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to grow a sustainable and comprehensive ecosystem

D1.4: Contributing to the European Cloud Computing Strategic Research and Innovation Agenda Q3-2021

Sub-title here if needed/appropriate

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Abstract

This deliverable has a threefold goal. First, it presents the methodology followed for the research roadmap. Secondly, it presents a multi-sourced context analysis and finally, the initial findings of research topics.

Keywords: Research roadmap, research venues, Cloud Computing Continuum research topics and challenges

Document Revision History

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V0.3	22/09/2021	Contributions to Sections 3.1,3.2, 3.4	Enrique Areizaga/Leire Orue-Echevarria /Guillermo Gil (TECNALIA)
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Dissemination Level		
PU	Public, fully open, e.g. web	√
CI	Classified, information as referred to in Commission Decision 2001/844/EC	
CO	Confidential to HUB4CLOUD project and Commission Services	

* *R: Document, report (excluding the periodic and final reports)*
DEM: Demonstrator, pilot, prototype, plan designs
DEC: Websites, patents filing, press & media actions, videos, etc.
OTHER: Software, technical diagram, etc

EXECUTIVE SUMMARY

This deliverable documents the findings on the focus topics tackled up to M09 by HUB4CLOUD in support of ECC roadmap development that will feed into the H-CLOUD Strategic Research and Innovation Agenda (SRIA). This document will also indicate how HUB4CLOUD will take over road mapping activities after the end of H-CLOUD.

In order to be able to generate a quality set of recommendations feeding into the European Cloud Computing (ECC) Strategic Research and Innovation Agenda, several deep analysis tasks have been carried out in three parallel directions: What is the research community doing in Cloud Computing in Europe and other relevant areas such as the US, What is the opinion of the stakeholders, gathered through interviews and surveys and What are the relevant topics that will need to be addressed in the near/long future to become competitive with their counterparts in USA and Asia, mainly China.

A thorough, extensive and in-depth analysis of academic venues has been carried out in order to analyse the trends in the research and academia community. These topics have been further enriched and extended with the results obtained from “surveys” and “interviews” to relevant Cloud Computing stakeholders from Academia, SMEs, Big players and Institutions representatives, as well as with the documentation already available from existing initiatives. The result is a list of seven topics described as research challenges along with the potential impact that they could bring.

The next version of this document (due in M14 and M18) will develop a scoring and a classification methodology of said topics and will end up with a set of recommendations and prioritizations for the European Commission to include in the upcoming work programmes.

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1 INTRODUCTION

This document is the first of a series of three documents that aims to present the proposal for a research roadmap in the domain of cloud computing continuum. HUB4CLOUD partners follow a multi-sourced methodology, gathering content from relevant stakeholders such as existing RIA projects, interviews, surveys, analysis of the current context and running initiatives but also following more formal methods inspired by systematic literature reviews. The main goal is to come up with a list of research challenges and topics that can later on be classified, scored and prioritized.

The document is structured as follows.

Section 2 presents the approach and methodology followed for the elucidation of the research roadmap.

Section 3 analyses the landscape and context, that is, presents on one hand, different initiatives that are running in Europe as well as in the US and China to understand how these could affect the research landscape, and on the other it analyses input from several stakeholders such as running projects, surveys and interviews carried out to people coming from SMEs, large industry and European initiatives.

Section 4 presents the methodology followed for the analysis of the research venues which is the last input for the findings of the research challenges and topics, which are presented in a structured way in this part of the document.

Section 5 contains the conclusions and future work.

Appendix A and Appendix B contain the Search queries and results of the analysis to allow the reproducibility of the method.

Appendix C includes the invitation text for the interviews held with the experts.

2 ROADMAPPING APPROACH AND METHODOLOGY

2.1 Introduction

This report is the first outcome of task *"T1.3 Road mapping and policy recommendation"* with the main objective to contribute to the ECC research roadmap and policy recommendations aligninig the view from different stakeholders (research, industry, users). In order to achieve this objective Task 1.3 proposes a multi-source analysis (see Figure 1) considering different sources to gather the input form the different types of stakeholders academia, practiotioners, industry and users. The result of this analysis will be reported in D1.4 (M9), D1.5 (M14) and D1.6(M18).

Figure 1. Multi source analysis in Task 1.3.

2.2 Methodology

The proposed methodology stands over 3 main pillars (Figure 2). The methodology is similar to the one already presented in D3.5 but tailored for the domain at hand. This demonstrates the repeatability and the scientific soundness of the approach:

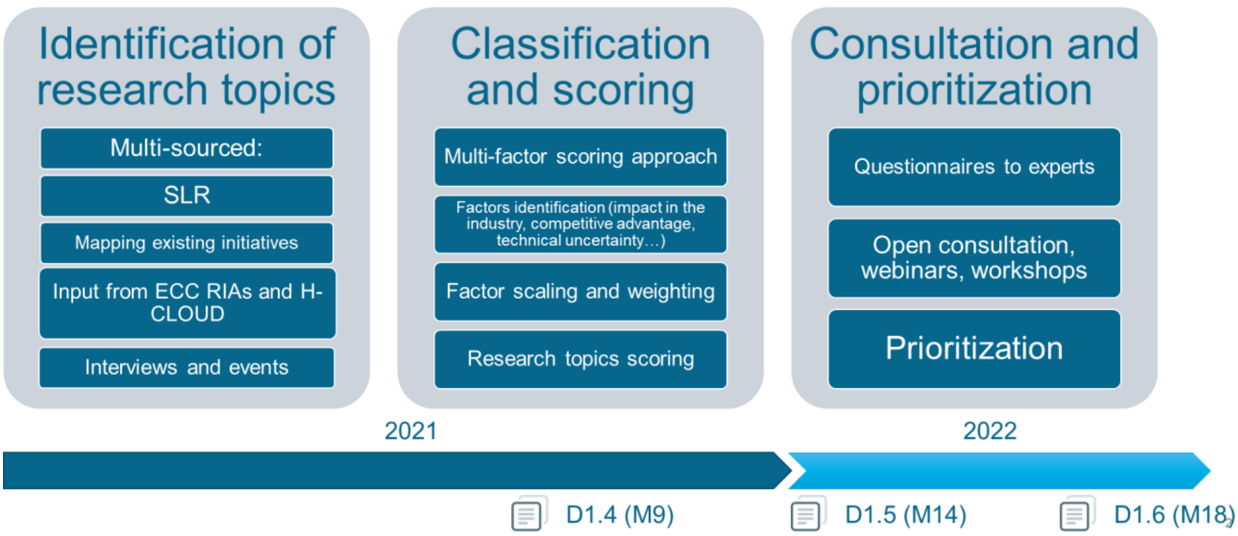

Figure 2. Methodology followed in Task 1.3

1. Identification of research topics from diverse sources:
   a. Analysis of publications from the most relevant academic venues (journals and conferences) (section 3.1 of the current document)
   b. Mapping of existing international Cloud Computing initiatives (section 3.2 of the current document).

c. Analysis of the inputs coming from the HUB4CLOUD RIAs through online surveys (section 3.3 of the current document) and the H-CLOUD CSA.
d. Analysis of the input from other relevant players mainly from the industry and the Future Cloud Cluster (section 3.3 of the current document).

2. Classification and scoring (Figure 3): Once the inputs are gathered an initial list of research topics will be created. This list will be classified and scored using a set of factors (i.e. impact in the industry, competitive advantage, technical uncertainty, etc).
3. Consultation and prioritization: The initial classification performed by HUB4CLOUD will be shared with the community through different channels (workshops, interviews) and as a result the final prioritization of the topics will be performed.

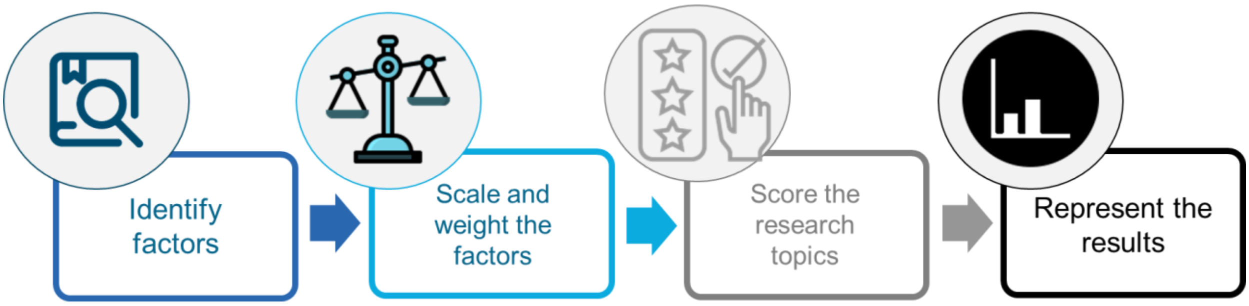

Figure 3. Multi-factor scoring methodology phases

This deliverable (D1.4) reports the work done for the first pillar in Figure 2.

3 CONTEXT ANALYSIS

This section aims at presenting the current landscape of cloud-related initiatives in three major geographical areas: Europe, USA and China

3.1 Mapping of existing initiatives: International research strategies in Cloud Computing

3.1.1 Europe

The European Commission and, in some cases, certain member states, have been promoting during the last three or four years new measures and initiatives aimed at promoting the European digital sovereignty through the development of digital, secure and sustainable digital infrastructures, and the promotion of the emergence of European operators in infrastructures and cloud services, as well as other actions to avoid possible risks related to interference from third countries in European data. These measures and initiatives include, among others, the following:

- GAIA-X.
- Important Project of Common European Interest in the New Generation of Infrastructures and Services in the Cloud / Edge - IPCEI CIS.
- International Data Space Association - IDSA.
- European Union Agency for Cybersecurity (ENISA) - Cybersecurity certification scheme on cloud services and Cloud Service Providers Certification Working Group.
- European Alliance on Industrial Data, Edge and Cloud.

3.1.1.1 Gaia-X

Gaia-X [1] is an initiative, originally Franco-German, launched in 2020 for the development of an efficient and competitive, secure and reliable data infrastructure for the European Union. The initiative, which pursues technological sovereignty in the cloud, has been extended to other EU member states. The associated ecosystem is currently constituted as a non-profit association.

Its concept is based on creating a federated, secure and interoperable system that complies with digital sovereignty standards and allows to support business innovation. Its implementation is supported by a series of services: Identity and Trust Services, Federated Catalog; Sovereign Data Exchange Services and Compliance Services [2]. These services can link existing cloud infrastructures and data ecosystems so that organizations retain sovereignty and control over their data and have more transparency and choice over the cloud platforms and resources they use, avoiding the, at the same time, excessive dependence on suppliers.

Gaia-X connects centralized and decentralized infrastructures to turn them into a homogeneous and usable ecosystem in which participants can use data and services sovereignly in sector-specific and cross-sectorial data spaces.

The principles that govern Gaia-X are openness-transparency, interoperability, federation, authenticity, and trust [1].

3.1.1.2 Important Project of Common European Interest in the New Generation of Infrastructures and Services in the Cloud / Edge - IPCEI CIS.

Several member states are promoting the development of an Important Project of Common European Interest (IPCEI) on the next generation of cloud / edge services and infrastructures - IPCEI CIS - to provide competitive and fair access to these capabilities from anywhere in the EU.

IPCEIs are public-private partnership projects carried out jointly by various member states in order to undertake large-scale transnational projects of strategic importance for the EU and for the achievement of common European objectives. The IPCEIs seek to bring together knowledge, experience, financial resources and economic agents across the Union, to overcome major market failures and societal challenges that could not be addressed otherwise. The IPCEIs are established to generate positive externalities beyond the participating member states, companies or sectors. These types of projects have different financing advantages: based on a wide set of eligible costs, including the costs of R&D&I and the first industrial deployment (that is, between the pilot / demo line and before the start of mass production), an IPCEI can receive support of up to 100% of the funding gap.

Currently participating in the definition of the IPCEI CIS project are Germany, Belgium, Slovenia, Spain, France, Hungary, Italy, Latvia, Luxembourg, the Netherlands and Poland.

The project is aimed at building the next generation of pan-European sovereign, interoperable, multipurpose and vendor-neutral data processing infrastructures that are interconnected, distributed and scalable. The development and deployment of real-time edge computing capabilities (very low latency) is included in its conception; the design of secure, low-power and interoperable middleware platforms for multiple industry uses; and the development and deployment of ultra-secure, real-time, low-power smart cloud and edge services. They refer to these infrastructures as "Distributed Multi Provider Cloud-Edge Continuum".

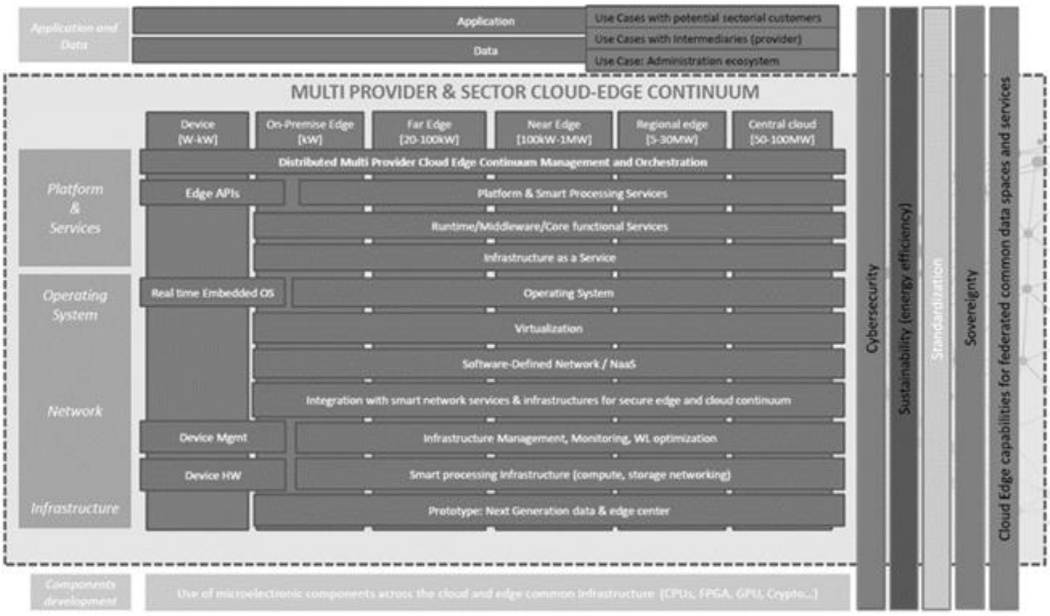

Figure 4. IPCEI-CIS Conceptual architecture (September 2021)

3.1.1.3 International Data Space Association – IDSA

The Initiative promoted by IDSA (International Data Spaces Association) [3] aims to contribute to the global digital economy through standardized and secure mechanisms for the exchange and sharing of data in reliable environments, while guaranteeing sovereignty over this data for its creators or suppliers, which constitutes the central element of the approach. These mechanisms form the basis for the development of new smart services and facilitate innovative trans-business processes.

IDSA is building a reference model that forms the basis for a data market based on European values, that is, data privacy and security, equal opportunities through a federated design, guaranteeing the sovereignty of the data for the creator of the data and the generation of trust among the participants.

The model is made up of five layers [4]:

- The Business Layer specifies and categorizes the different roles that the participants of IDSA can have. It also specifies how these roles can interact with each other.

- The Functional Layer defines the functional requirements as well as the features resulting from such requirements. These requirements are independent of the technologies and applications used.
- The Process Layer specifies the interactions that take place among the different components of IDSA. This layer is the dynamic view of the Reference Architecture Model.
- The Information Layer is domain-agnostic and defines the information model of IDSA. The information model in this case is a common language, that is, an agreement that is shared by all participants of the association with the aim of facilitating interoperability and compatibility.
- The system layer is the technical core of the IDSA reference architecture. On this layer, the roles identified in the business layer are mapped to specific data and services in order to meet the requirements defined in the functional requirements. This layer often results in three main components, which are the connector, the broker and the app store, which build the core of IDS.

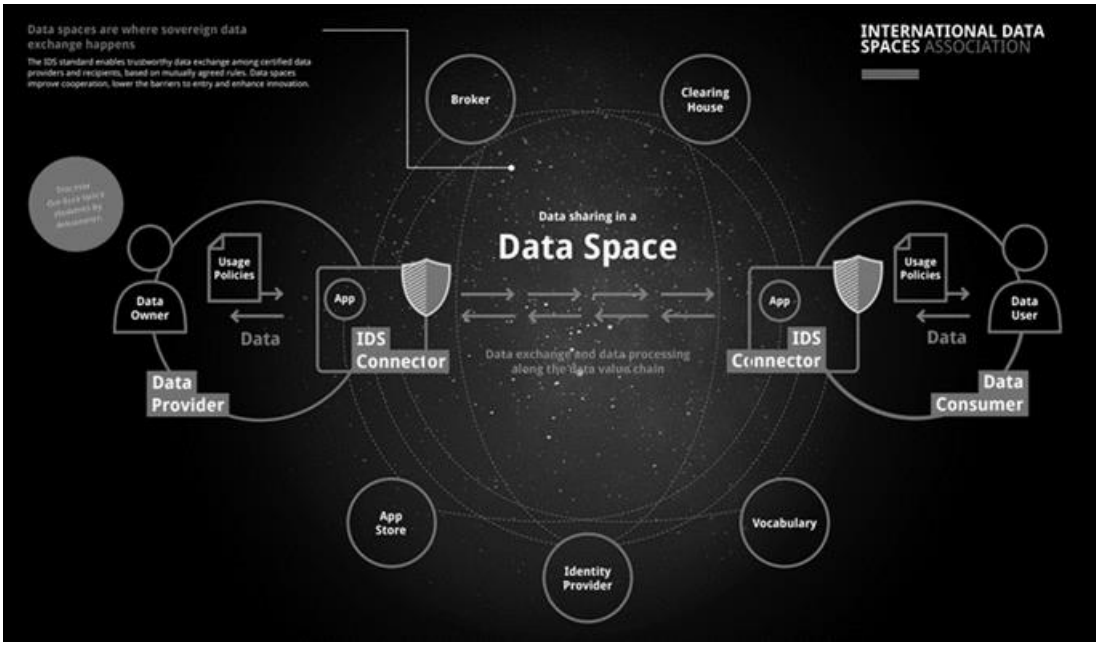

Figure 5. IDSA Concept [3] (September 2021)

3.1.1.4 European Union Agency for Cybersecurity (ENISA) - Cybersecurity certification scheme on cloud services and Cloud Service Providers Certification Working Group.

The European Union Cybersecurity Act (EU CSA) [5] lays the foundation for establishing an EU framework for the cybersecurity certification of IT services, products and processes, including services provided by Cloud Service Providers (CSP). The Cloud Service Provider Certification Working Group, CSPCERT [6], was created in December 2017 in anticipation to this Regulation with the aim of laying the foundations for a European framework for cybersecurity certification. of the CSPs.

ENISA Ad-Hoc Working Group 2 [7], Cloud Services, has been working on the implementation of the cybersecurity certification scheme on cloud services aligned with Regulation (EU) 2019/881, Cybersecurity Act.

This working group was launched in March 2020 and their work has been devoted to:

- The definition of the dimensions of the three different assurance levels as identified in the Cybersecurity Act
- The definition of the security requirements and their placement in the different assurance levels
- The definition of the meta-methodology for the conformity assessment method as well as

the associated documentation
- The certification process itself
- Compositional certification
- Requirements for Conformity Assessment Bodies Certification

All this has been performed in accordance with the provisions of the Regulation and, in general, support for ENISA in the performance of its tasks in relation to the cybersecurity certification scheme for cloud services.

The first draft of the European Cloud Services certification scheme (EUCS) [8] was published on December 2020 for open consultation. Currently, the working group is addressing the comments received, and extending the scheme with for instance application profiles, pen testing or the supply chain. The next steps include additional proof of concepts and the promotion to a standard CEN-CENELEC.

3.1.1.5 European Alliance on Industrial Data, Edge and Cloud.

The European Alliance for Industrial Data, Edge and Cloud [9] aims to foster the development and deployment of next generation edge and cloud technologies. The objective of the Alliance is to bring together businesses, Member States representatives and relevant experts to strengthen the position of EU industry on cloud and edge technologies, and with the ultimate goal of increasing the leadership of Europe in industrial data.

The main stakeholders of the Alliance are both the private and the public sector, who shall define, in a joint manner, the strategic investment roadmap for the next generation of highly secure, distributed, interoperable and resource-efficient computing technologies. Moreover, the Alliance shall serve as a platform for exchanges on issues of cloud governance, for example relating to the public procurement of cloud services.

To achieve these objectives, the Alliance will work on the following non-exclusive list of tasks [9]:

- bringing together relevant actors to prepare and update horizontal and technology specific investment roadmaps on cloud and edge.
- providing recommendations to ensure the coherent integration of investments with those foreseen for the deployment of common European data spaces in relevant areas.
- advising the Commission on requirements and standards for cloud services, including for public procurement.

The work of the Alliance will be facilitated by the European Commission’s Directorate-General for Communications Networks, Content and Technology (DG CONNECT). The operational work will be driven by an appointed Steering committee and relevant working groups.

3.1.1.6 Future Cloud Cluster

The Future Cloud Cluster was launched in 2015 by the European Commission as an environment where projects and stakeholders working in the field of distributed computing (Cloud, Multi-Cloud, Edge, Fog, Ad-hoc and Mobile computing) can get together to discuss and collaborate.

The Future Cloud Cluster is an on-demand group that publishes thematic papers under the request of the European Commission. One of these key papers recently published is the Research Roadmap [10].

The Future Cloud Research Roadmap has been published in August 2020 and has identified 13 research topics. Such research areas express the vision from the participants of the cluster.

The picture below depicts the main areas identified by the cluster:

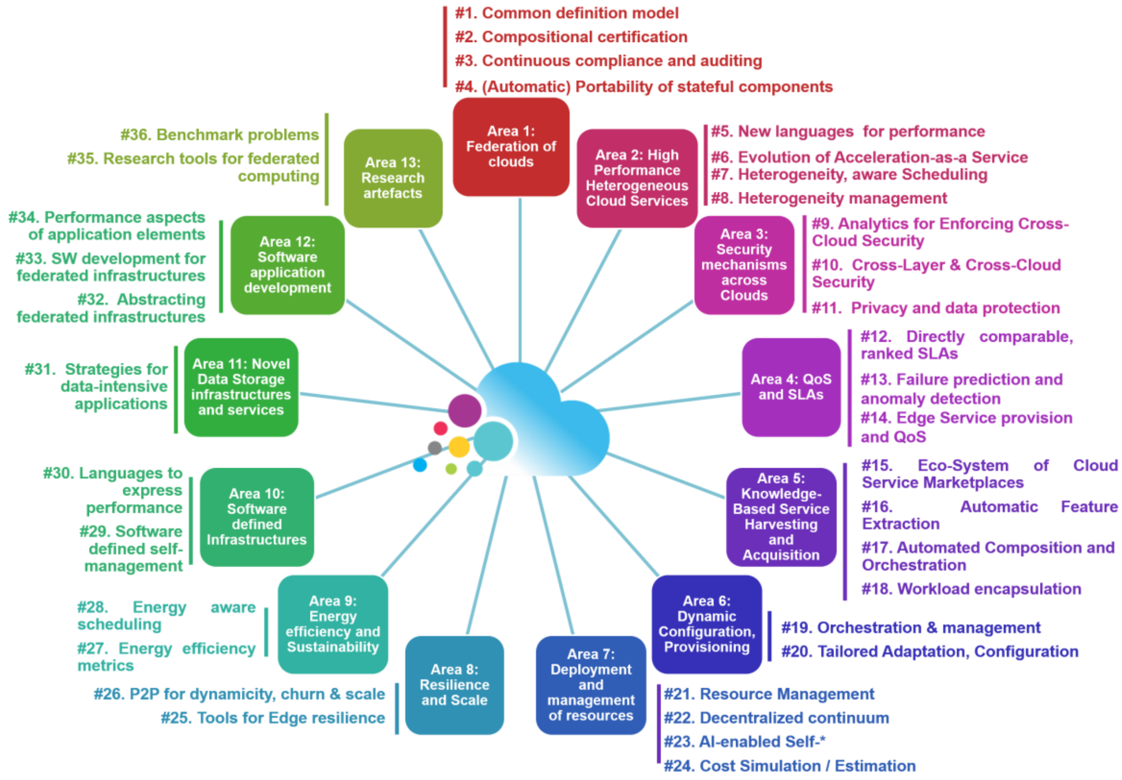

Figure 6. Future Cloud Cluster Research Areas priorities (Source: Future Cloud Cluster [10])

Another important document released by the Future Cloud Cluster recently is the reference architecture for a cloud federation [11].

