



## D.2.3. Critical success factors to overcome technical challenges for cloud expansion (interim version)

<b>Grant Agreement nr.</b>	612 053
<b>Project acronym</b>	CloudCatalyst
<b>Project title</b>	Reenergize productivity, efficiency and competitiveness of European economy through Cloud Computing
<b>Funding instrument</b>	Coordination and support actions (CSA)
<b>Due date</b>	31/07/2014
<b>Submission date</b>	31/07/2014
<b>Main editor (s)</b>	Portugal Telecom
<b>Contributor (s)</b>	UCM, UPTEC, EUROCLOUD, SI.MOBIL

Project Co-funded by the European Commission within the 7 <sup>th</sup> Framework Programme		
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DOCUMENT CHANGE LOG				
Version	Date	Editor	Modified pages	Summary of modifications
0.1.	24/06/2014	Andreia Jesus, Ignacio Llorente		Identification of technical challenges
0.2.	23/07/2014	Andreia Jesus, Carlos Bhatt		First draft
0.3.	25/07/2014	Ignacio Llorente		Technical challenges
0.4	28/07/2013	Andreia Jesus, Carlos Bhatt		Data analysis
0.5	29/07/2013	Andreia Jesus, Carlos Bhatt		Final review
1.0.	31/07/2013	Carlos Sanchez, Ignacio Llorente, Felipe Costa		Critical Success Factors, Key Survey Stats

FINAL VERSION CIRCULATED TO		
Recipient	Entity	Date
Coordinator	PORTUGAL TELECOM	31/07/2014
European Commission	LARS PEDERSEN (PO)	31/07/2014

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### Statement of Originality

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## Acknowledgements

The CloudCatalyst consortium thanks the following project representatives for their time, support and input during the course of this activity:

Alfredo Matos	PROSE
Dimosthenis Kyriazis	ORBIT
Agustin González	STORM CLOUDS
Richard Torbjørn Sanders	CLOUDSCALE
Benny Mandler	COMPOSE
Andreas Symeonidis	S-CASE
Andrea Manieri	VENUS-C
Silvana Muscella	CLOUDWATCH
Marta Patiño	CUMULONIMBO
Ana Juan Ferrer	ASCETiC
Ana Juan Ferrer	OPTIMIS
Rui Martins	MO-BIZZ
InnoPole	U-QASAR
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Paolo Romano	CLOUD TM
Eliot Salant	CLOUDWAVE
Pietro Michiardi	BIGFOOT
Clara Pezuela	ARTIST
N/A	BETAAS
Geir Horn, Keith Jeffery	PAASAGE
Olivier Brun	PANACEA
Elisabetta Di Nitto	MODACLOUDS
Carlos A Velasco	I2WEB
Andreas Weiss	CLOUDINGSMES
Daniel Dardailler	HTML5APPS

## Executive Summary

The purpose of this deliverable was to conduct a review of the current landscape within cloud computing to establish the extent to which existing European research meets encountered and envisioned technical challenges for using cloud technologies, in particular European funded projects in the area of Software Services and Cloud Computing. The final objective is to create a step-by-step guide for SMEs and startups with recommendations on critical success factors to address when adopting cloud solutions.

This report combines expert consultancy and desk research approaches. It started with stakeholder analysis, based on the expertise of UCM research group, paying particular attention to technical requirements and issues. In parallel, reference documents about cloud computing were taken into consideration, most importantly the reports of EC Cloud Computing Expert Group on Research and the NIST Cloud Computing Synopsis and Recommendations.

The primary purpose of the report is to summarize the main conclusions about the technical challenges of using Cloud, and produce a step-by-step guide for SMEs and startups developing cloud solutions. Therefore, it is important to highlight that this report is primarily addressing the supply side perspective of the cloud market. It provides the reader with key information about the main technical challenges and how to overcome these barriers.

The conclusions of the report are a reflection of an extensive literature research but, more importantly, of the challenges that key experts in the field are facing. Where possible we have tried to show how they have solved these problems. There are still many questions unanswered, in part because cloud computing for research is still on progress.

On a later stage, the information gathered in this report will also be discussed in conferences and project workshops to enrich our understanding of technical requirements, challenges, available solutions, and ongoing technical research activities. This information will be made available in the final report (D2.4), which will include the feedback collected during conferences and workshops and also an analysis of international research projects.

# 1 Purpose and scope of the deliverable

This report aims to be a useful guide for companies seeking advice about the implementation of a cloud computing strategy. It provides the reader with key information about the main technical challenges and how to overcome these barriers:

- Understanding the extent to which existing European research meets envisioned technical challenges for using cloud technologies
- Guidance on use, adoption, and migration to cloud computing by applying existing EU cloud research results and experts' views

These impact a number of stakeholders in the following way:

- Startups and SMEs (vendor / cloud supply perspective): Guidance to help companies finding gaps that may be new business opportunities to effectively target the cloud market
- Startups and SMEs (end user / cloud demand perspective): Guidance to help companies that will be "natural" adopters of cloud computing addressing technical challenges
- Incubators and entities providing support to new market entrants: Guidance to help their companies to define their IT strategy
- Project coordinators and cloud experts performing research activities: Recipient of recommendations for future research work

The purpose of this report was to conduct a review of the main technical challenges in EU funded cloud computing projects and identify critical success factors, to make recommendations on further development, and guidance. To achieve these aims, a sequence of actions was classified into four categories as detailed below:

## 1. Define the target scope

- Identify the main target group of the deliverable (supply perspective) and their requirements in terms of cloud adoption and expansion

## 2. Literature review

- Identify and classify the most important technical challenges in the current cloud ecosystem from a cloud adopter perspective
- Identify the most relevant EU research projects related to cloud computing
- Follow the most relevant discussions related to EU cloud computing strategy

## 3. Survey development and implementation

- Define the questions based on literature review
- Identify and interview primary stakeholders (EU research projects coordinators)
- Collect and analyse the answers using the defined tools
- Revise the technical challenges

## 4. Recommendations and guidance

- Revise solutions proposed by the primary stakeholders and state-of-the-art cloud technologies from professional, commercial, and industrial domains to fulfil the technical challenges identified
- Identify the key factors for adopting and expanding cloud solutions
- Suggest technical guidance and best practice for cloud adopters who use, or intend to use cloud solutions, with step-by-step guides and recommendations

## 2 WP description and interrelation with other WPs

This deliverable is part of WP2 – Cloud business model innovation. The main aim of this work package is to define a strategic planning framework for cloud decision makers focused on the implementation of innovative cloud solutions. The present report will mainly contribute to the identification of research trends in the EU landscape, taking current and future technical challenges for cloud expansion into account.

In the initial phase of this work package, the task 2.1 “Analysis of major Cloud trends in key EU industries” focuses on understanding the major Cloud trends, main market players, available solutions, support policies, and funding available. This deliverable complements this analysis by providing the insights from EU experts about the critical success factors that are considered most relevant to overcome the technical barriers for cloud expansion.

