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SEVENTH FRAMEWORK PROGRAMME

SEVENTH FRAMEWORK PROGRAMME

GREEK INTEROPERABILITY CENTER

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Introducing Interoperability in the Cloud:
A Preliminary Report on Cloud Interoperability

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LIST OF TERMS AND ABBREVIATIONS

API	**Application Programming Interface**
BPM	**Business Process Modelling**
CCIF	**Cloud Computing Interoperability Forum**
CCM	**Cloud Cube Model**
CCMN	**Cloud Computing Modelling Notation**
CEN	**European Committee for Standardization**
CIM	**Computation Independent Model**
CORBA	**Common Object Request Broker Architecture**
CPIP	**Cloud Portability and Interoperability Profile**
CRM	**Customer Relationship Management**
CSA	**Cloud Security Alliance**
CSPs	**Cloud Service Providers**
DCI	**Distributed Computing Infrastructures**
DMTF	**Distributed Management Task Force**
EC	**European Commission**
ECLC	**Enterprise Cloud Leadership Council**
EC2	**Elastic Compute Cloud**
EI	**Enterprise Interoperability**
EIF	**European Interoperability Framework**
EIRR	**Enterprise Interoperability Research Roadmap**
EISB	**Enterprise Interoperability Science Base**
ERP	**Enterprise Resource Planning**
ETSI	**European Telecommunications Standards Institute**
EU	**European Union**
FP5	**5th Framework Programme**
FP6	**6th Framework Programme**
FP7	**7th Framework Programme**

GIC	**Greek Interoperability Centre**
GRC	**Governance, Risk Management and Compliance**
IaaS	**Infrastructure as a Service**
ICT	**Information and Communication Technology**
IDE	**Integrated Development Environment**
IDEAS	**Interoperability Developments for Enterprise Application and Software**
IEC Council	**Interoperability Executive Customer Council**
IEEE	**Institute of Electrical and Electronics Engineers**
I-ESA	**Interoperability for Enterprise Systems and Applications**
ISM	**Implementation Specific Model**
IT	**Information Technology**
J2EE	**Java 2 Platform, Enterprise Edition**
MDA	**Model Driven Architecture**
MOF	**Meta Object Facility**
NESSI	**Networked European Software and Services Initiative**
NIST	**National Institute for Standards and Technology**
OASIS	**Organisation for the Advancement of Structured Information Standards**
OCCI	**Open Cloud Computing Interface**
OGF	**Open Grid Forum**
OMG	**Object Management Group**
OVF	**Open Virtualisation Format**
PaaS	**Platform as a Service**
PDA	**Personal Digital Assistant**
PIM	**Platform Independent Model**
PM	**Platform Model**
PSM	**Platform Specific Model**
QoS	**Quality of Service**
RDF	**Resource Description Framework**
REST	**Representational State Transfer**

S3	**Simple Storage Service**
SaaS	**Software as a Service**
SAF	**Symptoms Automation Framework**
SDOs	**Standard Development Organisations**
SIIF	**Standard for InterCloud Interoperability and Federation**
SLA	**Service-level Agreement**
SMEs	**Small and Medium Enterprises**
SOA	**Service-Oriented Architecture**
SOMA	**Service-Oriented Modelling and Architecture**
SOMF	**Service-Oriented Modelling Framework**
SRS	**Software Requirements Specification**
UML	**Unified Modelling Language**
XML	**Extensible Markup Language**

EXECUTIVE SUMMARY

With the significant advances in Information and Communication Technology (ICT) over the last half-century, there is an increasingly perceived vision that computing will one day be the 5th utility (after water, electricity, gas, and telephony). Today, the evolution of the Internet has introduced Cloud Computing as a very prominent computing method that although still in its infancy, appears as a promising approach for highly flexible and scalable software systems for individual-, community-, and business-use.

According to NIST, Cloud Computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (i.e. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. Due to its nature and particular characteristics (On-demand self-service; Broad network access; Resource pooling; Rapid elasticity; Measured Service), Cloud Computing holds the potential to help public organizations and businesses reduce IT costs, increase their business agility, focus on innovation activities and new business opportunities and make computing much more energy efficient.

Given the advantages of this new computing model, today numerous vendors have introduced cloud paradigms and services, which are however based on non-compatible underlying technologies, making thus the cloud landscape diverse, heterogeneous and vendor-locked. In this context, interoperability, which is definitely a challenge for on-premise applications, is magnified in the cloud, where its scope refers to both the links amongst different clouds and the connection between a cloud and an organization’s local systems.

Although many efforts to standardize clouds’ important aspects are currently underway and cloud standardization overall appears to be a worthwhile track, resolving the Cloud Interoperability problem is still far from reality. In fact, most approaches emphasize on cloud deployment issues with interoperability not having appeared yet on the pressing agenda of major industry cloud vendors and researchers.

However, interoperability is indisputably a high-impact factor, capable of dramatically decreasing the costs, risks and complexity of information systems, while also affecting the overall quality, duration and cost of business processes and digital services in both the private and public sector. Additionally, and as far Cloud Computing is concerned, it stands along with workload/data portability, security and privacy and adherence to standards, as one of the key requirements that organizations have to consider in order to fully exploit the potential of the cloud. On another level, it is an essential prerequisite for the emergence of new cloud business models, which are based on cloud providers’ collaboration and cloud service federation. In short, the exciting possibilities of Cloud

Computing and its success rely heavily on interoperability, and therefore on the establishment and adoption of a common set of rules and standards specific to their environment.

Tackling interoperability challenges though in the cloud, which represents a quite complex environment, is not easy, as it requires that issues and challenges inherited from lower level and less complex areas are tackled first. At the time being, the most appropriate strategy to promote interoperability in the cloud seems to be the use of cloud specifications and standards that are already widely accepted, along with the development of new standards only when actually needed. In the medium- to long-term horizon however, the ability to unlock the full potential of the cloud lies in the development and standardization of a Cloud Interoperability Framework that will support and guide the design, development, deployment and governance of services on top of cloud infrastructures towards a coherent and interoperable services environment.

#

1 Introduction

1.1 Scope of the Guide

The **objective** of the G.I.C. Interoperability Guide series is to provide a volume of concise and comprehensive information on Interoperability that can help its targeted audience, mainly managers, IT managers, decision makers of enterprises, policy makers of governments and citizens, to design their strategies, find solution tactics on specific interoperability problems and generally benefit from the Interoperability aspects in their everyday communications and transactions. For this purpose, the Interoperability Guide comprises, in its **six versions**, material on Interoperability from a multitude of sources:

- **Research results** from ongoing projects and initiatives in EU and international level, focusing on the specific sub-domains and applications of Interoperability.
- **Deliverables and Reports** from projects, initiatives, standardisation bodies and institutions on various issues that impact the Interoperability domain.
- National, EU and global **Best Practices** and **Strategie**s on specific areas of the Interoperability domain that describe how key Interoperability issues/problems have been tackled effectively by enterprises and governments.
- Reports on **standards from international organisations**, working groups and standardisation bodies on existing and emerging key technological approaches in the various domains associated with interoperability.
- **Legal and Statutory Framework documents**, reports and white papers that affect the Interoperability domain or shape specific areas of business/governmental practice where Interoperability has a major impact.

In order to make the previous material comprehensive to readers with limited knowledge on the Interoperability domain, the Guide incorporates declarative definitions in plain terms on the subjects it engages in its various versions and concludes by providing a set of straightforward recommendations to enterprise decision makers and government policy makers.

1.2 Focus of Previous Versions of the Guide

As interoperability is a vast and multilateral subject matter, attempting to provide a single, all-inclusive report would be futile and at best would render the document elaborate, lengthy, verbose and finally useless for its potential audience. Instead, the Interoperability Guide is published in six separate versions, each version focusing on different aspects of Enterprise and e-Government Interoperability, in order to provide a set of comprehensive reports and straightforward recommendations that could be used by decision makers and policy makers in enterprises and organisations. The previous published versions of the Guide cover the following topics:

- The ***first version*** provides guidance to Enterprises on *middleware platforms* and *architectures*, the technical aspects of the *European Interoperability Framework* and *web service standards*.

- The ***second version*** gives a glimpse on the *European Union research landscape* in three interoperability-related research domains and outlines the basic research results. Furthermore, the *European Union Legal Framework* is reviewed with regard to interoperability-related issues.
- The ***third version*** focuses on the frameworks, methods and tools for *Enterprise and Business Process Modelling* and proposes recommendations and guidelines to enterprises and organisations on what they should do and what they should avoid regarding Enterprise Modelling.
- The ***fourth version*** offers information and practical guidelines for enterprises, public sector bodies and citizens in establishing and using *interoperability services* in their everyday communications and transactions.
- The ***fifth version*** of the Interoperability Guide provides straightforward recommendations for the *design, development and maintenance of e-Government Interoperability Frameworks*.

1.3 Focus of the Current Version

The dawn of a new era that highlights service creation and delivery as its principal ingredient, has started to influence the public and the private sector that now need to drive services towards Future Internet advancements. Cloud Computing, as one of Future Internet advancements, is fast evolving from a futuristic technology into a commercially viable alternative for organizations and companies in search of cost-effective, flexible and scalable IT solutions and customizable services, while it is giving rise to powerful new business models that are based on service aggregation. An essential prerequisite however for this novel computing method to unveil its full potential with regard to the envisaged business models and service opportunities, is to deal beforehand with the everlasting challenge of interoperability, which being already difficult to tackle in on-premise applications, is magnified in the cloud.

In this context, and beside presenting Cloud Computing as a new computing model with a series of characteristics that make it extremely attractive for enterprises, the focus of the sixth version of this Guide is to introduce the concept of interoperability in the complex environment of the cloud, and to provide a preliminary, yet quite comprehensive analysis of the state of play with regard to the recently coined term of Cloud Interoperability in the domains of research, application and standardization. In addition to that, among the objectives of the Guide is also to highlight interoperability as a key requirement for exploiting the complete power of the cloud, and thereby taking advantage of emerging business models, as well as to place the former within the wider context of cloud migration decisions and to provide generic recommendations for taking up cloud deployment activities. Last but not least, the intention of the Guide is to emphasize the establishment and application of common standards as a means of accelerating the development of Cloud Computing, and in line with the former allegation to present the vision of the Greek Interoperability Centre towards achieving Cloud Interoperability, lying in the development and standardization of a Cloud

Interoperability Framework, capable of guiding the design, development, deployment and governance of services on top of cloud infrastructures towards a coherent and interoperable services environment.

The current version of the Interoperability Guide is addressed to all researchers, developers, ICT executives of both the public and the private sector, consultants and policy and decision makers, who wish to obtain a more concrete view of Cloud Computing under the prism of interoperability. In fact, this document is simultaneously:

- ✓ a research document providing researchers with a thorough state of the art analysis in the domain of Cloud Interoperability, along with suggestions for future research in the field.
- ✓ a white paper, offering developers useful, consolidated information on existing solutions and frameworks and their shortcomings if any.
- ✓ a practical guide offering recommendations and enabling ICT executives and consultants to reach more informed decisions when considering cloud deployment activities.
- ✓ an enlightening report, providing policy and decision makers the grounds and thereby the trigger for further speculations with regard to the future of Cloud Computing and the importance of interoperability.

1.4 Structure of the Document

This version of the Interoperability Guide is structured as follows:

Chapter 1 explains the scope of the G.I.C. Interoperability Guide and exposes the structure and focus of its current version, being interoperability and Cloud Computing.

Chapter 2 introduces the concept of Cloud Computing, identifies its benefits and added value for stakeholders and presents its key characteristics, including a series of essential features, service and deployment models, and main roles in the cloud. A short reference is also made to major cloud technology providers.

Chapter 3 exposes the complex nature of interoperability as well as its evolution as a concept from a mere one-dimensional aspect to a multi-faceted feature, which comprises several dimensions, including Cloud Interoperability. The Chapter presents moreover the anticipated evolution of Cloud Computing under the prism of interoperability, an overview of the current situation, and the challenges yet to be tackled, in order to embed interoperability on the cloud.