The following picture shows the proposed architecture for a cloud federation:

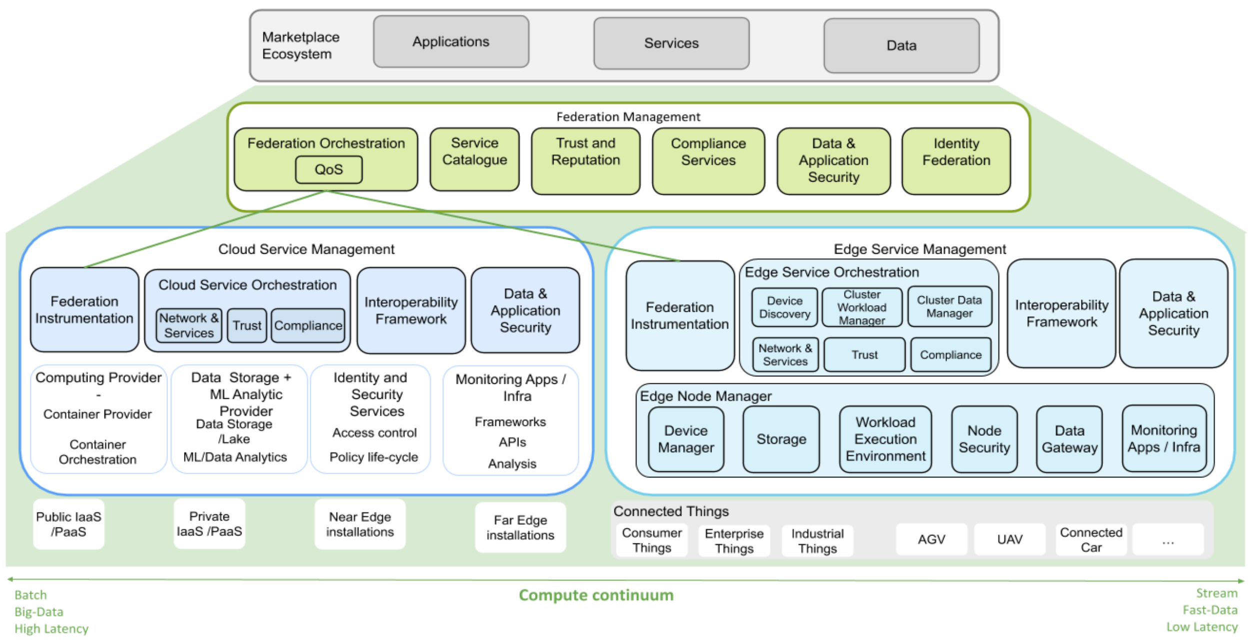

Figure 7. Future Cloud Cluster Cloud Federation Reference Architecture (Source: Future Cloud Cluster [11])

The document [11] presents not only the main building blocks of the architecture but also how the projects of the cluster map with these building blocks and also how the research areas identified (see above) map with said building blocks.

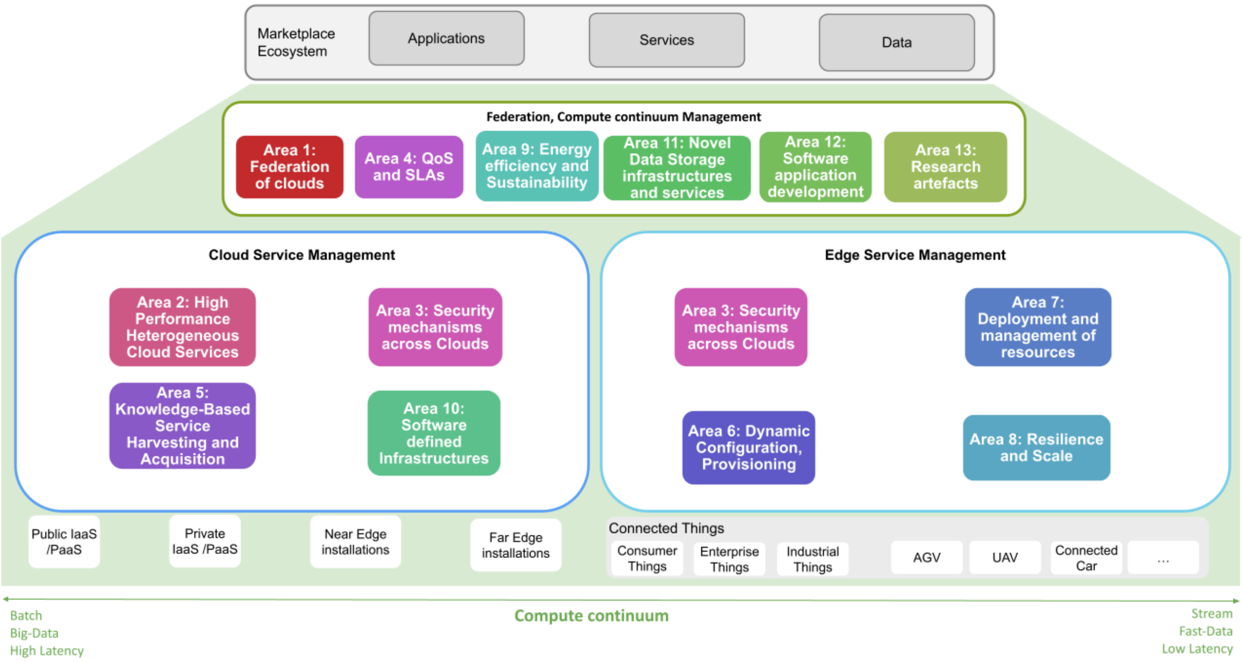

Figure 8. Mapping of Future Cluster Research Areas to Architecture levels (Source: Future Cloud Cluster) [11]

3.1.2 USA

Research activities in U.S.A., as in the rest of the world, are funded by a mix of public and private organizations. According to the "U.S. Research and Development Funding and Performance: Fact Sheet" report, January 2020 [12], the total estimated U.S. R&D expenditures in 2018 were $580.0 billion. Of this amount, $96.5 billion (16.6%) was for basic research, $115.0 billion (19.8%) was for applied research, and $368.5 billion (63.5%) was for development [12]. According to this report, close to 70% of research and development in scientific and technical fields is carried out by the industry. The remaining 30% is likely to be funded from various government agencies, institutions, and foundations. The federal funding for R&D represents roughly the 20%. There are several federal agencies that are primarily devoted to research and development, either independent (as the National Science Foundation, or as NASA) or associated to specific departments (such as Defense Advanced Research Projects Agency, DARPA, of the Department of Defense).

The National Science Foundation (NSF) is an independent federal agency that supports in U.S.A. fundamental research across virtually all fields of science, engineering, and education. NSF is the funding source for approximately the 24% of all federally supported fundamental research in American universities, according to the publication "NSF Strategic Plan for Fiscal Years 2018 – 2022" [13]. NSF also supports innovation by small businesses, partnerships among academia, industry and national laboratories, research in non-profit nonacademic organizations, and entrepreneurship training for the academic research community [13].

The Computer and Information Science and Engineering Program of NSF [14] supports "*investigator-initiated research in all areas of computer and information science and engineering that advances society, helps develop and maintain advanced cyberinfrastructure to enable and accelerate discovery and innovation across all disciplines, and contributes to the training of the next generation of computer and information scientists and engineers with skills essential for success in the increasingly competitive global market*" [13]. The divisions and offices within this area are: Advanced Cyberinfrastructure, Computing and Communication Foundations, Computer and Network Systems, Information & Intelligent Systems, and Information Technology Research

[15].

The data-intensive science (sensing, computing, storage, communications and analysis) is one of the areas in which NSF has had an increased investment in the latest years, both for its development -in order to close the loop from data generation to analysis- as well as for the potential that this knowledge brings to develop other fields -for example, the ability to work in a very wide spectrum of themes, from genomics, proteomics or chemical synthesis to the cosmos understanding.

When searching for the “Cloud computing” and “Edge computing” terms in the Research Spending and Results of the NSF´s database, the following results are obtained: An estimated total award amount of 332,2 million USD in the period from 2017 to mid-2021 for “Cloud Computing” and of 164,4 million USD for “Edge computing” in the same period. It should be noted that NSF funds research and engineering, as well as educational activities, and that under these terms are also included activities in other related fields -such as wireless networks. Also, the same project could be classifieds under both terms. Some of the most relevant projects for the HUB4CLOUD analysis are:

- *CarbonFirst*: A Sustainable and Reliable Carbon-Centric Cloud-Edge Software Infrastructure [16]. The project [17] aims at designing a sustainable and reliable cloud-edge software infrastructure that can enable continued exponential growth. The foundation of CarbonFirst is a software-defined energy virtualization layer that provides applications visibility into, and control of, their own energy and carbon usage. CarbonFirst aims at developing higher-level systems abstractions for supporting carbon-efficient applications at different geographical scales including: a cluster balloon technique, which automatically adjusts applications’ energy usage to match a volatile clean energy supply at local edge sites; edge hopping mechanisms, which exploit lower regional energy volatility to balance energy across edge sites; and carbon capping policies, which track applications’ global grid carbon emissions and restrict grid energy after reaching the cap.

- *Foundations of Clean and Balanced Datacenters*: The Treehouse project [18] aims to improve the energy efficiency of datacenter computing by making datacenter computing energy use accountable to users at a fine-grained level and by reducing unnecessary waste in the most frequently used parts of datacenter computation. To achieve that, it develops a new computational abstraction that allows new energy optimizations by both application developers (by making application energy use visible at a fine-grained level) and systems designers (by identifying when energy-efficient optimizations can be safely performed without compromising user goals for application performance and reliability).

- *Chameleon Phase III:* A Large-Scale, Reconfigurable Experimental Environment for Cloud Research. Chameleon [19] [20] is a reconfigurable experimental testbed supporting Computer Science (CS) systems experimentation. The platform consists of two sites, University of Chicago (UC) and Texas Advanced Computing Center (TACC), along with support functionalities from Northwestern University and the University of North Carolina. The platform balances investment in large-scale hardware to support Big Compute and Big Data experimentation with diversity reflected by smaller clusters of graphic processing units (GPUs), field programmable gate arrays (FPGAs), specialized architectures, and innovative networking hardware. Users can reconfigure this hardware at bare-metal level, boot from custom kernel, get access to serial console, or provision and reconfigure Software Defined Networking (SDN)-enabled switches. Chameleon is publicly available since July 2015 and has over 4,000 users working on over 600 education and research projects. This is the third phase of the project. In Phase III, Chameleon will expand its core capabilities by adding new hardware and new features such as Internet of Things (IoT) and edge computing, a broader range of networking experiments, and experimentation with disaggregated hardware. The system will also expand its support for reproducibility by providing tools that allow investigators to package their experiments for replication, and making it possible to publish, discover, and cite them easily. Finally, phase 3 will see a continuation of work on packaging CHameleon Infrastructure, known as CHI-in-a-Box, which allows others to deploy and manage testbeds similar to Chameleon. The.

- *Game Theoretic Updates for Network and Cloud Functions*. This project [21] aims to develop (1) a new game-theoretic foundation for network updates, (2) algorithms for synthesizing update controllers that are robust to failures and changing conditions during the update, (3) algorithms for explaining update failures, (4) a language design that allows synthesized controllers to be safely modified, and (5) implementations and evaluations of these mechanisms for virtual network functions and serverless-computing platforms. The project provides network operators with tools that make updates to networked systems easier, safer, and more reliable, and develops a framework that makes datacenter computing more reliable and secure.

- *Reducing Container Kernel Attack Surface with TRACKS*. The TRACKS (TRimming Augments Container Kernel Security) project aims to strengthen the security of container environments by hardening the Linux kernel. The project's novelties are its use of how frequently code is encountered as a way to measure how likely it is to have security flaws.

- *CloudBank:* Managed Services to Simplify Cloud Access for Computer Science Research and Education [22]. The University of California, San Diego's San Diego Supercomputer Center and Information Technology Services Division, the University of Washington's eScience Institute, and the University of California, Berkeley's Division of Data Science will develop and operate CloudBank [22], a cloud access entity that helps the computer science community access and use public clouds for research and education by delivering a set of managed services designed to simplify access to public clouds. CloudBank aims to serve as an integrated service provider to the research community by providing them a set of business operation functions that span from novel to advanced cloud users. These include front line user support, cloud solution consulting, training, and assistance in preparing proposals that need cloud resources. Moreover, CloudBank provides innovative financial engineering options for researchers, which means more flexible cloud terms tailored to their needs which in the end contribute to the sustainability of CloudBank operations. Thanks to this this aggregation and innovative financial contract types, CloudBank will pass along savings to researchers that would otherwise be unavailable to them.

- *Developing a Testbed for the Research Community Exploring Next-Generation Cloud Platforms*. This project [23] aims to construct and support a testbed for research and experimentation into new cloud platforms - the underlying software which provides cloud services to applications. The new testbed will combine proven software technologies with a real production cloud enhanced with programmable hardware - Field Programmable Gate Arrays (FPGA) - capabilities not present in other facilities available to researchers today. The combination of a testbed and production cloud allows a) larger scale compared to isolated testbeds, b) reproducible experimentation based on realistic user behavior and applications, as well as c) a model for transitioning successful research results to practice.

- *Next-Generation Cloud Federation via a Geo-Distributed Datastore*. This project [24] aims at developing new technologies that enable users to leverage multiple cloud infrastructures at once, safely and easily. In particular, it defines a new software abstraction for the scalable data management (datastore) layer, called DatGeo, that bridges geographically distributed cloud federations. DatGeo is used to develop new approaches for efficient transactions, partitioning and replication of data, and policy enforcement and mediation, across clouds. As a result, DatGeo will shield user applications from the complexities associated with low-level federation of individual cloud services, while facilitating location and privacy control, increased reliability, and transparent cross-cloud use and portability.

- *A Modular, Composable Hardware and Software Platform for Pervasive Edge Sensing and Computing*. This project [25] will design, create and evaluate a novel hardware and software platform where heterogeneous peripheral modules and modularized FPGA/software computation components can be easily composed electrically and computationally like interlocking Lego pieces, to create various customized edge sensing and computing devices required in these "smart" applications.

- *An 'On-the-fly' Deeply Programmable End-to-end Network-Centric Platform for Edge-to-Core Workflows*. This project [26] will provide tools that will allow researchers and drone application developers to address operational drone challenges by using advanced computer and network technologies. Moreover, it will provide an architecture and tools that will enable scientists to include edge computing devices in their computational workflows, which is critical for low latency and ultra-low latency applications like drone video analytics and route planning for drones.

The Defense Advanced Research Projects Agency (DARPA) is a research and development agency of the United States Department of Defense responsible for the development of emerging technologies for use by the military [27]. Even DARPA´s projects have had this specific focus domain, although it is mainly involved in key innovations in many other areas. In the ICT domain, DARPA has contributed to innovations for the personal computer or internet. DARPA has six technical offices that manage the agency's research portfolio [28].The Information Innovation Office (I2O) [29] is the responsible for basic and applied research in the areas of cyber security, data analytics, and human-machine symbiosis. Some of the active programs are:

- *Open, Programmable, Secure 5G (OPS-5G).* OPS-5G [30] seeks to create an open source software and system that enable secure 5G and subsequent mobile networks such as 6G. The program seeks to enable a "plug-and-play" approach to various software components which reduces reliance on untrusted technology sources.

- *Data Protection in Virtual Environments (DPRIVE).* DPRIVE [31] is a program that aims to develop novel hardware accelerator that will ease computational challenges preventing the widespread use of fully homomorphic encryption (FHE). According to DARPA [31], FHE enables computation on encrypted data, or ciphertext, to keep data protected at all times. While the benefits of FHE are significant, it requires enormous computation time to perform even simple operations, making it exceedingly impractical to implement with traditional processing hardware. The Data Protection in Virtual Environments (DPRIVE) [31] program seeks to enable FHE computation within a factor of ten of unencrypted computations, enabling data security for all states of data across DoD and commercial applications.

- *Dispersed Computing*. The Dispersed Computing program [32] seeks scalable, robust decision systems that enable secure, collective tasking of computing assets in a mission-aware fashion by users with competing demands, and across large numbers of heterogeneous computing platforms. Dispersed Computing seeks to design systems able to operate in environments where network connectivity is highly variable and degraded. It aims to enable the strategic, opportunistic movement of code to data, and data to code, in a fashion that best suits user, application, and mission needs.

3.1.3 P.R. CHINA

The big four Chinese cloud companies are Alibaba Cloud, Huawei Cloud, Tencent Cloud and Baidu AI Cloud, who collectively hold 81% of the market share in China. Alibaba Cloud is the clear leader with a 45% share. However, when looking at the global share, Amazon is the lead, with a market share of 33%, ahead of Microsoft Azure, Google Cloud and Alibaba Cloud.

In any case, there are good perspectives for China in the Cloud business with some forecast to grow around 22,1% per year. China cloud market is around US$10Billion, still low comparing with the US$30Billion per year of AWS. But it is expected to be multiplied by 20, around US$222.5 billion by year 2027.

The main problem that Chinese Cloud companies face is “Mistrust”. During the recent years, there has been a growing mistrust in China, mainly leaded by US. This situation has led to companies to consider not to take the risk to put sensitive data in Chinese Cloud providers.

On the other hand, China is a very closed market that protects its own enterprises. This implies that this big four “Alibaba, Huawei, Tencent and Baidu” will be able to expand their cloud business without the thread of US Cloud providers.

Other very interesting fact is also the higher proportion of Chinese Companies IT expenditure on hardware compared to the developed countries. They still prefer to spend on their own servers than going to the cloud what might still be related to trust in their own Chinese Cloud providers.

HUB4CLOUD has approached a few companies regarding cloud computing test requirements. Those companies are basically making Hardware infrastructure: switches/routers/storage devices, etc.

They all have similar concerns:

1. Stress/performance testing. Maximum capacity/simultaneous connections to the cloud testing. Maximum throughput, etc. Ethernet speed up to 400Gbps/port.
2. IoT to ensure the interoperability between server/network devices.
3. Security testing. Protocol fuzzing, Malware/attack testing are part of this concern.
4. Browser performance/stability testing.
5. Functional testing ex. maintenance, backup, etc.

3.2 Input from European projects

3.2.1 Input from the RIAs

HUB4CLOUD has carried out two surveys to gather input about different topic that are considered key for Cloud computing.

The first survey aimed to collect feedback on the different themes from SCB members to be included in the HUB4CLOUD Position Paper “HUB4CLOUD Position Paper Theme and Strategic Objectives”. This survey can be accessed through:

https://docs.google.com/forms/d/12PcEvtGFCmMIaIA_hIUntiG5NZFX9G9Xy3fXiggzDqk/edit

The second survey was an EUSurvey “HUB4CLOUD Survey for cloud/edge computing projects - collecting experiences and practices for the future”. Through this survey, the project HUB4CLOUD aimed to collect information from cloud/edge computing projects about their main research topics, potential impact, open source practices, standardization interest and business perspectives.

This survey can be accessed through:

https://ec.europa.eu/eusurvey/runner/HUB4CLOUD_Survey_2021_v1#page0

The topics that were covered within the surveys were:

- Cloud certification
- Cognitive Cloud
- Open Source
- Skill development
- Software engineering
- Cloud federation
- Cloud/Edge Continuum
- Green Cloud

- AI for Cloud
- Legislation awareness for Cloud
- Standardisation
- Security for Cloud
- Self-Healing Cloud

The number of surveys answered are 13 coming from coordinators of different EU projects like: FogProtect, PHYSICS, CHARITY, RAINBOW, H-CLOUD, AI-SPRINT, DATACLOUD, ACCORDION, PLEDGER, SMARTCLIDE, SERRANO.

From EUSurvey, 10 project coordinators answered to the survey: RAINBOW, SmartCLIDE, ACCORDION, INTELCOMP, PLEDGER, MARVEL, MORPHEMIC, H2020 MEDINA, Policy CLOUD, DECIDO. A scoring methodology has been established based on the answers per topic score (from 0 to 5). The maximum score is 50 points (10 participants * 5).

From the data collected, two graphs have been elaborated to identify at a glimpse what is the level of acceptance and rejection of the different topics.

Acceptance per topic (position paper)

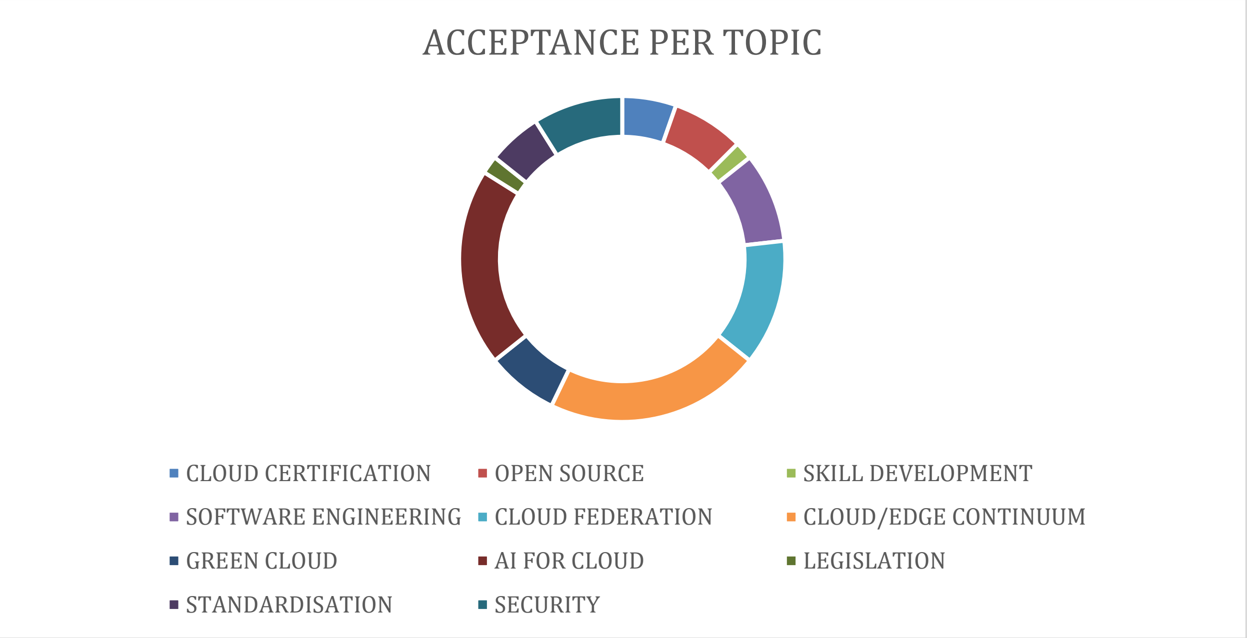

Figure 9. Acceptance per topic (position paper)

Relevance for Cloud research (EUSurvey)

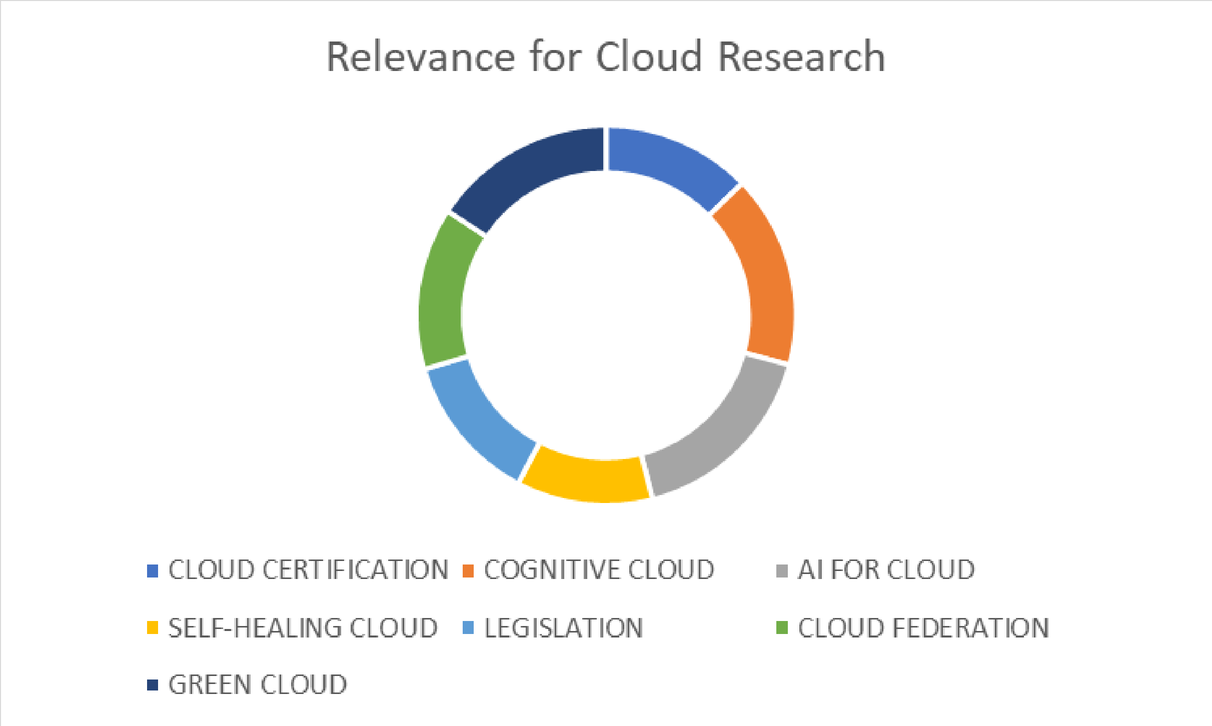

Figure 10. Acceptance per topic (EU Survey)

The conclusions for both surveys have been merged for understandability issues.

Cloud/Edge continuum

There is a common consensus that this topic is the most relevant now with 12 out of 13 surveys answered positively.

The strategic objectives related are:

- Privacy-preserving tools, reference architectures, NGI
- Important to improve the communication between cloud and edge, for the future utilization of the 2 environments (i.e. Smart Manufacturing)
- Orchestrating services and data in the cloud-edge bring a completely new level of complexity that today solutions don't tackle at scale yet.
- Scheduling and Orchestration of Continuum Resources, Management of the Computing Continuum, IoT Pipelines
- Dynamic Continuum; Interplay with network-centric initiatives (e.g., ETSI MEC); Decentralised management of the continuum
- Far and near edges, clusters on demand, smart contracts and QoS

Cognitive Cloud

Cognitive Cloud has also been identified as a very Hot topic by the research community with a score of 44 out of 50 (EUSurvey)

AI for Cloud

Artificial Intelligence is also a very hot topic and the feedback from the survey also shows the importance given by the industry. "11" out of 13 have answered positively but it has also got "1" negative feedback. AI for Cloud has also been identified as the most relevant "Research topic" scoring 45 out of 50.