It is important to mention that this report is an interim version. The activities related to the identification of critical success factors to overcome technical challenges for cloud expansion will continue until M17 of the project and completed with the delivery of the final report (D2.4). The main improvements expected in the next version are the following:

- Feedback received during the events and workshops organized by CloudCatalyst, allowing the consortium to enrich the report with more insights about technical challenges and success factors;
- Include the views of international (outside Europe) cloud research projects in the experts’ panel and compare these answers with the ones received from the EU representatives involved in this first stage;
- Additional analysis about new market opportunities for EU businesses will also be reflected in the next report.

### **Interrelation with other WPs**

During WP2 a set of recommendations will be produced and later shared with European/national/regional authorities and businesses (mainly startups and SMEs) during dissemination and exploitation activities in WP5. The results of this task will be fundamental for defining an outlook for entrepreneurs and business developers in T3.4. Cloud accelerator toolbox. This information will also be available in the Go-to-the-Cloud service that will be developed and implemented in WP4. Overall, the final purpose is to create a service that will contribute to stimulate the local stakeholders to adopt Cloud solutions, leading into future successful (e.g. value for money, in budget, on time, sustainable) deployments.

### 3 Background

Today's entrepreneurs have a powerful resource available at minimal cost – cloud computing. Thanks to cloud computing and social networking resources, the barriers to entry for many innovators are now much lower. Nevertheless, cloud computing still has several challenges to overcome until it reaches market maturity. Some of the most well-known problems it faces include scalability, interoperability, and security, not to mention more business-focused issues.

Businesses, public entities and EU citizens are eager to go-to-the-cloud, and, at this stage, ICT providers and other Cloud stakeholders have the means to fulfil the demand needs, but there are still several barriers that discourage consumers, business developers and entrepreneurs, including software developers, to start using Cloud services (see Figure 1)<sup>1</sup>.

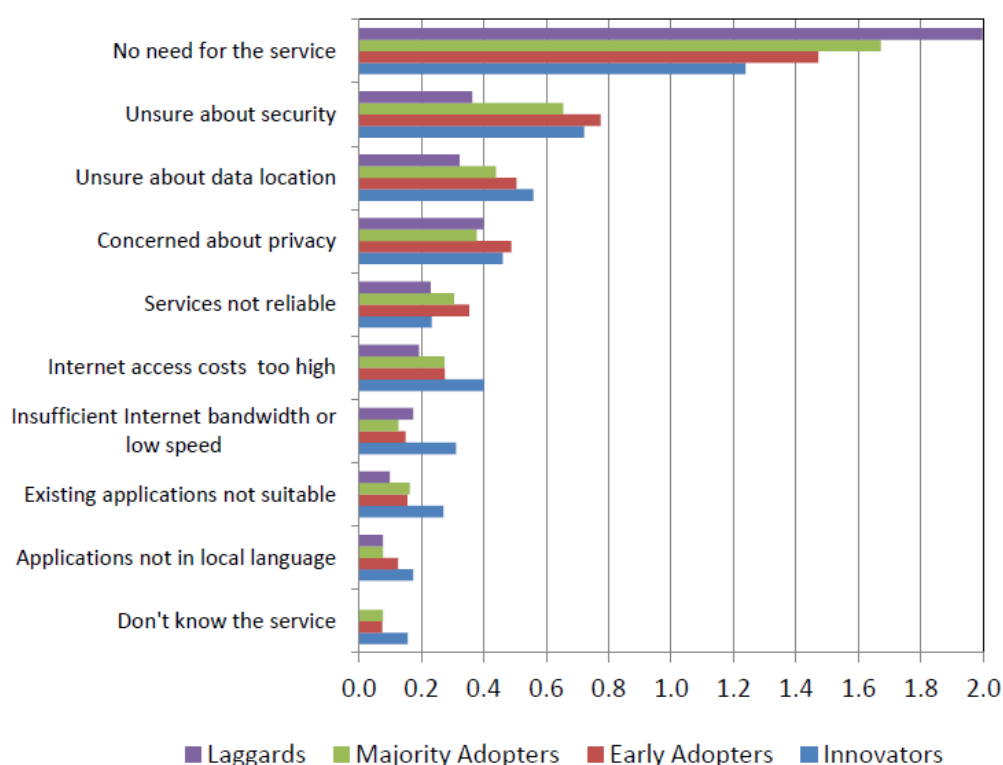


Fig. 1 - Reasons why consumers do not start using a Cloud service

53% of consumers said that lack of interest was the main reason for stopping the use of any particular service compared to 14% giving security as the main reason and 11% giving data location as the main reason (Fig. 1). The need for the service is a higher barrier to usage for the less "aggressive" adopters.

Having these constraints in mind, considerable resources have been devoted to research and development to solve these issues. The European Union has been involved in driving forward a Cloud Computing Strategy to promote the rapid adoption of cloud computing in all sectors of the economy and since 2009 a group of experts is developing the cloud computing vision for Europe and future research and policy directions. The results were published in 3 reports:

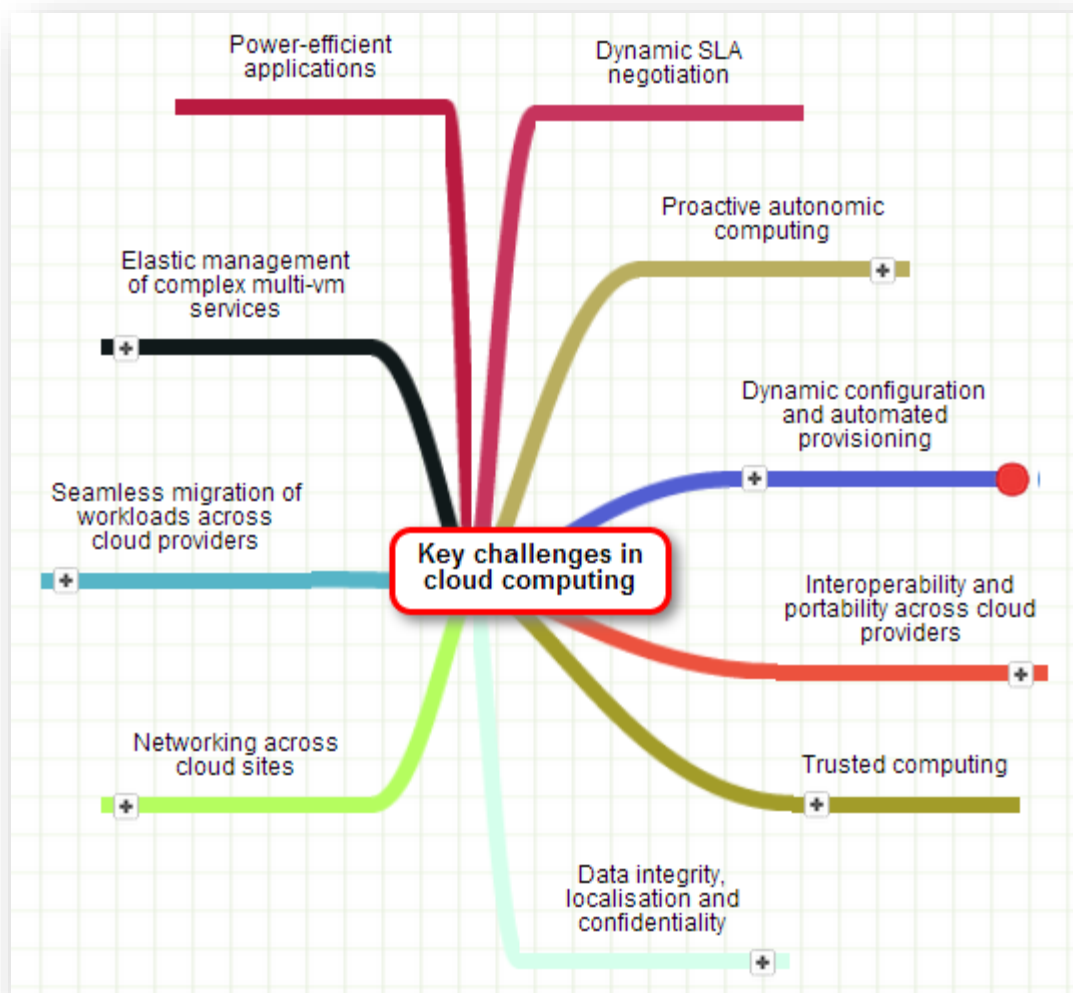
<sup>1</sup> [http://ec.europa.eu/information\\_society/activities/Cloudcomputing/docs/quantitative\\_estimates.pdf](http://ec.europa.eu/information_society/activities/Cloudcomputing/docs/quantitative_estimates.pdf)



