3.3 Self-Networking Functionality

The following table 3 is an illustrative collection of significant state of the art and activities in the area of Self Networking, which address different aspects of a control loop: *observation issues*, *knowledge issues, decision making*, *optimal control and execution*.

Self -x Topics	Results
Modelling of self –x methods	[38, 39] present network scale models to support different self-x methods: 1. topology models, reflecting the architecture of the supervised network; 2. behavioural models which are a description of how components / protocols / automated functions could/should react.
Self- diagnosis	[40, 41] presents the formalism of chronicles - graphs of events with time constraints used for learning from alarm logs and for fast recognition of patterns.
Self-Decision making	[42] describes the concepts of behavioural rule and

	matching degree of two behavioural conditions are defined, with related open issues being discussed as well. Then, according to this model, an algorithm for autonomic decision-making based on behavioural rules is presented. [43] exploits decision specification with fuzzy multi-objective decision making techniques. [59, 60] present decision making and resource allocation based on fuzzy logic approaches. [44, 45] present different protocol reconfiguration aspects and related work on composable and adaptable protocol stacks. [35, 36] present strategies for decision-making in network elements and in network segment.
Knowledge representation and administration	[19, 20] present concepts for knowledge sharing and dissemination aspects. [21] introduces a knowledge database to optimise autonomous decision making mechanisms whereas similar criteria have been outlined for optimal terminal operation both coupled with fuzzy logic mechanisms. [22] proposes an integrated solution for knowledge collection, structuring and representation within an Autonomic Element. [23] presents knowledge networks and tools for developing structured collections of related knowledge items for context aware, highly adaptable and autonomic applications and services. [24] introduces a set of knowledge repositories which have been designed for knowledge storage in a structured way so that it can be easily searched
Cognitive and learning systems	[25] explores context, profile, policy management capabilities combined with learning techniques and decision-making functionality. [26, 27] present context acquisition mechanisms which rely on Bayesian networks and Neural networks. [29, 30] present an approach for statically assigning weight values to user profiles. [31, 32] present different analytic hierarchy processes for advanced learning. [33, 34] present approaches for applying policy-based management to learning.
Self-contextualisation	[55] presents a comprehensive survey of network contextualization. [56, 57] presents contextualisation in dynamic environment.
Network Virtualisation	[52] is a virtual network infrastructure that allows researchers to deploy and evaluate their ideas with real

	routing software, traffic loads, and network events. [53] is a Network Virtualization Middleware for Virtual Networked Computing. [9] introduces a network vitualisation with a network operator concept. [51] presents a comprehensive survey of programmable network technology.
Service Computing Clouds	[54] describes the Xen open source hyperviser. [59] describes the definitions and tecnologies for computing clouds [60], [61] describe architectures for service computing clouds
Large scale experimentations	[47] describes testbeds, based on the concept of federation among different parties in a distributed geographical area allows achieving a scalable for testing new paradigms. [48] GENI (The Global Environment for Network Innovations) is a virtual laboratory for future networks which aims at supporting at-scale experimentation on shared, heterogeneous, highly instrumented infrastructure under a collaborative and exploratory environment.
Business modelling:	[21] presents the business model for introduction of wireless cognitive networks in the global market - the new players and roles and the corresponding market assessment for the proposed value chain. [49] presents the potential business models for the deployment of autonomic services. [50] explores the business actors and a set of business models in the autonomic ecosystem.

Table 3 – State-of-the-art on Self-Networking Functionality

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[5] 3GPP 3rd Generation Partnership Project www.3gpp.org
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4 Dissemination Activities

4.1 Publications

The AutoI Consortium aimed at reporting all major scientific results to the research community. A total of 39 papers were published during the lifetime of the project (e.g. 28 papers were published in the period 2 and 11 papers were published in the period 1 of the project).