The strategic objectives related are:

- Explainable AI, Ethical Guidelines, Best practices and use cases
- AI available on cloud will means scalability, less cost, increased productivity, reliability.
- In the cloud-edge complexity and scale, more automation is required. and this automation need to be more intelligent than applying static policies.
- There is a lot of interest by the EU Commission on this topic. Different solutions could be overviewed and stress the benefits with respect to other approaches (e.g., model based, optimisation based, heuristics and current best practice for resource management of the big players)
- Exploitation of Computing Accelerators (training) and FPGA (inference) at the Edge; Reinforcement Learning; Deep Learning; Federated Learning
- Automation and predictability, swarm computing

Cloud Federation

Considered as the European alternative to the US and China Big players, though supported by a bit more than half of the survey respondents (7 out of 13), there are still some doubts about its business model. Within the respondents of the EUSurvey is also identified as a relevant topic but not in the Top three priorities (37/55).

The strategic objectives related are:

- Development and deployment of cross-cloud applications
- Heterogeneous federations; Enabling services; Ephemeral and user-centred federations; Business models for the federation
- Interoperability, provider agnostic, on demand cloud

Security

This topic is always a main concern regarding security, especially when private data is concerned. However, in relation with Cloud computing only “5” out 13 survey respondents voted favourably and “1” negatively.

The strategic objectives related are:

- Secure and trustworthy cloud solutions for the various security requirements
- Security aware microservices based application orchestration.
- Automatic AI Based Testing

Software engineering

In relation with Cloud computing, this topic has only got “5” out 13 survey respondents voted favourably and “2” negatively.

The strategic objectives related are:

- Abstracted programming languages and workflow design, continuum in the sense of software stacks
- Developing native cloud applications needs to be simpler.
- Big Data Processing, Data Enrichment

Green Cloud

Though there is a lot of effort and support to reduce the CO_2 footprint, within the Cloud Computing community there is not much sensibility about it. As it can be further explored within the interview section, the ration of power consumption by data centers versus the computing power is improving which is greener than other technologies. It has got 4 out of 13 positives votes and no negatives.

However, from the "EUSurvey" results, Green Cloud is considered one of the most interesting topics for research (42/50)

The strategic objectives related are:

- Environmental impact of cloud, energy-efficient edge, best practices
- This is an important objective for the new program Horizon Europe, there is a need to develop something along these lines
- Energy efficiency, energy aware deployments

Open Source

Europe is very well known for favouring openness, but Open Source has received little support from the survey respondents, "4" out of 13 and "1" negative vote.

The strategic objectives related are:

- Open trusted fog computing platform
- Open source solutions for cloud are proliferating. This may bring to fragmentation.
- Promote European cloud developments, unified community, accessibility of results
- Enhance Open source

Standardisation

Most of the respondents were indifferent to Standardisation but the few that supported "3" out of 13 are very supportive.

The strategic objectives related are:

- Standards landscape for cloud services, positioning with ICT Standardisation priorities from EC, Liaison with AIOTI, BDVA/DAIRO, ETSI, CEN/CENELEC
- As a Cloud user, moving withing different providers is not easy indeed. Standardization will help a lot the users to freely choose the most suitable solution
- TPM standard

From the projects participating within the EUSurvey, most of them (4/10) are adopting the OASIS standards, the rest were each adopting different standards (OSCAL, ETSI-NFV, ISO19086, EUCS [8], TPM, OMG, Cloud Security Alliance, TOSCA, ISO27001, ISO27002, CSA CCM, StandICT). And contributing to OASIS TOSCA (3/10) and OSCAL, EUCS [8], ITU-T, CAMEL and Cloud Security Alliance.

Surprisingly, only one project, MEDINA, applies and contributes to the EUCS [8] (European Cybersecurity Certification Scheme for Cloud Services).

Cloud Certification

Very little interest only supported by "3" out of 13 and "1" negative. It is seen as something very specific for certain sectors. Also, one of the lowest scores from EUSurvey (34/55).

The strategic objectives related are:

- It is important for certain kind of users (like banks) to trust the platform

Legislation

No interest, "1" out of 13 and "1" negative. Also, one of the lowest scores from EUSurvey (34/55).

Skills

No interest, "1" out of 13 and "3" negatives. There is a perception that there is all knowledge needed and specialist are trained by the companies.

Self-Healing Cloud

Few interest from the community with the lowest rank (31 out of 50).

Other strategic objectives proposed:

- Support of Cloud for verticals: e.g., AI, smart-cities, self-driving cars: From verticals and novel application areas, interesting stories could be worked out. Analysis of what is missing to support new applications from current cloud technology and link to other topics.
- Handling massive datasets, incorporating different tools, frameworks, and processes to help organizations make sense of their data collected from various sources, Big Data enrichment pipelines

Rejection per topic

Though most of the results have already been analysed within the acceptance, it is interesting to remark that Skill Development got the highest number of negatives votes, underlining that there is no perception to train more specialist in Cloud computing technologies, followed by Software engineering.

The only topic that did not received any rejection are: Cloud/Edge continuum, Cloud Federation, Green Cloud and Standardisation.

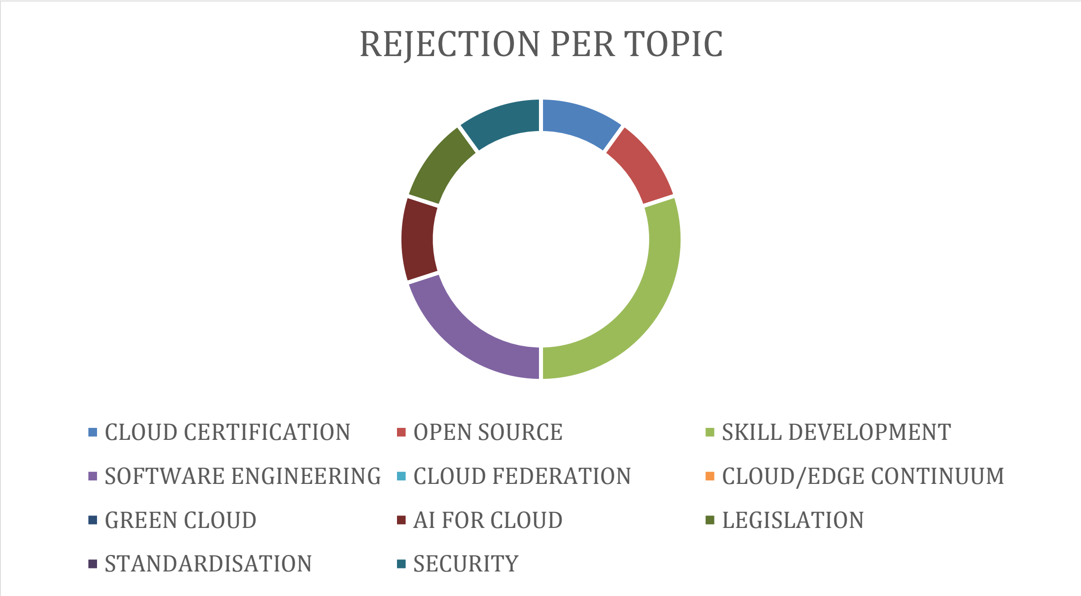

Figure 11. Rejection per topic (position paper)

Business Models

From a list of the most suitable business models:

- PaaS- Platform as a Service
- SaaS- Software as a Service
- IaaS- Infrastructure as a Service
- APIaaS- API as a Service
- AaaS- Analytics as a Service
- BaaS- Backend as a Service
- Dass- Data as a Service
- DBaaS- Database as a Service
- FaaS- Function as a Service
- SECaaS- Security as a Service

PaaS is the most popular under the RIA responding to the survey. With 8 out of 10 choosing it as the most suitable for their project.

SaaS is the second business model with 6 out 10

IaaS is also one of the most traditional business models, in this case, 3 out of the 10 projects plan to exploit their products as infrastructure.

The remaining business models are less considered: DaaS (2/10), AaaS (2/10), BaaS (1/10), APIaaS (1/10), SECaaS (1/10) and no one is interested in DBaaS or FaaS.

The pricing scheme for their business proposition is mainly "pay-per-use", Freemium model is also considered (or models with low entrance fee and payment for advanced features), but only one goes for OPEN SOURCE.

The role of Incubators and accelerators is still not very well understood by the research community. Only two of the projects were concerned about how to get knowledge from the market related their potential exploitable results. Most of the individual exploitation of the partners or in dissemination of their results which usually implies that either there is no interest in the exploitation or that they lack the knowledge on how to transform an idea into an innovative product.

3.3 Input from H-CLOUD

The H-CLOUD project aims to gather the European Cloud stakeholders in a sustainable, informed and coordinated open community through the H-CLOUD Forum, which brings together innovators, policy makers, the demand and supply side of the Cloud market, to remove fragmentation and increase collaboration in Europe and beyond, while aligning on a common direction to help creating a Cloud agenda for the future of Europe.

H-CLOUD is the CSA that, together with HUB4CLOUD, provides coordination and support within the Horizon Cloud programme. It started one year before HUB4CLOUD and is therefore an important source of information and valuable input for HUB4CLOUD.

In particular, when considering the role of HUB4CLOUD for this analysis, it is to be remarked that the two projects operate together but have slightly different focus. While HUB4CLOUD has separate work streams dealing with research on one side and business acceleration on the other, H-CLOUD received an earlier landscaping mandate that was to cover Cloud Computing projects and initiatives related to European Cloud Computing adoption.

The following sub-sections consider each major H-CLOUD output and extract from it the content dealing with research projects and initiatives, collecting the candidate research topics that have been mentioned or highlighted by the H-CLOUD source. It is then a matter of recognition and mapping of these topics to the chosen taxonomy from the Future Cloud Cluster, to be lastly able to merge them with the other relevant sources.

3.3.1 The H-CLOUD Green Paper

During its first year of activity in 2020, the H-CLOUD project found itself involved in support work related to the then upcoming Horizon Europe Work Programme, thus receiving contingent requirements that were blended with the original project agenda. The first major outcome of this dynamic activity was the H-CLOUD Green Paper[33], published in November 2020.

As an unplanned but very topical publication, made to suit the specific needs of the European Commission and the European Cloud Community at the time, the Green Paper adopted a focussed agenda and approach, which can be summed up as follows:

- Investigate the status, challenges, and opportunities of European Cloud Computing regarding its adoption and provision
- Situate the analysis against the policy background of the two major communications from the European Commission: "*A European strategy for data*" and "*A new Industrial Strategy for Europe*"

- Structure the analysis by separating the point of view of Cloud Service Providers ("supply side") from the point of view of Cloud Service Users ("demand side")
- For the supply side, consider three large themes as in scope of the investigation, as well as a more general landscape assessment:
  - *Cloud Federation*
  - *Edge Computing*
  - *Green Computing*
  - *Landscape*
  - *Technology and Infrastructure*
- For the demand side, analyse Cloud adoption scenarios from six major vertical sectors, plus one horizontal adopter segment:
  - *Public administration*
  - *Healthcare*
  - *Transport*
  - *Energy*
  - *Agriculture*
  - *Manufacturing*
  - *Small- and Medium-sized Enterprises (SMEs)*
- The three supply-side topics are analyzed with the same methodology, but there is no common framework imposed on all three, given the intrinsic differences among the themes of Cloud Federation, Edge Computing, and Green Computing
- On the other hand, a common framework is adopted for all the covered demand scenarios, where the identified issues are placed on a grid where the two-dimensions express the complexity of the adopting organisation (four levels, from a single, small institution to a large, cross sector coordination) and the complexity of the Cloud deployment (three levels, from simple to sophisticated)

For the purpose of this document, what is needed is the selection and extraction from the Green Paper of research challenges and topics that were (explicitly or implicitly) identified by the H-CLOUD project, both in supply and demand scenarios.

The output of the Green Paper is structured as a series of *Challenges* and *Recommendations*. These are labelled with an *S-* or *D-* prefix to attribute them to either the supply or demand side, and a domain identifier (F/E/G/L/T for supply, PA/H/T/E/A/M/S for demand): for example, an S-G recommendation will concern the supply-side topic of Green Computing, whereas a D-E challenge will belong to the demand scenario for the energy sector.

Additionally, both challenges and recommendation are tagged with one or more aspects of the overall Cloud Computing ecosystem, chosen among the following options:

- *Policy*
- *Research*
- *Deployment*

It is clear that the *Research* tag is the one to use to select the output from the Green Paper that is relevant to this document's analysis of research topics: some items will purely concern research, whereas others will belong to a hybrid combination of multiple aspect, but can still be relevant to the present work. The following Table 1 lists the found items.

Table 1. Relevant Items from the H-CLOUD Green Paper

Type and ID	Tags	Title / Description	Location (GP 1.0)
D-PA Rec. 1	[Research, Policy]	Collect and share best practices on data sovereignty and security across public sector entities.	Page 27
D-PA Rec. 4	[Research, Deployment]	To promote European innovations that can accelerate public sector legacy IT modernization, the EC should stimulate the IT industry and academia to develop legacy-to-cloud migration toolkits that make best practices re-usable across member states.	Page 28
D-PA Rec. 7.2	[Research, Deployment]	Stimulate the IT industry and academia to develop cloud management toolkits that make best practices re-usable across member states.	Page 29
D-PA Rec. 12.1	[Research]	Evaluate successful open-standard solutions.	Page 30
D-PA Rec. 13	Research, Deployment]	Evaluate successful smart city projects.	Page 31
D-T Rec. 4	[Policy, Research, Deployment]	Expand data interoperability.	Page 33
D-T Rec. 3.1	[Research]	Encourage academic institutions and industry associations to collect and disseminate best practices toolkits for cloud readiness assessment and migration toolkits that are specific to transportation processes and systems, such as booking, payment, navigation, fleet management.	Page 34
D-E Ch. 2	[Research]	Security must be identified as a priority aspect of applied research in this area and should be a fundamental component of all energy systems research (from project work-plan to programme design) rather than addressed as a separate issue.	Page 35
D-E Ch. 3	[Research]	Security aspects of federated cloud services might be inherently more secure than centralised cloud services.	Page 35
D-E Ch. 4	[Research]	Data sharing across the sector.	Page 35
D-E Ch. 5	[Research]	Edge-based IoT automation can enable efficiency increases in the generation, transmission and distribution components of the supply chain.	Page 35
D-E Ch. 6	[Research]	Air- and Space-Based Edge infrastructure	Page 35

Type and ID	Tags	Title / Description	Location (GP 1.0)
D-H Rec. 5	[Research]	ECRIN and custom regional/national data lake solutions should be examined to see if they contain the seeds of wider solutions to the problem of distributed personal health data management.	Page 43
S-L Rec. 3	[Research, Deployment]	A “GDPR compliant” cloud abstraction layer for cloud deployments (that sits above the physical infrastructure) might be useful for both large and small organizations looking to deploy cloud technology. Other tools to increase competitiveness could include creation of a centrally managed service and tool catalogue, potentially by the EC or at least endorsed by the EC, substantial marketing support for products appearing in that catalogue, and strong governance and audits to make sure that the catalogue is up to date and that security standards are met.	Page 56
S-T Rec. 3	[Research, Deployment, Policy]	Support development of “GDPR compliant” tools and/or frameworks that enable secure access and sharing to distributed data. These tools might function through peer-to-peer software components that are certified to be GDPR compliant, or through participation in coordinated structures such as federation.	Page 64
S-T Rec. 4.1	[Research]	Bring compute to the data.	Page 64
S-T Rec. 4.2	[Research]	Analyse data where it is generated.	Page 65
S-G Ch. 4	[Policy, Research]	The distribution of processing through federation and/or migration to the edge counters the environmentally beneficial trends toward processing centralized in the cloud (particularly in hyperscale data centres).	Page 70
S-G Ch. 6	[Research, Policy]	The impact of specific ICT activities on the environment is poorly understood.	Page 71
S-F Rec. 1.1	[Deployment, Research]	Develop detailed business cases for identified use cases in each of the nine sectoral data spaces described in the EUSD that quantify the societal gains and costs to achieve the desired benefits and ascertain feasibility and related ICT innovation needs.	Page 77

A second relevant part of the H-CLOUD Green Paper is Section 5.1 (starting on page 82), which includes a condensed summary of an initial analysis of 111 European Cloud Computing initiatives, classified along multiple dimensions (e.g., source of funding, research vs. deployment, main topic among Edge Computing, Cloud Federation, Green Computing).

While valuable, this analysis has been subsequently extended and superseded by the work carried out on the Cloud Computing Portfolio, described in the following Section 3.3.2, and will therefore not be covered more in this document.

3.3.2 The Cloud Computing Portfolio

The H-CLOUD project carried out outreach and liaison activities with a large number of European Cloud Computing initiatives in several domains; to document these ECC stakeholders and contribute to a landscaping of the overall ecosystem, H-CLOUD put together a Cloud Computing Portfolio, which has been recorded in two subsequent project deliverables [34], [35]. Even more importantly, an online version of such a portfolio [36] is available online and kept updated with new initiatives as they are identified. At the time of writing, the online catalogue includes 205 profiles, and supports interactive filtering across a number of dimensions:

- Profile type (public, private, public/private cooperation, research and innovation)
- Geographical scope
- Keywords (Cloud, Edge, Federation, Green)
- Cloud delivery model (IaaS, PaaS, SaaS)
- Cloud deployment model
- Industry
- Domains Targeted (Green Deal, Mobility, Science and Research, SMEs, Smart Cities)
- Technology
- Operating Model (Centralised, Consortium, Federated)
- Ownership and Control (Centralised, Collaborative)

Filtering profiles of type *Research and Innovation*, the filtered catalogue yields 100 profiles, geographically categorised as 18 *Global*, 80 *European*, and 2 *National*.

Using the *Keywords* filter, still coupled with the *Research and Innovation* profile type, results in 12 R&I initiatives with the *Cloud* keyword, 30 with the *Edge* keyword, 15 with *Federation*, and 5 with *Green*. This keyword distribution confirms other anecdotical evidence (gathered both in H-CLOUD and HUB4CLOUD consultations) that Edge Computing is the hottest theme among the three, and that somehow the Green Cloud vision, while very prominent on the European Commission vision and strategy, still hasn't been taken fully on board by the research and innovation community.

This document is not listing the 100 individual initiatives, given the dynamic evolution and superior search and filtering capabilities of an online catalogue such as [36]. Instead, these initiatives will be accounted for in Section 3.3.4 when counting the examples from H-CLOUD that fit into each of the thirteen research areas included in the Research Roadmap 2020 [10] from the Future Cloud Cluster. An additional input, connected to the Cloud Computing portfolio, is the specific classification of the research projects belonging to the Horizon 2020 calls ICT-15 and ICT-40. These projects are part of the *Horizon Cloud* programme and of special interest for both H-CLOUD and HUB4CLOUD. The chosen taxonomy for research areas is not as in this document, but stems from a 2018 *IEEE Access* paper [37]: the Table 2 summarizes the areas and the number of projects from both H2020 calls involved in each area (There are in total 11 projects funded within the two calls, but most are involved in more than one area).

Table 2. H-CLOUD classification of ICT-15 and ICT-40 research projects

Research Area (as per [Error! Bookmark not defined.**])**	**ICT-15 Projects**	**ICT-40 Projects**
DevOps / MLOps	2	1
Cloud-Edge Orchestration	5	5
Autonomic Adaptation	4	5

Research Area (as per [Error! Bookmark not defined.])	ICT-15 Projects	ICT-40 Projects
Ad-hoc Clouds	2	2
Data Protection	1	0
Security	1	1
Vulnerability Detection	1	0
Cloud Modelling	2	1
Multiple Runtimes	1	0
SLA & QoS	2	1
Trust	2	1
Distributed Data Processing	1	1
Discovery & Composition	1	1
Energy Efficiency	0	1

3.3.3 Mapping to Research Topics

The core analysis and consolidation of the multiple sources of input into a coherent list of research topics and challenges will be presented later in the Section 4 of this document. Here, a preliminary classification is made to map the gathered H-CLOUD input to one or more of the 13 research areas identified in the Future Cloud Cluster research roadmap.

The overall H-CLOUD input described in the previous sub-sections can be summarized as:

- Challenges and recommendations from the Green Paper 1.0 (20 items)
- Research and Innovation initiatives from the online Cloud Computing Portfolio (100 items)

The Table 3 that follows in this sub-section lists the number and identities of the H-CLOUD input items that can be mapped to each research area in the Future Cloud Cluster classification, thus preparing and harmonising the data for the overall analysis step taken in Section 4.

Table 3. Preliminary mapping of H-CLOUD input to research areas (adopted from H-CLOUD)

Research Area	Green Paper Ch/Rec	CCP Initiatives
Area 1: Federation of clouds	8	15
	D-T Rec. 4, D-E Ch. 3, D-E Ch. 4, D-H Rec. 5, S-L Rec. 3, S-T Rec. 3, S-G Ch. 4, S-F Rec. 1.1, ENTICE	ACTiCLOUD, ARTICONF, BEACON, BigDataStack, CloudSocket, CYCLONE, DECIDE, EOSCpilot, Fed4FIRE+, Fed4IoT, MELODIC, MUSA, RESTASSURED, SSICLOPS, SUNFISH
Area 2: High Performance Heterogeneous Cloud Services	6	18
	D-PA Rec. 12.1, D-E Ch. 4, D-E Ch. 5, S-T Rec. 4.1, S-T Rec. 4.2, S-G Ch. 4	5G-MEDIA, ACCORDION, ACTiCLOUD, ALIGNED, BigDataStack, Blue Cloud, Bright Beyond HPC, CLASS, CloudDBAppliance, CloudiFacturing, CloudPerfect, ENTICE, FAR-EDGE, Pledger, PrEstoCloud, RAPID, SODALITE, SWITCH

Research Area	Green Paper Ch/Rec	CCP Initiatives
Area 3: Security mechanisms across Clouds	7	30
	D-PA Rec. 1, D-E Ch. 2, D-E Ch. 3, D-E Ch. 6, D-H Rec. 5, S-L Rec. 3, S-T Rec. 3	ARTICONF, ATMOSPHERE, BEACON, CLARUS, CLOUD DIAGNOSIS, CloudTeams, COLA, CREDENTIAL, CYCLONE, DECIDE, DECODE, EOSCpilot, ESCUDO-CLOUD, Fasten, FogProtect, FutureTrust, KMaaS, MELODIC, mF2C, MUSA, PaasWord, Pledger, PRISMACLOUD, RAINBOW, RESTASSURED, SERECA, SSICLOPS, SUNFISH, UNICORE
Area 4: QoS and SLAs	4	32
	D-PA Rec. 13, D-E Ch. 5, D-E Ch. 6, S-G Ch. 6	5G-MEDIA, ACCORDION, BEBA, Bright Beyond HPC, CACTOS, Catalyst, CLARUS, CloudDBAppliance, CloudiFacturing, CloudPerfect, DITAS, ELASTEST, ENTICE, EOSCpilot, FAR-EDGE, Fed4IoT, FogProtect, FutureTrust, HyVar, mF2C, Morphemic, MUSA, NECOS, ONEEdge, Pledger, PrEstoCloud, RAPID, RECAP, SELFNET, SESAME, SWITCH, UNICORE
Area 5: Knowledge-Based Service Harvesting and Acquisition	5	9
	D-PA Rec. 4, D-PA Rec. 13, S-L Rec. 3, S-G Ch. 4, S-G Ch. 6	ALIGNED, AppHub, ARCADIA, CHOReVOLUTION, CloudSocket, RADON, RAPID, SmartCLIDE, SODALITE
Area 6: Dynamic Configuration, Provisioning, and Orchestration of Resources	7	40
	D-PA Rec. 7.2, D-E Ch. 5, D-E Ch. 6, S-T Rec. 3, S-T Rec. 4.1, S-T Rec. 4.2, S-G Ch. 4	ACCORDION, ACTiCLOUD, ARCADIA, ARTICONF, ATMOSPHERE, BEBA, BigDataStack, CACTOS, Catalyst, CHOReVOLUTION, CLASS, CloudLightning, CloudSocket, COLA, CYCLONE, DECIDE, DECODE, DITAS, ENTICE, Fed4IoT, FogProtect, HyVar, LightKone, MELODIC, mF2C, Morphemic, NECOS, ONEEdge, PaaSage, Pledger, PrEstoCloud, RADON, RAINBOW, RAPID, RECAP, SELFNET, SmartCLIDE, SODALITE, SSICLOPS, UNICORN
Area 7: Deployment and management of resources in a decentralised, autonomous way	8	32
	D-PA Rec. 7.2, D-E Ch. 4, D-E Ch. 5, D-H Rec. 5, S-T Rec. 3, S-T Rec. 4.1, S-T Rec. 4.2, S-G Ch. 4	ACTiCLOUD, AFarCloud, ARCADIA, ARTICONF, ATMOSPHERE, BEACON, BEBA, CHOReVOLUTION, CLASS, CLOUD DIAGNOSIS, CloudiFacturing, DECODE, DITAS, ESCUDO-CLOUD, Fed4FIRE+, Fed4IoT, FogProtect, KMaaS, LightKone, mF2C, Morphemic, NECOS, ONEEdge, PaasWord, Pledger, PrEstoCloud, RAINBOW, RESTASSURED, SELFNET, SESAME, SWITCH, UNICORE
	6	22

Research Area	Green Paper Ch/Rec	CCP Initiatives
Area 8: Resilience and Scale	D-E Ch. 2, D-E Ch. 5, D-E Ch. 6, S-T Rec. 4.1, S-T Rec. 4.2, S-F Rec. 1.1	ACTiCLOUD, ATMOSPHERE, BigDataStack, Blue Cloud, Bright Beyond HPC, CACTOS, CLASS, CLOUD DIAGNOSIS, CloudDBAppliance, CloudiFacturing, COLA, CREDENTIAL, CYCLONE, ELASTEST, ENTICE, EVOLVE, Fed4IoT, IOSTACK, Morphemic, RECAP, SELFNET, SSICLOPS
Area 9: Energy efficiency and Sustainability for Edge and Cloud Continuum	5	7
	D-E Ch. 5, D-E Ch. 6, S-G Ch. 4, S-G Ch. 6, S-F Rec. 1.1	AFarCloud, BEBA, Catalyst, CLOUD DIAGNOSIS, CloudLightning, FogProtect, SESAME
Area 10: Software defined Infrastructures and Novel composition model	5	26
	D-PA Rec. 4, D-PA Rec. 7.2, D-T Rec. 3.1, S-L Rec. 3, S-T Rec. 3	ACCORDION, ALIGNED, ARCADIA, BEACON, BEBA, CloudLightning, CloudSocket, DECIDE, DITAS, HyVar, IOSTACK, LightKone, Morphemic, NECOS, ONEEdge, PaaSage, RADON, RAINBOW, RAPID, RECAP, SELFNET, SESAME, SmartCLIDE, SODALITE, SSICLOPS, UNICORE
Area 11: Novel Data Storage infrastructures and services	7	23
	D-T Rec. 4, D-E Ch. 4, D-H Rec. 5, S-L Rec. 3, S-T Rec. 3, S-T Rec. 4.1, S-T Rec. 4.2	ACTiCLOUD, ALIGNED, BEBA, BigDataStack, Blue Cloud, Bright Beyond HPC, CLARUS, CLASS, CloudDBAppliance, DECODE, DITAS, EOSCpilot, ESCUDO-CLOUD, EVOLVE, FAR-EDGE, FogProtect, INDIGO-DataCloud, IOSTACK, mF2C, PaasWord, PRISMACLOUD, RAINBOW, RESTASSURED
Area 12: Software application development for the computing continuum	6	36
	D-PA Rec. 4, D-T Rec. 4, D-T Rec. 3.1, D-E Ch. 2, S-L Rec. 3, S-T Rec. 3	5G-MEDIA, ACCORDION, AFarCloud, ALIGNED, AppHub, ARCADIA, ARTICONF, ArtomatixSuite, CHOReVOLUTION, CloudiFacturing, CloudSocket, CloudTeams, COLA, CYCLONE, DECIDE, DICE, DITAS, ELASTEST, FAR-EDGE, Fasten, Fed4IoT, FutureTrust, HyVar, IOSTACK, MELODIC, MUSA, PaaSage, Pledger, RADON, RAINBOW, RAPID, SmartCLIDE, SODALITE, SWITCH, UNICORE, UNICORN
Area 13: Research artefacts for the computing continuum	3	12
	D-PA Rec. 12.1, S-G Ch. 6, S-F Rec. 1.1	Amable, AppHub, Blue Cloud, CACTOS, Catalyst, CloudPerfect, EOSCpilot, EVOLVE, Fed4FIRE+, FNS-Cloud, GEANT, INDIGO-DataCloud

3.4 Input from other relevant stakeholders: interviews

3.4.1 Methodology

Interviews with relevant stakeholders have been carried out to gather their opinion on selected topics related to cloud computing (Business models, Skills, Data Sovereignty, Green ICT, Cloud federation, Cybersecurity, Open Source, and software engineering). These interviews have been performed in collaboration with the CSA SWForum.eu. Complete interviews and transcript are available in the HUB4CLOUD web site and YouTube channel.