"The future of Cloud Computing" in January 2010; "Advances in Clouds" in May 2012; "A roadmap for Advanced Cloud Technologies under H2020" in December 2012.

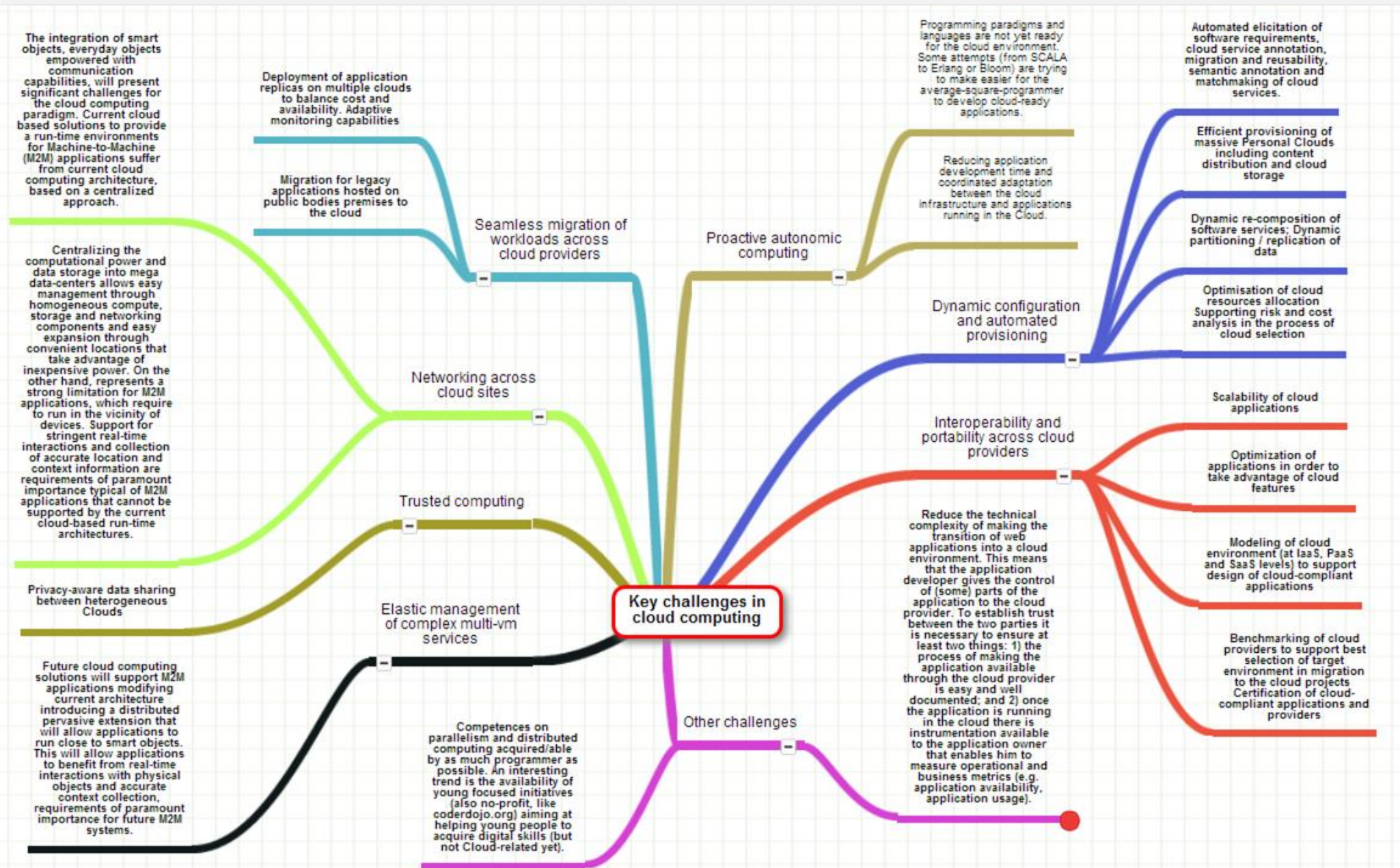
The Consortium has evaluated these reports and studies in relevant publications<sup>2</sup> in order to identify the main topics that need to be addressed in order to overcome the deficiencies and offer the capabilities needed to realise the full potential of cloud computing:

1. Interoperability and portability across cloud providers
2. Seamless migration of workloads across cloud providers
3. Trusted computing
4. Proactive autonomic computing
5. Elastic management of complex multi-vm services
6. Power-efficient applications
7. Networking across cloud sites
8. Dynamic SLA negotiation
9. Dynamic configuration and automated provisioning
10. Data integrity, localisation and confidentiality



<sup>2</sup> Internet Computing, Key Challenges in Cloud Computing: Enabling the Future Internet of Services, July-Aug. 2013 (vol. 17 no. 4)

A more extensive list of challenges has been suggested by the experts, according to the priorities addressed in their projects:



## 4 The Expert's View

The CloudCatalyst consortium asked coordinators of European funded projects about their views on technical challenges for cloud expansion and critical success factors to overcome these challenges. The issues raised in the literature review were the starting points for the questions asked at the interview stage.



The screenshot shows the 'Welcome to the CloudCatalyst Survey' page. It features the CloudCatalyst logo at the top left. Below the logo, the title 'Technical challenges for Cloud expansion – The Experts' View' is displayed in a teal header. The main content area is light beige and contains a welcome message, a brief description of the survey's purpose, and a 'Next' button at the bottom center.

**CloudCatalyst**

**Technical challenges for Cloud expansion – The Experts' View**

Welcome to the CloudCatalyst Survey

CloudCatalyst project is asking coordinators of European funded projects about their views on technical challenges for cloud expansion. This information will be included in a report analyzing the challenges identified in previous EC reports and EC financed projects. The key outcome will be a step-by-step guide identifying the critical success factors to overcome the current technical challenges for Cloud expansion.

Please analyze the technical challenges for cloud expansion by answering the 3 questions of the survey.