Chapter 4 goes into more detail on the field of Cloud Interoperability, presenting to the extent possible the state of play in research and application in the specific area.

Chapter 5 continues with the state of play in Cloud Interoperability standardization efforts and emphasizes in particular the exploitation of existing and commonly used standards where possible as a means of accelerating the attainment of interoperability on the cloud.

Chapter 6 analyses the capacity of Cloud Computing to support new business models and provides some considerations on the transition from current monolithic cloud service offerings to more dynamic and flexible ones, based on the federation of different cloud providers.

Chapter 7 discusses the composite nature of cloud-migration decisions, reports relevant cloud-migration scenarios and provides recommendations for considering such decisions from all business, technology and economic perspectives.

Finally, **Chapter 8** concludes the Guide with final remarks and the Greek Interoperability Centre’s vision towards achieving interoperability on the cloud.

2 Cloud Computing: Concept, Benefits and Key Characteristics

With the significant advances in Information and Communication Technology (ICT) over the last half-century, there is an increasingly perceived vision that computing will one day be the 5th utility (after water, electricity, gas, and telephony) [1]. Computers have since many years established themselves as a powerful utility in the hands of man in order to complete his every day tasks, and this is evident in every single aspect of human activities. According to Daryl Plummer [2], "*During the past 15 years, a continuing trend toward IT industrialisation has grown in popularity as IT services delivered via hardware, software and people are becoming repeatable and usable by a wide range of customers and service providers. This is due, in part to the commoditisation and standardisation of technologies, in part to virtualisation and the rise of service-oriented software architectures, and most importantly, to the dramatic growth in popularity of the Internet.*"

It is this evolution of the Internet that has introduced Cloud Computing as well, as a very prominent computing method that although still in its infancy, appears as a promising approach for highly flexible and scalable software systems for individual-, community-, and business-use [1]. In particular, enterprises can use cloud services for their whole IT infrastructure, ranging from "renting" online data storage and utilising combined cloud processors for heavy calculations needed in specific fields, to utilising ERPs and other enterprise related platforms on the cloud.

According to NIST [3], Cloud Computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (i.e. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model [3] promotes availability and is composed of five essential characteristics (On-demand self-service; Broad network access; Resource pooling; Rapid elasticity; Measured Service), three service models (Cloud Software as a Service - SaaS; Cloud Platform as a Service - PaaS; Cloud Infrastructure as a Service - IaaS), and four deployment models (Private cloud; Community cloud; Public cloud; Hybrid cloud) [4]. These characteristics, service and deployment models along with the advantages that Cloud Computing may bring to enterprises are analysed in the following paragraphs.

> ***Cloud Computing*** *is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (i.e. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.*
>
> *Definition by NIST*

2.1 Cloud Potential for Enterprises

Cloud Computing holds the potential to provide small and large enterprises with a flexible model for delivering added-value solutions by composing best of breed internal and external services which combine diverse data sources deployed across multiple cloud infrastructure providers and possibly reconfigured while running, or with limited interruption, to respond to changes in usage patterns or resource availability. According to the Digital Agenda for Europe, Cloud Computing is one the key enabling information technologies that can help public organizations and businesses – especially SMEs – to drastically reduce IT costs, supply services to customers at a lower cost, improve the quality of their services, and make computing much more energy efficient. The main advantages of Cloud Computing and thereby its value for organizations are more specifically placed in the following axes:

- **Reducing IT costs.** A major advantage of Cloud Computing for public administrations and companies, regardless of the sector in which they are active, is that they no longer need to install and maintain software and computing equipment of their own, nor they need to employ personnel to update software and manage data storage facilities in-house. Instead, they can enjoy remote access, through networks such as the internet, to state-of-the-art software and data storage systems offered by specialist outside suppliers and therefore take advantage of much more affordable and efficient IT systems. This reduces significantly the expenditures for procuring and managing IT infrastructure, decreases operating costs, while, since Cloud Computing follows a utility model in which service costs are based on consumption, it allows companies to pay only for what they use.
- **Increasing agility.** Because of its privy nature which supports dynamic allocation of resources, one of the advantages of Cloud Computing is its flexibility and scalability, and thereby the fact that cloud resources can be quickly and easily scaled up and down according to demand. This is particularly advantageous, when enterprises encounter temporary peaks in demand, as well as when organisations wish to start small and try certain applications out to see how it works for them, before expanding their use. To that one should moreover add the wide range of cloud services that allow companies to select and better yet combine the applications that best suit their needs as well as a significant degree of mobility, which allows employees, partners and clients to remotely access the company's resources. All these aspects contribute to increased business agility.
- **Opening new business opportunities – promoting innovation.** By placing storage and server needs in the hands of external cloud service providers, organizations shift the burden placed on their in - house IT team to a third-party provider. This, apart from reducing operating and maintenance costs, enables organizations to free-up internal resources that can be devoted hereinafter to other business-critical tasks, without having to incur additional costs in manpower and training. It further allows companies to focus more on innovation

activities and to consider new business opportunities, while it contributes in balancing competition and creating an even playing field particularly for small firms, as it places at their disposal tools and services of sophistication and complexity equivalent to those used by larger companies on a pay per use basis.

- **Respecting the environment.** Study says that Cloud Computing can seriously slash carbon emissions. In fact, it is claimed that a company can reduce by 50% their carbon emissions if they migrate their storage operations to the cloud, since they no longer need to power an entire server. This affects primarily the environment in general, but it also benefits greatly companies that wish to introduce themselves with green credentials.

These advantages are better perceived through analyzing in the following paragraphs the key characteristics, service models and deployment methods of Cloud Computing.

2.2 Cloud Computing Characteristics

Cloud Computing is identified through five essential features:

- **On-demand self-service.** A consumer can unilaterally provision computing capabilities, such as server time and network storage, as needed automatically without requiring human interaction with each service's provider.
- **Broad network access.** Capabilities are available over the network and accessed through standard mechanisms that promote use by heterogeneous thin or thick client platforms (e.g., mobile phones, laptops, and PDAs).
- **Resource pooling**. The provider's computing resources are pooled to serve multiple consumers using a multi-tenant model, with different physical and virtual resources dynamically assigned and reassigned according to consumer demand. There is a sense of location independence in that the customer generally has no control or knowledge over the exact location of the provided resources but may be able to specify location at a higher level of abstraction (e.g., country, state, or data-center). Examples of resources include storage, processing, memory, network bandwidth, and virtual machines.
- **Rapid elasticity.** Capabilities can be rapidly and elastically provisioned, in some cases automatically, to quickly scale out and rapidly released to quickly scale in. To the consumer, the capabilities available for provisioning often appear to be unlimited and can be purchased in any quantity at any time.
- **Measured Service.** Cloud systems automatically control and optimize resource use by leveraging a metering capability at some level of abstraction appropriate to the type of service (e.g., storage, processing, bandwidth, and active user accounts). Resource usage can be monitored, controlled, and reported providing transparency for both the provider and consumer of the utilized service.

2.3 Cloud Computing Service Models

The following three service models are associated with Cloud Computing:

- **Cloud Software as a service (SaaS).** The capability provided to the consumer is to use the provider's applications running on a cloud infrastructure. The applications are accessible from various client devices through a thin client interface such as a web browser (e.g., web-based email). The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user-specific application configuration settings.
- **Cloud Platform as a service (PaaS).** The capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications created using programming languages and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, or storage, but has control over the deployed applications and possibly application hosting environment configurations.
- **Cloud Infrastructure as a service (IaaS).** The capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, deployed applications, and possibly limited control of select networking components (e.g., host firewalls).

2.4 Cloud Computing Deployment Models

Moving on to the deployment of cloud infrastructures, NIST [5] identifies four deployment models:

- **Private cloud.** The cloud infrastructure is operated exclusively for one organization. It may be managed by the organization itself or a third party and may exist either on premise or off premise.
- **Community cloud**. The cloud infrastructure is shared by several organizations and supports a specific community that has shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be managed by the organizations or a third party and may exist either on premise or off premise.
- **Public cloud.** The cloud infrastructure is made available to the general public or a large industry group and is owned by an organization selling cloud services, that may range from IT infrastructure to business services.
- **Hybrid cloud.** The cloud infrastructure is a composition of two or more clouds (private, community, or public) that remain unique entities but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load-balancing between clouds).

2.5 Main Actors in the Cloud

A conceptual model of a Cloud Computing Reference Architecture has also been defined by NIST [6]. The NIST Cloud Computing Reference Architecture identifies five major actors: *cloud provider*, *cloud consumer*, *cloud carrier*, *cloud auditor* and *cloud broker*. Each actor is an entity (a person or an organization) that participates in a transaction or process and/or performs tasks in Cloud Computing:

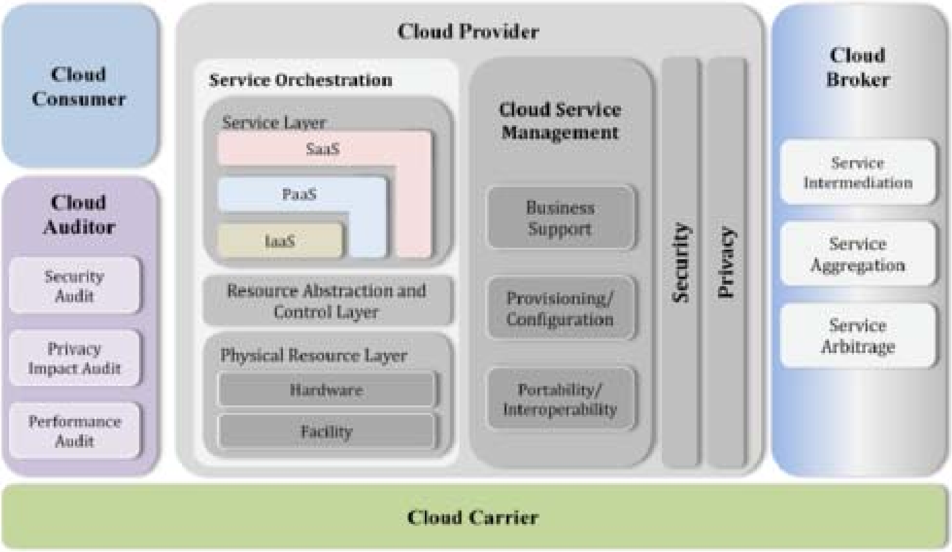

Figure 2-1: NIST Cloud Computing Reference Architecture - Conceptual Reference Model

- **Cloud Provider.** Cloud service providers may be public cloud vendors offering cloud services (e.g. Amazon, Google, Microsoft), hosters offering hosted applications running in cloud environments, teams supporting cloud platforms for internal or private use, or SaaS cloud vendors offering finished, hosted software running in their cloud-based data centers.
- **Cloud Consumer.** The final recipient of the cloud services, also referred to as cloud user.
- **Cloud Auditor.** A body in charge of auditing security, privacy and performance capabilities on the cloud
- **Cloud Carrier.** A cloud provider integrating wide area communication networks, which serve as the base for the deployment of cloud services.
- **Cloud Broker.** A mediator offering consumer/provider brokering/matching services for capabilities offered by other cloud service providers.

Complementary or more specialised roles include:

- **Cloud Application Developers.** Independent software developers developing or porting applications for cloud platforms and environments (includes IaaS/PaaS/SaaS clouds).
- **Cloud Identity Provider.** A mediator offering federated identity and access control services.

- **Cloud Procurement Officer.** Role assuming responsibility of cloud services procurement.

2.6 Major Cloud Technology Providers

Today, numerous vendors have introduced Cloud Computing paradigms and services. Representative players include:

- **Microsoft.** Microsoft offering includes the Azure application infrastructure, Office 365 and Windows Server Hyper-V (a private cloud tool).
- **Google.** Most popular offerings include the Google App Engine and Google Apps.
- **Amazon.** Offering includes cloud system infrastructure services, Elastic Compute Cloud (EC2) and Simple Storage Service (S3).
- **VMware.** VMware provides a suite of products under the vCloud brand for private clouds, and application infrastructure services with Cloud Foundry.
- **salesforce.com.** Offerings enumerate CRM application services, and the Force.com and Heroku application infrastructure services.