From a list of potential candidates for the interview, a small set have been selected based on the criteria of relevance on a specific sector (technical SME, Open Source, European initiative, Academia). Each of the candidates have received an official invitation where it is explained the objective of the interview as well as information is provided about how the interview was going to be carried out (length: minutes, tool used: Zoom). Apart from the invitation a letter of consent has been shared to request their permission to record the session as well as to publish it later within the HUB4CLOUB YouTube channel. Both documents are included in Appendix C.

The interviews are set up to last a maximum of 20 minutes, but this also depends on the availability of the interviewee and on the flow of the interview. As mentioned before, the interviews are performed in collaboration with the coordination and support action SWForum as there are topics that are of common interest. In this section, only the contents related to HUB4CLOUD are detailed.

Next, the script prepared for the interviews is shown. While all these questions are not mandatory nor expected to be asked, they are used as guidance to have a common thread in all interviews. Questions are adjusted depending on the profile of the interviewee as well as on the flow of the conversation.

Business Modelling questions:

- Would it be possible to know about your company business model patterns or pricing strategy (e.g., tiered, subscription)?
- What are acceleration options to boost uptake of CC technologies and solutions?
- What timeframe would be acceptable for research and innovation outcomes generated within the context of ECC publicly funded projects to become market-ready?
- What should a business model be like to engage SMEs and Entrepreneurs?
- How should a cloud infrastructure be exploited to facilitate creation of cloud-enabled ventures?
- How do you identify potential business opportunities in CC? What do you look for in a business opportunity? Which metrics do you analyse to understand whether your business model / pricing strategy is adequate or not? How frequent do you collect these metrics? Have these metrics led you to pivot the business model / pricing strategy?
- What methodologies do you use to evaluate business opportunities in CC?
- What types of actors are you interacting with in CC business opportunities? What is each actor’s role?
- How do you commercialise CC-based business opportunities?
- What types of cloud-based acceleration services do you provide?

Technical innovation/Skills questions:

- What is the main reason to the gap between Cloud Computing in USA/ASIA and EUROPE?
- In which areas should Europe invest in to accelerate its (cloud) deployment and compare with alternatives currently available in other regions?
- As a European user, what do you miss from current CC offerings?
- If CC from other regions become unavailable. How far is Europe to have a CC that will offer at least the same level of performance and security?

- From your perspective, what are the skills required on emerging cloud technologies to achieve a successful European Cloud Computing ecosystem?
- Is the academia already providing open training on those skills? Do you know of any initiative on this direction?

Governance/Organizational structure:

- What organisational structure is more suitable to support active collaboration and stakeholders´ participation?
- What advantages should a Cloud federated model to be successful (from the point of view of acceptance by providers/consumers)?

Cybersecurity:

- What are the characteristics of trustworthy software/infrastructure for your organization? i.e. Reliable, stable, frequently updated, secure.
- In your opinion, which compliance issues are most difficult to address? i.e. General Data Protection Regulation (GDPR), No "back doors" / vulnerabilities, Cybersecurity, Quality metrics, etc.
- Despite the conspicuous benefits to customer's trustworthiness in cloud services, which result from leveraging recognized security certifications (just as evidenced by the EU Cybersecurity Act (EU CSA)), it is also true that European cloud providers currently face multiple challenges to certify their services specially related with the big fragmentation in the domain of existing certification schemes. What do you think in this respect? Do you know EUCS?

3.4.2 Results from the interviews

The selected candidates for the interviews have been:

- ELASTISYS (Swedish SME, spin-off from a renowned research group in distributed systems and cloud computing in Umeå, Sweden. The company is a leading security expert within the cloud native ecosystem)
- GAIA-X (Project initiated by Europe for Europe and beyond. Its aim is to develop common requirements for a European data infrastructure)
- REDHAT (world's leading provider of enterprise open source solutions, using a community-powered approach to deliver high-performing Linux, cloud, container, and Kubernetes technologies)
- CANONICAL Ltd (UK-based privately held computer software company to market commercial support and related services for Ubuntu and related projects)
- EVERIS (an NTT DATA Company, dedicated to consulting and outsourcing in all sectors)

The following section collects extracts from the different interviews regarding each specific topic. They are the exact wordings from the experts as agreed within the Letter of consent. Some of the sentences might sound strange as they are part of the natural language during a fluent conversation.

BUSINESS MODELS:

<u>ELASTISYS</u>

- There is a lot of public cloud infrastructure offering in Europe also acceleration on Data Centres, and a big increase of cloud infrastructure service.
- Managed services on top of cloud. Regular, smaller, European cloud do not have a full catalogue of services like the Americans cloud (managed containers platforms, managed databases other type of services that cloud users will need and in particular developers that want to build applications for the cloud)

- Professional services dedicated to onboarding new and old applications onto this European cloud platforms that are quite diverging both in technology and maturity.
- It is quite a challenge to work with ECC compared with USA clouds, in aspects such as Georedundancy of deployment in different clouds.

GAIA-X

- GAIA-X does not want to be one software authority, like been a European policeman, the idea is to bring transparent access to structure and verifiable service description. Transparent because it should be easy, an initial onboarding and easy access.
- Service deployment, there is a need to find first the services we are looking for. Truth and verifiable service description services need to be elaborated on that. To have a structure and a verifiable service manifest file. Structure because you will be able to compare things with one to another.
- There is a need to agree on a common ontology on how to write those manifest files and it has to be verifiable because if a provider or a consume claims to be certified with one regulation you need to be able to verify that such claims are true. So, technically speaking, GAIA-X will be, for the first phase, a transparent access to structure and verifiable service description. And if it is done in a decentralized and distributed way then it can be competitive. Not saying that ECC can compete but that will be competitive. There are some numbers to consider: the amount of workload of cloud is a 15-20% from what are not cloud, depending on market regulation. It means that we have a huge field in front of us that can be explored. Even if some giants are taking 80% of this 20%, if ECC is efficient, we will be able to do something very great for Europe.

REDHAT

Cloud as strategy to build a governance model

Cloud computing is a very important part because it helps to orchestrate and govern infrastructure on various levels. So, we can think of cloud, as a group of data centers of networking across data centers, is a very basic level enabling cloud.

IaaS, PaaS & SaaS Layer

Then we can think about the so-called IaaS layer (Infrastructure as code). If you would like to consume it, it feels a little bit like you're sitting on top of a server operating system where you can consume compute storage and network that is no longer running only on one box, but across data centers.

Even then, you have a PaaS layer where you have a platform as a service. And this is not a platform for businesses, but it's a platform to develop code, to drive innovation, to build stuff like micro service architectures.

And then above you have a SaaS (Software as a Service) layer software as a service. This could be a simple component, like a technical service, providing a DNS or providing a billing for transactions of an e-commerce company, that wants a payment being provided via this (SaaS based) billing service. Or it could be something more complex. One example is the SaaS CRM “SalesForce” as a customer relationship management tool. Or it could be workday or Google Mail or something like that falls from my point of view in such a category.

Why the right Cloud Abstraction needs to fit Operational Business Model

What is the model of the organization we are looking at? What is their problem?

Cloud computing is helping a lot on speeding up processes. It's more a governance model and this is possibly explaining on what you need to apply this governance model.

And is there more than just that to governance and then becoming a discussion of what our platform models, what our ecosystems to build on top of clouds in the industry sectors across the industry or sectors across the value chain of those companies.

Example of a very specific platform model on top of an edge cloud – Oil Industry example

And then if you're looking on the underlying infrastructure of a very complex value chain, we can think maybe because it's a complex picture, something like an oil drilling company that is having refineries.

If you think about this diverse and very expensive infrastructure, this high amount of security (needed): You need to have a data center on an oil rig to control it, to measure data, to identify whether you have an issue on that oil rig, to alert security/rescue teams, in case of an issue that implies the need to evacuate people etc. It might also be that this oil rig is an issue then on having a constant flow of the material. So, you can also immediately orchestrate ships in a different manner.

And then you have your (complete value stream from) refinery, you need to sell and trade materials on a related stock market. And you need to balance all and optimise.

And if you think about the communication on an oil rig that is far off (the coast-based infrastructure) the limitation of bandwidth, increased latency - you can imagine many technical problems on an (communication) infrastructure layer.

But if you look about the many oil rigs that you need to manage, it might be that you have a oil rig management system that you want to roll out (centralized yet distributed), same on your logistic of the ships etc.

Cloud vs Edge Evolution

And then you will see the cloud computing is emerging into an Edge where you have different technical constraints on those parts. There is a need to solve those. And then you are not only governing the compute and Edge layer, what is more or less the same, it's just the distribution off of the computer network and storage power.

Governance model for Cloud plus Business Systems on top?

But for managing your business architecture on a much higher level, it is very important to understand whether you are in a case where you need to manage a complete distributed architecture

It could also apply for banks, for example, or airlines or people running different airports or stuff like that. You will see that the government needs to be very good on a much higher abstraction layer on the platform level, integrated with other companies, providing services for other companies involved in the value chain.

If you are, for example, an investor that is just having a bunch of different companies, maybe you just need to have compute and mail services and a content management system. And then each of your departments or organization are having a totally different kind of business architecture. The cloud would be the common denominator and the problem you should focus on.

Completely centralized vs distributed governance?

This is very important also to understand, do I need to own the technical cloud infrastructure below to have a secure operation on my oil rig? Or am I a consulting company that has a less complex business infrastructure and maybe I'm operating worldwide and need to be totally flexible and then maybe a public cloud provider would be a good choice.

And you see how the operational model and business targets and the IT targets and how they need to speak together. This is one of the problems that network architect are facing, that there is kind of a communication gap between those very important parties.

DATA SOVEREIGNTY /DATA PROTECTION

ELASTISYS

- US is not foreign to the concept of privacy and Data Protection. In their Healthcare regulation they are much like GDPR regarding medical records.
- There is an industry with a business model based on harvesting data from users, profiling them, and serving them as adds rather than a business model where one carefully thinks about the purpose of collecting data and you really specify why.
- Regarding Healthcare data the mindset of the two continents is pretty much shared
- When it comes to any kind to personal data (email address, phone number,) there is a big gap between continents but there are some states like California which issued GDPR-like laws. And though at federal level nothing seems to be moving, there might be GDPR laws in all the states instead of waiting the federal government to fix it for them. Thus, this gap will be closed in the future.
- Security is defined as protecting data from attackers while privacy protects the data from sales. There is an uneven territory across the continents, but the gap is also closing very quickly. Silicon Valley's companies will play everything according to the book to stop federal government to enact privacy protection laws.
- When Data protection and Data rights are explained to the customers, they will really want it. There is a bit of misunderstanding with data protection because it is a very abstract notion what has already existed for around 3 years but once it is clear, all will want it what will put more pressure on the companies. It is comparable to when companies were forced to exchange a product in 40 days for no reason, this was hard for them at the beginning but finally they adjusted. Seems to be the same for data protection, the business model will just need to adapt to add more value to the consumer.

GAIA-X

- Define sovereignty as being in charge of your resources.
- About the policies and the data usage right, they can separate them in two categories: one category that it is known very well how to address and the other that there is no way to automate it yet.
- The first one is about execution policies: imagine that you have your data, you are the owner of your data and you allow someone to process that data, you can take their raw code (i.e. an image) and you want to make sure that is does not contain any malicious workload (execution code) that damages your infrastructure or duplicate your data outside of your control. Basically, you can execute this code in a sandbox environment, so we know how to mitigate risk of code execution and copying data outside of where the data is supposed to be. That we know how to enforce that. That is what I called execution policy.
- However, we do not yet how to enforce the data usage rights. Taking the example of PSD2 in Europe (European regulation inviting banks to share data from their accounts of their users to the fintech). The very same data from a user can be used to build a personal finance planner or can be used to do targeting marketing which in that case this is nothing the user would like to have something to do with. The same data can be used for two different usages and that is what is called Data Usage Policy. Now the data usage enforcement is done by the trust that you have with the partner you are going to delegate access rights. This is one of the friction points that needs to be overcome to enable more data usage, basically, how is my data going to be used and if I see there is anything I don't

like I have the right to see that there is no copy of my data left somewhere.
- There are ways to mitigate that risk by federated learning, multiparty computation, and data watermarking.

REDHAT

- There are two perspectives on cloud computing in the European context from Gaia-X: Following this idea about digital sovereignty based on European values, and this is leading into something that needs to have a broader discussion, because from my point of view, sovereignty is for state.
  - For an organization like the European Union, it's a classic concept in international law. Sovereignty means, from my understanding, being able to make laws to execute on our territory.
  - As a citizen or as someone who is representing a company, sovereignty is a totally different: it means an ability to deal with complexity in a competitive worldwide landscape, being able to understand what is going on, what are the trends, what is relevant for our business, for the business of our customers and partners that are crucial for our business and to understand how can we support them to solve problems that other customers have and how can we solve those common problems with our services so that those customers can solve the differentiation issue that they need to solve to keep their companies running in this competitive landscape, not only in the next year, but for a long time. So, it's concrete enablement on short term engagement but also to invest in the right strategies.
- He believes that if data is shared, is shared. When is out, is out. You cannot guarantee that data won't go further from there.
- With the notion of data spaces, the view is been limited because data is one important aspect in digitalization another one is to have those business processes implementing and interaction. At the end, people are interested in information and information is an aggregation and importation of data when you come out with items, with decisions that you can make or that you don't make.
- Instead of data, we should focus on how to control the data, what are the control points and there is to distinguish if data is stored or is it addressed, is it at use or is it at transfer.
- One aspect on GDPR is who has stored the data, who has accessed on the data source. Very strong focus on data store.
- The thoughts behind DevOps, Cloud and automation could help on being clean on a company level to deal with that data. All of this is a governance level because automation helps to check whether your operations are working or not. Cloud is something like an airport, it has many layers like freight, you need to get the fuel to the airport, you have the passengers, the ticketing system, the radio tower, it's all tremendously complex (from the technical point is tremendously complex). If you go to an airport and you are tired from a long weekend or you have a cold or a party in the evening, even then all people manage to get to their destination because is so standardized, it has been tested how to lead the people through the airport and if there would be an accident , it is analyzed so that this error is not happening again. This is a very strict and supportive governance model which you don't think of so much as a passenger, that is supportive governance.
- A good digital ecosystem is providing the supportive governance for the developer, they are giving you infrastructure, even on a layer, or a coding context with its APIs to the systems that you use so you can work proactively and you are investing on the governance model for the sake to be faster on bringing things out to the market on one place, on the second place to have less effort on operating it on a day-to-day basis and the third part is to avoid risks of all kinds and not been GDPR compliant is a risk that should b part of the governance model
- Then, routing to check whether there is data, is there a date when I need to delete those data, adding some meta data to the data itself about to whom can I share it and so on, that is allowing automation on this data handling. This could also be reviewed by auditors

or legal departments which is much easier if things are automated to include this in the overall picture on how to securely run digital platforms.
- What RedHat has been doing in Open Source with communities where technology is been built with customers, competitors, academia and many other people in this evolutionary way, they are providing the freedom that you are running the cloud infrastructure and building up those governance models in your own data center. And you own data center could be of providers, of large companies or small companies, of developers and so on. This is one aspect to increase the degree of freedom and to have options if you are afraid of been isolated. They provide options to choose.
- Sovereignty on digital is important for the national's states, for the EU, for citizens, for companies and openness is something that we should not forget.

CLOUD FEDERATION

ELASTISYS

- Elastisys has been involved in research in cloud federation for more than a decade. And though technically possible there are many implications and business reasons why this will not be a great idea. It will complicate operations a lot. You can get some cloud services from one provider and other from another so there is no need to connect them in a tight federation neither from the consumer side or across the providers. It is not like roaming, these are different services offered by different providers with different payment schemes, technical solutions (very little need). More in favour of some kind of connection on top of the services catalogue rather than federation of the cloud.

GAIA-X

- Interoperability with existing cloud providers will be extremely difficult and when we have mentioned interoperability and portability, what we usually have in mind is migrating data. Data is our static asset that are really easy to migrate. In terms of increasing complexity, the next step is moving among clouds and thus there are moving licenses. Usually licenses are a bound contract that you have with one provider so you cannot buy the license from one and use it in another and on top of that you have the identity and the access management. Once you have started to work with one cloud provider or a set of them, then you define the entire set of rules for your employee department in terms of ID and authorization it is very time consuming and not driven by business. If you want to take the decision to migrate to another cloud provider because you will probably have to do the work for a second time.
- So, interoperability in terms of complexity rely on identity and access management so cross cloud identity management that is the top topic. There are protocols but now there are no incentive to try to address that.
- However, that is if we talk about public cloud, there are other domain of expertise, other green area, where a new paradigm can be used, thinking about edge computing and IoT. So, besides the nice work that it might represent there are concrete example let's talk about this new idiom saying that data is the new gold or the new oil. Gold or black oil are the tangible assets you cannot duplicate it, it does not have much value if it isn't processed, you need to refine it and it is heavy to move from one place to another. Data, on the other hand, its process, you can duplicate data as much as you want, and you can move all around the world in a couple of seconds. Gold has value by itself, however, data if you do not process it, it doesn't have much value. What I believe is on "Data gravity", when we say that data will migrate from cloud to the edge. I don't think that will happens, there is not enough business incentive to move data from one place to the edge.
- However, we know that we are creating more and more data, so, at some point in time, there will be quantity of data will be bigger at the edge than at the central and it will

probably not migrate and when we are mentioning data gravity it means that is becoming obvious now that is a lot easier and efficient, in financial terms, to move a workflow than to move data.
- So, in terms of cloud federation, it is a tricky and complex topic. However, if we want to enable a new scenario about edge computing we will have to do that and since it is a new market there is no history of business that will prevent from doing that.

REDHAT

- Large enterprises are often using different clouds: for the enterprise, for the production line and so on. It is difficult to say why they are using different providers but using an analogy when the iPhone came up, every company wanted to have apps and that was very marketing driven and IT was not prepared to deliver apps, so each department was writing its own app as they did not want to wait for IT and the level of integration was not so fast and at that point of time IT lost its power to control and govern everything that was develop within the company and if you see the complexity of the organization is very likely that you are starting initiatives and then you land with having tools with cloud that does not mean that they are well integrated and also some departments might have started to do something in the public cloud, some with strategic thinking behind to win time to start in a public cloud to develop but then to have them on premises in their data center to control the production data and intellectual property in there.
- There is a need to be a strong and capable organization to provide security to protect your intellectual property on prem, otherwise for those big companies will be a very appealing part to really own your complete stack to do the governance on the business architecture on top while for smaller companies will make more sense to just buy it. One of the things that RedHat is doing is on onsite, they have invested a lot in a technology called Kubernetes, it is at the PaaS layer of the infrastructure. For example, if you want to have capacity to develop on a common development and operation model but you are outsourcing in India which is a common in an European company developing code that you want to find something that is running on an hyper-scale infrastructure but Redhat technology can be used in the PaaS layer to run on public cloud and you are giving them the same interface on developing and having all those operations processes on the layer on top and if it's development you can take the same stuff and put it in your on prem environment. And that is where there is a need to provide a management across those different clusters of infrastructures where you are running devs and test and then the operational system and that is one way of federation that RedHat is working on.
- But a federation about different providers should work, what is the right level of abstraction, it is very difficult to know what is the right level of equipment, how should the packaging work and there is a need to have real world customers with real cases and it is very hard to do in a classical industry: specification, implementation phase, there is a need to learn on the living object is more on an evolution of what is going on in cloud.

CYBERSECURITY

ELASTISYS

- Cybersecurity is more what you do in the basement while GDPR is more what it is on the table
- It is not only technical but also organisational
- Risk profile, depending on the amount of personal data you are dealing with
- Security is companywide effort, everyone is responsible.
- They are dealing with a lot of sensible data, so they take measures to keep them all secure.

GAIA-X

- Part of the business role to take it into account in any task of the architecture and software development. In terms of infrastructure, the services are provided by the provider itself, so they have everything in place to mitigate virus and similar attacks. In terms of software developers, they need to have good software development practices, there are numerous books and tutorials on how to do that. I will leave cybersecurity in the hands of experts that know how to do that.

REDHAT

- Hope that European cloud schemes are leading to a simplification on the standards at an European level because if there is one standard that would help across all industries sectors it will be a tremendous reduction of complexity for customers, it also would help to use infrastructure for various customers to use the cloud as it should be with mandates and the providers be more flexible on what workloads to put on their data centers. And that would increase the capacity used in individual data centers so better use of existing capacity can be achieved which has an economical advantage and as environment is also an economy aspect, it will also help to reduce consumption of energy and resources and providing compute power.
- When they are running high complex PoCs where customers want to have this infrastructure. PaaS, SaaS layer integrated in their environments for PoC, they use Infrastructure as code that means building our solution bricks in an automated way and layering the IaaS layer, the PaaS, the SaaS and the surrounding systemin different packages that the teams can work and deal with problems on these various layers and it allows also to test, so different teams can test in different parts and finally do the integration tests. And finally, they push a button, and everything is deployed.
- Security test can be written against the setup over cloud. A cloud can be deployed like a piece of software that can be tested with automated tests. So, the infrastructure can be tested before going into production. Then, the same tests can be run in the production environment to see if there is something going wrong on production, it is possible to check if there is something from the outside, does it fit with the firewall.
- If we go the Edge where everything is distributed, the whole setup is becoming more complex and to understand the systems there is a need to have a very good understanding not only on the software, not only on the infrastructure but how everything is working together. On the Edge is not necessary that I just have a small device on a robot , there are also micro data centers where I have several servers , it can be quite some compute power there , and if I am resetting up parts of the infrastructure continuously and one of those servers have been hacked, my private server is been attacked from the outside, maybe one of those servers has been corrupted but I can be assured that one or two hours later this attack is been diminished because it is reducing the time for hackers to use that machine and from their point of view the infrastructure as code is making people much more happy because they can work on problems, they can analyze on a change, the change that I have checked in and what was the result (was good or bad) and putting even security test on that I am getting more information if I have this infrastructure as code and can also audit it. Thus, what infrastructure as code adds more or less is a repository of binaries or code you want to deploy functionality you have a script that is applying thins on a very complex distributed landscape and then you have an inventory file that is describing the landscape what is part of my infrastructure. What all these three pieces you can see if it is fitting within the certification scheme, is it working properly, how are the people dealing with it. If you are re-running it, you can know whether there has been a change on that environment. To ensure that all is properly running.

GREEN ICT

ELASTISYS

- 2/3% global electricity demand. Even if the whole ICT goes green, the world will still be facing a 97% of the electricity problem.
- There is a bit of dichotomy with Cloud computing providers working on green energy and then it is Bitcoin mining. And All the improvements done by green cloud computing providers are far offset by the bitcoin mining.
- There are a lot of data centres in Sweden due to the cool weather and cooling systems. Northern Europe is becoming the commodity for data centres.