Next

### 4.1 Key survey statistics

In July 2014, CloudCatalyst consortium conducted a survey about the challenges and critical success factors of cloud computing. The answers provide a comprehensive perspective on the position of the key experts participating in EU funded projects.

This stakeholder review was conducted through email, and online questionnaires. Feedback was received from 29 experts, from FP7, CIP, AAL and eINFRASTRUCTURES project coordinators representing various stakeholder groups including academia and industries.

The survey contained the following questions:

- Rank the technical challenges for Cloud expansion according to the priorities addressed in your project.
- In case you think your project addresses other important challenges that are not on the list, please describe them.
- Define critical success factors to overcome the top 3 technical challenges that you have identified.

Survey responses were aggregated and analyzed wherever possible and insightful and the viewpoint from different market players have been contrasted.

#### Statistics:

All respondents = 29

- FP7 projects respondents = 25
- Other respondents (CIP, AAL and eInfrastructures) = 4

FP7 projects response rate = 36%

- From a universe of 69 coordinators (Call 5, 8 and 10), 25 responded to the questionnaire.

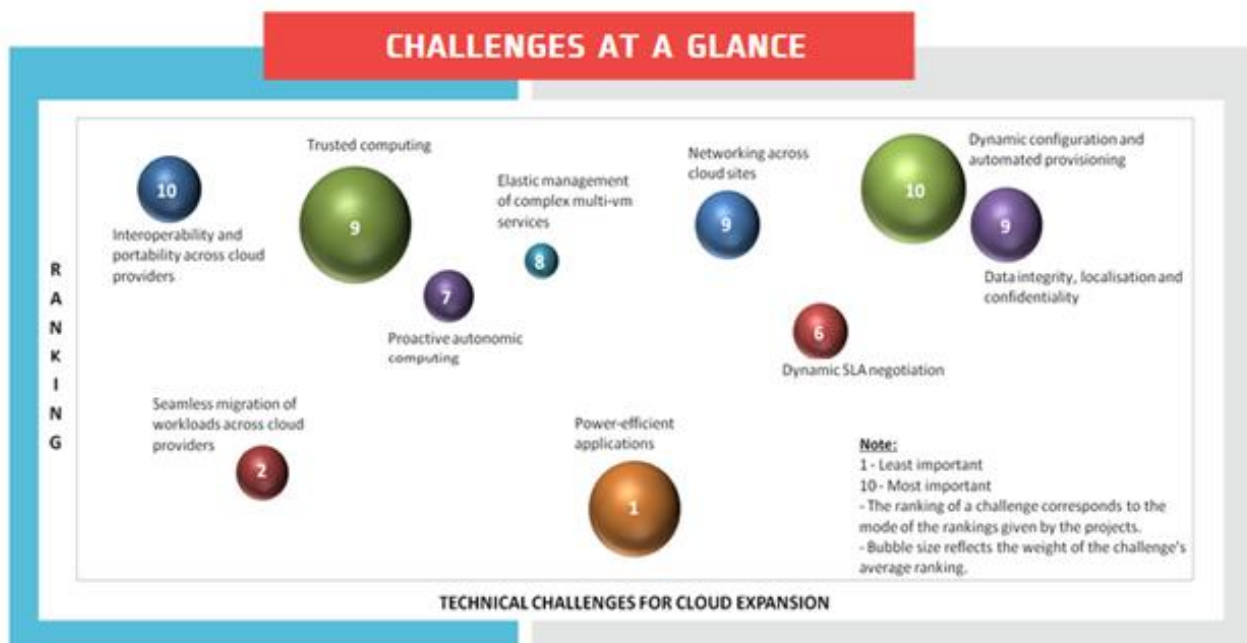
## 4.2 Challenges for cloud expansion

In a first stage, the respondents ranked a set of technical challenges for Cloud expansion according to the priorities addressed in their respective project. While the value 1 sets the challenge to be the least important, the value 10 sets it as being the most important for the respondent.

The figure below illustrates the results obtained. The ranking associated to each challenge represents the mode of the answers, while the size of the bubbles reflects the weight of the challenge's average ranking.

Since we are interested in understanding how many times a certain challenge is ranked in a certain position, statistically speaking it is more coherent to calculate the mode. This analysis is completed by calculating the average ranking of the challenge and reflecting its weight in the respective bubble size. If we would only analyze the average ranking of a challenge, it would somehow "hide" the real classifications given by the projects.

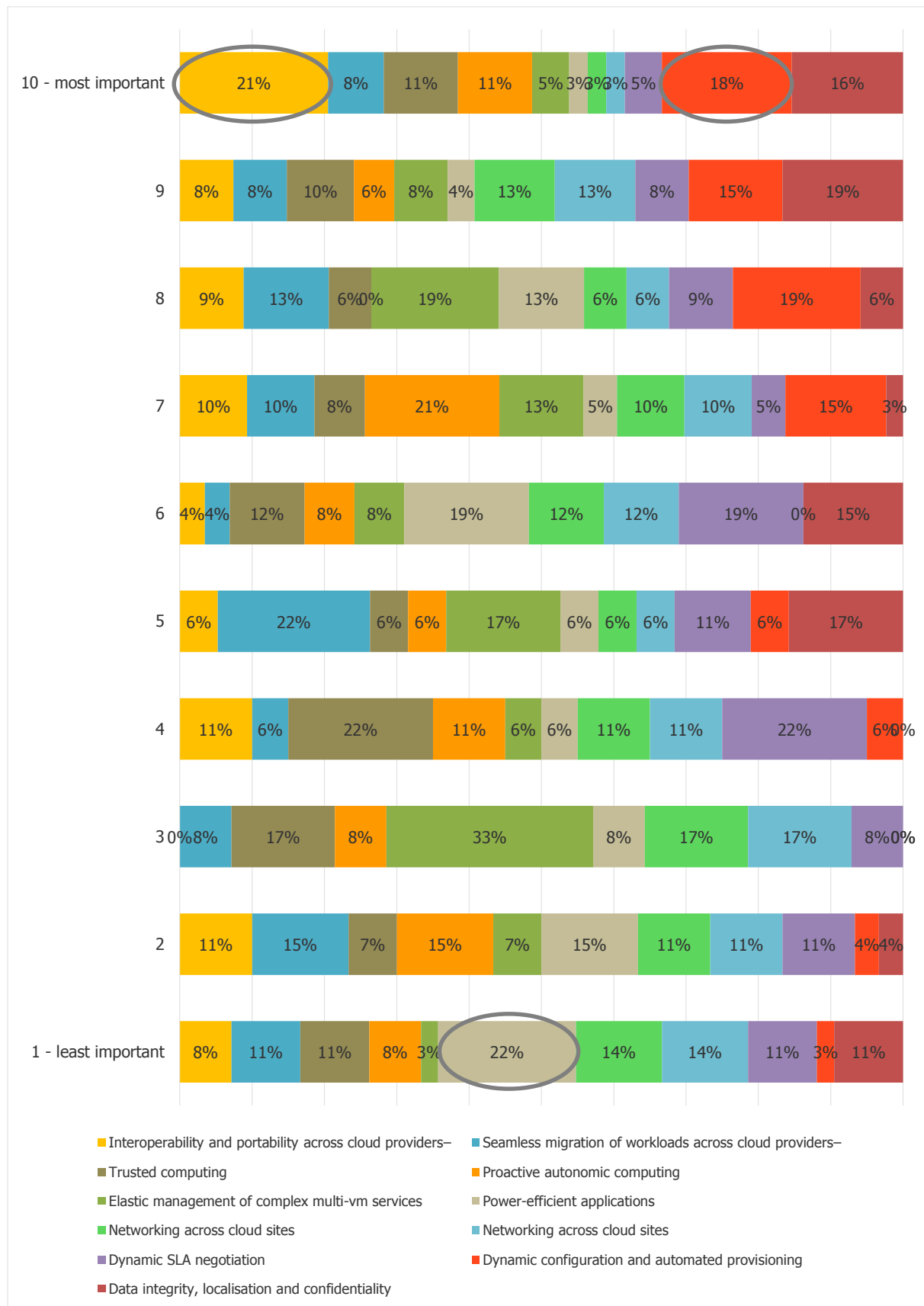
For instance, the challenges Dynamic configuration and automated provisioning and Interoperability and portability across cloud providers, were both more often ranked with 10 (mode). Although, the average ranking of the former challenge is higher than the latter, leading us to the conclusion that Dynamic configuration and automated provisioning might be more relevant. The graph presented in the next page confirms this analysis.