3 From Interoperability to Cloud Interoperability

Currently, Cloud Computing infrastructures are widely offered to organisations, enterprises and consumers globally; yet ***Cloud Interoperabiliy*** along the stack of offered services still remains an unsolved issue. Reasons for this can be found, amongst others, in the *fragmentation of solutions* offered, on the *wide range of proprietary technological infrastructures and standards* used, and in the *absence of a coherent, solid and globally accepted definition of the various stakeholders/actors and thus their touch points with the cloud services.*

This issue however, did not emerge from the nature of the cloud technologies itself; it was inherited by the IT technologies which are being used all these years and the lower level aspects of interoperability, and as such it was ported also in the cloud. As the domain of Enterprise Interoperability (EI) points out, one of the most common challenges of enterprises is the task of making different systems from different vendors, work together. From a simple data exchange to the more complex identity propagation, the attainment of interoperability between various software components is apparently required from the end user point of view.

Today, as numerous vendors have introduced paradigms and services based on non-compatible underlying technologies, the cloud landscape has turned out to be diverse, heterogeneous and vendor-locked [7]. In this context, the issue of interoperability, which definitely remains a challenge for on-premise applications is magnified in the cloud.

3.1 The complex and evolving concept of Interoperability

Interoperability is undoubtedly recognised as a key enabler towards unlocking the full potential of organisations, processes and systems of the public and private sector. Since its inception as *"the ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces and to use the services so exchanged to enable them to operate effectively together* [8] and throughout the years, interoperability tends to obtain a broader, all-inclusive scope of a repetitive, well organised, and automated at ICT level feature of organisations. This scope is reflected in the definition of the EIF 2.0 [9], which states that *"interoperability, is the ability of disparate and diverse organisations to interact towards mutually beneficial and agreed common goals, involving the sharing of information and knowledge between the organisations, through the business processes they support, by means of the exchange of data between their respective ICT systems"*. The intricate nature of interoperability as well as its evolution as a concept from a mere one-dimensional aspect to an all-inclusive, multi-faceted feature is unfolded in the following paragraphs.

Interoperability of systems has been a major concern from the beginning of ICT innovations, however the initial conceptualisation of dividing the playing field of Interoperability, as a separate yet important domain of ICT became a reality under FP5 (1998-2002) as workshops were held to discuss this emerging field. One of the most important projects that was funded to address aspects of this field, was IDEAS[1], which aimed at creating and managing a Working Group to elaborate a strategic roadmap in the domain of enterprise application and software interoperability for the next ten years and proposing to the EC a structure and an organisation to support the implementation of this roadmap in FP6. As a result the major future research challenges and the existing gaps were defined and a roadmap in interoperability was implemented.

During FP6 a vast number of research and policy activities took place. Eight large projects were funded (like ATHENA[2], INTEROP[3], etc.) and the domain experts have identified relations to other “external” domains (like Content & Knowledge, Software, eGovernment, etc.), and have worked towards creating the necessary links and communication channels for knowledge exchange that could benefit both sides. In parallel, links with well known ICT domain players (CEN[4], ETSI[5], NESSI[6], etc.) were also constructed and with existing services like IDABC. One of the major achievements of the EI community during the FP6 era was the creation of the EI Research Roadmap (EIRR). Acknowledging the importance of EI, the domain grew quite fast and evolved from a cluster of 8 projects to a wide, international community of more than 250 members, and gave birth to its own conference, I-ESA[7] (Interoperability for Enterprise Systems and Applications), in order to gather annually in a scientific forum to discuss, envision and promote innovative ideas and research results.

Since the publication of the fourth version Enterprise Interoperability Research Roadmap [10] (EIRR) in 2006, a trend towards implementing larger Integrated Projects (IP) was noticed, with ambitious and clearly defined objectives for the domain, capable of mobilising a 'critical mass of resources'. The EIRR v4, which was presented at the end of 2006, became a major reference document for European research by establishing EI as a capability for the purpose of business and not only as an ability of entities to work together. In that specific document, EI moved away from being defined in strictly technological terms as “a way to integrated technological infrastructures of enterprises”, and was re-introduced as a “vehicle for innovation requiring new services, new approaches and new frameworks to be developed”.

[1] http://www.ist-world.org/ProjectDetails.aspx?ProjectId=0a4c4fabe92e4743a8c1fffaec13cf1f&SourceDatabaseId=081fd37e0ca64283be207ba37bb8559e
[2] http://www.athena-ip.org/
[3] http://www.interop-vlab.eu/
[4] http://www.cen.eu
[5] http://www.etsi.org
[6] http://www.nessi-europe.com
[7] http://www.i-esa.org

During FP7 (2007-present), the community that was formed during the past years became even more active. A new updated version of the EIRR evolved (v5.0), more projects were funded and the population of the community numbers more than 1000 members. Having in mind that FP5 and FP6 research projects delivered mostly platforms and web applications and in parallel a noticeable lack of synergies and scientific manpower was evident, the focus now was to order to group and re-orientate the community and to include the on-going projects of the domain.

In this context, all the work carried out throughout the years was reviewed in an effort to analyse the internal characteristics of interoperability, its ingredients and their nature. Despite the numerous approaches that were developed, quite ample consensus was achieved, denoting the main interoperability levels or facets as follows:

- *Technical Interoperability*, investigating problems and proposing solutions for the technical-level interconnection of ICT systems and the basic protocols, digital formats or even security and accessibility mechanisms.
- *Semantic Interoperability*, including methods and tools, usually in the form of ontologies or standardised data schemas, to tackle issues of automated information sharing, during the various process execution steps.
- *Organisational Interoperability*, relating to the problems and solutions relevant to business processes, functional organisation or cross-enterprise collaboration activities – usually involving various different ICT systems and data sources.
- *Enterprise Interoperability*, referring to the alignment of higher enterprise functions or government policies, usually to be expressed in the form of legal elements, business rules, strategic goals or collaborative supply chain layouts.

***Cloud Interoperability** is defined as the ability to federate multiple clouds to support a single application and refers to customers' ability to use the same artifacts, such as management tools, virtual server images, and so on, with a variety of Cloud Computing providers and platforms.*

Particularly, bibliography regarding Enterprise Interoperability is full of different definitions, approaches and various layered models. In the context of this guide of particular interest is the approach of the ENSEMBLE project [11], which has come up with a quite detailed division of the various constructs of Enterprise Interoperability, based on the basic ingredients of an enterprise (and their systems), as shown in Figure 3-1.

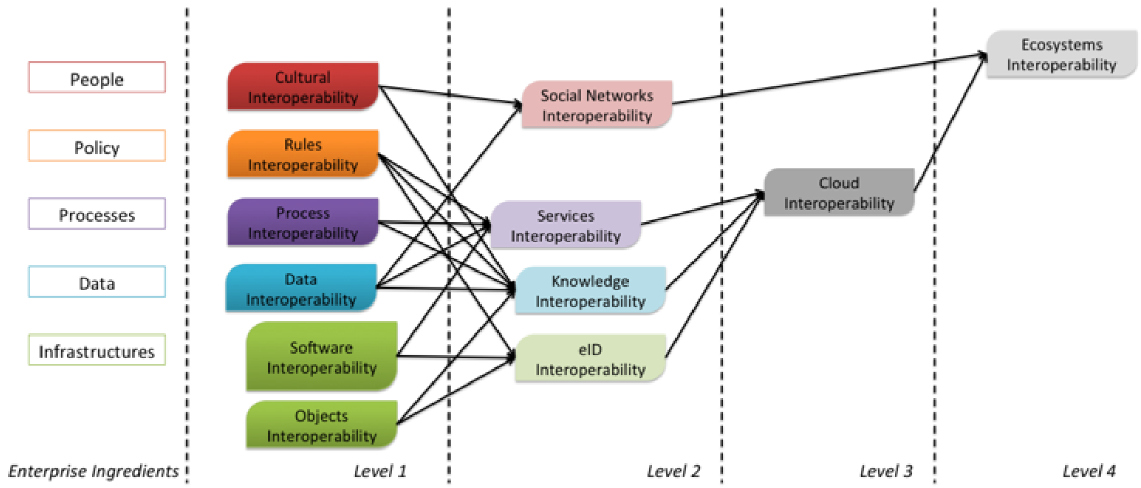

Figure 3-1: Enterprise Interoperability constructs and their relation

According to this structure, which is also the basis for the Enterprise Interoperability Science Base (EISB) [12], **Cloud Interoperability** is strongly related with Services Interoperability, eID Interoperability and Knowledge Interoperability, which in turn are based on areas such as Data interoperability, Process Interoperability, Software Interoperability, etc. In fact, **Cloud Interoperability** is defined as the ability to federate multiple clouds to support a single application [13, 14] and refers to customers' ability to use the same artifacts, such as management tools, virtual server images, and so on, with a variety of Cloud Computing providers and platforms [15]. In other words, Cloud Interoperabiliy involves software and data simultaneously active in more than one cloud infrastructure, interacting to serve a common purpose.

3.2 Evolution of Cloud Computing under the prism of Interoperability and related Challenges

The scope of Cloud Interoperabiliy refers, based on the definition provided in the previous paragraph, both to the links amongst different clouds and the connection between a cloud and an organisation's local systems [16] in order to realise the seamless flow of data across clouds and between cloud and local applications.

As far as the federation of different clouds is concerned, the near future evolution of Cloud Computing under the scope of interoperability is hypothesised, according to Celesti et al. [17], in three subsequent stages:

- Stage 1 - "*Monolithic*" (now), where cloud services are based on independent proprietary architectures;
- Stage 2 - "*Vertical Supply Chain*", where cloud providers will leverage cloud services from other providers;
- Stage 3 - "*Horizontal Federation*", where smaller, medium, and large cloud providers will federate themselves to gain economies of scale and an enlargement of their capabilities.

Consistent with the first stage of the former model, the current landscape in Cloud Computing is characterised by cloud providers that are working with either proprietary technology stacks or have alliances with certain industry partners for providing specific interoperable solutions. Most of the cloud providers offer homogenised services, e.g. IaaS, PaaS or SaaS, which however cannot be combined cross-clouds: the technology stacks are horizontally homogenised and vertically optimised, making it difficult to combine services from different cloud providers, and imposing contractual agreements for the use of on-demand additional resources. The migration of data from one cloud provider to another cloud provider is also difficult, and often there is a need to manually transform the data, as cloud providers are not supporting interoperability. This leads often to situations with vendor lock-in.

Although standardisation appears to be a worthwhile track and many efforts are under way to standardise clouds' important technical aspects, such as interfaces and reference architectures, *resolving the Cloud Interoperability problem is still far from reality*. Most approaches emphasise on cloud deployment issues, with interoperability not having appeared yet on the pressing agenda of major industry cloud vendors and researchers. There are some positions, definitions and visions on the benefits from addressing Cloud Interoperabiliy, yet experimentation efforts and proof-of-concept implementations are rather limited.

> *At the time being,* ***Cloud Interoperabiliy is more of a philosophical discussion*** *amongst diverse cloud players, and the only realisation of this feature is evident between limited applications that are based on the same technology stack and reside in most cases on the same clouds.*

Therefore, Cloud Interoperability needs to evolve further as a concept and interoperability services need to be closely analysed and developed among cloud service providers. From a high level standpoint, the main ***challenges*** yet to be overcome in the path towards enabling Cloud Interoperability involve:

- The integration of diverse computer, network, and storage services from multiple cloud service providers into businesses and IT processes as transparent and homogenised services.
- The management of security and business continuity across several cloud providers, addressing security requirements at both cloud level and and on-premise solutions.
- Service lifecycle management in a distributed multiple-provider environment in order to satisfy service-level agreements (SLAs) with end customers or users and ensure the elasticity of service performance.
- Effective governance and audit processeses across integrated datacentres and cloud providers.
- Increased portability and replication/distribution of IaaS, PaaS or SaaS solutions to other clouds to meet changing business models and needs (distributed clouds/cloud clustering)
- The development of a common reference framework in the form of a cloud service taxonomy enabling an interoperable marketplace for cloud services
- Combining SOA architectural concepts with a cloud service marketplace.