GAIA-X

- There is lot that has been done and a lot to be done.
- Energy consumption has not increased much over the last years however the amount of computational resources has multiplied by 4. It means that with one kilowatt we can have at least four more compute power than we have a few years ago. Definitely, the ICT industry is getting greener and greener with an environmental engagement. Heating devices in the data centre is wasting money so you want to make sure that either you heat as less as possible or reuse the heat somehow. The ratio of energy consumption and computational power is getting better and better and I am confident that even in the energy consumption increase that ratio is in our favour. Every company and provider are very sensitive in this topic.

3.4.3 Conclusions

Though the different interviews have shared their own opinion or company vision, it is possible to infer repetitive patterns that allow us to rise some conclusions.

- Business models: ECC is still far from Asia and US in terms of monetizing their services offer. The plethora of Cloud service providers make it difficult for the consumers to just go from one provider. Cloud Federation seems to be the way forward as there is a huge market demand to be covered. However, though it is now technically feasible, there is still a long way for an attractive European Cloud computing business offer that might make current American cloud customers to consider the European alternative.
- Data Sovereignty/Data protection: Europe is far more advanced as community than the US in terms of Data protection as each state follows its own law. European customers really support GDPR thus business models will need to adapt to add more value to their customers. Sovereignty on digital is important to make it clear that everyone is owner of their own data and can define what it can or it cannot be done with it, but somehow there has to be a balance between complete control and efficiency (rights delegation to trust partners).
- Cloud federation: Common consensus that is the European alternative to compete against the big players in USA and ASIA. However, interoperability between cloud computing service providers, though technically feasible, is still a big challenge. Besides, current ECCs follow different business models and cross-cloud identity management is one of the main stoppers for further integration. Regarding the cloud continuum, there do not seem to be enough incentives to move data from the cloud to the edge at this moment, but there is a common belief that in a near future the amount of data will be so big that it will be more economic to move workflows than data.
- Cybersecurity: Still a complex issue, securing all parts still does not imply that the whole system is secure. Security is a responsibility of all, not only technical but also organisational. This problem is increasing as the Edge is becoming more popular as edge devices are more prone to be attacked. A common security framework in Europe that will enable the possibility to automate Security tests might ease the pain.
- Green ICT: Energy consumption of ICT is just around 2%-3% of global electricity demand. Besides, Cloud computing is becoming greener simply because the computational ratio is

increasing at a path much higher than the energy consumed. There is also a feeling that while there is a lot of improvement towards making data centres more energy efficient and environmentally friendly, these are far offset by energy-intensive activities such as Bitcoin mining.

4 INITIAL CLOUD COMPUTING RESEARCH TOPICS AND CHALLENGES

4.1 Analysis of research venues

4.1.1 Methodology

The analysis of the inputs from the academia has been implemented following the approach depicted abovebelow:

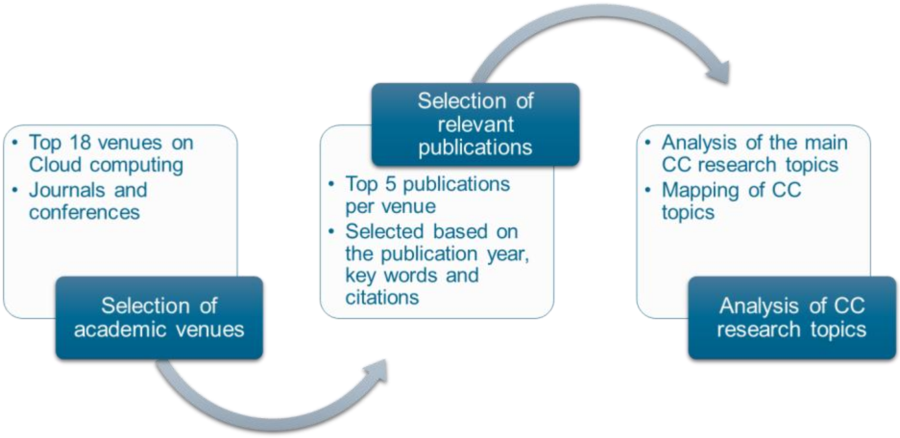

Figure 12. Methodology followed in HUB4CLOUDe for the analysis of the academic publications.

The data gathering and analysis methodology unfolds over three subsequent phases, and can be described as follows:

1. **Phase 1- Selection of academic venues:** The academic venues (journals and conferences) were selected based on the own experience of the HUB4CLOUD partners and Google Scholar under "Engineering and Computer Science > Computing Systems"[1]. Out of these, the following list of venues was selected:

Table 4. List of the selected academic venues

Journal of Cloud Computing	Future Generation Computer Systems
IEEE access	Procedia Computer Science
IEEE Transactions on Services Computing	Concurrency Computation: Practice and Experience
IEEE Transactions on Cloud Computing	mdpi computation
Journal of Systems and Software	Springer Nature Computer Science
Scalable computing	Computing & Control Engineering Journal
International Journal of Computational Science and Engineering	IET Communications
IEEE international conference on cloud computing	CLOSER- International Conference on Cloud Computing and Service Science
CloudCom (IEEE)	

[1] https://scholar.google.com/citations?view_op=top_venues&hl=en&vq=eng_computingsystems

2. **Phase 2- Selection of relevant publications:** The criteria to select the publications per venue have been the following:
    a. Selection of publications from the last 5 years (2016-2021). This criterion was selected because of the fast evolution of the Cloud Computing technologies.
    b. Usage of Key words to narrow the search specially in venues not only focused on Cloud Computing. These Key words were adapted to the publication but always related with Cloud Computing topics. i.e. Cloud Computing, Edge Computing, Fog Computing, Cloud Service Provider, etc. The keywords and selection criteria can be found on Appendix B.
    c. Selection of top 5 publications per venue based on the number of citations. The source for citations was Scopus.
    d. Free/open access to the publications.

    For the filtering and selection of the publications Scopus database was used. In the cases in which the selected venue was not indexed in Scopus other sources (usually publication's own platform) where used to gather the publications following the same criteria. In Appendix A the search queries and the results obtained from the application of these criteria are shown.

    During the application of these criteria some venues were discarded, such as:

    - Concurrency Computation: Practice and Experience: No open access to retrieve the publications
    - Computing & Control Engineering Journal: Published only between 2003 and 2007
    - International Journal of Computational Science and Engineering: No open access to retrieve the publications
    - IEEE International Conference on Cloud Computing: No open access to retrieve the publications
    - IEEE Transactions on Cloud Computing: No open access to retrieve the publications
    - IEEE Transactions on Services Computing: No open access to retrieve the publications

    In the same manner, when performing the literature review some publications were discarded because they were finally found irrelevant for the topics selected.

    As a result, the number of the selected publications for the phase 3 has resulted in 35.

3. **Phase 3 - Analysis of Cloud Computing research topics:** The selected articles were analysed with the objective of extracting the main research topics cited in each publication. As a first stage the research topics were classified using the taxonomy created by the Future Cloud Cluster in 2020 [1]. Nevertheless, when new relevant topics that were not part of the taxonomy were identified these were also included. Special attention was paid to topics or themes of special interest to HUB4CLOUD such as skills development, business models, standardization, or AI for the Cloud.

4.1.2 Analysis of research topics: mapping of the Future Cloud taxonomy and the analysed research papers

As explained in the previous section, the relevant research topics from the selected articles were mapped into the Future Cloud Cluster research topics taxonomy. As a reminder, these topics are briefly detailed next [10]:

- Federation of Clouds: The creation of an enabler that would facilitate the data economy through the federation of different clouds:

- High Performance Heterogeneous Cloud Services: This includes the aggregation of cloud resources from private and public Cloud Service Providers (CSPs), edge providers, other infrastructural environments (e.g. IoTs) to build a platform tailored to the application's needs. Here the high level of abstraction of the application, the services and the resources are of paramount importance.
- Security mechanisms across Clouds: to manage security concerns across multiple clouds (e.g. in a multi-cloud environment, in a cloud federation, …)
- Quality of Service (QoS) and Service Level Agreements (SLAs): Ensure the quality of service of all infrastructural resources, as well as comparable and enforceable SLAs.
- Knowledge-Based Service Harvesting and Acquisition: this includes the discovery, composition and orchestration of cloud services to satisfy customer requirements
- Dynamic Configuration, Provisioning, and Orchestration of Resources: adaptation, configuration, orchestration and management of the cloud continuum and dynamic computing models
- Deployment and management of resources: this includes resource management using for instance machine learning and cognitive techniques
- Resilience and Scale: need that these applications continue to provide their services from the Edge even when network links to cloud are down or seriously overloaded
- Energy efficiency and Sustainability for Edge and Cloud Continuum: optimization of energy consumption in data centers as well as energy aware scheduling
- Software defined Infrastructures and Novel composition models: Management of programmable infrastructures (infrastructure as code)
- Novel Data Storage infrastructures and services: management and exécution of data intensive applications
- Software application development for the computing continuum: software engineering tools and methods for federated infrastructures
- Research artefacts for the computing continuum: access to the necessary tools and data, to avoid that each researcher has to spend time to create the necessary tools and data for themselves

To this taxonomy, HUB4CLOUD has added additional topics that are relevant for the action in course such as Cloud business models, skills, cloud certification, AI for the cloud / Cognitive cloud, Cloud standardization. In the case of cloud business models, skills and cloud standardization the rationale behind is because these are key topics of HUB4CLOUD. In the case of cloud certification, that was a recommendation of the European Commission in the kick-off meeting as it is one of the key policy aspects that will be considered in the EU Cloud rulebook. AI for cloud / Cognitive Cloud demonstrated to be a topic of interest during the SCB meeting held with the RIAs.

- Cloud (security) certification: the EUCS is one of the upcoming security certification schemes being defined under the EU Cybersecurity Act which will enter into force in 2023. It will not be mandatory, but it will be part of the EU Cloud rule book that is identified in the EU Data strategy.
- AI for the Cloud / Cognitive Cloud: Use of AI to improve the capabilities of the cloud computing services
- Cloud business models: this includes the pricing strategies as well as the licensing schemas and business models.
- Cloud Skills: skills needed to work in the cloud computing domain.
- Cloud Standardization: important standards used, adopted and extended in the cloud computing domain.

The following table shows the coverage of the analysed papers with respect to the extended taxonomy of the Future Cloud topics. The green cells in the table below mark the main topics addressed by the papers.

Table 5. Mapping of the coverage of the analysed articles with respect to the extended Future Cloud Cluster taxonomy

Venue	Article title	topic 1: Federation of clouds	topic 2: High Performance Heterogeneous Cloud Services	topic 3: Security mechanisms	topic 4: QoS and SLAs	topic 5: Knowledge-Based Service Harvesting and Acquisition	topic 6: Dynamic Configuration, Provisioning, and Orchestration of Resources	topic 7: Deployment and management of resources	topic 8: Resilience and Scale	topic 9: Energy efficiency and Sustainability for Edge and Cloud Continuum	topic 10: Software defined Infrastructure and Novel composition models	topic 11: Novel Data Storage infrastructures and services	topic 12: Software application development for the computing	topic 13: Research artefacts for the computing continuum	Others: Cloud certification	Others: AI for the Cloud / Cognitive Cloud	Others: Cloud business models	Other: Cloud Skills	Other: Cloud Standardization
Journal of Cloud computing	Fog computing security: a review of current applications and security solutions [38]																		
Journal of Cloud computing	Intrusion detection systems for IoT-based smart environments: a survey [39]																		
Journal of Cloud computing	Multi-access edge computing: open issues, challenges and future perspectives [40]																		

Venue	Article title	topic 1: Federation of clouds	topic 2: High Performance Heterogeneous Cloud Services	topic 3: Security mechanisms	topic 4: QoS and SLAs	topic 5: Knowledge-Based Service Harvesting and Acquisition	topic 6: Dynamic Configuration, Provisioning, and Orchestration of Resources	topic 7: Deployment and management of resources	topic 8: Resilience and Scale	topic 9: Energy efficiency and Sustainability for Edge and Cloud Continuum	topic 10: Software defined Infrastructures and Novel composition models	topic 11: Novel Data Storage infrastructures and services	topic 12: Software application development for the computing	topic 13: Research artefacts for the computing continuum	Others: Cloud certification	Others: AI for the Cloud / Cognitive Cloud	Others: Cloud business models	Other: Cloud Skills	Other: Cloud Standardization
Journal of Cloud computing	Critical analysis of vendor lock-in and its impact on cloud computing migration: a business perspective [41]																		
Journal of Cloud computing	Task scheduling and resource allocation in cloud computing using a heuristic approach [42]																		
IEEE access	A Survey on the Edge Computing for the Internet of Things [43]																		
IEEE access	Adaptive Energy-Aware Computation Offloading for																		

Venue	Article title	topic 1: Federation of clouds	topic 2: High Performance Heterogeneous Cloud Services	topic 3: Security mechanisms	topic 4: QoS and SLAs	topic 5: Knowledge-Based Service Harvesting and Acquisition	topic 6: Dynamic Configuration, Provisioning, and Orchestration of Resources	topic 7: Deployment and management of resources	topic 8: Resilience and Scale	topic 9: Energy efficiency and Sustainability for Edge and Cloud Continuum	topic 10: Software defined Infrastructures and Novel composition models	topic 11: Novel Data Storage infrastructures and services	topic 12: Software application development for the computing	topic 13: Research artefacts for the computing continuum	Others: Cloud certification	Others: AI for the Cloud / Cognitive Cloud	Others: Cloud business models	Other: Cloud Skills	Other: Cloud Standardization
	Cloud of Things Systems [44]																		
IEEE access	Energy-Efficient Offloading for Mobile Edge Computing in 5G Heterogeneous Networks [45]																		
IEEE access	Energy-Saving Offloading by Jointly Allocating Radio and Computational Resources for Mobile Edge Computing [46]																		
IEEE access	Offloading Schemes in Mobile Edge Computing for Ultra-Reliable Low Latency																		

Venue	Article title	topic 1: Federation of clouds	topic 2: High Performance Heterogeneous Cloud Services	topic 3: Security mechanisms	topic 4: QoS and SLAs	topic 5: Knowledge-Based Service Harvesting and Acquisition	topic 6: Dynamic Configuration, Provisioning, and Orchestration of Resources	topic 7: Deployment and management of resources	topic 8: Resilience and Scale	topic 9: Energy efficiency and Sustainability for Edge and Cloud Continuum	topic 10: Software defined Infrastructures and Novel composition models	topic 11: Novel Data Storage infrastructures and services	topic 12: Software application development for the computing	topic 13: Research artefacts for the computing continuum	Others: Cloud certification	Others: AI for the Cloud / Cognitive Cloud	Others: Cloud business models	Other: Cloud Skills	Other: Cloud Standardization
	Communications [47]																		
Journal of Systems and Software	An improved genetic algorithm for task scheduling in the cloud environments using the priority queues: Formal verification, simulation, and statistical testing [48]																		
Scalable computing	RESEARCH ON AUTO-SCALING OF WEB APPLICATIONS IN CLOUD: SURVEY, TRENDS AND FUTURE DIRECTIONS [49]																		

Venue	Article title	topic 1: Federation of clouds	topic 2: High Performance Heterogeneous Cloud Services	topic 3: Security mechanisms	topic 4: QoS and SLAs	topic 5: Knowledge-Based Service Harvesting and Acquisition	topic 6: Dynamic Configuration, Provisioning, and Orchestration of Resources	topic 7: Deployment and management of resources	topic 8: Resilience and Scale	topic 9: Energy efficiency and Sustainability for Edge and Cloud Continuum	topic 10: Software defined Infrastructures and Novel composition models	topic 11: Novel Data Storage infrastructures and services	topic 12: Software application development for the computing	topic 13: Research artefacts for the computing continuum	Others: Cloud certification	Others: AI for the Cloud / Cognitive Cloud	Others: Cloud business models	Other: Cloud Skills	Other: Cloud Standardization
Scalable computing	DATA PLACEMENT IN ERA OF CLOUD COMPUTING: A SURVEY, TAXONOMY AND OPEN RESEARCH ISSUES [50]																		
Scalable computing	DYNAMIC TASK SCHEDULING USING BALANCED VM ALLOCATION POLICY FOR FOG COMPUTING PLATFORMS [51]																		
Scalable computing	INFLUENCE OF MONTORING: FOG AND EDGE COMPUTING [52]																		

Venue	Article title	topic 1: Federation of clouds	topic 2: High Performance Heterogeneous Cloud Services	topic 3: Security mechanisms	topic 4: QoS and SLAs	topic 5: Knowledge-Based Service Harvesting and Acquisition	topic 6: Dynamic Configuration, Provisioning, and Orchestration of Resources	topic 7: Deployment and management of resources	topic 8: Resilience and Scale	topic 9: Energy efficiency and Sustainability for Edge and Cloud Continuum	topic 10: Software defined Infrastructures and Novel composition models	topic 11: Novel Data Storage infrastructures and services	topic 12: Software application development for the computing	topic 13: Research artefacts for the computing continuum	Others: Cloud certification	Others: AI for the Cloud / Cognitive Cloud	Others: Cloud business models	Other: Cloud Skills	Other: Cloud Standardization
CLOSER	Deploying Fog Applications: How Much Does It Cost, By theWay? [53]																		
CLOSER	CLOUDLIGHTNIN G: a framework for a self-organising and self-managing heterogeneous cloud [54]																		
CLOSER	A Review of Cloud Computing Simulation Platforms and Related Environments [55]																		
Future Generation Computer Systems	Efficient IoT-based sensor BIG Data collection–processing and analysis																		

Venue	Article title	topic 1: Federation of clouds	topic 2: High Performance Heterogeneous Cloud Services	topic 3: Security mechanisms	topic 4: QoS and SLAs	topic 5: Knowledge-Based Service Harvesting and Acquisition	topic 6: Dynamic Configuration, Provisioning, and Orchestration of Resources	topic 7: Deployment and management of resources	topic 8: Resilience and Scale	topic 9: Energy efficiency and Sustainability for Edge and Cloud Continuum	topic 10: Software defined Infrastructures and Novel composition models	topic 11: Novel Data Storage infrastructures and services	topic 12: Software application development for the computing	topic 13: Research artefacts for the computing continuum	Others: Cloud certification	Others: AI for the Cloud / Cognitive Cloud	Others: Cloud business models	Other: Cloud Skills	Other: Cloud Standardization
	in smart buildings [56]																		
Future Generation Computer Systems	Integration of Cloud computing and Internet of Things: A survey [57]																		
IET Communications	Time saving protocol for data accessing in cloud computing [58]																		
IET Communications	Mobile cloud computing with a UAV-mounted cloudlet: optimal bit allocation for communication and computation [59]																		
IET Communications	Workload scheduling toward																		

Venue	Article title	topic 1: Federation of clouds	topic 2: High Performance Heterogeneous Cloud Services	topic 3: Security mechanisms	topic 4: QoS and SLAs	topic 5: Knowledge-Based Service Harvesting and Acquisition	topic 6: Dynamic Configuration, Provisioning, and Orchestration of Resources	topic 7: Deployment and management of resources	topic 8: Resilience and Scale	topic 9: Energy efficiency and Sustainability for Edge and Cloud Continuum	topic 10: Software defined Infrastructures and Novel composition models	topic 11: Novel Data Storage infrastructures and services	topic 12: Software application development for the computing	topic 13: Research artefacts for the computing continuum	Others: Cloud certification	Others: AI for the Cloud / Cognitive Cloud	Others: Cloud business models	Other: Cloud Skills	Other: Cloud Standardization
	worst-case delay and optimal utility for single-hop Fog-IoT architecture [60]																		
IET Communications	Computation offloading and resource allocation for mobile edge computing with multiple access points [61]																		
IET Communications	Integration of Internet of Things and cloud computing: a systematic survey [62]																		
mdpi computation	An Elaborate Preprocessing Phase (p3) in Composition and																		

Venue	Article title	topic 1: Federation of clouds	topic 2: High Performance Heterogeneous Cloud Services	topic 3: Security mechanisms	topic 4: QoS and SLAs	topic 5: Knowledge-Based Service Harvesting and Acquisition	topic 6: Dynamic Configuration, Provisioning, and Orchestration of Resources	topic 7: Deployment and management of resources	topic 8: Resilience and Scale	topic 9: Energy efficiency and Sustainability for Edge and Cloud Continuum	topic 10: Software defined Infrastructures and Novel composition models	topic 11: Novel Data Storage infrastructures and services	topic 12: Software application development for the computing	topic 13: Research artefacts for the computing continuum	Others: Cloud certification	Others: AI for the Cloud / Cognitive Cloud	Others: Cloud business models	Other: Cloud Skills	Other: Cloud Standardization
	Optimization of Business Process Models [63]																		
mdpi computation	A Comprehensive Review of Evolutionary Algorithms for Multiprocessor DAG Scheduling [64]																		
Procedia Computer Science	A Study on Data Storage Security Issues in Cloud Computing [65]																		
Procedia Computer Science	Analysis of Eight Data Mining Algorithms for Smarter Internet of Things (IoT) [66]																		
Procedia Computer Science	Big Data, Fast Data and Data Lake Concepts [67]																		

Venue	Article title	topic 1: Federation of clouds	topic 2: High Performance Heterogeneous Cloud Services	topic 3: Security mechanisms	topic 4: QoS and SLAs	topic 5: Knowledge-Based Service Harvesting and Acquisition	topic 6: Dynamic Configuration, Provisioning, and Orchestration of Resources	topic 7: Deployment and management of resources	topic 8: Resilience and Scale	topic 9: Energy efficiency and Sustainability for Edge and Cloud Continuum	topic 10: Software defined Infrastructures and Novel composition models	topic 11: Novel Data Storage infrastructures and services	topic 12: Software application development for the computing	topic 13: Research artefacts for the computing continuum	Others: Cloud certification	Others: AI for the Cloud / Cognitive Cloud	Others: Cloud business models	Other: Cloud Skills	Other: Cloud Standardization
Procedia Computer Science	Exploring Data Security Issues and Solutions in Cloud Computing [68]																		
Procedia Computer Science	Long Short Term Memory Recurrent Neural Network (LSTM-RNN) Based Workload Forecasting Model For Cloud Datacenters [69]																		
SN Computer Science	A Survey on Cloud Computing Simulation and-Modeling [70]																		
SN Computer Science	A Survey on the Current Challenges of Energy-Efficient Cloud Resources Management [71]																		

Venue	Article title	topic 1: Federation of clouds	topic 2: High Performance Heterogeneous Cloud Services	topic 3: Security mechanisms	topic 4: QoS and SLAs	topic 5: Knowledge-Based Service Harvesting and Acquisition	topic 6: Dynamic Configuration, Provisioning, and Orchestration of Resources	topic 7: Deployment and management of resources	topic 8: Resilience and Scale	topic 9: Energy efficiency and Sustainability for Edge and Cloud Continuum	topic 10: Software defined Infrastructures and Novel composition models	topic 11: Novel Data Storage infrastructures and services	topic 12: Software application development for the computing	topic 13: Research artefacts for the computing continuum	Others: Cloud certification	Others: AI for the Cloud / Cognitive Cloud	Others: Cloud business models	Other: Cloud Skills	Other: Cloud Standardization
SN Computer Science	Real-Time Cloud-Based Load Balance Algorithms and analysis [72]																		
SN Computer Science	A Blockchain-based Decentralized Electronic Marketplace for Computing Resources [73]																		

4.2 Overview of identified Cloud Computing Continuum research topics

The following picture shows an overview of the identified research topics, classified initially by the temporal horizon and the potential business impact. While several of these challenges can have multiple of these business impacts only the most relevant one has been selected for visibility purposes.

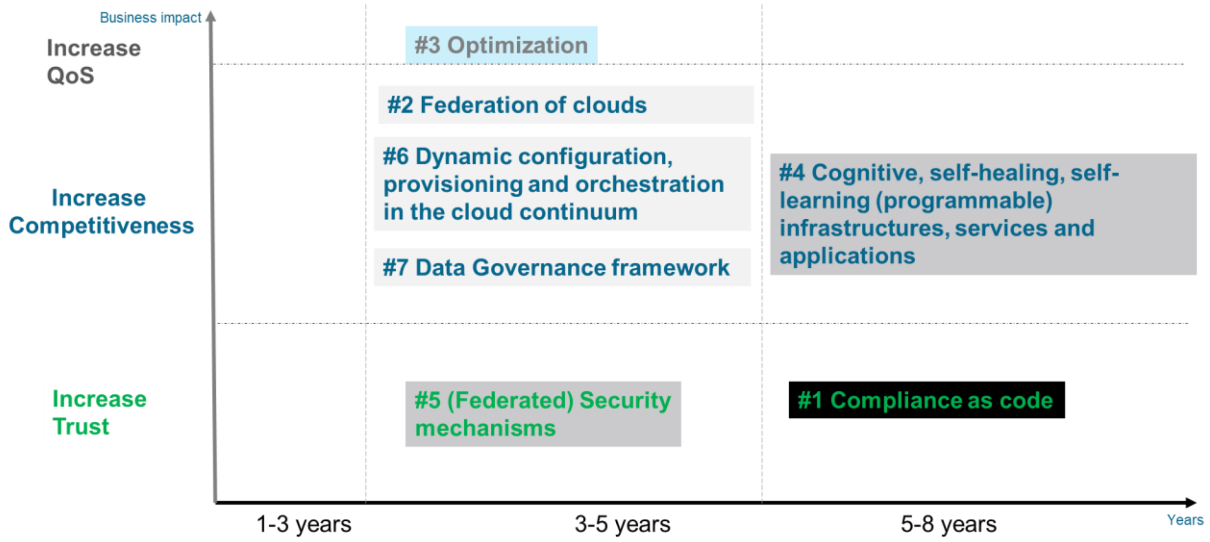

Figure 13. Overview of identified cloud computing continuum research topics (source: editors' own contribution)

4.3 Description of Cloud Computing Continuum research topics and challenges

Next, the initial set of research topics and challenges are described. While the primary source for the research challenges is the analysis of the research venues, this has been complemented with the inputs from the sections above, namely the context analysis, the surveys, interviews and the research projects.