One can determine from the figure, that both "Interoperability and portability across cloud providers" and the "Dynamic configuration and automated provisioning" are the challenges more often considered by experts as being the most important.

On the other hand, both "Seamless migration of workloads across cloud providers" and "Power-efficient applications" were the challenges more often considered by experts as being the least important.





In a second stage, experts were asked to describe other challenges according to the priorities addressed in their projects. The list below is a selection of the answers provided:

Migration for legacy applications hosted on public bodies premises to the cloud

Dynamic re-composition of software services and dynamic partitioning / replication of data

Optimization of applications in order to take advantage of cloud features

Automated elicitation of software requirements, cloud service annotation, migration and reusability, semantic annotation and matchmaking of cloud services

Develop new programming paradigms and languages to make easier for the average-square-programmer to develop cloud-ready applications

Reducing application development time and coordinated adaptation between the cloud infrastructure and applications running in the Cloud

Modeling of cloud environment (at IaaS, PaaS and SaaS levels) to support design of cloud-compliant applications

Competences on parallelism and distributed computing acquired/able by as much programmers as possible

Deployment of application replicas on multiple clouds to balance cost and availability. Adaptive monitoring capabilities

Optimisation of cloud resources' allocation, supporting risk and cost analysis in the process of cloud selection

Reduce technical complexity of making the transition of web applications into a cloud environment. Usually this implies that application developer gives the control of (some) parts of the application to the cloud provider

Privacy-aware data sharing between heterogeneous clouds

Benchmarking of cloud providers to support best selection of target environment in migration to the cloud. Certification of cloud-compliant applications and providers

Efficient provisioning of massive personal clouds including content distribution and cloud storage

Integration of smart objects, everyday objects empowered with communication capabilities, presents significant challenges for the cloud computing paradigm

Support for stringent real-time interactions and collection of accurate location and context information are requirements of paramount importance typical of M2M applications that cannot be supported by the current cloud-based run-time architectures

Future cloud computing solutions will support M2M applications, modifying current architecture, introducing a distributed pervasive extension that will allow applications to run close to smart objects

## 5 Major cloud challenges and critical success factors

In this section we will analyze from a company's point of view the most relevant technical factors that need to be considered by an organization providing cloud services. Based on the recommendation of the experts' panel, we will also analyze the critical success factors of each of the following challenges:

1. Interoperability and portability across cloud providers,
2. Seamless migration of workloads across cloud providers,
3. Trusted computing,
4. Proactive autonomic computing,
5. Elastic management of complex multi-vm services,
6. Power-efficient applications,
7. Networking across cloud sites,
8. Dynamic SLA negotiation,
9. Dynamic configuration and automated provisioning,
10. Data integrity, localisation and confidentiality.

### 5.1 Interoperability and portability across cloud providers

Keywords: FEDERATION, INTEROPERABILITY, PORTABILITY, INTEGRATION

Providing support for interoperability and portability across cloud providers is a necessary condition for the development of a competitive infrastructure cloud market in Europe. One of the key features of a competitive infrastructure cloud market is the ability for users to compare cloud offerings, select the offer that best suits his needs, and change providers if they are unsatisfied with the service or find a more competitive offering. While interoperability implies the ability to ensure that the available cloud services work with more than one cloud provider simultaneously, regardless of the differences between the providers, portability is the ability to run components or systems written for one environment in another environment. This includes software and hardware environments (both physical and virtual). This goes beyond the heterogeneity problems of the resource description and portability of the application onto different destination platforms: it also needs to address interoperability across infrastructures (administrative and legislative) boundaries, data structures etc., including understanding of the application behavior in such cases and so on.

## Critical success factors:



### Avoid lock-in

- Reducing lock-in to proprietary solutions through means of increased portability and interoperability, to give organisations confidence that they can transport their application and data from one cloud infrastructure or platform provider to another and also can interoperate with applications hosted by other cloud providers (e.g. B2B)

### Assure standardization

- For operations such as transferring a virtual machine image and data between providers, standardized formats are needed for data being transferred, billing and identity management
- Before a decision is made to develop new applications in a cloud, consumers should ensure that the application infrastructure interfaces' provided in that cloud are generic or, at least, that data adaptors could be developed so that portability and interoperability of the application is not significantly impacted



### Business strategy and support tools

- Creation of practical guidelines and best practices' catalog
- Identification of key elements in applications that ease or prevent their migration to the cloud

### Open clouds and federation

- Creating bridges between global communities - especially standardisation efforts;
- Massive adoption of open source Cloud Computing projects
- Cloud federation, sustainable collaboration schemes
- Ability to build full-fledged multi-cloud applications





## 5.2 Seamless migration of workloads across cloud providers

Keywords: PORTABILITY, QoS, SERVICE DISRUPTION

A user should be able to seamlessly migrate workloads that are running in a specific cloud provider to another one. The implementation of this scenario is fundamental in the context of a dynamic cloud market with changing conditions like the fluctuation of cloud service providers, new instance types being offered while old ones are retired and dynamic pricing models and available features (e.g. security levels or quality of service levels). In this situation a user can decide to move a running service or a part of it to a different provider, in order to reduce cost, or improve quality of service. The main challenge to be addressed in this scenario is how to migrate running applications from one cloud service provider to another one with a minimum of downtime and service disruption.

### Critical success factors:



#### Migration

- Number of processes needed to apply for a migration
- Ability to migrate applications and associated data from cloud to cloud

#### Cost control

- Ability to assess costs and risks in cloud usage and to define an optimal configuration (with respect to cost and performance) of cloud applications



#### SLA control

- Ability to control the SLA with cloud providers and perform proper recovery actions when it is violated

### 5.3 Trusted computing

Keywords: SECURITY, PRIVACY, AUTHENTICATION, AUTHORIZATION, AUDITING MECHANISMS

Although all cloud providers incorporate different mechanisms and technologies to guarantee the security and privacy of users' data and resources hosted in the cloud, significant improvement potential exists regarding the authentication, authorization, and auditing mechanisms implemented in current clouds. Authentication mechanisms are responsible for verifying and confirming the identity of users that try to access cloud resources. Authorization policies are responsible for controlling and managing users privileges and permissions to access different cloud resources (compute resources, networks, storage, and data), and they are essential to guarantee the data protection and resource isolation in a multi-tenant cloud environment. Auditing mechanisms are aimed at providing information about activity on the cloud resources, and identifying who is accessing cloud resources, when they are gaining access, and what operations they are doing. Cloud interoperation also opens new challenges in the management of security parameters between cloud providers. One of the first issues to be solved is the authentication across multiple clouds, since each cloud can use a particular authentication mechanism and technology.