The State of Play in the area of Cloud Interoperability along with the main challenges and issues in both the research and and application domains are analysed in Chapter 4 of this Guide, while in Chapter 5 special reference is made to the corresponding standardisation efforts.

4 Cloud Interoperability State of Play

As Cloud Interoperability is a fairly new concept, and therefore a not well defined one, there is considerable difficulty in mapping the former as a research field and documenting its major problems and challenges. In addition to that, and as already stated in Chapter 3, Cloud Interoperability appears as a high level construct of Enterprise Interoperability, and as such it inherits all the issues and problems that are encountered in lower level constructs. This thwarts as well the delineation of Cloud Interoperabiliy as a research area, as it creates ambiguity among the individual dimensions of interoperability, while it imposes that issues and challenges pertaining to lower level dimensions have to be tackled first. As a result, and keeping in mind that Cloud Interoperabiliy is not an autonomous and self-existent concept, but it bears strong links with the rest of the interoperability dimensions, an analysis of the state of play in the field is attempted in the following paragraphs through the presentation of state of play, the documentation of the corresponding solutions, and the identification of the respective challenges in both the research domain and in a series of related application fields. These fields, primarily associated with software and service engineering, and thereby the respective lower level aspects of interoperability, are presented where appropriate under the notion of Cloud Computing and include in brief broker APIs and open cloud deployment platforms, software requirements and architecture modelling frameworks, service front-ends and service mashups engines, and security and authentication frameworks. A more detailed study of the lower level constructs of Enterprise Interoperability and their associated issues and challenges exceeds the objectives of this guide and is left to the reader.

Software Interoperability *refers to the ability of an enterprise software application to work with another enterprise software application without special effort from the stakeholders [18].*

Service Interoperability *refers to the ability of an enterprise to dynamically register, aggregate and consume composite services of an external source, such as a business partner or an internet-based service provider, in seamless manner [19].*

4.1 Cloud Interoperability in Research

The promotion of interoperability is strongly encouraged by the Digital Agenda for Europe (adopted on 19th May 2010), as "Interoperability and Standards" stands – along with Digital Single Market, Trust and Security, Very Fast Internet, Research and Innovation, Enhancing e-skills, and ICT for Social Challenges – as one of the seven priority areas for action, while the same applies for Cloud Computing, regarding which, the Digital Agenda dictates, that *"Europe should also build its innovative advantage in key areas through reinforced eIfrastructures and […] should develop an EU-wide strategy on 'Cloud Computing' notably for government and science"* [20]. Following the policy requirements, EU research in the former domains flourishes with more and more calls – indicatively including the most recent, ICT Call 8 (Objective ICT-2011.1.2 on “Cloud Computing, Internet of Services and Advanced Software Engineering”), and CIP 2011 (Objective 4.1 “Towards a cloud of public services”) – and consequently research projects attempting to tackle related research challenges. Research projects and initiatives that combine Cloud Computing with the notion of interoperability indicatively include:

The **RESERVOIR**[8] project concerns how a European Cloud Computing infrastructure could be built. It has defined a Reference Architecture for a service-oriented infrastructure that facilitates the dynamic interoperability of cloud providers for the reliable delivery of services and resources. RESERVOIR focuses on developing software that would make available underused computing resources from various suppliers and provide them as a service to companies and public administrations in need of such resources. The aim is to enable companies with underused computing resources to make their infrastructure available as a "cloud service".

The **Cloud4SOA initiative**[9] focuses on resolving the semantic interoperability issues that exist in current cloud platforms and infrastructures and on introducing a user-centric approach for applications which are built upon and deployed using cloud resources. Cloud4SOA aims to enhance cloud-based application development, deployment and migration by semantically interconnecting heterogeneous Platform as a Service (PaaS) offerings across different providers that share the same technology, and will facilitate the access and lifecycle management for cloud-based application developers to the PaaS offering that best matches their computational and business needs.

CONTRAIL[10] promotes an open source system in which resources that belong to different operators are integrated into a single homogeneous federated cloud that users can access seamlessly, through the use of standardised interfaces. According to CONTRAIL’s vision, any organisation should be able to be both a cloud provider when its infrastructure is not used at its maximum and a cloud customer in periods of peak activity.

SITIO[11] gathers several emerging concepts, including SaaS, semantic technologies and business process modelling, in order to foster the dramatic evolution of a new platform oriented towards interoperability and cost reduction which can impact significantly on industry. SITIO can be defined as a Business Process based on Semantics platform where services are executed from a SaaS perspective. It allows external developers to

[8] http://www.reservoir-fp7.eu
[9] http://www.cloud4soa.eu
[10] http://contrail-project.eu
[11] http://innovation-labs.com/sitio/index.php

create add-on applications that integrate into the main SITIO application and are hosted on Cloud Computing infrastructure.

REMICS[12] aims to specify, develop and evaluate a tool-supported model driven methodology for migrating legacy applications to interoperable Service Cloud platforms. For this purpose, REMICS will address the specific architectural patterns and model driven methods for architecture migration, and cover specificities of service clouds development paradigm. Moreover, REMICS focuses on open source meta-models and is actively involved in standardisation.

VENUS-C[13] is building a Cloud Computing platform at the platform as a service level for research and science promoting interoperability of public and private cloud infrastructures and testing it with real application users. There is a wide range of applications ranging from biology, physics, earth sciences and data-intensive marine biodiversity to anti-seismic engineering, social media and forest fire civil protection, thus engaging not only pure research but also governmental and social activities. Regarding cloud providers, there are both public ones (MS Azure) and other private/commercial or open source platforms and toolkits such as OpeNebula and COMP superscalar.

4CaaSt[14] aims to create an advanced PaaS Cloud platform, which supports the optimised and elastic hosting of Internet-scale multi-tier applications. 4CaaSt will embed all the necessary features, easing programming of rich applications and enabling the creation of a true business ecosystem where applications coming from different providers can be tailored to different users, mashed up and traded together.

CumuloNimbo[15] aims to develop a new Platform as a Service, which will provide high scalability without sacrificing data consistency and ease of programming. CumuloNimbo's approach lies in deconstructing transactional processing at fine granularity components and scaling each component in an independent but composable manner.

Cloud-TM[16] aims to define a novel programming paradigm to facilitate the development and administration of cloud applications. It will develop a Self-Optimizing Distributed Transactional Memory middleware that will spare programmers from the burden of coding for distribution, persistence and fault-tolerance, letting them focus on delivering differentiating business value. Further, the Cloud-TM platform aims at

[12] http://www.remics.eu
[13] http://www.venus-c.eu
[14] http://4caast.morfeo-project.org
[15] http://www.cumulonimbo.eu
[16] http://www.cloudtm.eu

minimizing the operational costs of cloud applications, pursuing optimal efficiency via autonomic resource provisioning & pervasive self-tuning schemes.

mOSAIC[17] aims to create, promote and exploit an open-source Cloud API and platform targeted for designing and developing multi-Cloud-oriented applications. mOSAIC's architecture consist of the Resource Broker, responsible for resource negotiation and booking, and the Application Executor in charge of application execution based on the booked resources and negotiated SLAs.

VISION Cloud[18] aims to introduce a powerful ICT infrastructure for reliable and effective delivery of data-intensive storage services, facilitating the convergence of ICT, media and telecommunications. This infrastructure will support the setup and deployment of data and storage services on demand, at competitive costs, across disparate administrative domains, while providing QoS and security guarantees.

StratusLab[19] aims at service provisioning, networking and research of cloud and virtualisation technologies to simplify and optimise the use and operation of existing distributed infrastructures like the European Grid Infrastructure. StratusLab is developing the StratusLab Toolkit, an open source cloud distribution. It incorporates cloud and virtualisation innovation into existing grid infrastructures by integrating cloud technologies and services within grid sites. Further, it enriches existing computing infrastructures with IaaS cloud-like delivery paradigms.

OPTIMIS[20] aims to optimise cloud services, using techniques that take advantage of an OPTIMIS architectural framework and a development toolkit that takes trust, risk, eco-efficiency, cost and legal issues into account. The motivation for OPTIMIS is the vision that hybrid clouds will become commonplace, realised by private clouds interacting with a rich ecosystem of public and other cloud providers. OPTIMIS will enable organisations to automatically externalise services and applications to trustworthy and auditable cloud providers in the hybrid model. ng infrastructures with IaaS cloud-like delivery paradigms.

Attention has to be drawn to the fact that the former list of projects is not exhaustive, but aims at providing an overall rough picture of the research landscape in the field.

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[17] http://www.mosaic-cloud.eu
[18] http://www.visioncloud.eu
[19] http://www.stratuslab.eu/index.php
[20] http://www.optimis-project.eu

Overview of Related Issues & Challenges:

- *The requirement of interoperability is mostly addressed with regard to specific dimensions (e.g. semantic interoperability), indicating that there is still room for a more holistic approach with the regard to the issue at hand.*
- *Approaches focus mainly on federating providers that use the same technology stack, denoting that there is a long way ahead until global interoperability across the cloud is achieved.*
- *The necessity and business value of mashing up applications to develop interoperable cloud services, tailored to different users have to be further highlighted and promoted within research endeavours.*
- *More projects have to get actively involved in Cloud Interoperabiliy standardization.*

4.2 Cloud Interoperability in Application Areas

4.2.1 Broker APIs and Open Cloud Platforms

Even though cloud service providers offer similar services regarding IaaS and PaaS, due to insufficient standardisation each provider offers their own specific API that allows consumers to deploy and manage their cloud infrastructure [21]. The lack of data and application portability leads to vendor lock-ins, as the consumer needs to re-implement the same functionality and transform data to suit the new provider's environment, thus increasing migration costs substantially. As to this, several third parties have developed open source or proprietary cross-platform cloud APIs, in order to reduce the cost of migrating among cloud providers and allow users to deploy applications spanning multiple cloud infrastructures. Such APIs provide a higher level of abstraction through a generic API to access or leverage cloud resources on more than one provider's Cloud Computing platforms.

For instance, the **Apache LibCloud** API[21] is an open-source Python client library that abstracts away differences among multiple cloud provider APIs. Currently, LibCloud allows users to manage cloud server instances, storage engines and load balancers. Another open-source project supported by RedHat, the **DeltaCloud** API[22], abstracts the differences between cloud providers in order to provide a common cloud instance management programming interface, while several similar proprietary solutions for managing cloud deployments among multiple cloud providers have emerged, such as the **Rightscale**[23] **and Enomaly**[24] APIs.

[21] http://libcloud.apache.org
[22] http://incubator.apache.org/deltacloud
[23] http://www.rightscale.com/products/features
[24] http://www.enomaly.com

Furthermore, cloud providers are trying to support Cloud Interoperabiliy and standardisation by releasing open specifications of their APIs. Oracle has contributed the **Oracle Cloud Elemental Resource Model** API[25], a subset of the **Oracle Cloud** API[26], to the Distributed Management Task Force (DMTF) for consideration in DMTF's proposed IaaS Cloud API standard. VMWare has also shown support for open standards by submitting their **vCloud** API[27] to the DMTF. Finally, GoGrid has released the specification of their **OpenSpec** API[28] under a Creative Commons license in order to allow any Cloud Computing provider to build an API based on their specification.

Another approach to guarantee cloud deployment among heterogeneous hardware and virtualisation solutions has been the development of open platforms, which support the creation and management of both private and public clouds.