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- S. Davy, C. Fahy, L. Griffin, Z. Boudjemil, A. Berl, A. Fischer, H. de Meer, J. Strassner "Towards a Policy-based Autonomic Virtual Network to support Differentiated Security Services"; - TEMU 2008, International Conference on Telecommunications and Multimedia, 16-18 July, Crete
- Fahy, S. Davy, Z. Boudjemil, S. van der Meer,J. Rubio-Loyola, J. Serrat, J. Strassner, A. Berl, H. de Meer, D. Macedo ""Towards an Information Model supporting Service-aware Self-Managing Virtual Resources" http://nmg.upc.es/bscw/bscw.cgi/d69866/MACE_2008_InformationModelReqs_camready.pdf MACE 2008 at the 4th International Week on Management of Networks and Services - Manweek 2008 22-26 September, Samos Island, Greece
- Bassi, S. Denazis, A. Galis,C. Fahy, M. Serrano, J. Serrat, - "Autonomic Internet: A Perspective for Future Internet Services Based on Autonomic Principles" invited paper at IEEE 3rd International Week on Management of Networks and Services End-to-End Virtualization of Networks and Services (Manweek 2007) / MACE 2007 2nd IEEE International Workshop on Modelling Autonomic Communications Environments, 29 October – 2 November 2007, San José, California, USA; http://magellan.tssg.org/2007/mace/mace.php

4.2 Workshops Presentations

During its lifetime 27 project related presentations (e.g. and 21 presentation in the second period of the project and 6 presentations in the first period of the project) and one demonstration were made at 15 workshops as follows:

- Management of Virtual Infrastructure – A. Galis (UCL) - FIA Valencia 15th April 2010 - http://www.future-internet.eu/home/future-internet-assembly/valencia-april-2010/session-agendas/architectures.html

- Network Virtualisation A. Fischer (University of Passau)- Future Internet Cluster Meeting 9th March 2010 Sofia Antipolis http://cordis.europa.eu/fp7/ict/future-networks/events_en.html
- Orchestration Overview A. Galis (UCL) – FIA Stockholm 24th Noverber 2009 http://www.future-internet.eu/home/future-internet-assembly/stockholm-november-2009/cross-topic-sessions.html#c204
- Service-aware Architectures A. Galis (UCL) – FIA Prague – 12th May 2009 http://www.future-internet.eu/home/future-internet-assembly/prague-may-2009/management-and-service-aware-networking-architectures.html
- Evolutionary Service-aware Architectures G. Pavlou (UCL) – FIA Madrid 9th December 2008 http://www.future-internet.eu/home/future-internet-assembly/madrid-dec-2008/mana.html
- AutoI presentation & Demonstrations L. Mamatas (UCL) -- 10-12 June 2009, Santander, ICT-Mobile Summit 2009 http://www.futurenetworksummit.eu/2009/default.asp?page=exhib
- Autonomic Networking for Future Internet A. Galis (UCL) – 23rd September 2009 Workshop: Autonomic Computing and Networking for Service Ecosystems: Opportunities and Technological Challenges - Torino 23rd Sept 2009 http://www.telecomfuturecentre.com/ecosistemi/workshop_programme.shtml#text
- Future Internet – System Functions, Capabilities and Challenges A. Galis (UCL) - Dagstuhl Seminar Management of the Future Internet 27-30 January 2009 http://www.dagstuhl.de/en/program/calendar/semhp/?semnr=09052
- Joint EMANICS, AutoI, Self-Net Workshop on Autonomic Management - 28-29 April 2009 London http://www.ee.ucl.ac.uk/nsrl/events/auto-mgmt-ws Presentations:
    - Autonomic Management of Service Clouds – A. Galis (UCL)
    - A Service Enabler Infrastructure for the Future Internet - L. Lefevre (INRIA), A. Cheniour (INRIA)
    - Knowledge Management Requirements in Autonomic Network Management – G. Koumoutsos (University of Patras)
    - Information and Knowledge Management for an Autonomic Internet– S. Davy (WIT)
    - Towards an Information Management Overlay for the Future Internet- L. Mamatas (UCL)
    - An Autonomous Management System for the AUTOI Approach- J.R. Loyola (UPC)
    - Towards a Service-aware Future Internet and its Management – G. Pavlou (UCL)
- AutoI Presentation Future Internet Scenarios – J.R. Loyola (UPC)- Management and Service-aware Networking Architectures (MANA) Workshop, Brussels, 25th February 2009 http://cordis.europa.eu/fp7/ict/future-networks/event-20090225_en.html
- FP7 AutoI – SFI Fame Workshop on Autonomic Network Management – S.Davy (WIT) Application of DEN-ng in the FP7 Autonomic Internet, 26th May, 2009
- WIT Masters in Communications Network Management – Course Module / Research Support Module - S.Davy (WIT)- Techniques and Tools to support

Knowledge Engineering with applications to Network Management, Sept 2009 http://www.wit.ie/Research/ResearchDay/ConferenceProgramme/