#### Critical success factors:



Fulfilment of SLAs and implementation of certification schemes

- Check the existing security measurements and SLA metrics
- Fair and safe contract terms

Check transparency and interoperability among providers

- Management of security parameters between cloud providers
- Step-by-step analysis of the full cloud service supply chain
- Proven data provenance and enforcement of related policies



Verifiable devices

- Overcome security / privacy challenges from IoT devices through cloud based processing

## 5.4 Proactive autonomic computing

Keywords: MANAGEMENT OF RESOURCES, SELF-CONFIGURATION, SELF-HEALING, SELF-ADAPTING, SELF-PROTECTING

New innovative solutions are needed for a proactive autonomic management of cloud resources. These new techniques could predict anomalies, like time to failure of cloud applications or DDoS attacks, before they occur. Autonomic systems have the ability to define themselves “on-the-fly”(self-configuring); discover, diagnose, and react to disruptions (self-healing); monitor and tune resources automatically (self-adapting); and anticipate, detect, identify and protect themselves against threats from anywhere (self-protecting).

### Critical success factors:



#### Accurate prediction model

- Prediction of the time to crash of applications or the violation of server response times, so as to be able to proactively reconfigure the system before anomalies occur. Advanced Machine Learning techniques requiring the monitoring of as few performance metrics as possible are needed for that. In addition, since proactive autonomic computing requires much more measures than traditional approaches, you need a highly scalable monitoring system focusing the monitoring effort on where it is really needed.

#### Understand execution needs

- A core challenge is monitoring of applications to understand their execution needs and make autonomic migration or re-deployment decisions.



#### New useful programming models are needed:

- Parts of applications can be managed (moved, relocated, etc.) without the need to check-point a full machine for migration, or to restart the application in a new configuration. This new programming model should be compatible with existing languages, and not require major changes to existing applications (only a matter of recompilation with new libraries or management at the code execution environment, i.e. the JVM).

## 5.5 Elastic management of complex multi-vm services

Keywords: ELASTICITY, WORKLOADS, PERFORMANCE, PROVISIONING, AUTO-SCALING, QoS

Although many applications can be static from the point of view of service capacity or size, in a general case, applications can experience fluctuating workloads. Variable workloads require that the service capacity be adapted to demand in order to avoid service performance degradation (in case of increasing demand) or service over-sizing (in case of lowering demand). An optimal service provisioning can be attained if the cloud providers offer some tools for service elasticity management and service auto-scaling. Some IaaS cloud providers offer simple mechanisms for auto-scaling groups of instances, based on alert mechanisms that trigger the deployment of new instances when some condition is met. Future directions and research lines in this area should be oriented to improve the support for complex multi-VM service auto-scaling in cloud providers, by the definition of more complex elasticity rules based on different types of metrics (including both infrastructure-level metrics and QoS metrics); the analysis of correlation between infrastructure metrics and QoS metrics for different service types and workload profiles to implement efficient auto-scaling mechanisms in the absence of service metrics; and the implementation of proactive auto-scaling mechanisms based on the prediction of future service load to take scaling decisions ahead of time. Capabilities can be rapidly and elastically provisioned, in some cases automatically, to scale rapidly matching with demand. To the consumer, the capabilities available for provisioning often appear to be unlimited and can be appropriated in any quantity at any time.

### Critical success factors:



Adapt service capacity to demand in order to avoid service performance degradation or service over-sizing

- Ensure design-time support for application-level elasticity, dynamic configuration, and resource management.

Access to large scale experimental platforms

- These experiments will provide deeper understanding in how to improve the support for complex multi-VM service auto-scaling in cloud providers



Close collaboration with industrial leaders

- An optimal service provisioning can be attained if the cloud providers offer some tools for service elasticity management and service auto-scaling.

## 5.6 Power-efficient applications

Keywords: ENERGY EFFICIENCY, DATA CENTRES, SMART CITIES, POWER SUPPLY

Since global and national goals for carbon-footprint reduction must be met, in addition to compensation for noticeable increase in energy expenditures, technological energy saving measures are a mandatory ingredient of any emerging information and communication technology. In this context, cloud providers must evaluate and assess different strategies to improve the energy efficiency in their data centers, including computing, cooling, and power supply equipment. This involves the definition and use of unified metrics that enable cloud providers to measure the energy efficiency of their data centers, to compare the results against other cloud infrastructures, and to decide what improvements need to be made. Some open issues and future research directions regarding the energy efficiency of cloud infrastructures include the development of more efficient energy-proportional servers that consume power proportionally to the utilization level; the improvement of allocation, consolidation, and migration strategies of cloud resources, considering the workload profile of each particular service (e.g. the reallocation of services components for consolidation purposes can be efficient from a power-saving perspective, but can be counterproductive for the service performance in case of workloads with tightly coupled communications requirements); or the research on mechanisms for advanced resource provisioning, based on the historical execution profile of the service to predict the resources that the service will consume, allowing for optimal provisioning that results in lower energy consumption.



*Fig. 2 - PT Data Center in Covilhã*

**Critical success factors:****Definition of energy-efficiency cloud metrics and APIs**

- Cloud providers must evaluate and assess different energy efficiency issues including computing, cooling, and power supply equipment.
- Assessment of performance in terms of novel more fine-grained PUE-, CUE- and WUE-related KPIs to measure the energy efficiency of data centers, compare the results against other cloud infrastructures, and decide what improvements need to be made.

**Mechanisms for advanced resource provisioning**

- Implement integrated data centre management platforms operating on top of current data centre software providing real-time decisions on optimal data centre operation taking into account IT demand, energy supply, global energy/heating demand, predicted user behaviour, grid status, and availability of renewable sources and harvested energy.
- Power efficient placement of virtual machines
- Development of energy consumption modeling and prediction in large-scale data centres

**Implement an integrated data centre and smart city management approach**

- Paradigms for autonomic integrated management and optimization of energy usage and cost across heterogeneous types of resources as well as across geographical and organizational boundaries
- Monitoring and optimisation of IT processes, power and cooling, and utilization of renewable sources and waste streams on the basis of regional weather and data centre production forecasts, respectively.



## 5.7 Networking across cloud sites

Keywords: DISTRIBUTED INFRASTRUCTURES; DISRUPTIONS; BANDWIDTH; LATENCY; FEDERATION; INTER-CLOUD NETWORKING

There is a strong industry demand for automated solutions to federate cloud network resources, and to derive the integrated management cloud layer that enables an efficient and secure deployment of resources and services independent of their location across distributed infrastructures. Cloud systems generally depend on networking and hence any limitations on networking, such as data import/export bottlenecks or service disruptions, reduce cloud utility, especially for applications that are not tolerant of disruptions. The degree of scale in terms of users, applications and data does not match the physical capabilities of communication both with respect to bandwidth as well as latency. Along the same line, users will expect increments in terms of access and accessibility non-regarding those deficiencies.