The most prominent open platform is **OpenNebula**[29], which has been used as a reference open stack for Cloud Computing in several large research and infrastructure projects. OpenNebula provides an open, flexible, extensible, and comprehensive management layer to automate and orchestrate the operation of virtualised data centres by leveraging and integrating existing deployed solutions for networking, storage, virtualisation, monitoring or user management, in order to deploy both private and public clouds. In terms of interoperability, OpenNebula's API supports the creation and control of cloud resources based on the **OGF OCCI** specification[30], as well as **Amazon's EC2** API[31].

Similarly, **OpenStack**[32] is a global collaboration of developers and Cloud Computing technologists producing a ubiquitous open source Cloud Computing platform for public and private clouds. OpenStack consists of two core components; the **OpenStack Compute** which provides the software, APIs and management tools required to orchestrate a Cloud Computing platform, supporting a variety of hardware configurations and virtualisation hypervisors, and the **OpenStack Storage** component which Ois used to create redundant, clustered object storage. In addition to the core projects described above, OpenStack is supported by several unofficial community projects to provide other services, such as load balancing and identity federation.

[25] http://www.oracle.com/us/corporate/press/184426
[26] http://www.oracle.com/technetwork/topics/cloud/oracle-cloud-resource-model-api-154279.pdf
[27] http://communities.vmware.com/community/vmtn/developer
[28] http://www.gogrid.com/about/press-releases/gogrid-moves-cloud-computing-api-to-creativecommons
[29] http://opennebula.org/start
[30] http://occi-wg.org
[31] http://aws.amazon.com/developertools/351
[32] http://www.openstack.org

Finally, VMWare has introduced **CloudFoundry**[33], currently in the beta stage of development, as an open Platform-as-a-Service which will allow developers a choice of frameworks, application infrastructure services and deployment clouds. CloudFoundry aims to enable developers to move applications between environments, between cloud providers and datacentres without modification to the application.

Overview of Related Issues & Challenges:

- *Standardisation of APIs for Cloud Computing is insufficient and has to evolve further.*
- *Currently, there is lack of data and application portability, leading to vendor lock-in.*
- *Open Cloud Platfoms that support cloud deployment over heterogeneous resources are limited.*

4.2.2 Software Requirements and Architecture Analysis/Modelling Frameworks

A Software Requirements Specification (SRS) is a comprehensive description of the intended purpose and environment for software under development[34]. The SRS fully describes what the software will do and how it is expected to perform. According to IEEE standards[35], the basic issues that the SRS writer should address are functionality, external interfaces, performance (in terms of availability, response time, etc.), attributes (in terms of portability, security, etc.) and possible design constraints. For systems consisting of many software elements the system requirements specification also includes the software architecture analysis, i.e. definition of the structure of the system, the externally visible properties of the software elements and the relationships among them[36].

As the service-oriented era is emerging and more and more new technologies are supporting the "service" notion there is an increasing demand for service-oriented modelling, i.e. designing and specifying service-oriented business systems within a variety of architectural styles, such as service-oriented architectures (SOA) and Cloud Computing. The notion of SOA, referring to a flexible set of design principles used during the phases of systems development and integration [22], is itself inherent to Cloud Computing, given the variety of the as-a-service deployment models, as well as the growing trend for developing marketplaces for cloud services based on SOA architectural concepts. As in physical systems, models of the service software and architecture provide abstractions of the system that allow engineers to reason about that system by ignoring extraneous details while focusing on relevant ones. As far as Cloud

[33] http://www.cloudfoundry.org
[34] http://searchsoftwarequality.techtarget.com/definition/software-requirements-specification
[35] http://www.ieee.org
[36] http://www.sei.cmu.edu/architecture/start/moderndefs.cfm

Computing is concerned, the following approaches for architecture analysis and modelling frameworks are distinguished:

The **IBM's Service-Oriented Modelling and Architecture (SOMA)**[37] approach provides modelling, analysis, design techniques, and activities to define the foundations of a SOA. It helps by defining the elements in each of the SOA layers and making critical architectural decisions at each level. It does so using a combination of a top-down, business-driven manner of service identification, coupled with a stream of work that conducts service identification through leveraging legacy assets and systems.

The **Service-Oriented Modelling Framework (SOMF)** [23], authored by Michael Bell, provides a technology-independent notation that encourages a holistic view of enterprise software entities, treated as service-oriented assets, namely services. SOMF introduces a transparency model by enabling three major modelling time frames, often named modelling generations, i.e. *Used-to-Be* (Design scheme of software components and related environments that were deployed, configured, and used in the past), *As-Is* (Design of software components and corresponding environments that are currently being utilised) and *To-Be* (Design of software components and corresponding environments that will be deployed, configured, and used in the future). Moreover, it offers a 360º view of any software development life cycle, starting at the conceptualisation phase, supporting design and architecture activities, and extending modelling best practices for service operations in a production environment. To achieve these underpinning milestones, six distinct software development disciplines offer corresponding models whose language notation guides practitioners in designing, architecting, and supporting a service ecosystem, namely Service-Oriented Conceptualisation Model, Service-Oriented Discovery and Analysis Model, Service-Oriented Business Integration Model, Service-Oriented Logical Design Model, Service-Oriented Software Architecture Model and Cloud Computing Toolbox Model. The latter comprises one of the latest additions to SOMF, the **Cloud Computing Modelling Notation (CCMN)**[38]. This model identifies a cloud as a structural and a contextual entity that can be modelled like any other service in the enterprise. The cloud of services concept in SOMF is driven by the theme "Everything as a Service".

OMG's Model Driven Architecture (MDA)[39] provides an open, vendor-neutral approach which separates business and application logic from the underlying platform technology. Platform independent models of an application or integrated system's business functionality and behaviour can be realised through the MDA on any platform

[37] http://www.ibm.com/developerworks/library/ws-soa-design1/
[38] http://www.modelingconcepts.com/pages/download.htm
[39] http://www.omg.org/mda

including Web Services, .NET[40], CORBA[41], J2EE[42], etc. Four principles underlie the OMG's view of MDA[43]:

- Models expressed in a well-defined notation are a cornerstone to understanding systems for enterprise-scale solutions.
- The building of systems can be organised around a set of models by imposing a series of transformations between models, organised into an architectural framework of layers and transformations.
- A formal underpinning for describing models in a set of meta models facilitates meaningful integration and transformation among models, and is the basis for automation through tools.
- Acceptance and broad adoption of this model-based approach requires industry standards to provide openness to consumers, and foster competition among vendors.

To support these principles, the OMG has defined a specific set of layers and transformations that provide a conceptual framework and vocabulary for MDA. Notably, OMG identifies four types of models: Computation Independent Model (CIM), Platform Independent Model (PIM), Platform Specific Model (PSM) described by a Platform Model (PM), and an Implementation Specific Model (ISM).

The models are built by using OMG’s associated modelling standards and mainly UML[44], which is a standard that can be used for analysis, design, and implementation of software-based systems as well as for modelling business and similar processes and therefore can be used to create software architecture. The UML, along with the Meta Object Facility (MOF[45]), a specification where models can be exported from one application, imported into another, transported across a network, stored in a repository, retrieved, rendered into different formats, transformed and used to generate application code, provide the key foundation for MDA.

Research Challenges:

- *Current approaches to software requirements and architecture analysis/modelling frameworks show limited pertinence to the context of Cloud Computing, and present therefore a low degree of application to it.*

[40] http://msdn.microsoft.com/en-us/netframework
[41] http://www.corba.org
[42] http://java.sun.com/j2ee/overview.html
[43] http://www.ibm.com/developerworks/rational/library/3100.html
[44] http://www.uml.org/
[45] http://www.omg.org/mof

4.2.3 Service Front-Ends and Services Mashups Engines

Mash-ups are an other innovative concept that was born as a result of the prevalence of a new and elaborate vision for next-generation services provided via the Internet, known as the "Internet of Services" [24]. The key idea of Mash-ups is that arbitrary third party users can combine services from different vendors and provide completely new usage scenarios that were not originally foreseen by the developers of the contributing services [25]. Mashups simplify the development of new services by simplifying their composition: in most cases they adapt the pipes and filter approach to work with web services. Each component is a REST-style web service that can "consume" one or more REST-style web services and produces an XML-based output stream. This way, a number of these services can be combined together to form a processing chain.

The first known mashup began with the API provided by Google for Google Maps and then Google Earth. Google but also Amazon, eBay and others, made available gradually thousands of APIs, transforming the Web in a large platform for collaborative development and information sharing. Knowing the success that the mashup approach encountered, and the business benefits it may generate, it's easy to understand why editors and major software players took interest in this business. Indeed, mashups imply no complex coding, are quick to adapt to frequent changes, and would be able to address the "long-tail" of users needs.

Environments to build and deploy mashups multiplied then, driving to more sophistication, security and access control enhancement. Also, the scope of mashup composition widened, introducing the concept of "process" in the theoretical capabilities of mashup assembly. Consequently, the mashup definition evolved, and the so called "Process Mashup" was added next to the concept of "SOA orchestration". Currently, editors offer to "draw workflow" with mashup composer. Cordys[46] promotes "process-centric" mashup, while Convertigo[47] claims that its Enterprise Mashup Server allows "business process orchestration".

Given the new broader scope of the concept, the are three kinds of mashups that one can distinguish:

- Presentation mashups, where composition is made at user interface level. Interactions between data from different sources and services calls can be configured.
- Data mashups, where data is retrieved from different sources and systems. Tools offering this type of composition have to include connectors for a wide range of existing data sources as well as mash mechanisms like "join", "filter".

[46] http://www.cordys.com
[47] http://www.convertigo.com

- Process workflow mashups, where different web services are called and orchestrated to create a composite application. The resulting application can be either provided as a web service, if back-end processes are being defined, or exposed as a standalone application.

In the context of Cloud Computing, the mashup approach aspires to guide the development of modelling and management tools that will allow to design cloud applications from a set of available services. Such tools need to provide service repositories where already developed and deployed services will be available, as well as a design platforms for developing new applications, using the already available ones as building blocks.

Research Challenges:
- *Process design editors are solely available in classical desktop integrated development environments (IDE), thus not being cloud-enabled.*
- *Mashup editors are not integrated with service repositories.*
- *Service mashups do not allow deploying applications to the cloud.*

4.2.4 Security, Trust and Authentication Frameworks and the Cloud

Security, trust and authentication are normally a series of attributes that are critical for almost all kinds of services and software systems, apparently including cloud deployments as well, where security and privacy requirements are particularly high. The imperative to ensure security, trust and authentication in services and systems deployments is reflected in the relevant standardisation initiatives, which although limited, have to demonstrate some samples of work that touch upon the notion of the cloud in particular.

The **Cloud Security Alliance (CSA)**[48] is the most active organisation, dealing specifically with cloud security issues. CSA is a non-profit organisation with a mission to promote the use of best practices for providing security assurance within Cloud Computing, and to provide education on the uses of Cloud Computing to help secure all other forms of computing. CSA has undertaken a number of research initiatives, such as:

- The **Cloud Security Alliance GRC Stack**[49], that provides a toolkit for enterprises, cloud providers, security solution providers, IT auditors and other key stakeholders to instrument and assess both private and public clouds against industry established best practices, standards and critical compliance requirements.

[48] https://cloudsecurityalliance.org
[49] https://cloudsecurityalliance.org/research/grc-stack

- The **Security Guidance for Critical Areas of Focus in Cloud Computing**[50], that provides security practitioners with a comprehensive roadmap for being proactive in developing positive and secure relationships with cloud providers.
- The **Trusted Cloud Initiative**[51], that helps cloud providers develop industry-recommended, secure and interoperable identity, access and compliance management configurations, and practices. The Initiative targets the development of reference models, education, certification criteria and a cloud provider self-certification toolset, in a vendor-neutral manner.
- **CloudAudit**[52], that aims to provide a common interface and namespace that allows Cloud Computing providers to automate the Audit, Assertion, Assessment, and Assurance (A6) of their IaaS, PaaS, and SaaS environments and allow authorised consumers of their services to do likewise via an open, extensible and secure interface and methodology.