All research challenges are presented following the same structure:

- Description: brief description of the challenge.
- Expected time: time in which this challenge is expected to become deployed
- Societal impact: expected impact in the society as a whole
- Technological impact: main technology result
- Business impact: expected impact in the business domain
- Source: it indicates where this research challenge comes from, such as the research venue analysis, the interviews, the context analysis, surveys, etc.

4.3.1 Compliance as code in cloud security certification

Description: Compliance as code ensures that all regulatory compliance requirements are fulfilled using tools to automatically configure requirements to later on collect, gather evidence and assess said evidence against a set of predefined metrics / requirements. Compliance as code allows to prevent, detect and remediate non-compliance points, especially when seeking high levels of security assurance. Compliance as code in technical measures such as checking protocol versions, managing and handling vulnerabilities, while challenging can be achievable. However, compliance as code for organizational measures (e.g. policies and procedures), which involve the processing of natural language and the need of a machine-readable language and a large corpus of data is a challenging task. Finally, the characteristics and the complexity of the cloud supply chain makes the task of compliance as code even more complex, as the certifications shall also be composed.

Expected time: 5-8 years

Societal Impact: Increased trust in cloud services

Technological Impact: Natural Language Processing (NLP), need to create a corpus data, catalogue metrics, cloud security certification

Business Impact: increased trust in cloud services, more degree of automation, decrease of effort in meeting regulatory requirements.

Source: EUCS [8], Gaia-X [2].

4.3.2 Federation of clouds

Description: the federation of clouds presents several challenges not only from the technical point of view but also from the operational point of view that in the end also affect the adopted technical solution. In the context of this research challenge, federation of cloud encompasses also edge nodes, IoT and other infrastructural resources with enough computational power.

The main challenges in this respect are:

- Common description model to describe all resources and their (non-)functional characteristics in all the different layers (infrastructure, platform, service)
- Common description model to describe the services and resources (non-)functional characteristics in the different phases of the lifecycle: on-boarding and creation
- Mechanisms and protocols that allow for the verification of the credentials of the service and the instances in their lifecycle: configuration, provision, orchestration, operation, un-provisioning and post-mortem
- Mechanisms for dynamic stateless and stateful portability of data and applications
- Mechanisms for dynamic and automatic contract and un-contract of cloud and edge services
- Tools and mechanisms for the dynamic selection and composition of services based on the users' needs (see challenge 3)
- Tools and mechanisms for the dynamic configuration, provisioning and orchestration (see challenge 6) of programmable infrastructures
- Federated security mechanisms such as identity and access management, authentication and authorization, confidentiality and integrity, multi-access, privacy, …
- Task scheduling and workload optimization (see challenge 3)

Expected time: 3-5 years

Societal Impact: Europe will be able to get back its digital sovereignty, enjoying cloud services that comply with European regulations.

Technological Impact: Bring forward the innovation in the field of cloud, edge and software development

Business Impact: Create new business models and increase competitiveness of Europe

Source: Gaia-X [2], IPCEI-CIS, Future Cloud Cluster Roadmap [10], Future Cloud Cluster Reference Architecture [11], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47]–[49], [51], [52], [53], [69], [73].

4.3.3 Optimization techniques for non-functional characteristics of the cloud continuum such as energy consumption, resource selection, reliability, performance, latency minimization, …

Description: The use of heuristics and evolutionary algorithms has a strong potential to improve non-functional characteristics of various domains of the cloud continuum.

Some of these include:

- Energy consumption: minimize the consumption of energy of the data center and the edge nodes. Analyse the energy consumed by the workloads of the services and the VMs and be able to predict, fine-tune and optimize the energy that the workloads would consume, as well as to offload the computation.
- (Dynamic) Resource allocation: For resource allocation, the challenge is to apply heuristics and to use for that as input not only "static" characteristics such as location of the service, CPU, etc. but also dynamic characteristics such as stream data coming from supervised (and potentially) unsupervised monitored metrics such as performance, mean time between failures in a given period of time, that can also help select an optimized combination of resources for an application.
- Latency minimization: optimize the latency while looking for a tradeoff between latency and reliability, for instance.
- Data transmission minimization.

Expected time: 3-5 years

Societal Impact: in the case of energy consumption, reduce the carbon footprint of data centers. In other cases, the consumers shall enjoy services with better QoS.

Technological Impact: novel algorithms

Business Impact: Improve the quality of service of the provided services.

Source: Future Cloud Cluster Roadmap [10], Future Cloud Cluster Reference Architecture [11], [40], [43], [44], [45], [46], [47]–[49], [57], [59], [61], [63], [64], [66], [69], [70], [72]

4.3.4 Cognitive, self-healing, self-learning (programmable) infrastructures, services and applications

Description: The goal with cognitive cloud computing is to mimic the decision making that a DevOps team member would make under a certain situation and execute that decision in an automatic way. To achieve that, artificial intelligence techniques and algorithms have a strong potential. Some example situations include better decision making in dynamic resource and service composition and better prediction of errors and anomalies of resources, applications and services, learning from past failure situations, launching automatic self-configurable mechanisms.

Cognitive cloud computing needs therefore to classify and analyse large amounts of data (structured and unstructured) and from various sources, tune it, create and improve the algorithms and their execution time, detect and recognize patterns, process natural language and finally self-learn from data and situations.

Some research attempts have been made towards the development of tools and mechanisms for self-healing and self-adaptive distributed applications. The self-healing strategies varied from not porting the application or part of the application to another resource but just scaling the resource or restart / reconfigure the virtual machine remotely in an automatic way to seek another optimal resource configuration, provisioning it, configuring it, and porting the application. The main challenge in this last strategy strives in porting the stateful components on the fly maintaining the integrity of the data and doing it in a secure way.

For a cloud to be really cognitive there has to be a clear understanding of the metrics that need to be collected, the sources, the frequency and the purpose of such metrics, but not only that.

The cause-effect and the what-if's must also be understood in order to create the proper self-healing strategies for each possible situation, although the model must also learn from past situations (self-learn).

In the case of programmable infrastructure or infrastructure as code, this is a challenge that it is still not being fully tackled.

Expected time: 5-8 years

Societal Impact: Better quality of service

Technological Impact: novel algorithms

Business Impact: Increase competitiveness of the European industry, greater automation and higher efficiency

Source: Surveys, HUB4CLOUDSCB, Future Cloud Cluster Roadmap [10], Future Cloud Cluster Reference Architecture [11], [54]

4.3.5 (Federated) Security mechanisms

Description: Security in federated clouds which include multiple clouds but also cloud, edge and fog present several challenges. These shall be divided into the following:

- Identity management: how to ensure the segregation of duties: managing, approving and assigning user accounts
- Access management in a multi-layered context
- Authorization: management of authorization not only to user accounts but also to technical accounts, that is accounts that are assigned to machines for automatic compliances or checks for instance.
- Confidentiality, integrity and availability

In the current context, digital identities are being stored in centralized data bases which entail several risks, as users in most cases expose their data voluntarily even if they are not aware of it. OpenID is an effort to create a universal solution but also presents problems. The European Commission has developed the eIDAS, which is the European digital identity, that while it presents many advantages (e.g. cross – border interoperability), the citizen also must provide all its data containing its digital identifier which in many cases it is excessive.

The federated identity model allows to start the session just once and avoids sharing unnecessary data with third parties. In this context, the user must trust that the identity provider only transfers the information that he really wants to share, and the service provider must trust the attributes of the digital identity that it receives from the broker (identity provider). Hence, there is the need for a model that gives the user back the control over their own information and identity, and that ends the silos of information that are attractive to malicious actors. In this way, it is the user himself who has custody and full control of his data, sharing only what he wants and when he wants it. One of these models is Self-Sovereign Identity (SSI), where the user is the owner, manager and exclusive custodian of his data and identity. Complementary to this there is the option to self-manage the personal identity using decentralized identity (DID). In the case of the cloud continuum, as expressed above, the accounts that manage the services are technical accounts. Solutions like the ones mentioned above have not yet been researched in such technical and impersonalized contexts.

Expected time: 3-5 years

Societal Impact: trustworthiness

Technological Impact: mechanisms, protocols, policies

Business Impact: trust at all layers of the cloud federation, ability to prevent and rapidly react to intruders and malicious attacks, integrity and confidentiality.

Source: Gaia-X [2], EUCS [8], Future Cloud Cluster Roadmap [10], Future Cloud Cluster Reference Architecture [11], [38], [39], [57], [58], [62], [65], [68], [73].

4.3.6 Dynamic configuration, provisioning and orchestration in the cloud continuum

Description: Application developers and operators in the Cloud continuum are faced today with the challenge of embracing new paradigms such as DevOps or MLOps but often lack the proper languages. tools and mechanisms to configure, plan, prepare and execute tasks in heterogeneous computational environments. Moreover, they are faced with the tasks of continuous optimization and autonomous (re-)deployment of complex context-aware stateless and stateful applications and data in a federated environment (including edge, cloud and network services) assuring the service continuity and anticipating potential failures in the underlying infrastructure, especially in critical systems that must be resilient and whose response time becomes vital.

In the case of (infrastructural) languages, the plethora of existing languages covering the lifecycle of the infrastructure (configuration, provision, deployment and orchestration) and their limited focus on some of the activities to be automated, results in several problems: lengthy tool selection, difficulties in hiring developers specialized in all the selected tools, lack of integration between the different activities, need of time to learn and experiment with new tools, lots of effort to integrate tools selected for different activities, lack of support in multilingualism, generating therefore potential errors in the chain. Furthermore, most of these languages and tools do not currently fully support the edge or other infrastructural computational resources.

Now that processing data at the edge is becoming more important in order to reduce data transmission and to avoid network latency, the automatic deployment of analytical pipelines along with the dynamic provisioning and configuration of the workload at the edge node is an unresolved challenge.

Expected time: 3-5 years

Societal Impact: better quality of services

Technological Impact: tools and mechanisms

Business Impact: higher competitiveness, greater automation, increase productivity, higher added value

Source: Gaia-X [2], Future Cloud Cluster Roadmap [10], Future Cloud Cluster Reference Architecture [11], [40], [41], [42], [45], [46], [47]–[49], [51], [53], [54], [57], [67].

4.3.7 Data Governance frameworks

Description: Data is becoming the new asset for organizations. The creation of sectorial and cross-sectorial data spaces is expected to become a reality. However, there are still challenges that need to be solved:

- Implementation of the data usage policies: while the requirements related to data use are usually expressed in an informal way and by non-technical people, the usage policies must be formally expressed, so that they can be read by machines and consumed thereby. These usage policies often require a prior negotiation provider-consumer.
- Enforcement of the data usage polices: the access to the data is often done just once but the use of the data is done multiple times in one session. Hence, the enforcement of the policies is very important.
- Traceability: keep track, especially in distributed and federated systems, of the application of the policies by the consumers. This way, the provider can always verify the correct compliance of the usage requirements.
- Monetization and revenue models for data sharing
- Data sharing mechanisms

- Privacy-preserving technologies, multi-party computation (MPC), homomorphic encryption, differential privacy, obfuscation, privacy risk assessment.
- Interoperability: technical and semantic interoperability; need for connectors, curators and sanitizers of the data.

Expected time: 3-5 years

Societal Impact: better services, processes and products

Technological Impact: connectors, policies, mechanisms, tools.

Business Impact: better decision making, higher competitiveness.

Source: IDSA [4], Gaia-X [2].

5 CONCLUSIONS

This deliverable has presented the HUB4CLOUD road mapping approach in what respects the research challenges methodology followed.

The document starts analysing several initiatives in order to understand the context and the landscape. These initiatives are not only in Europe and include Gaia-X, IPCEI-X or the European Alliance for data, cloud and edge but it also analyses the ones in the US and China. In the case of the US the focus has been in the analysis of research projects funded by the NSF while in China, HUB4CLOUD has approached companies to understand their feeling towards cloud computing. In addition to that, the context analysis also includes the consultation and surveys ran within the projects funded under the topic of "Cloud Computing", the experience and knowledge gathered from the CSA H-CLOUD and the interviews performed to relevant selected stakeholders coming from key organizations in the cloud and open source domains.

Once the context has been understood, the research topics have been extracted following a systematic and reproducible approach, in which more than 30 journals and papers have been thoroughly reviewed out of 100 research venues. From these venues, and the input coming from the context analysis, seven broad topics have been identified and described. Their description includes also the expected time in which these could be realized, and their impact in terms of technology, society and business.

The next version of this document will be focused on the classification and scoring methodology of the research topics already identified. This can also entail detailing these topics further so that this classification and scoring can be more exact. The last version of this document, due towards the end of the project, would contain the final recommendations to the European Commission for the upcoming research work programmes.

REFERENCES

[1] Gaia-x AISBL, ‘gaia-x’, *gaia-x*. https://gaia-x.eu/

[2] Gaia-x AISBL, ‘Gaia-X Architecture Document’. Jun. 21, 2021. [Online]. Available: https://community.gaia-x.eu/s/5rDZrGLwjfEL7Qn

[3] International Data Spaces Association (IDSA), ‘IDSA’. https://internationaldataspaces.org/

[4] International Data Spaces Association (IDSA), ‘IDSA Reference Architecture Model’. 2019. [Online]. Available: https://internationaldataspaces.org/wp-content/uploads/IDS-RAM-3.0-2019.pdf

[5] Euoprean Commission, ‘Regulation (EU) 2019/881 of the European Parliament and of the Council of 17 April 2019 on ENISA (the European Union Agency for Cybersecurity) and on information and communications technology cybersecurity certification and repealing Regulation (EU) No 526/2013 (Cybersecurity Act) (Text with EEA relevance)’. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32019R0881

[6] CSPCERT, ‘European Trusted Cloud Service Provuder Working Group’. https://cspcerteurope.blogspot.com/

[7] ENISA, ‘Ad-hoc Working Groups calls’. https://www.enisa.europa.eu/topics/standards/adhoc_wg_calls/

[8] ENISA, ‘EUCS – CLOUD SERVICES SCHEME: a candidate cybersecurity certification scheme for cloud services’. Dec. 2020. [Online]. Available: https://www.enisa.europa.eu/publications/eucs-cloud-service-scheme

[9] European Commission, ‘European Alliance for Industrial Data, Edge and Cloud’. https://digital-strategy.ec.europa.eu/en/policies/cloud-alliance

[10] Future Cloud Cluster, ‘Future Cloud Cluster Research Roadmap’. 2021. [Online]. Available: https://drive.google.com/drive/folders/1PSMOP5Rgin8y7tKRuOU8IO0wJaK77HLn

[11] Future Cloud Cluster, ‘Future Cloud Cluster Reference Architecture Position Paper’. 2021. [Online]. Available: https://drive.google.com/drive/folders/1fo77GLI9NqB6Ce6uBqH9BuH0WjPi3Yqp

[12] U.S. Research and Development Funding and Performance;, ‘U.S. Research and Development Funding and Performance: Fact Sheet report’. Jan. 2020. [Online]. Available: https://fas.org/sgp/crs/misc/R44307.pd

[13] National Science Foundation, ‘NSF Strategic Plan for Fiscal Years (FY) 2018-2022’. [Online]. Available: https://nsf.gov/pubs/2018/nsf18045/nsf18045.pdf

[14] National Science Foundation, ‘Programs: Directorate for Computer and Information Science and Engineering (CISE)’. https://www.nsf.gov/funding/programs.jsp?org=CISE

[15] Congressional Research Service, ‘The National Science Foundation: An Overview’. 2021. [Online]. Available: https://sgp.fas.org/crs/misc/R46753.pdf

[16] carbonfirst.org, ‘CarbonFirst - Decarbonizing Cloud Computing’. http://www.carbonfirst.org/

[17] NSF, ‘Collaborative Research: NGSDI: CarbonFirst: A Sustainable and Reliable Carbon-Centric Cloud-Edge Software Infrastructure’. https://www.nsf.gov/awardsearch/showAward?AWD_ID=2105564&HistoricalAwards=false

[18] NSF, ‘Collaborative Research: NGSDI: Foundations of Clean and Balanced Datacenters: Treehouse’. https://nsf.gov/awardsearch/showAward?AWD_ID=2104548&HistoricalAwards=false

[19] Chameleon.org, ‘A configurable experimental environment for large-scale edge to cloud research’, *https://www.chameleoncloud.org/*.

[20] NSF, ‘Collaborative Research: Chameleon Phase III: A Large-Scale, Reconfigurable Experimental Environment for Cloud Research’. https://www.nsf.gov/awardsearch/showAward?AWD_ID=2027176&HistoricalAwards=false

[21] NSF, ‘Collaborative Research: FMitF: Track I: Game Theoretic Updates for Network and Cloud Functions’. https://www.nsf.gov/awardsearch/showAward?AWD_ID=2018910

[22] cloudbank.org, ‘Cloudbank’. https://www.cloudbank.org/

[23] NSF, ‘CCRI: Grand: Developing a Testbed for the Research Community Exploring Next-Generation Cloud Platforms’. https://www.nsf.gov/awardsearch/showAward?AWD_ID=1925658&HistoricalAwards=false

[24] NSF, 'CSR: Medium: Next-Generation Cloud Federation via a Geo-Distributed Datastore'. https://www.nsf.gov/awardsearch/showAward?AWD_ID=1703560&HistoricalAwards=false
[25] NSF, 'CRI: II-New: Pebbles: A Modular, Composable Hardware and Software Platform for Pervasive Edge Sensing and Computing'. https://nsf.gov/awardsearch/showAward?AWD_ID=1730291&HistoricalAwards=false
[26] NSF, 'CC* Integration-Large: An "On-the-fly" Deeply Programmable End-to-end Network-Centric Platform for Edge-to-Core Workflows'. https://www.nsf.gov/awardsearch/showAward?AWD_ID=2018074
[27] Defense Advanced Research Projects Agency, 'Defense Advanced Research Projects Agency (DARPA)'. https://www.darpa.mil/
[28] wikizero, 'DARPA'. https://wikizero.com/m/DARPA
[29] Wikipedia, 'Information Innovation Office'. https://en.wikipedia.org/wiki?curid=51708323
[30] US GOV OPS, 'Open Programmable Secure- 5G (OPS-5G) program'. https://usgovops.org/ops5g/
[31] DARPA, 'Building Hardware to Enable Continuous Data Protections'. https://www.darpa.mil/news-events/2020-03-02
[32] R. Richards, 'Dispersed Computing'. https://www.darpa.mil/program/dispersed-computing
[33] H-CLOUD, 'H-CLOUD Green Paper'. [Online]. Available: https://h-cloud.eu/download/green-paper/?wpdmdl=764&masterkey=5fad315e7100d
[34] H-CLOUD, 'H-CLOUD Project. D 1.1 – Cloud Computing Portfolio'. [Online]. Available: https://h-cloud.eu/download/d1-1/?wpdmdl=982&masterkey=6034fdc6262cf
[35] H-CLOUD, 'H-CLOUD Project. D 1.2 – Cloud Computing Portfolio – Second Release'. [Online]. Available: https://h-cloud.eu/download/hcloud_d1-2_cloud-computing-portfolio_second-release_v2-0_final/?wpdmdl=1169&masterkey=60a7b11877c27
[36] H-CLOUD Project, 'Online Cloud Computing Portfolio'. [Online]. Available: https://catalogue.h-cloud.eu/?page_id=1034
[37] A. Taherkordi, F. Zahid, Y. Verginadis, and G. Horn, 'Future Cloud Systems Design: Challenges and Research Directions', *IEEE Access*, vol. 6, pp. 74120–74150, 2018, doi: 10.1109/ACCESS.2018.2883149.
[38] S. Khan, S. Parkinson, and Y. Qin, 'Fog computing security: a review of current applications and security solutions', *J Cloud Comp*, vol. 6, no. 1, p. 19, Dec. 2017, doi: 10.1186/s13677-017-0090-3.
[39] M. F. Elrawy, A. I. Awad, and H. F. A. Hamed, 'Intrusion detection systems for IoT-based smart environments: a survey', *J Cloud Comp*, vol. 7, no. 1, p. 21, Dec. 2018, doi: 10.1186/s13677-018-0123-6.
[40] S. Shahzadi, M. Iqbal, T. Dagiuklas, and Z. U. Qayyum, 'Multi-access edge computing: open issues, challenges and future perspectives', *J Cloud Comp*, vol. 6, no. 1, p. 30, Dec. 2017, doi: 10.1186/s13677-017-0097-9.
[41] J. Opara-Martins, R. Sahandi, and F. Tian, 'Critical analysis of vendor lock-in and its impact on cloud computing migration: a business perspective', *J Cloud Comp*, vol. 5, no. 1, p. 4, Dec. 2016, doi: 10.1186/s13677-016-0054-z.
[42] M. B. Gawali and S. K. Shinde, 'Task scheduling and resource allocation in cloud computing using a heuristic approach', *J Cloud Comp*, vol. 7, no. 1, p. 4, Dec. 2018, doi: 10.1186/s13677-018-0105-8.
[43] W. Yu *et al.*, 'A Survey on the Edge Computing for the Internet of Things', *IEEE Access*, vol. 6, pp. 6900–6919, 2018, doi: 10.1109/ACCESS.2017.2778504.
[44] Y. Nan *et al.*, 'Adaptive Energy-Aware Computation Offloading for Cloud of Things Systems', *IEEE Access*, vol. 5, pp. 23947–23957, 2017, doi: 10.1109/ACCESS.2017.2766165.
[45] K. Zhang *et al.*, 'Energy-Efficient Offloading for Mobile Edge Computing in 5G Heterogeneous Networks', *IEEE Access*, vol. 4, pp. 5896–5907, 2016, doi: 10.1109/ACCESS.2016.2597169.
[46] P. Zhao, H. Tian, C. Qin, and G. Nie, 'Energy-Saving Offloading by Jointly Allocating Radio and Computational Resources for Mobile Edge Computing', *IEEE Access*, vol. 5, pp. 11255–11268, 2017, doi: 10.1109/ACCESS.2017.2710056.
[47] J. Liu and Q. Zhang, 'Offloading Schemes in Mobile Edge Computing for Ultra-Reliable Low

Latency Communications', *IEEE Access*, vol. 6, pp. 12825–12837, 2018, doi: 10.1109/ACCESS.2018.2800032.
[48] B. Keshanchi, A. Souri, and N. J. Navimipour, 'An improved genetic algorithm for task scheduling in the cloud environments using the priority queues: Formal verification, simulation, and statistical testing', *Journal of Systems and Software*, vol. 124, pp. 1–21, Feb. 2017, doi: 10.1016/j.jss.2016.07.006.
[49] P. Singh, P. Gupta, K. Jyoti, and A. Nayyar, 'Research on Auto-Scaling of Web Applications in Cloud: Survey, Trends and Future Directions', *SCPE*, vol. 20, no. 2, pp. 399–432, May 2019, doi: 10.12694/scpe.v20i2.1537.
[50] A. Kaur, P. Gupta, M. Singh, and A. Nayyar, 'Data Placement in Era of Cloud Computing: a Survey, Taxonomy and Open Research Issues', *SCPE*, vol. 20, no. 2, pp. 377–398, May 2019, doi: 10.12694/scpe.v20i2.1530.
[51] S. P. Singh, A. Nayyar, H. Kaur, and A. Singla, 'Dynamic Task Scheduling using Balanced VM Allocation Policy for Fog Computing Platforms', *SCPE*, vol. 20, no. 2, pp. 433–456, May 2019, doi: 10.12694/scpe.v20i2.1538.
[52] V. K. Prasad, M. D. Bhavsar, and S. Tanwar, 'Influence of Montoring: Fog and Edge Computing', *SCPE*, vol. 20, no. 2, pp. 365–376, May 2019, doi: 10.12694/scpe.v20i2.1533.
[53] A. Brogi, S. Forti, and A. Ibrahim, 'Deploying Fog Applications: How Much Does It Cost, By the Way?':, in *Proceedings of the 8th International Conference on Cloud Computing and Services Science*, Funchal, Madeira, Portugal, 2018, pp. 68–77. doi: 10.5220/0006676100680077.
[54] T. Lynn *et al.*, 'CLOUDLIGHTNING: A Framework for a Self-organising and Self-managing Heterogeneous Cloud':, in *Proceedings of the 6th International Conference on Cloud Computing and Services Science*, Rome, Italy, 2016, pp. 333–338. doi: 10.5220/0005921503330338.
[55] J. Byrne *et al.*, 'A Review of Cloud Computing Simulation Platforms and Related Environments':, in *Proceedings of the 7th International Conference on Cloud Computing and Services Science*, Porto, Portugal, 2017, pp. 679–691. doi: 10.5220/0006373006790691.
[56] A. P. Plageras, K. E. Psannis, C. Stergiou, H. Wang, and B. B. Gupta, 'Efficient IoT-based sensor BIG Data collection–processing and analysis in smart buildings', *Future Generation Computer Systems*, vol. 82, pp. 349–357, May 2018, doi: 10.1016/j.future.2017.09.082.
[57] A. Botta, W. de Donato, V. Persico, and A. Pescapé, 'Integration of Cloud computing and Internet of Things: A survey', *Future Generation Computer Systems*, vol. 56, pp. 684–700, Mar. 2016, doi: 10.1016/j.future.2015.09.021.
[58] S. Namasudra and P. Roy, 'Time saving protocol for data accessing in cloud computing', *IET Communications*, vol. 11, no. 10, pp. 1558–1565, Jul. 2017, doi: 10.1049/iet-com.2016.0777.
[59] S. Jeong, O. Simeone, and J. Kang, 'Mobile cloud computing with a UAV-mounted cloudlet: optimal bit allocation for communication and computation', *IET Communications*, vol. 11, no. 7, pp. 969–974, May 2017, doi: 10.1049/iet-com.2016.1114.
[60] Y. Deng, Z. Chen, D. Zhang, and M. Zhao, 'Workload scheduling toward worst-case delay and optimal utility for single-hop Fog-IoT architecture', *IET Communications*, vol. 12, no. 17, pp. 2164–2173, Oct. 2018, doi: 10.1049/iet-com.2018.5077.
[61] Q. Li, J. Zhao, and Y. Gong, 'Computation offloading and resource allocation for mobile edge computing with multiple access points', *IET Communications*, vol. 13, no. 17, pp. 2668–2677, Oct. 2019, doi: 10.1049/iet-com.2019.0446.
[62] M. Nazari Jahantigh, A. Masoud Rahmani, N. Jafari Navimirour, and A. Rezaee, 'Integration of Internet of Things and cloud computing: a systematic survey', *IET Communications*, vol. 14, no. 2, pp. 165–176, Jan. 2020, doi: 10.1049/iet-com.2019.0537.
[63] G. Tsakalidis, K. Georgoulakos, D. Paganias, and K. Vergidis, 'An Elaborate Preprocessing Phase (p3) in Composition and Optimization of Business Process Models', *Computation*, vol. 9, no. 2, p. 16, Feb. 2021, doi: 10.3390/computation9020016.
[64] E. C. da Silva and P. H. R. Gabriel, 'A Comprehensive Review of Evolutionary Algorithms for Multiprocessor DAG Scheduling', *Computation*, vol. 8, no. 2, p. 26, Apr. 2020, doi: 10.3390/computation8020026.