Federated cloud networking is needed to unify and consolidate data-centers in a virtual way, so that different distributed data-centers can be exposed as a single cloud-like virtual data-center, and networks of different data centers can be interconnected in a virtual overlay. One of the existing challenges for cloud expansion is the automatic provision of inter-cloud networking to support the automated deployment of applications and services across different clouds and data-centers. Research must be done to overcome the physical constraints of hardware and to compensate the deficiencies from a software side. From big companies and large cloud providers interested in unifying and consolidating multiple data centers or cloud sites to SMEs building hybrid cloud configurations, federated cloud networking is needed to support the automated deployment of applications across different clouds and data centers.

### Critical success factors:



#### Discover the shortest paths in an overlay network with the minimum monitoring effort

- Networking across cloud sites should be based on a self-healing and self-optimizing overlay network between cloud sites. You have to constantly measure the quality of Internet paths between the clouds so as to be able to quickly react to path outages or performance degradation by reconfiguring the overlay network. For large networks, this rise scalability issues since the monitoring effort scales as  $N^2$  (where  $N$  is the number of clouds).

#### Overcome limitations on networking, such as data import/export bottlenecks or service disruptions

- Identify at real time components of a composite applications which have failed and switch to an alternative component without overall application disruption



## 5.8 Dynamic SLA negotiation

Keywords: QoS METRICS; PERFORMANCE; AVAILABILITY; RESPONSE TIME

Cloud computing platforms should support standardized service expressions for QoS and SLA negotiation mechanisms between consumers and providers to state the terms under which the service needs to be provided. An SLA is contract between a provider and a consumer that specifies consumer requirements and the provider's commitment to them. Typically, an SLA includes items such as uptime, privacy, security and backup procedures. Most current IaaS platforms provide simple SLAs based on the availability of the resources, but they lack advanced SLA mechanisms based on service-oriented QoS metrics, such as service performance, service availability, service response time, or service cost, among others. Moreover, as different cloud providers can offer different types of SLAs, defined with a variety of service level objectives (SLOs) and QoS metrics, which makes difficult the negotiation of similar SLAs with different cloud providers, and can become an obstacle for the expansion of aggregated cloud infrastructures. Open issues and future directions in this area include the definition of a standard set of SLA levels so that all the cloud providers can agree and commit to fulfill. Each SLA level should be defined by means of a well-known and rich set of SLOs and service-oriented QoS metrics.

### Critical success factors:



#### Develop advanced SLA mechanisms

- Implement service-oriented quality of service (QoS) metrics, such as service performance, service availability, service response time, or service cost, among others.

#### Negotiation of similar SLAs with different cloud providers

- Definition of a standard set of SLA levels that all the cloud providers can agree and commit to fulfill.
- Techniques to control service delivery
- Protocols for SLA negotiation





## 5.9 Dynamic configuration and automated provisioning

Keywords: VIRTUALIZATION, MULTI-TIER

To provide efficient service virtualization, cloud platforms should decouple the service interface from the service implementation in a way that allows mapping the services dynamically on the resources. While SaaS clouds provide access to applications on-demand, and PaaS clouds enable the development and execution of application on specific platforms, IaaS clouds enable users to build their own customized applications and platforms, without being tied to a specific environment (e.g. operating system, platform technology, software library, etc.). However, most current clouds are too infrastructure oriented and lack of the advanced service oriented capabilities needed to manage services (i.e. groups of interconnected compute, network, and storage elements) as basic entities, and to provide elasticity and quality of service (QoS) for a broad range of multi-tier applications deployed in the cloud. Therefore the efficient deployment and management of these applications in the cloud still require complex IT scenarios and skilled technology staff. Services should be atomic to be combined dynamically as required; the composition being controlled astronomically, with middleware matching the user requirements to available services, data, and other resources. Service offerings need to improve over time to maintain competitiveness. Future directions and research lines in this area should be aimed to enable the dynamic provisioning of multi-tier services on top of cloud infrastructures.

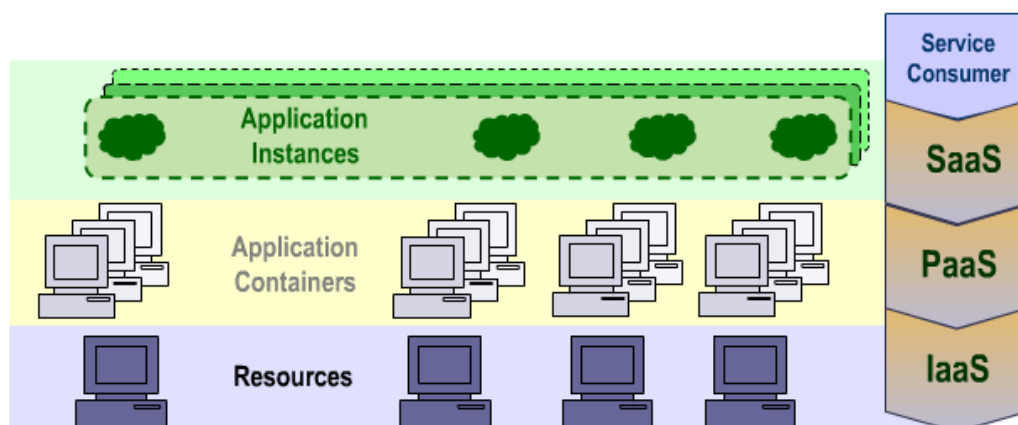


Fig. 3 - Scalability and multi-tenancy of application containers ([dsa-research.org](http://dsa-research.org))

### Critical success factors:



#### Proper analysis/prediction of adaptation actions

- Use of model-driven and software patterns, intelligent software, context-aware systems

#### Mapping the services dynamically on the resources

- Applications and services running in a cloud environment must provide interface endpoints for provisioning, configuration, and monitoring;
- Applications must be classified by compliance levels (e.g. applications that implement all the interfaces should be more highlighted than other applications that are not fully compliant)



#### Reduce the degree of human intervention in provisioning

- Monitoring must be done continuously and SLA levels should be formally described so that automatic reactions can be deployed.

#### Dynamic configuration and automated provisioning of analytics as a service

- Enabling this through simple interfaces that do not require the specification of low-level details about a cloud deployment (how many VMs, flavors, networks, etc.) is surely a critical factor to consider.



## 5.10 Data integrity, localisation and confidentiality

Keywords: TRUST, PRIVACY, CONFIDENTIALITY, STANDARDS

Regarding data protection, confidentiality, and privacy issues, the movement of resources and data between cloud providers can be limited by the different legislations of the countries where the cloud providers are located. To avoid privacy and confidentiality risks cloud providers should be adapted to different legislations, and some standards of good practices, policies and procedures should be defined. Security vulnerabilities need to be understood and handled better to overcome the lack of trust in utilising clouds and the fears of privacy invasions and confidentiality breaches. This includes aspects such as improved identification and authentication, but also transparency for the user.