- Panel on the AutoI viewpoint at the ICNT 2009, Valencia, 22-23 April J. Serrat.
- Panel on the Management of the Future Internet in the FIA framework, Prague, 12th May 2009, J. Serrat.
- Poster presentation of the AutoI approach at ICAC 2009, Barcelona, 15-19 June 2009, J. Serrat.
- Joint ACF, AUTOI, EMANICS Workshop on Autonomic Management in the Future Internet 14th May 2008 Barcelona; http://emanics.org/content/view/127/36/ Presentations:
  - AutoI Overview – A. Bassi (HITACHI)
  - Context Information Service Network – A. Galis (UCL)
  - SLA Modeling for E-negotiations, Enforcement and Management in an Autonomic Environment- G. Koumoutsos (University of Patras)
  - Using an Information Model for Network Configuration and Management via Domain Specific Languages- S. Davy (WIT)
  - Modelling Support for Autonomic Communications – J. Strassner (MOTOROLA)
  - Virtualization in AutoI – H. De Meer (University of Passau)

4.3 Project Web Site

The project web-site (http://www.ist-autoi.eu) was set-up and updated at regular intervals as needed to reflect the advances of the project.

4.4 Project Solutions as Released Open Source Systems

Two releases of the open source systems developed by the AutoI team were made in October 2009 and in June 2010 (http://www.ist-autoi.eu). AutoI partners have committed to update, maintain and use these open source systems beyond the project period. The following is a short description of the open solutions developed during the lifetime of the project:

vCPI

Virtual Component Programming Interface (vCPI) Programmability is necessary to achieve a virtual plane that is flexible enough to adapt to unforeseen changes. The vCPI allows a localized monitoring and management of virtual resources (e.g. management of virtual routers (VRs)). The goal of making the control functions of autonomic networks context-aware is therefore essential in guaranteeing both a degree of self-management and adaptation as well as supporting context-aware communications that efficiently exploit the available network resources. Context-aware networking enables new types of applications and services in the Future Internet.

Model Based Translator - MBT

The Model-based Translator (MBT) is a package that translates commands and messages from a technology independent network language to device specific commands and configurations. It is capable of converting device specific monitoring messages into a technology independent language. The MBT uses a detailed information model of communications networks with model-to-text translations templates to carry out the translations. It is intended for use by network management software to manage heterogeneous networking equipment and services without understanding the associated data models. It supports both vCPI and ANPI templates.

Context & Information Service Platform - CISP

The Context and Information Service Platform (CISP) is a new infrastructure for collection, process and dissemination of context information, as a support for the deployment, evolution and autonomy of communication services and applications. CISP has the role of managing the context information, including its distribution to context clients / consumers. The presence of CISP functionality helps to make the interactions between the different context sources and context clients simpler and more efficient. CISP is realised by two basic context-specific functional entities, one interfacing with context clients and the other implementing the core internal operations required by the context provisioning system.

Monitoring Platform for Virtual Networks - LATTICE

The Lattice Monitoring Framework provides functionality to add powerful and flexible monitoring facilities to systems. Lattice has a minimal runtime footprint and is not intrusive, so as not to adversely affect the performance of the system itself or any running applications. The monitoring can be built up of various components provided by the framework, so creating a bespoke monitoring sub-system. The framework provides data sources, data consumers, and a control strategy. In a large distributed system there may be hundreds or thousands of measurement probes, which can generate data. It would not be effective to have all of these probes sending data all of the time, so a mechanism is needed that controls and manages the relevant probes.

AutoI Policy Engine

This software implements the AutoI Policy-Based System used to manage the life-cycle of the AutoI Project. A policy-based management system that includes a fully functional policy engine that takes policies has also been implemented. It comes with a user-friendly graphical user interface (GUI), which shows the policy hierarchy tree and the process messages. Each AMS implements a number of control loops in order to exhibit self-* capabilities. A policy-based AMS is similar to a traditional policy-based management system except that it is able to operate with entities outside the scope of its administrative domain. The AMSs influence their policies based on learning. The control loop requires monitoring applications to determine the current state and respective context of the managed resources. This sensed information is translated (via model based translation) and analysed. The analysis process investigates the state of the managed resources. If the analysis process determines that the managed resources are in an undesired state, an appropriate action is executed onto the managed resources using the concepts of actuators and effectors.