The OASIS **Identity in the Cloud Technical Committee**[53] works to address the serious security challenges posed by identity management in Cloud Computing. The TC identifies gaps in existing identity management standards and investigates the need for profiles to achieve interoperability within current standards. It performs risk and threat analyses on collected use cases and produces guidelines for mitigating vulnerabilities.

The NIST Computer Security Division has published a draft of the **Guidelines on Security and Privacy in Public Cloud Computing**[54], which provides an overview of the security and privacy challenges for public Cloud Computing and gives recommendations that organisations should consider when outsourcing data, applications, and infrastructure to a public cloud environment.

Finally, the **Open Data Center Alliance** has published two Usage Models[55] relating to cloud security federation. The Security Monitoring Usage Model requests that the industry develop and drive adoption of a standard interface that permits the organisation subscribing to the cloud services, to query the actual security status of specific elements of a provider's services, while the Producer Security Assurance Usage Model seeks to define requirements for standardised definitions of security levels within the cloud.

Research Challenges:

- *Standardisation on security, trust and authentication frameworks for the cloud is rather limited.*
- *The few existing standardisation approaches for cloud security, trust and authentication are uncoordinated.*

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[50] https://cloudsecurityalliance.org/research/security-guidance
[51] https://cloudsecurityalliance.org/research/tci
[52] http://cloudaudit.org/CloudAudit/Home.html
[53] http://www.oasis-open.org/committees/tc_home.php?wg_abbrev=id-cloud
[54] http://csrc.nist.gov/publications/drafts/800-144/Draft-SP-800-144_cloud-computing.pdf
[55] http://www.opendatacenteralliance.org/ourwork/usagemodels

- *Security and trust standards are too generic and do not sufficiently address the notion of interoperability.*

5 Cloud Interoperability Standardisation

Standardisation bodies, non-profit groups and member-operated organisations have initiated several standardisation efforts in order to address interoperability and portability issues in the cloud. However, as standardisation efforts are very recent, very few standards have currently been approved or show wide market adoption. In addition to that, these efforts seem to have been working independently and not in a coordinated manner, while they have been either too generic or too specific, resulting thereby in frameworks that have weak ties with each other, and failing to provide a common reference point which could be used as the ground for the development of more specific, yet intrinsically correlated solutions. As a result, standardisation by itself does not provide a solution to the issues stated above; adhering to standards, and more specifically leveraging existing and commonly used standards where possible, and developing new only when needed, are keys to accelerating the development of a Cloud Computing environment that can satisfy the interoperability and portability needs of the widest possible range of cloud consumers and providers. In this frame, awareness of the state of play with regard to standardisation initiatives in the area of Cloud Computing is quite significant. The most important standardisation efforts and the corresponding standardisation frameworks are presented in the following paragraphs.

To meet interoperability requirements, stakeholders should use whenever possible existing cloud specifications and standards that are known to work for several critical use cases, that can be easily used by cloud service providers and consumers, and that are extensible.

One of the first cloud standardisation efforts is the Open Grid Forum's **Open Cloud Computing Interface (OCCI)**[56] that comprises a set of open community-lead specifications delivered through the Open Grid Forum. OCCI is a Protocol and API for all kinds of management tasks. OCCI was originally initiated to create a remote management API for IaaS model based Services, allowing for the development of interoperable tools for common tasks including deployment, autonomic scaling and monitoring. It has since evolved into a flexible API with a strong focus on integration, portability, interoperability and innovation while still offering a high degree of extensibility. The current release of the Open Cloud Computing Interface is suitable to serve many other models in addition to IaaS, including e.g. PaaS and SaaS.

[56] http://occi-wg.org

The Distributed Management Task Force (DMTF) has developed the **Open Virtualisation Format (OVF)**[57], a packaging standard designed to address the portability and deployment of virtual appliances. OVF enables simplified and error-free deployment of virtual appliances across multiple virtualisation platforms. Several virtualisation providers, including IBM, VMWare and Oracle have adopted the standard.

Furthermore, DMTF has introduced the **Open Cloud Standards Incubator** and the **Cloud Management Working Group**[58] focusing on standardizing interactions between cloud environments by developing specifications that deliver architectural semantics and implementation details to achieve interoperable cloud management between service providers and their consumers and developers.

The **Cloud Computing Interoperability Forum (CCIF)**[59] was formed in order to enable a global Cloud Computing ecosystem whereby organisations are able to seamlessly work together for the purposes of wider industry adoption of Cloud Computing technology and related services. CCIF's Unified Cloud Interface Project[60] is an attempt to create an open and standardised cloud interface for the unification of various cloud APIs, as a singular programmatic point of contact that encompasses the entire infrastructure stack as well as emerging cloud centric technologies all through a unified interface. The unified cloud interface is achieved through the use of the resource description framework (RDF) to describe a semantic cloud data model (taxonomy & ontology).

The **Cloud Data Management Interface**[61], developed by the Storage Networking Industry Association, defines the functional interface that applications will use to create, retrieve, update and delete data elements from the Cloud. As part of this interface the client will be able to discover the capabilities of the cloud storage offering and use this interface to manage containers and the data that is placed in them. In addition, metadata can be set on containers and their contained data elements through this interface. This interface is also used by administrative and management applications to manage containers, accounts, security access and monitoring/billing information, even for storage that is accessible by other protocols. The capabilities of the underlying storage and data services are exposed so that clients can understand the offering.

The **Open Data Center Alliance**[62], formed in 2010, is an independent organisation that intends to speed the migration to Cloud Computing by enabling the solution and service

[57] http://www.dmtf.org/standards/ovf
[58] http://dmtf.org/standards/cloud
[59] http://www.cloudforum.org
[60] http://code.google.com/p/unifiedcloud
[61] http://www.snia.org/cdmi
[62] http://www.opendatacenteralliance.org

ecosystem to address IT requirements with the highest level of interoperability and standards. The Alliance has adopted a usage model approach to define and share their priorities with standards bodies, solution providers, and the industry at large. So far, eight Open Data Center Usage Models have been published, focusing on secure cloud federation, automation of cloud infrastructure, common management, and transparency of cloud service delivery.

The TM Forum's **Cloud Services Initiative**[63] aims to stimulate growth of a vibrant and open marketplace for cloud services by bringing together the entire eco-system of enterprise customers, cloud service providers and technology suppliers to remove barriers to adoption based on industry standards. Furthermore, the **Enterprise Cloud Leadership Council (ECLC)**[64] seeks to accelerate the effective adoption of Cloud Computing on a global scale. ECLC aims to accelerate standardisation and commoditisation of cloud services, enable benchmarking and achieve transparency of cost, service levels and reporting across the ecosystem.

The Object Management Group's **Cloud Standards Customer Council**[65] is an end user advocacy group dedicated to accelerating cloud's successful adoption, and drilling down into the standards, security and interoperability issues surrounding the transition to the cloud. The Council will provide cloud users with the opportunity to drive client requirements into standards development organisations and deliver materials such as best practices and use cases to assist other enterprises.

The **European Telecommunications Standards Institute (ETSI)**'s TC CLOUD (previously TC GRID) aims to address issues associated with the convergence between IT (Information Technology) and Telecommunications. The focus is on scenarios where connectivity goes beyond the local network. This includes not only Grid computing but also the emerging commercial trend towards Cloud Computing which places particular emphasis on ubiquitous network access to scalable computing and storage resources. Since TC CLOUD has particular interest in interoperable solutions in situations which involve contributions from both the IT and Telecom industries, the emphasis is on the Infrastructure as a Service (IaaS) delivery model. TC CLOUD focuses on interoperable applications and services based on global standards and the validation tools to support these standards. Evolution towards a coherent and consistent general purpose infrastructure is envisaged. This will support networked IT applications in business, public sector, academic and consumer environments.

[63] http://www.tmforum.org/EnablingCloudServices/8006/home.html
[64] http://www.tmforum.org/EnterpriseCloudBuyers/8009/home.html
[65] http://www.cloud-council.org

The **Cloud Industry Forum**[66] was established in 2009 to provide transparency through certification to a Code of Practice for credible online Cloud service providers and to assist end users in determining core information necessary to enable them to adopt these services.

The **SIENA Initiative**[67] will contribute to defining a future eInfrastructures roadmap focusing on interoperability and standards, in close collaboration with the European Commission, Distributed Computing Infrastructures (DCI) projects and Standard Development Organisations (SDOs) to gain an in-depth understanding of how distributed computing technology is being developed in this context. The roadmap will define scenarios, identify trends, investigate the innovation and impact sparked by cloud and grid computing, and deliver insight into how standards and the policy framework is defining and shaping current and future development and deployment in Europe and globally.

The **Open Cloud Consortium**[68] supports the development of reference Cloud Computing implementations, benchmarks and standards, such as the **MalStone Benchmark**[69], as well as frameworks for interoperation between different Cloud Computing providers. The Working Group on Standards and Interoperability for Large Data Clouds focuses on developing standards for the interoperation of cloud data infrastructures.

The **Open Group Cloud Work Group**[70] exists to create a common understanding among buyers and suppliers of how enterprises of all sizes and scales of operation can include Cloud Computing technology in a safe and secure way in their architectures to realise its significant cost, scalability and agility benefits. It includes some of the industry's leading cloud providers and end-user organisations, collaborating on standard models and frameworks aimed at eliminating vendor lock-in for enterprises looking to benefit from cloud products and services.

The **Global Inter-Cloud Technology Forum**[71] aims to promote standardisation of network protocols and the interfaces through which cloud systems interwork with each other, and to enable the provision of more reliable cloud services than those available today.

[66] http://www.cloudindustryforum.org
[67] http://www.sienainitiative.eu
[68] http://opencloudconsortium.org
[69] http://code.google.com/p/malgen/wiki/Malstone
[70] http://www.opengroup.org/cloudcomputing
[71] http://www.gictf.jp/index_e.html

The Organisation for the Advancement of Structured Information Standards (OASIS) sees Cloud Computing as a natural extension of SOA and network management models, and has been committed to building Cloud models, profiles, and extensions on existing standards. The OASIS **Symptoms Automation Framework (SAF) TC**[72] is a catalogue-based XML collaborative knowledge framework that is designed to address these challenges by automating appropriate responses to changing business conditions and integrating contributions from diverse domains to provide competitive advantage. SAF facilitates knowledge sharing, allowing consumer and provider to work cooperatively together to ensure adequate capacity, maximise quality of service, and reduce cost. The SAF technical committee considers Cloud Computing to be an area where the value of existing and developing standards could be significantly enhanced using SAF.

Finally, IEEE currently has two interoperability-related standards under active development:

- **P2301 - Guide for Cloud Portability and Interoperability Profiles (CPIP)**[73]. This guide advises Cloud Computing ecosystem participants (cloud vendors, service providers, and users) of standards-based choices in areas such as application interfaces, portability interfaces, management interfaces, interoperability interfaces, file formats, and operation conventions. This guide groups these choices into multiple logical profiles, which are organised to address different cloud personalities.
- **P2302 - Standard for InterCloud Interoperability and Federation (SIIF)**[74]. This standard defines topology, functions, and governance for cloud-to-cloud interoperability and federation. Topological elements include clouds, roots, exchanges (which mediate governance between clouds), and gateways (which mediate data exchange between clouds). Functional elements include name spaces, presence, messaging, resource ontologies (including standardised units of measurement), and trust infrastructure. Governance elements include registration, geo-independence, trust anchor, and potentially compliance and audit. The standard does not address intra-cloud (within cloud) operation, as this is cloud implementation-specific, nor does it address proprietary hybrid-cloud implementations.