### Critical success factors:



#### Overcome barriers related to different legislations

- Assure consistency in data schemas migration (by using data models), fulfilment of SLAs, and implementation of privacy warranty mechanisms

#### Implement an open cloud philosophy

- Adoption of open standards and open format in cloud-related solutions
- Cloud standardization needs to happen the OpenStand way. See Open-stand.org.



#### Foster awareness raising actions

- Create a new culture around the importance of data security and new competences to empower the end-users

#### Promote certification mechanisms

- Implement certification schemes for applications and services offered in the cloud.



## 6 Conclusions and recommendations

The outputs from the project are a reflection of an extensive literature research but more importantly of the challenges that practitioners in the cloud computing field are facing. The stimulation of the adoption of cloud in European Small and Medium Enterprises (SMEs) and startups is of utmost priority for the European Union. This report has shown some ways of overcoming these problems, yet there are still many questions unanswered, in part because cloud computing is still a relatively new concept for the masses.

In order to understand how cloud computing can be used by organizations providing cloud services, there are a few points which need to be highlighted:

- Under the research area ICT-2013.1.2 Software Engineering, Services and Cloud Computing, the European Commission has been supporting activities to accelerate the development and deployment of cloud computing and internet services. Most of these projects addressed the following priorities: 1. Interoperability and portability across cloud providers, 2. Seamless migration of workloads across cloud providers, 3. Trusted computing, 4. Proactive autonomic computing, 5. Elastic management of complex multi-vm services, 6. Power-efficient applications, 7. Networking across cloud sites, 8. Dynamic SLA negotiation, 9. Dynamic configuration and automated provisioning, 10. Data integrity, localisation and confidentiality.
- Although experts have shared some useful information about the key challenges addressed in their projects, allowing the validation of these priorities, it is difficult to rank them from 1 to 10, once this information is constrained by the scope of the projects. Nevertheless, these priorities already show the way that companies should follow to develop a cloud service and the critical success factors that should be considered for each of the challenges.
- These key challenges and success factors will allow the consortium to detect new market opportunities for EU businesses. This will be reflected in the next report dedicated to this topic. In order to design a global cloud computing strategy for these companies, we need to learn from successful experiences and use them for research cloud service delivery. This report will be presented during the Cloud-related workshops and conferences organized by CloudCatalyst and the inputs will also be included in the next report (D.2.4).

Based on the correlation between cloud challenges and critical success factors identified by the EU experts, it was possible to outline some **recommendations to companies adopting and developing cloud solutions**. These recommendations can serve as guidance to help companies that will be “natural” adopters of cloud computing defining their IT strategy by addressing these technical challenges. This may also serve to stimulate actions leading towards EU cloud research, complementing the work done by the experts’ group developing the cloud computing vision for Europe and future research and policy directions.

## KEY RECOMMENDATIONS:

### Interoperability and portability across cloud providers

- One of the key features of a competitive infrastructure cloud market is the ability for users to compare cloud offerings, select the offer that best suits his needs, and change providers if they are unsatisfied with the service or find a more competitive offering.

### Seamless migration of workloads across cloud providers

- The main challenge to be addressed is how to migrate running applications from one cloud service provider to another one with a minimum of downtime and service disruption.

### Trusted computing

- Cloud interoperation opens new challenges in the management of security parameters between cloud providers. One of the first issues to be solved is the authentication across multiple clouds, since each cloud can use a particular authentication mechanism and technology

### Proactive autonomic computing

- New innovative solutions are needed for a proactive autonomic management of cloud resources. These new techniques should predict anomalies, like time to failure of cloud applications or DDoS attacks, before they occur.

### Elastic management of complex multi-vm services

- An optimal service provisioning can be attained if the cloud providers offer some tools for service elasticity management and service auto-scaling. Future directions in this area should be oriented to improve the support for complex multi-VM service auto-scaling in cloud providers.

### Power-efficient applications

- Cloud providers must evaluate and assess different strategies to improve the energy efficiency in their data centers, including computing, cooling, and power supply equipment. This involves the definition and use of unified metrics that enable cloud providers to measure the energy efficiency of their data centers, to compare the results against other cloud infrastructures, and to decide what improvements need to be made.

### Networking across cloud sites

- Federated cloud networking is needed to unify and consolidate data-centers in a virtual way, so that different distributed data-centers can be exposed as a single cloud-like virtual data-center, and networks of different data centers can be interconnected in a virtual overlay. One of the existing challenges for cloud expansion is the automatic provision of inter-cloud networking to support the automated deployment of applications and services across different clouds and data-centers.

### Dynamic SLA negotiation

- Most current IaaS platforms lack advanced SLA mechanisms based on service-oriented QoS metrics, such as service performance, service availability, service response time, or service cost, among others. Moreover, as different cloud providers can offer different types of SLAs, defined with a variety of service level objectives (SLOs) and QoS metrics, which makes difficult the negotiation of similar SLAs with different cloud providers, and can become an obstacle for the expansion of aggregated cloud infrastructures. It is important to define of a standard set of SLA levels that all the cloud providers can agree and commit to fulfill.

### Dynamic configuration and automated provisioning

- Most current clouds are too infrastructure oriented and lack of the advanced service oriented capabilities needed to manage services (i.e. groups of interconnected compute, network, and storage elements) as basic entities, and to provide elasticity and quality of service (QoS) for a broad range of multi-tier applications deployed in the cloud. Future directions should aim to enable the dynamic provisioning of multi-tier services on top of cloud infrastructures.

### Data integrity, localisation and confidentiality

- To avoid privacy and confidentiality risks, cloud providers should be adapted to different legislations, and some standards of good practices, policies and procedures should be defined. Security vulnerabilities need to be understood and handled better to overcome the lack of trust in utilising clouds and the fears of privacy invasions and confidentiality breaches.

## 7 References

Expert Group, "The Future of Cloud Computing", Jan. 2010. Online available at:

<http://cordis.europa.eu/fp7/ict/ssai/docs/cloud-report-final.pdf>

Open Cloud Discussion Group, "Cloud Computing Use Case White Paper (version 3.0)", Feb. 2010 Online available at:

[http://opencloudmanifesto.org/Cloud\\_Computing\\_Use\\_Cases\\_Whitepaper-3\\_0.pdf](http://opencloudmanifesto.org/Cloud_Computing_Use_Cases_Whitepaper-3_0.pdf)

Recommendations of the National Institute of Standards and Technology, May 2012. Online available at: <http://csrc.nist.gov/publications/nistpubs/800-146/sp800-146.pdf>

European Cloud Computing Strategy – an overview, 2011. Online available at:

<http://cordis.europa.eu/fp7/ict/ssai/docs/future-cc-2may-ducatel-presentation.pdf>

IDC report. Online available at:

[http://ec.europa.eu/information\\_society/activities/Cloudcomputing/docs/quantitative\\_estimates.pdf](http://ec.europa.eu/information_society/activities/Cloudcomputing/docs/quantitative_estimates.pdf)

The Open Group, Cloud Computing for Business: Establishing your Cloud Vision Jul. 2014.

Online available at: [http://www.opengroup.org/cloud/cloud/cloud\\_for\\_business/vision.htm](http://www.opengroup.org/cloud/cloud/cloud_for_business/vision.htm)