Autonomic Network Programming Interface - ANPI

The Autonomic Network Programming Interface (ANPI) is a software platform that interacts with the Autonomous Management Systems (AMSs) by supporting them during negotiation and federation process as well as to discover network services, to manage their life cycle and enabling a suitable deployment of software components onto virtual resources. It is designed to have the functionality of new programmatic enablers that allow codes to be deployed and then executed on the network entities and a safe and controlled deployment of services (resource-facing and / or consumer-facing services). It consists of a set of primitive functions dealing with all service requests. It deals with the deployment and administration of services / service components / management components. ANPI consists in a Service Deployment Daemon which can be run in a virtual machine / router and / or a physical machine.

Programmable Management Platform - XINA

XINA is a modular scalable architecture that enables the deployment, control and management of active sessions over virtual entities (e.g. virtual routers or servers). A proof-of-concept prototype is implemented and integrates the rest of the open source components given above. It allows the deployment of different management components that realize self management functionalities. XINA consists of an active engine and a Forwarding element, namely a router, wireless local area network (WLAN) access point, media gateway etc. The active engine consists of three main components: (1) the Diverter, (2) the Session Broker and (3) the Virtualisation Broker. In addition, any number of other brokers can run in parallel and give enhanced services to the main components through broker interfaces. Communication between XINA's modules is carried out through UDP transactions or TCP connections.

Reasoning and Negotiation module

The AutoI Reasoning and Negotiation module is an implementation of the DOC. It aims to demonstrate the basic functionality of a DOC in mediating the negotiation among AMSs for the deployment of a user requested Customer Facing Service (CFS) according to the selected use-case scenario. It mainly consists of two components: The Dynamic Planner component. The Negotiation component In general, the CFS is requested by a client from an AMS. If it is not capable of providing the requested SLA that includes the CFS on its own, this specific AMS delegates the request to the DOC that it is attached to. The role of the DOC is to locate alternatives for delivering the requested SLA through multi-AMS cooperation and orchestrate the delivery process.

5 Standardisation Activities

There are 4 relevant standardisation groups for the AutoI project. The following measures and activities were performed during the project lifetime:
ACF Autonomic Communication Forum (e.g. http://www.autonomic-communication.org) was inactive during the lifetime of the AutoI project and as such there was no incentive or value in contributing to its activities.
ETSI ISG "Autonomic Network Engineering for the Self-Managing Future Internet (AFI)" (e.g. http://portal.etsi.org/portal/server.pt/community/default_community/redirect_page?AFI http://portal.etsi.org/portal/server.pt/community/AFI/344) is in early exploratory stage of setting up its work scope and it appears that it does not aim to cover the topics of management of virtual networks which are specific to the AutoI project. AutoI representative (i.e. S. Denazis – Hitachi) has participated in one ETSI AFI meeting in May 2010 in Athens.
IETF Virtual Networks Research Group (VNRG) – (e.g. http://trac.tools.ietf.org/group/irtf/trac/wiki/vnrg) has being established in March 2010. It does not aim to cover the topics of management of virtual networks, which are specific to the AutoI project. The VNRG timescale is practically outside the project lifetime and as such there were no specific contributions from the AutoI. Monitoring and contributing to VNRG activities and it work plan would be undertaken in the future by interested partners of the AutoI consortium.
ITU-T FG-FN "Focus Group Future Networks (FG-FN)" (e.g. http://www.itu.int/ITU-T/focusgroups/fn/) has being establish in July 2009 and A. Galis (UCL) has became its vice chair in Nov 2009.
AutoI representatives have participated and contributed to this standardisation activities as follows: first meeting 29 June – 3 July 2009, Lulea, Sweden – A. Bassi (Hitachi); third meeting 26-28 January 2010, Geneva, Switzerland – A. Galis (UCL); forth meeting 29 March – 2 April 2010, Tokyo, Japan – A. Galis (UCL); fifth meeting 15-18 June 2010, Geneva, Switzerland – A. Galis (UCL)
This FG-FN group is targeted towards setting up relevant standardisation sub-group in ITU-T in Future Internet in the period 2011- 2015. FG-FN recommendations are planned for Dec 2010 as part of the main report "Future Networks: Vision and Concepts". Currently this draft document is progressing on the following topics: Network Virtualization, In-system Network Management, Energy Saving of Networks, Identification, Mobility and Self-optimization Network. AutoI's results in virtual networks concepts, deployment, interfaces and management are now fully represented and it will continue to be represented in the ITU-T FG FN main recommendations report.

6 Conclusions

This deliverable constitutes the results of the work performed under Task 7.4 "Final market assessment and exploitation" during the second project period. The document includes the Future Internet assessment and trends, similar to AutoI approaches and technologies and the consortium dissemination and exploitation plans.