[65] N. vurukonda and B. T. Rao, 'A Study on Data Storage Security Issues in Cloud Computing', *Procedia Computer Science*, vol. 92, pp. 128–135, 2016, doi: 10.1016/j.procs.2016.07.335.
[66] F. Alam, R. Mehmood, I. Katib, and A. Albeshri, 'Analysis of Eight Data Mining Algorithms for Smarter Internet of Things (IoT)', *Procedia Computer Science*, vol. 98, pp. 437–442, 2016, doi: 10.1016/j.procs.2016.09.068.
[67] N. Miloslavskaya and A. Tolstoy, 'Big Data, Fast Data and Data Lake Concepts', *Procedia Computer Science*, vol. 88, pp. 300–305, 2016, doi: 10.1016/j.procs.2016.07.439.
[68] P. R. Kumar, P. H. Raj, and P. Jelciana, 'Exploring Data Security Issues and Solutions in Cloud Computing', *Procedia Computer Science*, vol. 125, pp. 691–697, 2018, doi: 10.1016/j.procs.2017.12.089.
[69] J. Kumar, R. Goomer, and A. K. Singh, 'Long Short Term Memory Recurrent Neural Network (LSTM-RNN) Based Workload Forecasting Model For Cloud Datacenters', *Procedia Computer Science*, vol. 125, pp. 676–682, 2018, doi: 10.1016/j.procs.2017.12.087.
[70] I. Bambrik, 'A Survey on Cloud Computing Simulation and Modeling', *SN Computer Science*, vol. 1, no. 5, p. 249, Aug. 2020, doi: 10.1007/s42979-020-00273-1.
[71] I. Hamzaoui, B. Duthil, V. Courboulay, and H. Medromi, 'A Survey on the Current Challenges of Energy-Efficient Cloud Resources Management', *SN Computer Science*, vol. 1, no. 2, p. 73, Feb. 2020, doi: 10.1007/s42979-020-0078-9.
[72] S. R. Gundu, C. A. Panem, and A. Thimmapuram, 'Real-Time Cloud-Based Load Balance Algorithms and an Analysis', *SN Computer Science*, vol. 1, no. 4, p. 187, May 2020, doi: 10.1007/s42979-020-00199-8.
[73] M. Nardini, S. Helmer, N. El Ioini, and C. Pahl, 'A Blockchain-based Decentralized Electronic Marketplace for Computing Resources', *SN Computer Science*, vol. 1, no. 5, p. 251, Aug. 2020, doi: 10.1007/s42979-020-00243-7.

APPENDIX A: SEARCH QUERIES AND RESULTS FOR THE ANALYSIS OF PUBLICATIONS

This appendix shows the results for the analysis of the publications as extracted directly by Scopus. The content has been transcribed directly from the source.

Source: Journal of Cloud Computing

Scopus
EXPORT DATE:16 Jul 2021

Khan, S., Parkinson, S., Qin, Y.
57195396187;24829532500;23390357100;
Fog computing security: a review of current applications and security solutions
(2017) Journal of Cloud Computing, 6 (1), art. no. 19, . Cited 135 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85027710475&doi=10.1186%2fs13677-017-0090-3&partnerID=40&md5=37d52f0839f380a349f368b3a7ff5c0a

DOI: 10.1186/s13677-017-0090-3
AFFILIATIONS: Department of Informatics, School of Computing and Engineering, University of Huddersfield, Queensgate, Huddersfield, United Kingdom
ABSTRACT: Fog computing is a new paradigm that extends the Cloud platform model by providing computing resources on the edges of a network. It can be described as a cloud-like platform having similar data, computation, storage and application services, but is fundamentally different in that it is decentralized. In addition, Fog systems are capable of processing large amounts of data locally, operate on-premise, are fully portable, and can be installed on heterogeneous hardware. These features make the Fog platform highly suitable for time and location-sensitive applications. For example, Internet of Things (IoT) devices are required to quickly process a large amount of data. This wide range of functionality driven applications intensifies many security issues regarding data, virtualization, segregation, network, malware and monitoring. This paper surveys existing literature on Fog computing applications to identify common security gaps. Similar technologies like Edge computing, Cloudlets and Micro-data centres have also been included to provide a holistic review process. The majority of Fog applications are motivated by the desire for functionality and end-user requirements, while the security aspects are often ignored or considered as an afterthought. This paper also determines the impact of those security issues and possible solutions, providing future security-relevant directions to those responsible for designing, developing, and maintaining Fog systems. © 2017, The Author(s).
AUTHOR KEYWORDS: Fog computing; Internet of things; Malware protection; Performance; Security threats; Wireless security
DOCUMENT TYPE: Review
PUBLICATION STAGE: Final
SOURCE: Scopus

Elrawy, M.F., Awad, A.I., Hamed, H.F.A.
57190344175;42961080300;57216775417;
Intrusion detection systems for IoT-based smart environments: a survey
(2018) Journal of Cloud Computing, 7 (1), art. no. 21, . Cited 65 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85057804579&doi=10.1186%2fs13677-018-0123-6&partnerID=40&md5=a3cb95cb8728a27779cd29b7b2ea4842

DOI: 10.1186/s13677-018-0123-6

AFFILIATIONS: Department of Electronics and Communication Engineering, MUST University, 6th of October, Egypt;
Institute of Public Administration, Abha, Asir, Saudi Arabia;
Department of Computer Science, Electrical and Space Engineering, Luleå University of Technology, Luleå, SE-97187, Sweden;
Faculty of Engineering, Al-Azhar University, P.O. Box 83513, Qena, Egypt;
Faculty of Engineering, Minia University, P.O. Box 61111, Minia, Egypt
ABSTRACT: One of the goals of smart environments is to improve the quality of human life in terms of comfort and efficiency. The Internet of Things (IoT) paradigm has recently evolved into a technology for building smart environments. Security and privacy are considered key issues in any real-world smart environment based on the IoT model. The security vulnerabilities in IoT-based systems create security threats that affect smart environment applications. Thus, there is a crucial need for intrusion detection systems (IDSs) designed for IoT environments to mitigate IoT-related security attacks that exploit some of these security vulnerabilities. Due to the limited computing and storage capabilities of IoT devices and the specific protocols used, conventional IDSs may not be an option for IoT environments. This article presents a comprehensive survey of the latest IDSs designed for the IoT model, with a focus on the corresponding methods, features, and mechanisms. This article also provides deep insight into the IoT architecture, emerging security vulnerabilities, and their relation to the layers of the IoT architecture. This work demonstrates that despite previous studies regarding the design and implementation of IDSs for the IoT paradigm, developing efficient, reliable and robust IDSs for IoT-based smart environments is still a crucial task. Key considerations for the development of such IDSs are introduced as a future outlook at the end of this survey. © 2018, The Author(s).
AUTHOR KEYWORDS: Internet of things; Intrusion detection systems; Smart environments
DOCUMENT TYPE: Review
PUBLICATION STAGE: Final
SOURCE: Scopus

Gawali, M.B., Shinde, S.K.
55657852100;26422588200;
Task scheduling and resource allocation in cloud computing using a heuristic approach
(2018) Journal of Cloud Computing, 7 (1), art. no. 4, . Cited 63 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85041544706&doi=10.1186%2fs13677-018-0105-8&partnerID=40&md5=6e07cb9b68781bdf5098c4ad4ea0894c

DOI: 10.1186/s13677-018-0105-8
AFFILIATIONS: Department of Information Technology, Thadomal Shahani Engineering College, Bandra (W), University of Mumbai, Mumbai, MS, India;
Lokmanya Tilak College of Engineering, Kopar Khairane, University of Mumbai, Mumbai, MS, India
ABSTRACT: Cloud computing is required by modern technology. Task scheduling and resource allocation are important aspects of cloud computing. This paper proposes a heuristic approach that combines the modified analytic hierarchy process (MAHP), bandwidth aware divisible scheduling (BATS) + BAR optimization, longest expected processing time preemption (LEPT), and divide-and-conquer methods to perform task scheduling and resource allocation. In this approach, each task is processed before its actual allocation to cloud resources using a MAHP process. The resources are allocated using the combined BATS + BAR optimization method, which considers the bandwidth and load of the cloud resources as constraints. In addition, the proposed system preempts resource intensive tasks using LEPT preemption. The divide-and-conquer approach improves the proposed system, as is proven experimentally through comparison with the existing BATS and improved differential evolution

algorithm (IDEA) frameworks when turnaround time and response time are used as performance metrics. © 2018, The Author(s).
AUTHOR KEYWORDS: Analytic hierarchy system; BAR; BATS; Cloud computing; Heuristic; Resource management; Task scheduling
DOCUMENT TYPE: Article
PUBLICATION STAGE: Final
SOURCE: Scopus

Opara-Martins, J., Sahandi, R., Tian, F.
55507070000;6505931183;55186571600;
Critical analysis of vendor lock-in and its impact on cloud computing migration: a business perspective
(2016) Journal of Cloud Computing, 5 (1), art. no. 4, . Cited 62 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85006223178&doi=10.1186%2fs13677-016-0054-z&partnerID=40&md5=54ea810477d69e9916d03ba9855894e4

DOI: 10.1186/s13677-016-0054-z
AFFILIATIONS: Faculty of Science and Technology, Bournemouth University, Bournemouth, United Kingdom
ABSTRACT: Vendor lock-in is a major barrier to the adoption of cloud computing, due to the lack of standardization. Current solutions and efforts tackling the vendor lock-in problem are predominantly technology-oriented. Limited studies exist to analyse and highlight the complexity of vendor lock-in problem in the cloud environment. Consequently, most customers are unaware of proprietary standards which inhibit interoperability and portability of applications when taking services from vendors. This paper provides a critical analysis of the vendor lock-in problem, from a business perspective. A survey based on qualitative and quantitative approaches conducted in this study has identified the main risk factors that give rise to lock-in situations. The analysis of our survey of 114 participants shows that, as computing resources migrate from on-premise to the cloud, the vendor lock-in problem is exacerbated. Furthermore, the findings exemplify the importance of interoperability, portability and standards in cloud computing. A number of strategies are proposed on how to avoid and mitigate lock-in risks when migrating to cloud computing. The strategies relate to contracts, selection of vendors that support standardised formats and protocols regarding standard data structures and APIs, developing awareness of commonalities and dependencies among cloud-based solutions. We strongly believe that the implementation of these strategies has a great potential to reduce the risks of vendor lock-in. © 2016, Opara-Martins et al.
AUTHOR KEYWORDS: Cloud adoption; Cloud API's; Cloud computing; DevOps; Enterprise migration; Interoperability; Portability; Standards; Vendor lock-in
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Shahzadi, S., Iqbal, M., Dagiuklas, T., Qayyum, Z.U.
57196186026;24824592700;55890836600;54785279200;
Multi-access edge computing: open issues, challenges and future perspectives
(2017) Journal of Cloud Computing, 6 (1), art. no. 30, . Cited 55 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85038831594&doi=10.1186%2fs13677-017-0097-9&partnerID=40&md5=5cfdbed073ef67a73236dda8890e013e

DOI: 10.1186/s13677-017-0097-9
AFFILIATIONS: Swan Mesh Networks Ltd, London, United Kingdom;
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ABSTRACT: Latency minimization is a pivotal aspect in provision of real time services while adhering to Quality of Experience (QoE) parameters for

assuring spectral efficiency. Edge Cloud Computing, being a potential research dimension in the realm of 5G networks, targets to enhance the network efficiency by harnessing effectiveness of both cloud computing and mobile devices in user's proximity. Keeping in view the far ranging impact of Edge Cloud Computing in future mobile generations, a comprehensive review of the prevalent Edge Cloud Computing frameworks and approaches is presented with a detailed comparison of its classifications through various QoS metrics (pertinent to network performance and overheads associated with deployment/migration). Considering the knowledge accumulated, procedures analysed and theories discussed, the paper provides a comprehensive overview on sate-of-the-art and future research directions for multi-access mobile edge computing. © 2017, The Author(s).
AUTHOR KEYWORDS: Cloud computing; Cloudlets; Edge cloud; Fog computing; Internet of things; Mobile cloud computing
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Zhang, K., Mao, Y., Leng, S., Zhao, Q., Li, L., Peng, X., Pan, L., Maharjan, S., Zhang, Y.
56404886100;10739057700;16203001500;56542166800;7501446895;57191267092;57207151403;36028399100;56602599100;
Energy-Efficient Offloading for Mobile Edge Computing in 5G Heterogeneous Networks
(2016) IEEE Access, 4, pp. 5896-5907. Cited 475 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85027058852&doi=10.1109%2fACCESS.2016.2597169&partnerID=40&md5=a5fcde1e122182cc0e4609788abbf0a7

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ABSTRACT: Mobile edge computing (MEC) is a promising paradigm to provide cloud-computing capabilities in close proximity to mobile devices in fifth-generation (5G) networks. In this paper, we study energy-efficient computation offloading (EECO) mechanisms for MEC in 5G heterogeneous networks. We formulate an optimization problem to minimize the energy consumption of the offloading system, where the energy cost of both task computing and file transmission are taken into consideration. Incorporating the multi-access characteristics of the 5G heterogeneous network, we then design an EECO scheme, which jointly optimizes offloading and radio resource allocation to obtain the minimal energy consumption under the latency constraints. Numerical results demonstrate energy efficiency improvement of our proposed EECO scheme. © 2013 IEEE.
AUTHOR KEYWORDS: 5G; Energy-efficiency; mobile edge computing; offloading
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Yu, W., Liang, F., He, X., Hatcher, W.G., Lu, C., Lin, J., Yang, X.
34973528100;57199151578;55807733400;57190836609;55733537200;55978739900;55683797600;
A Survey on the Edge Computing for the Internet of Things
(2017) IEEE Access, 6, pp. 6900-6919. Cited 421 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85037656743&doi=10.1109%2fACCESS.2017.2778504&partnerID=40&md5=18536d9f7de0904ba56a9d3d95746050

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ABSTRACT: The Internet of Things (IoT) now permeates our daily lives, providing important measurement and collection tools to inform our every decision. Millions of sensors and devices are continuously producing data and exchanging important messages via complex networks supporting machine-to-machine communications and monitoring and controlling critical smart-world infrastructures. As a strategy to mitigate the escalation in resource congestion, edge computing has emerged as a new paradigm to solve IoT and localized computing needs. Compared with the well-known cloud computing, edge

computing will migrate data computation or storage to the network 'edge,' near the end users. Thus, a number of computation nodes distributed across the network can offload the computational stress away from the centralized data center, and can significantly reduce the latency in message exchange. In addition, the distributed structure can balance network traffic and avoid the traffic peaks in IoT networks, reducing the transmission latency between edge/cloudlet servers and end users, as well as reducing response times for real-time IoT applications in comparison with traditional cloud services. Furthermore, by transferring computation and communication overhead from nodes with limited battery supply to nodes with significant power resources, the system can extend the lifetime of the individual nodes. In this paper, we conduct a comprehensive survey, analyzing how edge computing improves the performance of IoT networks. We categorize edge computing into different groups based on architecture, and study their performance by comparing network latency, bandwidth occupation, energy consumption, and overhead. In addition, we consider security issues in edge computing, evaluating the availability, integrity, and the confidentiality of security strategies of each group, and propose a framework for security evaluation of IoT networks with edge computing. Finally, we compare the performance of various IoT applications (smart city, smart grid, smart transportation, and so on) in edge computing and traditional cloud computing architectures. © 2013 IEEE.
AUTHOR KEYWORDS: Edge computing; Internet of Things; survey
DOCUMENT TYPE: Review
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Zhao, P., Tian, H., Qin, C., Nie, G.
57193835657;7202161757;55559493500;55337102500;
Energy-Saving Offloading by Jointly Allocating Radio and Computational Resources for Mobile Edge Computing
(2017) IEEE Access, 5, art. no. 7938331, pp. 11255-11268. Cited 147 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85028777460&doi=10.1109%2fACCESS.2017.2710056&partnerID=40&md5=dd05c74f6679ffd3aed9740e115a96d8

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AFFILIATIONS: State Key Laboratory of Networking and Switching Technology, Beijing University of Posts and Telecommunications, Beijing, 100876, China
ABSTRACT: Mobile edge computing (MEC) providing information technology and cloud-computing capabilities within the radio access network is an emerging technique in fifth-generation networks. MEC can extend the computational capacity of smart mobile devices (SMDs) and economize SMDs' energy consumption by migrating the computation-intensive task to the MEC server. In this paper, we consider a multi-mobile-users MEC system, where multiple SMDs ask for computation offloading to a MEC server. In order to minimize the energy consumption on SMDs, we jointly optimize the offloading selection, radio resource allocation, and computational resource allocation coordinately. We formulate the energy consumption minimization problem as a mixed interger nonlinear programming (MINLP) problem, which is subject to specific application latency constraints. In order to solve the problem, we propose a reformulation-linearization-technique-based Branch-and-Bound (RLTBB) method, which can obtain the optimal result or a suboptimal result by setting the solving accuracy. Considering the complexity of RTLBB cannot be guaranteed, we further design a Gini coefficient-based greedy heuristic (GCGH) to solve the MINLP problem in polynomial complexity by degrading the MINLP problem into the convex problem. Many simulation results demonstrate the energy saving enhancements of RLTBB and GCGH. © 2013 IEEE.
AUTHOR KEYWORDS: branch-and-bound method; computation offloading; energy minimization; Gini coefficient; Mobile edge computing; reformulation-linearization-technique
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Liu, J., Zhang, Q.
57200563926;56230219300;
Offloading Schemes in Mobile Edge Computing for Ultra-Reliable Low Latency Communications
(2018) IEEE Access, 6, pp. 12825-12837. Cited 102 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85041693987&doi=10.1109%2fACCESS.2018.2800032&partnerID=40&md5=dff7c4adb6d44b23c469485d8b8c1399

DOI: 10.1109/ACCESS.2018.2800032
AFFILIATIONS: Department of Engineering, Aarhus University, Aarhus, 8000, Denmark
ABSTRACT: The ultra-reliable low latency communications (uRLLC) in the fifth generation mobile communication system aims to support diverse emerging applications with strict requirements of latency and reliability. Mobile edge computing (MEC) is considered as a promising solution to reduce the latency of computation-intensive tasks leveraging powerful computing units at short distance. The state-of-art work on task offloading to MEC mainly focuses on the tradeoff between latency and energy consumption, rather than reliability. In this paper, the tradeoff between the latency and reliability in task offloading to MEC is studied. A framework is provided, where user equipment partitions a task into sub-tasks and offloads them to multiple nearby edge nodes (ENs) in sequence. In this framework, we formulate an optimization problem to jointly minimize the latency and offloading failure probability. Since the formulated problem is nonconvex, we design three algorithms based on heuristic search, reformulation linearization technique and semi-definite relaxation, respectively, and solve the problem through optimizing EN candidates selection, offloading ordering and task allocation. Compared with the previous work, the numerical simulation results show that the proposed algorithms strike a good balance between the latency and reliability in uRLLC. Among them, the Heuristic Algorithm achieves the best performance in terms of the latency and reliability with the minimal complexity. © 2013 IEEE.
AUTHOR KEYWORDS: 5G; computation offloading; mobile edge computing; ultra-reliable low latency communications
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Nan, Y., Li, W., Bao, W., Delicato, F.C., Pires, P.F., Dou, Y., Zomaya, A.Y.
57193067051;57214815586;36930061600;55887461400;55595376300;15131095400;7005128430;
Adaptive Energy-Aware Computation Offloading for Cloud of Things Systems
(2017) IEEE Access, 5, art. no. 8081765, pp. 23947-23957. Cited 45 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85032443450&doi=10.1109%2fACCESS.2017.2766165&partnerID=40&md5=33c77d1883e6d85bb09af1746f4208a5

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ABSTRACT: Cloud computing has become the de facto computing platform for application processing in the era of the Internet of Things (IoT). However, limitations of the cloud model, such as the high transmission latency and high costs are giving birth to a new computing paradigm called edge computing (a.k.a fog computing). Fog computing aims to move the data processing close

to the network edge so as to reduce Internet traffic. However, since the servers at the fog layer are not as powerful as the ones in the cloud, there is a need to balance the data processing in between the fog and the cloud. Moreover, besides the data offloading issue, the energy efficiency of fog computing nodes has become an increasing concern. Densely deployed fog nodes are a major source of carbon footprint in IoT systems. To reduce the usage of the brown energy resources (e.g., powered by energy produced through fossil fuels), green energy is an alternative option. In this paper, we propose employing dual energy sources for supporting the fog nodes, where solar power is the primary energy supply and grid power is the backup supply. Based on that, we present a comprehensive analytic framework for incorporating green energy sources to support the running of IoT and fog computing-based systems, and to handle the tradeoff in terms of average response time, average monetary, and energy costs in the IoT. This paper describes an online algorithm, Lyapunov optimization on time and energy cost (LOTEC), based on the technique of Lyapunov optimization. LOTEC is a quantified near optimal solution and is able to make control decision on application offloading by adjusting the two-way tradeoff between average response time and average cost. We evaluate the performance of our proposed algorithm by a number of experiments. Rigorous analysis and simulations have demonstrated its performance. © 2017 IEEE.
AUTHOR KEYWORDS: fog computing; green energy; Internet of things; Lyapunov optimization
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Wei, W., Fan, X., Song, H., Fan, X., Yang, J.
57198566861;7403393808;57199094588;25627484600;25959803600;
Imperfect Information Dynamic Stackelberg Game Based Resource Allocation Using Hidden Markov for Cloud Computing
(2018) IEEE Transactions on Services Computing, 11 (1), art. no. 7422131, pp. 78-89. Cited 165 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85032339833&doi=10.1109%2fTSC.2016.2528246&partnerID=40&md5=e1f868ecb500785901720d72da9a21b3

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ABSTRACT: Existing static grid resource scheduling algorithms, which are limited to minimizing the makespan, cannot meet the needs of resource scheduling required by cloud computing. Current cloud infrastructure solutions provide operational support at the level of resource infrastructure only. When hardware resources form the virtual resource pool, virtual machines are deployed for use transparently. Considering the competing characteristics of multi-Tenant environments in cloud computing, this paper proposes a cloud resource allocation model based on an imperfect information Stackelberg game (CSAM-IISG) using a hidden Markov model (HMM) in a cloud computing environment. CSAM-IISG was shown to increase the profit of both the resource supplier and the applicant. Firstly, we used the HMM to predict the service provider's current bid using the historical resources based on demand. Through predicting the bid dynamically, an imperfect information Stackelberg game (IISG) was established. The IISG motivates service providers to choose the optimal bidding strategy according to the overall utility, achieving maximum profits. Based on the unit prices of different types of resources, a resource allocation model is proposed to guarantee optimal gains for the infrastructure supplier. The proposed resource allocation model can support synchronous allocation for both multi-service providers and various resources. The simulation results demonstrated that the predicted price was close to the actual transaction price, which was lower than the actual value in the game model. The proposed model was shown to increase the profits of service providers and infrastructure suppliers simultaneously. © 2008-2012 IEEE.
AUTHOR KEYWORDS: Cloud computing; game theory; hidden Markov model; resource allocation
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Chang, V., Ramachandran, M.
56926234700;8676632200;
Towards Achieving Data Security with the Cloud Computing Adoption Framework
(2016) IEEE Transactions on Services Computing, 9 (1), art. no. 7299312, pp. 138-151. Cited 159 times.

https://www.scopus.com/inward/record.uri?eid=2-s2.0-84962038954&doi=10.1109%2fTSC.2015.2491281&partnerID=40&md5=6915710310dfd584e34ddaeabf32a5cf