[72] http://www.oasis-open.org/committees/tc_home.php?wg_abbrev=saf
[73] http://standards.ieee.org/develop/project/2301.html
[74] http://standards.ieee.org/develop/project/2302.html

6 Cloud Computing as the base for new business models

6.1 Cloud Business Models

With its emerging and evolving business models for delivering innovative, feasible, IT-based solutions [17, 26], Cloud Computing differs from previous computing paradigms, while it is staking a growing presence on the market. So far, we have witnessed the emergence of ***"as-a-service" business models*** empowered by cloud technologies through transforming conventional IT services into business value. Such "as-a-service" paradigm shifts are taking place anywhere. The successes of leading public Cloud Service Providers (CSPs), such as Google, Amazon, and Microsoft, act as a major catalyst in development of the "IaaS/PaaS" market and also as the technological foundation for Cloud Computing. Traditional enterprise software vendors are also struggling and making huge attempts to transform on-premise offerings to customers in the "Software-as-a-service" form. These emerging new business models in the IT market are giving rise to completely new value added networks that offer customers new sourcing options.

IaaS offers infrastructure-based services directly to the needs of customers where customers are charged according to the actual usage. ***PaaS*** offers programming and runtime environments for customers to create, debug, and deploy Cloud Computing applications. ***SaaS*** offers cloud-ready application services with flexible pricing models. From a value-chain perspective, the fundamental Cloud Computing structure with the elements, IaaS, PaaS, and SaaS, can be perceived as certain market places, where Cloud Computing resources can be integrated and offered to customers.

Strategic Trends in Cloud Computing

- ✓ Through 2012, IT organizations will spend more on private Cloud Computing investments than on offerings from public cloud providers.
- ✓ Starting in 2014, spending on external cloud services will accelerate as these offerings mature to address business concerns.
- ✓ By 2014, the cloud services broker vendor landscape will have grown from dozens to hundreds of providers.
- ✓ By 2014, Cloud Computing experience will be a listed or demanded skill in most hiring decisions for IT software projects.
- ✓ By 2015, 50% of all new application independent software vendors will be pure software-as-a-service providers.
- ✓ Through 2015, more than 90% of private Cloud Computing deployments will be for infrastructure as a service.
- ✓ By 2015, 50% of Global 1000 enterprises will rely on external Cloud Computing services for at least one of their top 10 revenue-generating processes.
- ✓ By 2016, all Global 2000 companies will use some level of public cloud services.
- ✓ Through 2020, the most common use of cloud services will be a hybrid model combining on-premises and external cloud services.

Source: Gartner

Current "as-a-service" offerings though, set simply the starting point for developing feasible Cloud Computing business models. According to Gartner [27], by 2014 , the cloud services broker vendor landscape will have grown from dozens to hundreds of providers, while with this year as a starting point spending on external cloud services will accelerate as these offerings will gradually mature to address business concerns. Additionally, by 2015, 50% of all new application independent software vendors will be pure software-as-a-service providers, while through 2020, the most common use of cloud services will be a hybrid model combining on-premises and external cloud services.

It is worth noting that the Cloud Computing landscape is still very unstructured, with different actors seeking their market places and business models alongside the evolution of a Cloud Computing paradigm. In addition to the three identified business models in the Cloud Computing market, i.e. IaaS, PaaS, and SaaS, and consequently, the corresponding service providers, recent studies [28, 29] envision new opportunities to integrate individual component services to create value-added services, giving rise to new roles that can be found in Cloud Computing from a value chain perspective.

Figure 6-1: Cloud Computing Value Chain

As described in Figure 5-1 aggregate service providers, a.k.a. ***aggregators***, will combine existing cloud services in the market and offer new services with added value to customers. ***Integrators***, having a similar role, will deliver added value by providing system integration, business process integration, or service mediation to customers. ***Consulting actors*** will also take advantage of the emerging opportunities, in order to offer to business analysis, vendor and performance management services, as companies will shrink their IT departments and rely on external Cloud Computing services for several of their operations. It is envisioned that all these emerging active cloud players will enhance partnership relations or cloud federations and eventually contribute to the cloud ecosystem.

Last but not least, the emergence of new business models will also be characterized by a shift from the provision of ***capacity on demand*** to the provision of ***capability on demand***, transforming the way enterprises deliver and consume technology solutions [30]. Such a shift will on the one side enable IT organisations that have mastered the delivery of complex business processes as customisable services, such as the supply chain management, to deliver these services through the cloud, being therefore able to compete with software vendors, offering only software and tools, and allow on the other side less IT-savvy enterprises to buy and apply several capabilities without needing access to the IT skills, required with respect to software, while also avoiding vendor lock-in and the high price of software maintenance contracts.

As a result, the evolving cloud paradigm will create a diversity of market opportunities for new cloud players to find their position in the value chain and to define appropriate business models to offer value-added services to customers with benefits to each.

6.2 Towards adopting new business models

Existing cloud business models are dominated by heavyweight cloud innovators based on bulk services and proprietary architectures, which isolates cloud services from different Cloud Service Providers (CSP) and breaks the value chain of a cloud ecosystem. Instead of volume-based business models that provide monolithic cloud service offerings, the basis for successful cloud business models is partnership relations founded on open security and trusted cloud environments. This vision can be better understood using Jericho Forum's Cloud Cube Model (CCM) [31], which differentiates cloud formations from each other and the manner of their provision using four-dimensional criteria:

- **External (E) or Internal (I)** – defines the physical location of the data, i.e. inside or outside organisation boundaries.
- **Proprietary (P) or Open (O)** – defines the state of ownership of the cloud technology, services, interfaces, where proprietary means that the cloud service providers keep the means of provision under their control, while open service means there are likely to be more suppliers and customers able to share data and collaborate with selected parties using the same open protocols.
- **Perimeterised (Per) or De-perimeterised (Dep)** – represents the "architectural mindset", i.e. operating inside or outside the traditional IT perimeter. Perimeterised environment implies continuing to operate within the traditional IT perimeter, often signalled by "network firewalls". In a de-perimeterised environment an organisation can collaborate securely with selected parties.
- **Outsourced (O) or Insourced (I)** – as the fourth dimension refers to primarily a policy issue or a business decision on whether would run its own cloud service or outsource to third parties. This 4th dimension is coloured differently in the CCM.

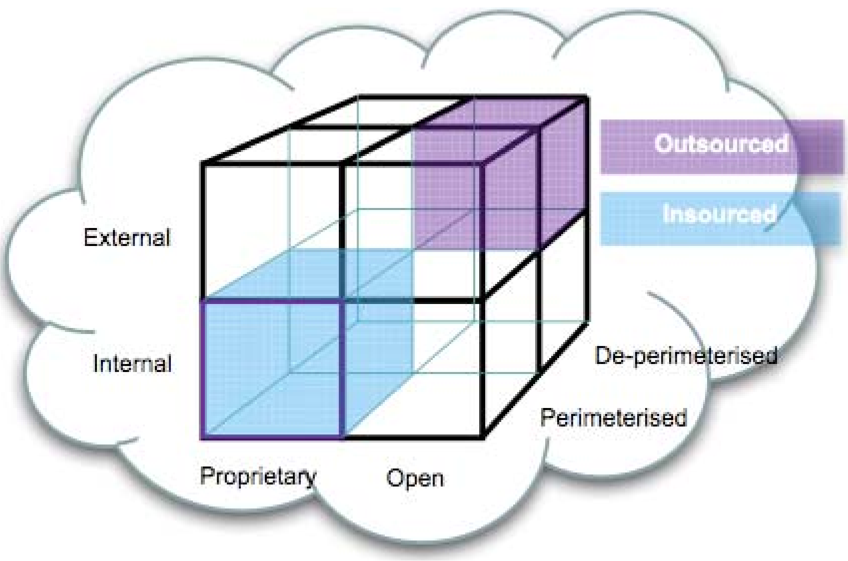

Figure 6-2: Cloud Cube Model

Most existing cloud service providers defined their business models to deliver cloud services in the left side of the cube model by limiting the means of migrating from the proprietary domain or continuous innovation that adds value. Moving from left-side cloud forms to right-side cloud forms will necessitate such new stages as cloud service aggregation and system integration in the value chain. New business models can be created by linking, sharing, and combining services within the entire Cloud Computing ecosystem. However such movement cannot be made unless several key issues are solved.

Existing cloud business models hamper cloud adoption and ruin the cloud ecosystem by limiting cloud choice because of vendor lock-in, portability, ability to use cloud services from multiple vendors, and seamless integration to customers' resources of their own data centre. A trusted and secure framework is also critical to success in enabling large-scale collaboration and system integration across multiple organisations over the cloud. Finally Service Level Agreements (SLAs) play an important role where end-to-end SLAs between customer and cloud service providers as well as between cloud service providers in the cloud ecosystem are met in terms of availability, performance, and scalability.

7 Taking up Cloud Computing initiatives/ventures

Given the plethora of capabilities offered and the wide range of new business models associated with it, the Cloud Computing paradigm is frequently considered by organisations as one of the most attractive routes for promoting innovation and thereby advancing their business strategy through the delivery of new or added value services, as well as the best solution for enhancing particular aspects of their business, such as optimising IT assets or improving the supply chain performance.

According to Gartner [32], organizations seeking to move applications to the cloud have five options from a practical perspective: re-host on infrastructure as a service (IaaS), refactor for platform as a service (PaaS), revise for IaaS or PaaS, rebuild on PaaS, or replace with software as a service (SaaS). However, none of these options offers a silver bullet, as all of them, have their own advantages, but also disadvantages that cannot be neglected and several of which (e.g. vendor lock-in, inconsistent data semantics, data access issues, scalability barriers etc.) derive due to the lack of interoperability, involved in the first place, i.e. in the actual deployment of the required services. It is worth noting though that interoperability stands, along with workload/data portability, security and privacy and adherence to standards, as one of the key requirements for successful Cloud Computing deployments, as well as that the former requirements and the standards that help to meet them apply equally across all cloud variations, i.e. whether an organisation is moving an application from its own infrastructure to the cloud, or from one cloud (public/private) to another [33].

Given the compound nature of interoperability and the multitude of aspects that it affects, the decision to move applications to the cloud is already a complex one and requires decision makers to understand application migration from multiple aspects and criteria, such as IT staff skills, the suitability of existing technology investments in relation to the cloud, the application architecture etc. On top of that, the decision in question is not solely a cloud-migration issue, but is truly one of optimisation and as such it needs to be approached in the broader context of application or infrastructure portfolio management programs [32], so as to be in line with and to contribute to the organisation's business and IT goals.

Therefore, beside thorough knowledge of the state of play in Cloud Computing and thereby Cloud Interoperability, any cloud-migration decision requires considering in parallel economic, risk and business enablement issues. In this context, in the following paragraphs we provide a set of migration scenarios and a series of guidelines that generally apply when considering taking up Cloud Computing ventures in order to either attract innovation or optimise various aspects of an organisation's operation.

7.1 Cloud Computing Migration Scenarios

In an effort to set the context for understanding evolving needs as customers move to Cloud Computing, and to identify the technical capabilities and degree of standardization required across cloud environments to meet those needs, the Cloud Computing work stream of the Interoperability Executive Customer (IEC) Council, established by Microsoft, identifies ten of the most common Cloud Computing migration scenarios. These scenarios are platform-centric as far as the lifecycle of a cloud application is concerned, i.e. they refer to building, porting and maintaining cloud application on top of IaaS or PaaS cloud platforms and enumerate in growing complexity the following cases:

- Moving three-tier application from on-premises to cloud
- Moving three-tier cloud application to another cloud
- Moving part of on-premises application to cloud to create "hybrid" application
- Hybrid application with shared user ID and access services
- Moving hybrid application to another cloud with common infrastructures
- Hybrid cloud application that uses platform services
- Porting cloud application that uses platform services to another cloud
- Creating cloud application with components that run on multiple clouds
- Cloud application workload requiring use of multiple clouds (cloudburst)
- "Shopping around" for cloud services scenario

> ***Interoperability**, **workload/ data portability**, **security and privacy** and **adherence to standards** are the key requirements for successful Cloud Computing deployments. These requirements apply equally across all cloud variations, i.e. whether an organisation is moving an application from its own infrastructure to the cloud, or from one cloud (public/private) to another.*
>
> *IEC Council, Microsoft*

7.2 Generic Recommendations

As already discussed, cloud migration scenarios are frequently considered by eneterprises as a strategic alternative either for pursuing innovation or for enhancing particular aspects of their business. Although, a cloud migration decision is quite complex and needs to be examined under the particular conditions that concern the enterprise's needs, market position and competitive environment, a set of generic recommendations to start with, directed towards business, technology and economic issues may provide a fertile ground for further and deeper considerations.

7.2.1 Pursuing Innovation (recommendations for prospective cloud service providers)

The emergence of new cloud business models and more specifically the arrival of capability of demand as an emerging trend that accompanies these models, are leading businesses to consider new strategic options. Enterprises that will take advantage of the new capability on demand models, hold the potential to come across new business opportunities and to become full-blown profit centers. Proper preparation to be in position to reap the benefist of these business opportunities, requires decision makers to:

<u>Business perspective:</u>

- ✓ Understand what Cloud Computing is, how it will evolve and under what circumstances it can offer value.
- ✓ Identify scenarios where the adoption of Cloud Computing is likely to promote innovation.
- ✓ Explore how these scenarios will affect your business, i.e. identify their impact on business goals and risks.
- ✓ Investigate how these scenarios will affect the strategy and direction of IT.
- ✓ Examine your organisation's promptitude and preparedness to adapt to the changes and exploit the innovation.
- ✓ Identify concrete ways and prepare plans to adopt and use this innovation.

<u>Technology perspective:</u>

- ✓ Determine the current and future technologies that apply to this innovation.
- ✓ Decide whether it is more appropriate to build exclusively a private Cloud Computing environment or use external services as well. If so, explore the most important vendors offerings and investigate how IT will secure, manage and govern cloud services (workloads and data) across a hybrid environment (read more under the technology perspective in section 7.2.2).
- ✓ Build your service environment using existing standards and specifications that are known to work and already in widespread use accounting for interoperability, in order to offer prospective consumers' a choice in tools, languages and runtimes and to enable them leverage the IT staff's current skills and existing investments.
- ✓ When conforming to a particular standard, cite its specific version and publish the implementation details, errata, testing notes that concern the offered services, to provide the transparency necessary for informed consumer choice.

Economic perspective:

- ✓ Estimate the acquisition, setup and configuration, data and application migration, training and operational costs related to your venture.

7.2.2 Optimising the Enterprise's IT Assets and Business Processes (recommendations for prospective cloud service consumers)

Leveraging cloud services to improve business process performance is driven by the business goals of increasing revenue opportunities or market share, decreasing costs and enabling business, and requires aligning and prioritizing investment in internally and externally managed technologies and services, as well as considering security risks and data ownership issues. In view of optimising business processes, decision makers and executives are advised to:

Business (benefit/risk) perspective:

- ✓ Identify the enterprise's short- and medium term needs (for a time window of approximately ten years) and set the corresponding optimisation goals.
- ✓ Examine whether the organisation is ready to adopt cloud services and determine where there is value in migrating applications to the cloud and where there are opportunities to create new cloud-optimised applications.
    - o Identify current business processes (e.g. planning, manufacturing, logistics, sourcing, supplier management, customer relationship management etc.) that would benefit from a Cloud Computing style of architecture and deployment.
    - o Identify mission-critical internal processes – or parts of internal processes – that are not conducive to Cloud Computing either due to data sensitivity or unacceptable degree of latency between the cloud service and the organisation's operation.
- ✓ Examine which models, architectures, technologies and IT organization best practices from Cloud Computing best serve the organisation's goals (e.g. private cloud versus public cloud, IaaS, PaaS, SaaS etc.).
- ✓ Explore the vendor offering on cloud services in the application area of your interest.
- ✓ Determine how these services will meet business needs.
- ✓ Carefully assess their risks (e.g. vendor viability, security and business continuity issues) and benefits (e.g. speed, ease of use and pricing).

Technology perspective:

- ✓ Explore the vendor offering on cloud services in the application area of your interest.
- ✓ Explore in particular the security and privacy capabilities provided by the vendor (including data confidentiality).

- ✓ Investigate data portability, integrity and interoperability issues (e.g. capability to move data from one service provider to another or manage the activity internally, by reliably deleting it at the same time from the old service provider).
- ✓ Work closely with the IT organization and pay attention to important issues such as enterprise integration, to ensure interoperability and seamless cooperation between cloud services and existing internal applications if needed.
- ✓ In the same context, and provided that the vendor or service provider claims conformance to a given standard or specification, request information on the specific version of the standard, the implementation details of any ambiguous or optional portions of the specification, errata documents describing any bugs or issues with the implementation, and results of interoperability conformance tests.

Economic perspective:

- ✓ Scrutinize the pricing terms and conditions and service-level agreements (SLAs) offered by the cloud service providers to avoid unexpected future costs.
- ✓ Estimate the acquisition, setup and configuration, data and application migration, training and operational costs.
- ✓ Calculate and compare the cumulative costs for both on-premises and cloud solutions over a time horizon that reflects the application replacement cycle for the specific area of application applications.
- ✓ Estimate the actual financial benefits, including cash flow, investment amortization and savings from reducing over-/undercapacity usage from running applications and business processes in the own premises for the same time horizon.
- ✓ Consort with a well-defined contract that establishes service levels and controls for data access and usage to mitigate remaining risks.

8 Towards Cloud Interoperability: The Greek Interoperability Centre's Vision

The dawn of a new era that highlights service creation and delivery as its principal ingredient, has started to influence the public and the private sector who now need to drive services towards Future Internet advancements. Future Internet holds the potential to take computing to environments never experienced before, offering to public bodies, businesses and consumers unlimited transfer speeds, enormous storage repositories, uncountable personalised and extendable applications and services, and in overall a complete new user experience in terms of both quantity and quality of information.

In this context, Cloud Computing, being one of Future Internet advancements, is fast evolving from a futuristic technology into a commercially viable alternative for organisations and companies in search of cost-effective storage and server solutions, as well as flexible and customisable mashable applications, while in combination with profound changes in the nature of technology, including Web 2.0, it is giving rise to powerful new models of doing business. Such models are predominantly based on network collaboration, self-organisation, service cogeneration and openness rather on vertical hierarchy and central control. Organisations that will take advantage of the solutions offered by Cloud Computing and will dive into the yet unexplored waters of these new models, will indisputably be from the very beginning, in position to gain competitive advantage or even establish themselves as core players in emerging business domains.

An essential precondition however for these developments to come about, is to deal beforehand with everlasting issues that hold back progress, one of them being interoperability. In order to achieve more specifically the desired degree of flexibility and collaboration, avoiding thereby the fragmentation of solutions that can lead eventually in unfriendly, unusable and deprecated systems, it is essential to agree upon and apply a set of common interoperability rules.

> ***GIC vision towards Cloud Interoperability*** *lies in elevating at at the cloud level the already acquired knowledge of the best of breed Interoperability Frameworks and of the major advancements in Enterprise Interoperability science, with the aim of developing and standardising a* ***Cloud Interoperability Framework****.*

In line with existing practices to promote interoperability of legacy and conventional enterprise architecture systems and departing from the current advances in Interoperability Science and Cloud Computing, the vision of the Greek Interoperability Centre towards achieving Cloud Interoperability lies in developing and standardising a *Cloud Interoperability Framework* that will support and guide the design, development, deployment and governance of services on top of cloud infrastructures towards an interoperable services environment that will utilise the complete power of the cloud with no restraining rules.

Such a Framework should be built upon the principles of visibility, reusability, security and data and process alignement and should exploit the knowledge of the most well known and successful interoperability frameworks - such as the European Interoperability Framework (EIF)[75], the Belgian Interoperability Framework[76], the United Kingdom's Interoperability Framework (UK eGIF)[77], the German Interoperability Framework (SAGA)[78], the Estonian Interoperability Framework[79], the Greek eGovernment Interoperability Framework (GR eGIF)[80], etc. – elevating the formers' recommendations and practices to the level of the cloud.

Indicatively, and in accordance to the structure of existing frameworks, the main ingredients of such a tool for promoting interoperability on the cloud would be:

- *A Cloud Interoperability Reference Architecture.* Typically an interoperability framework includes:
    i. standardised models for the most important services that are present in B2B, B2G, G2C, etc. transactions, based on enterprise and business process modelling methodologies,
    ii. data schema and meta-schemas for documenting common information that is shared by all services, mostly using XML representations and structures that could be utilised by the systems with no further modifications
    iii. technical specifications and designs for interoperability middleware solutions, where the common requirements for all systems and platforms are taken into consideration and the required interfaces and processing nodes are designed.

  A Cloud Interoperability Reference Architecture should be the core component of a Cloud Interoperability Framework, containing all the necessary information with regard to service development and deployment, ranging from ready-to-use and to-adopt metadata models and common XML libraries, code lists and core components published by European and International standardisation

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[75] European Interoperability Framework. Available at: http://ec.europa.eu/idabc/en/document/2319/5938.html
[76] Belgian Interoperability Framework. Available at: http://www.belgif.be/index.php/Main_Page
[77] UK eGIF. Available at: http://interim.cabinetoffice.gov.uk/govtalk/schemasstandards/e-gif.aspx
[78] German SAGA. Available at: http://www.cio.bund.de/DE/Architekturen-und-Standards/SAGA/saga_node.html
[79] Estonian Interoperability Framework. Available at: http://www.riso.ee/en/information-policy/interoperability
[80] Greek eGIF. Available at: http://www.e-gif.gov.gr

organisations and national bodies (such as UN/CEFACT, SEMIC.EU, CEN/ISSS) with a view to achieving interoperability, core components technical specifications for data structures, to good practice development guidelines that should be taken under consideration by service designers and developers.

- *A Security, Trust and Authentication Framework.* Security barriers are essential in the modern Information Society, as they do not only protect the systems themselves, but most important they seek to sandbox the personal and sensitive information of individuals that utilise and interact with the various systems. In this context, it is essential to develop services in a way that at the same time interoperation is possible but also that information security is not threatened. Therefore a Security, Trust and Authentication Framework should accompany the Cloud Interoperability Reference Architecture by specifying the security, trust and authentication mechanisms that should be designed in order to enable interoperability between various services, applications and systems to be developed.
- *A Cloud Services Lifecycle Governance Framework.* A Cloud Interoperability Framework should also analyse the lifecycle of cloud based services and should define software quality assessment and evaluation metrics, that foresee the complexity and scale of Future Internet. In this context, both the services but also the framework itself would be constantly monitored and updated based on the demands and the evolutions of the domains, achieving in such a manner long-term sustainability and applicability.
- *A Cloud Interoperability Registry.* This should be an open and searchable catalogue, containg all the meta-data, data structures, services blueprints and other elements of the Cloud Interoperability Framework, in order for any interested partner to have access to all the information needed for developing interoperable cloud services.

Such a Cloud Interoperability Framework could potentially be complemented by a supportive platform, targeting to aid developers and other stakeholders involved to discover the rules and guidelines defined by the framework, check the conformance of their implementations to the former, retrieve plug and play services and other standardised and interoperable modules and structures and reach more comprehensive decisions with regard to the value of current offerings in the Cloud Computing market against their needs.

The Greek Interoperability Centre, loyal to its mission of promoting e-Government and e-Business Interoperability, follows closely the research and standardisation developments in Enterprise Interoperability and Cloud Computing, while also keeping track of relevant needs and emerging opportunities from a practical perspective. The development of a Cloud Interoperability Framework appears indeed as the cornerstone towards the creation of a sound and interoperable services environment that will exploit the full potential of the cloud, and constitutes among others a fundamental axis towards which the Greek Interoperability Centre will direct its research activities. More findings and the updated state of play in the domain of Cloud Interoperability, along with future research advancements of the Greek Interoperability Centre in the field are to be presented when appropriate in subsequent versions of the Interoperability Guide.

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