DOI: 10.1109/TSC.2015.2491281
AFFILIATIONS: School of Computing, Creative Technologies and Engineering, Leeds Beckett University, Headinely campus, Leeds, LS6 3QR, United Kingdom; Electronics and Computer Science, University of Southampton, Southampton, SO17 1BJ, United Kingdom
ABSTRACT: Offering real-time data security for petabytes of data is important for cloud computing. A recent survey on cloud security states that the security of users' data has the highest priority as well as concern. We believe this can only be able to achieve with an approach that is systematic, adoptable and well-structured. Therefore, this paper has developed a framework known as Cloud Computing Adoption Framework (CCAF) which has been customized for securing cloud data. This paper explains the overview, rationale and components in the CCAF to protect data security. CCAF is illustrated by the system design based on the requirements and the implementation demonstrated by the CCAF multi-layered security. Since our Data Center has 10 petabytes of data, there is a huge task to provide real-time protection and quarantine. We use Business Process Modeling Notation (BPMN) to simulate how data is in use. The use of BPMN simulation allows us to evaluate the chosen security performances before actual implementation. Results show that the time to take control of security breach can take between 50 and 125 hours. This means that additional security is required to ensure all data is well-protected in the crucial 125 hours. This paper has also demonstrated that CCAF multi-layered security can protect data in real-time and it has three layers of security: 1) firewall and access control; 2) identity management and intrusion prevention and 3) convergent encryption. To validate CCAF, this paper has undertaken two sets of ethical-hacking experiments involved with penetration testing with 10,000 trojans and viruses. The CCAF multi-layered security can block 9,919 viruses and trojans which can be destroyed in seconds and the remaining ones can be quarantined or isolated. The experiments show although the percentage of blocking can decrease for continuous injection of viruses and trojans, 97.43 percent of them can be quarantined. Our CCAF multi-layered security has an average of 20 percent better performance than the single-layered approach which could only block 7,438 viruses and trojans. CCAF can be more effective when combined with BPMN simulation to evaluate security process and penetrating testing results. © 2016 IEEE.
AUTHOR KEYWORDS: Business Process Modeling Notation (BPMN); Cloud Computing Adoption Framework (CCAF); Data security in the Data Center; multi-layered security protection; security framework
DOCUMENT TYPE: Article
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Li, J., Lin, X., Zhang, Y., Han, J.
26661714200;57196220298;7601317493;36449096100;
KSF-OABE: Outsourced Attribute-Based Encryption with Keyword Search Function for Cloud Storage
(2017) IEEE Transactions on Services Computing, 10 (5), art. no. 7434646, pp. 715-725. Cited 156 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85032285888&doi=10.1109%2fTSC.2016.2542813&partnerID=40&md5=05a3d02d75955931460298e96e3ab272

DOI: 10.1109/TSC.2016.2542813
AFFILIATIONS: College of Computer and Information, Hohai University, Nanjing, 211100, China;
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ABSTRACT: Cloud computing becomes increasingly popular for data owners to outsource their data to public cloud servers while allowing intended data users to retrieve these data stored in cloud. This kind of computing model brings challenges to the security and privacy of data stored in cloud. Attribute-based encryption (ABE) technology has been used to design fine-grained access control system, which provides one good method to solve the security issues in cloud setting. However, the computation cost and ciphertext size in most ABE schemes grow with the complexity of the access policy. Outsourced ABE (OABE) with fine-grained access control system can largely reduce the computation cost for users who want to access encrypted data stored in cloud by outsourcing the heavy computation to cloud service provider (CSP). However, as the amount of encrypted files stored in cloud is becoming very huge, which will hinder efficient query processing. To deal with above problem, we present a new cryptographic primitive called attribute-based encryption scheme with outsourcing key-issuing and outsourcing decryption, which can implement keyword search function (KSF-OABE). The proposed KSF-OABE scheme is proved secure against chosen-plaintext attack (CPA). CSP performs partial decryption task delegated by data user without knowing anything about the plaintext. Moreover, the CSP can perform encrypted keyword search without knowing anything about the keywords embedded in trapdoor. © 2017 IEEE.
AUTHOR KEYWORDS: Attribute-based encryption; cloud computing; keyword search; outsourced decryption; outsourced key-issuing
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SOURCE: Scopus

Li, J., Yao, W., Zhang, Y., Qian, H., Han, J.
26661714200;56879699200;7601317493;56032064100;36449096100;
Flexible and Fine-Grained Attribute-Based Data Storage in Cloud Computing
(2017) IEEE Transactions on Services Computing, 10 (5), art. no. 7390098, pp. 785-796. Cited 150 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85032255532&doi=10.1109%2fTSC.2016.2520932&partnerID=40&md5=cfa6365d38489cde104cb4144660abce

DOI: 10.1109/TSC.2016.2520932
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Jiangsu Provincial Key Laboratory of E-Business, Nanjing University of Finance and Economics, Nanjing, 210003, China
ABSTRACT: With the development of cloud computing, outsourcing data to cloud server attracts lots of attentions. To guarantee the security and achieve flexibly fine-grained file access control, attribute based encryption (ABE) was proposed and used in cloud storage system. However, user revocation is the primary issue in ABE schemes. In this article, we provide a ciphertext-policy attribute based encryption (CP-ABE) scheme with efficient user revocation for cloud storage system. The issue of user revocation can be solved efficiently by introducing the concept of user group. When any user leaves, the group manager will update users' private keys except for those who have been revoked. Additionally, CP-ABE scheme has heavy computation cost, as it grows linearly with the complexity for the access structure. To reduce the computation cost, we outsource high computation load to cloud service providers without leaking file content and secret keys. Notably, our scheme can withstand collusion attack performed by revoked users cooperating with existing users. We prove the security of our scheme under the divisible computation Diffie-Hellman assumption. The result of our experiment shows computation cost for local devices is relatively low and can be constant. Our scheme is suitable for resource constrained devices. © 2017 IEEE.
AUTHOR KEYWORDS: attribute-based encryption; Cloud computing; collusion attack; outsource decryption; user revocation
DOCUMENT TYPE: Article

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Al-Dhuraibi, Y., Paraiso, F., Djarallah, N., Merle, P.
57193484476;55368138900;26643950000;56240953000;
Elasticity in Cloud Computing: State of the Art and Research Challenges
(2018) IEEE Transactions on Services Computing, 11 (2), pp. 430-447. Cited 130 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85045377245&doi=10.1109%2fTSC.2017.2711009&partnerID=40&md5=1cc70c9e36479a0cd20b9b4c0d4d12bc

DOI: 10.1109/TSC.2017.2711009
AFFILIATIONS: Scalair Company, Hem, 59510, France;
Lille - Nord Europe Villeneuve D'Ascq, Inria, 59650, France
ABSTRACT: Elasticity is a fundamental property in cloud computing that has recently witnessed major developments. This article reviews both classical and recent elasticity solutions and provides an overview of containerization, a new technological trend in lightweight virtualization. It also discusses major issues and research challenges related to elasticity in cloud computing. We comprehensively review and analyze the proposals developed in this field. We provide a taxonomy of elasticity mechanisms according to the identified works and key properties. Compared to other works in literature, this article presents a broader and detailed analysis of elasticity approaches and is considered as the first survey addressing the elasticity of containers. © 2018 IEEE.
AUTHOR KEYWORDS: auto-scaling; cloud computing; containers; Elasticity; resource provision; scalability
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Sarkar, S., Chatterjee, S., Misra, S.
7403239199;56148870800;7401768547;
Assessment of the Suitability of Fog Computing in the Context of Internet of Things
(2018) IEEE Transactions on Cloud Computing, 6 (1), pp. 46-59. Cited 264 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85036660454&doi=10.1109%2fTCC.2015.2485206&partnerID=40&md5=6190c830e7ce3766095de773d4c540e9

DOI: 10.1109/TCC.2015.2485206
AFFILIATIONS: School of Information Technology, School of Medical Science and Technology, Indian Institute of Technology, Kharagpur, 721302, India; School of Information Technology, Indian Institute of Technology, Kharagpur, 721302, India
ABSTRACT: This work performs a rigorous, comparative analysis of the fog computing paradigm and the conventional cloud computing paradigm in the context of the Internet of Things (IoT), by mathematically formulating the parameters and characteristics of fog computing - one of the first attempts of its kind. With the rapid increase in the number of Internet-connected devices, the increased demand of real-time, low-latency services is proving to be challenging for the traditional cloud computing framework. Also, our irreplaceable dependency on cloud computing demands the cloud data centers (DCs) always to be up and running which exhausts huge amount of power and yield tons of carbon dioxide (CO2) gas. In this work, we assess the applicability of the newly proposed fog computing paradigm to serve the demands of the latency-sensitive applications in the context of IoT. We model the fog computing paradigm by mathematically characterizing the fog computing network in terms of power consumption, service latency, CO2 emission, and cost, and evaluating its performance for an environment with high number of Internet-connected devices demanding real-time service. A case study is performed with traffic generated from the 100 highest populated cities being served by eight geographically distributed DCs. Results show that as the number of applications demanding real-time service increases, the fog computing paradigm outperforms traditional cloud computing. For an environment with 50 percent applications requesting for instantaneous, real-time services, the overall service latency for fog computing is noted to decrease by 50.09 percent. However, it is mentionworthy that for an environment with less percentage of applications demanding for low-latency services, fog computing is observed to be an overhead compared to the traditional cloud computing. Therefore, the work shows that in the context of IoT, with high number of latency-sensitive applications fog computing outperforms cloud computing. © 2013 IEEE.
AUTHOR KEYWORDS: Carbon-dioxide emission; Cloud computing; Fog computing; Internet of things (IoT); Power consumption; Service latency
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SOURCE: Scopus

Shojafar, M., Cordeschi, N., Baccarelli, E.
26436114300;8552714800;7006549462;
Energy-Efficient Adaptive Resource Management for Real-Time Vehicular Cloud Services
(2019) IEEE Transactions on Cloud Computing, 7 (1), art. no. 7448886, pp. 196-209. Cited 236 times.

https://www.scopus.com/inward/record.uri?eid=2-s2.0-85057957993&doi=10.1109%2fTCC.2016.2551747&partnerID=40&md5=7db0d1f630386e57a2c1e6a944f6b5aa

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ABSTRACT: Providing real-time cloud services to Vehicular Clients (VCs) must cope with delay and delay-jitter issues. Fog computing is an emerging paradigm that aims at distributing small-size self-powered data centers (e.g., Fog nodes) between remote Clouds and VCs, in order to deliver data-dissemination real-time services to the connected VCs. Motivated by these considerations, in this paper, we propose and test an energy-efficient adaptive resource scheduler for Networked Fog Centers (NetFCs). They operate at the edge of the vehicular network and are connected to the served VCs through Infrastructure-to-Vehicular (I2V) TCP/IP-based single-hop mobile links. The goal is to exploit the locally measured states of the TCP/IP connections, in order to maximize the overall communication-plus-computing energy efficiency, while meeting the application-induced hard QoS requirements on the minimum transmission rates, maximum delays and delay-jitters. The resulting energy-efficient scheduler jointly performs: (i) admission control of the input traffic to be processed by the NetFCs; (ii) minimum-energy dispatching of the admitted traffic; (iii) adaptive reconfiguration and consolidation of the Virtual Machines (VMs) hosted by the NetFCs; and, (iv) adaptive control of the traffic injected into the TCP/IP mobile connections. The salient features of the proposed scheduler are that: (i) it is adaptive and admits distributed and scalable implementation; and, (ii) it is capable to provide hard QoS guarantees, in terms of minimum/maximum instantaneous rates of the traffic delivered to the vehicular clients, instantaneous rate-jitters and total processing delays. Actual performance of the proposed scheduler in the presence of: (i) client mobility; (ii) wireless fading; and, (iii) reconfiguration and consolidation costs of the underlying NetFCs, is numerically tested and compared against the corresponding ones of some state-of-the-art schedulers, under both synthetically generated and measured real-world workload traces. © 2013 IEEE.
AUTHOR KEYWORDS: adaptive resource management; cognitive computing; energy-efficiency; TCP/IP-based vehicular cloud computing; virtualized fog centers
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Pahl, C., Brogi, A., Soldani, J., Jamshidi, P.
55049859200;57193752782;56203938200;34880055700;
Cloud container technologies: A state-of-the-art review
(2019) IEEE Transactions on Cloud Computing, 7 (3), art. no. 2702586, pp. 677-692. Cited 128 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85050374433&doi=10.1109%2fTCC.2017.2702586&partnerID=40&md5=ba46e14ad12f81852ca97648461e4504

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AFFILIATIONS: Faculty of Computer Science, Free University of Bozen-Bolzano, Bolzano, 39100, Italy;
Department of Computer Science, University of Pisa, Pisa, 56126, Italy;
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ABSTRACT: —Containers as a lightweight technology to virtualise applications have recently been successful, particularly to manage applications in the cloud. Often, the management of clusters of containers becomes essential and the orchestration of the construction and deployment becomes a central problem. This emerging topic has been taken up by researchers, but there is currently no secondary study to consolidate this research. We aim to

identify, taxonomically classify and systematically compare the existing research body on containers and their orchestration and specifically the application of this technology in the cloud. We have conducted a systematic mapping study of 46 selected studies. We classified and compared the selected studies based on a characterisation framework. This results in a discussion of agreed and emerging concerns in the container orchestration space, positioning it within the cloud context, but also moving it closer to current concerns in cloud platforms, microservices and continuous development. © 2017 IEEE. Personal use is permitted, but republication/redistribution requires IEEE permission.
AUTHOR KEYWORDS: Cluster; Container; Container technologies; Index Terms—Cloud; Orchestration; Systematic review
DOCUMENT TYPE: Article
PUBLICATION STAGE: Final
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Xu, X., Dou, W., Zhang, X., Chen, J.
55706201200;7006874536;35148680700;16506246700;
EnReal: An Energy-Aware Resource Allocation Method for Scientific Workflow Executions in Cloud Environment
(2016) IEEE Transactions on Cloud Computing, 4 (2), art. no. 7276993, pp. 166-179. Cited 102 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84976588157&doi=10.1109%2fTCC.2015.2453966&partnerID=40&md5=08980cc191d10bca2dc09ef67c1074b4

DOI: 10.1109/TCC.2015.2453966
AFFILIATIONS: State Key Laboratory for Novel Software Technology, Department of Computer Science and Technology, Nanjing University, Nanjing, 210023, China;
Machine Learning Research Group, NICTA Victoria, Melbourne, VIC, Australia;
Faculty of Engineering and Information Technology, University of Technology, Sydney, P O Box 123, Broadway, NSW 2007, Australia
ABSTRACT: Scientific workflows are often deployed across multiple cloud computing platforms due to their large-scale characteristic. This can be technically achieved by expanding a cloud platform. However, it is still a challenge to conduct scientific workflow executions in an energy-aware fashion across cloud platforms or even inside a cloud platform, since the cloud platform expansion will make the energy consumption a big concern. In this paper, we propose an Energy-aware Resource Allocation method, named EnReal, to address the above challenge. Basically, we leverage the dynamic deployment of virtual machines for scientific workflow executions. Specifically, an energy consumption model is presented for applications deployed across cloud computing platforms, and a corresponding energy-aware resource allocation algorithm is proposed for virtual machine scheduling to accomplish scientific workflow executions. Experimental evaluation demonstrates that the proposed method is both effective and efficient. © 2013 IEEE.
AUTHOR KEYWORDS: cloud computing; Energy-aware method; resource allocation; scientific workflow
DOCUMENT TYPE: Article
PUBLICATION STAGE: Final
SOURCE: Scopus

Wang, K., Yang, K., Magurawalage, C.S.
55597457500;35214178400;57190579634;
Joint Energy Minimization and Resource Allocation in C-RAN with Mobile Cloud
(2018) IEEE Transactions on Cloud Computing, 6 (3), art. no. 7393804, pp. 760-770. Cited 91 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85053005814&doi=10.1109%2fTCC.2016.2522439&partnerID=40&md5=3d3c88a3272509d475913b9997592c69

DOI: 10.1109/TCC.2016.2522439
AFFILIATIONS: School of Computer Sciences and Electrical Engineering, University of Essex, Colchester, CO3 4HG, United Kingdom
ABSTRACT: Cloud radio access network (C-RAN) has emerged as a potential candidate of the next generation access network technology to address the increasing mobile traffic, while mobile cloud computing (MCC) offers a prospective solution to the resource-limited mobile user in executing computation intensive tasks. Taking full advantages of above two cloud-based techniques, C-RAN with MCC are presented in this paper to enhance both performance and energy efficiencies. In particular, this paper studies the joint energy minimization and resource allocation in C-RAN with MCC under the time constraints of the given tasks. We first review the energy and time model of the computation and communication. Then, we formulate the joint energy minimization into a non-convex optimization with the constraints of task executing time, transmitting power, computation capacity and fronthaul data rates. This non-convex optimization is then reformulated into an equivalent convex problem based on weighted minimum mean square error (WMMSE). The iterative algorithm is finally given to deal with the joint resource allocation in C-RAN with mobile cloud. Simulation results confirm that the proposed energy minimization and resource allocation solution can improve the system performance and save energy. © 2013 IEEE.
AUTHOR KEYWORDS: C-RAN; joint energy minimization; mobile cloud computing; resource allocation
DOCUMENT TYPE: Article
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Source: Journal of Systems and Software

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Mao, K., Capra, L., Harman, M., Jia, Y.
57188561866;7003753918;7006379048;25822621600;
A survey of the use of crowdsourcing in software engineering
(2017) Journal of Systems and Software, 126, pp. 57-84. Cited 168 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84995569607&doi=10.1016%2fj.jss.2016.09.015&partnerID=40&md5=6afcf90b7efddb88a3b8359f254d2a3f

DOI: 10.1016/j.jss.2016.09.015
AFFILIATIONS: Department of Computer Science, University College London, Malet Place, London, WC1E 6BT, United Kingdom
ABSTRACT: The term 'crowdsourcing' was initially introduced in 2006 to describe an emerging distributed problem-solving model by online workers. Since then it has been widely studied and practiced to support software engineering. In this paper we provide a comprehensive survey of the use of crowdsourcing in software engineering, seeking to cover all literature on this topic. We first review the definitions of crowdsourcing and derive our definition of Crowdsourcing Software Engineering together with its taxonomy. Then we summarise industrial crowdsourcing practice in software engineering and corresponding case studies. We further analyse the software engineering domains, tasks and applications for crowdsourcing and the platforms and stakeholders involved in realising Crowdsourced Software Engineering solutions. We conclude by exposing trends, open issues and opportunities for future research on Crowdsourced Software Engineering. © 2016
AUTHOR KEYWORDS: Crowdsourced software engineering; Crowdsourcing; Literature survey; Software crowdsourcing
DOCUMENT TYPE: Article
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Keshanchi, B., Souri, A., Navimipour, N.J.
57189383744;56901126500;55897274300;
An improved genetic algorithm for task scheduling in the cloud environments using the priority queues: Formal verification, simulation, and statistical testing
(2017) Journal of Systems and Software, 124, pp. 1-21. Cited 168 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84994005147&doi=10.1016%2fj.jss.2016.07.006&partnerID=40&md5=10b2ce0fd6a0978dff7932f9205a4132

DOI: 10.1016/j.jss.2016.07.006
AFFILIATIONS: Young Researchers and Elite Club, Tabriz Branch, Islamic Azad University, Tabriz, Iran;
Department of Computer Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran
ABSTRACT: Cloud computing is a new platform to manage and provide services on the internet. Lately, researchers have paid attention a lot to this new subject. One of the reasons to have high performance in a cloud environment is the task scheduling. Since the task scheduling is an NP-Complete problem, in many cases, meta-heuristics scheduling algorithms are used. In this paper to optimize the task scheduling solutions, a powerful and improved genetic algorithm is proposed. The proposed algorithm uses the advantages of evolutionary genetic algorithm along with heuristic approaches. For analyzing the correctness of the proposed algorithm, we have presented a behavioral modeling approach based on model checking techniques. Then, the expected specifications of the proposed algorithm is extracted in the form of Linear Temporal Logic (LTL) formulas. To achieve the best performance in

verification of the proposed algorithm, we use the Labeled Transition System (LTS) method. Also, the proposed behavioral models are verified using NuSMV and PAT model checkers. Then, the correctness of the proposed algorithm is analyzed according to the verification results in terms of some expected specifications, reachability, fairness, and deadlock-free. The simulation and statistical results revealed that the proposed algorithm outperformed the makespans of the three well-known heuristic algorithms and also the execution time of our recently meta-heuristics algorithm. © 2016 Elsevier Inc.
AUTHOR KEYWORDS: Cloud computing; Directed acyclic graph; Formal verification; Genetic algorithm; Model checking; Task scheduling
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SOURCE: Scopus

Manikas, K.
6506359449;
Revisiting software ecosystems Research: A longitudinal literature study
(2016) Journal of Systems and Software, 117, pp. 84-103. Cited 125 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84960154891&doi=10.1016%2fj.jss.2016.02.003&partnerID=40&md5=8114cbaff593456b53c3c4d8a1d911b8

DOI: 10.1016/j.jss.2016.02.003
AFFILIATIONS: Department of Computer Science, University of Copenhagen, Denmark
ABSTRACT: 'Software ecosystems' is argued to first appear as a concept more than 10 years ago and software ecosystem research started to take off in 2010. We conduct a systematic literature study, based on the most extensive literature review in the field up to date, with two primarily aims: (a) to provide an updated overview of the field and (b) to document evolution in the field. In total, we analyze 231 papers from 2007 until 2014 and provide an overview of the research in software ecosystems. Our analysis reveals a field that is rapidly growing, both in volume and empirical focus, while becoming more mature. We identify signs of field maturity from the increase in: (i) the number of journal articles, (ii) the empirical models within the last two years, and (iii) the number of ecosystems studied. However, we note that the field is far from mature and identify a set of challenges that are preventing the field from evolving. We propose means for future research and the community to address them. Finally, our analysis shapes the view of the field having evolved outside the existing definitions of software ecosystems and thus propose the update of the definition of software ecosystems. © 2016 Elsevier Inc. All right sreserved.
AUTHOR KEYWORDS: Longitudinal literature study; Software ecosystem maturity; Software ecosystems
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Soldani, J., Tamburri, D.A., Van Den Heuvel, W.-J.
56203938200;35488974800;7005472245;
The pains and gains of microservices: A Systematic grey literature review
(2018) Journal of Systems and Software, 146, pp. 215-232. Cited 106 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85054175054&doi=10.1016%2fj.jss.2018.09.082&partnerID=40&md5=fa91692f126bd35cc53bca9866c6583f

DOI: 10.1016/j.jss.2018.09.082
AFFILIATIONS: Dipartimento di Informatica, Universitá di Pisa, Pisa, Italy; Jheronimus Academy of Data Science, TU/e, Universiteit van TilburgNL, Netherlands
ABSTRACT: The design, development, and operation of microservices are picking up more and more momentum in the IT industry. At the same time, academic work

on the topic is at an early stage, and still on the way to distilling the actual "Pains & Gains" of microservices as an architectural style. Having witnessed this gap, we set forth to systematically analyze the industrial grey literature on microservices, to identify the technical/operational pains and gains of the microservice-based architectural style. We conclude by discussing research directions stemming out from our analysis. © 2018 Elsevier Inc.
AUTHOR KEYWORDS: Microservices; Microservices design; Microservices development; Microservices operation; Systematic grey literature review; Systematic literature review
DOCUMENT TYPE: Article
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Rodríguez, P., Haghighatkhah, A., Lwakatare, L.E., Teppola, S., Suomalainen, T., Eskeli, J., Karvonen, T., Kuvaja, P., Verner, J.M., Oivo, M.
56063740800;56319178400;56728797500;6507996183;30567825000;25924804000;56843496200;56202183100;56217137100;6603040928;
Continuous deployment of software intensive products and services: A systematic mapping study
(2017) Journal of Systems and Software, 123, pp. 263-291. Cited 95 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84957818901&doi=10.1016%2fj.jss.2015.12.015&partnerID=40&md5=d1237921af6321ad5318118207a87143

DOI: 10.1016/j.jss.2015.12.015
AFFILIATIONS: Department of Information Processing Sciences, 90014 University of Oulu, Box 3000, Finland;
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ABSTRACT: The software intensive industry is moving towards the adoption of a value-driven and adaptive real-time business paradigm. The traditional view of software as an item that evolves through releases every few months is being replaced by the continuous evolution of software functionality. This study aims to classify and analyse the literature related to continuous deployment in the software domain in order to scope the phenomenon, provide an overview of the state-of-the-art, investigate the scientific evidence in the reported results and identify areas suitable for further research. We conducted a systematic mapping study and classified the continuous deployment literature. The benefits and challenges related to continuous deployment were also analysed. RESULTS: The systematic mapping study includes 50 primary studies published between 2001 and 2014. An in-depth analysis of the primary studies revealed ten recurrent themes that characterize continuous deployment and provide researchers with directions for future work. In addition, a set of benefits and challenges of which practitioners may take advantage were identified. CONCLUSION: Overall, although the topic area is very promising, it is still in its infancy, thus offering a plethora of new opportunities for both researchers and software intensive companies. © 2016 Elsevier Inc.
AUTHOR KEYWORDS: Continuous deployment; Software development; Systematic mapping study
DOCUMENT TYPE: Article
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Singh, P., Gupta, P., Jyoti, K., Nayyar, A.
57210392587;57221036106;56872785800;55201442200;
Research on auto-scaling of web applications in cloud: Survey, trends and future directions
(2019) Scalable Computing, 20 (2), pp. 399-432. Cited 29 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85065506118&doi=10.12694%2fscpe.v20i2.1537&partnerID=40&md5=584141c4a94c33978a0992dc5a027d18

DOI: 10.12694/scpe.v20i2.1537
AFFILIATIONS: Lovely Professional University, India;
Guru Nanak Dev Engineering College, India;
Duy Tan University, Da Nang, Viet Nam
ABSTRACT: Cloud computing emerging environment attracts many applications providers to deploy web applications on cloud data centers. The primary area of attraction is elasticity, which allows to auto-scale the resources on-demand. However, web applications usually have dynamic workload and hard to predict. Cloud service providers and researchers are working to reduce the cost while maintaining the Quality of Service (QoS). One of the key challenges for web application in cloud computing is autoscaling. The auto-scaling in cloud computing is still in infancy and required detail investigation of taxonomy, approach and types of resources mapped to the current research. In this article, we presented the literature survey for auto-scaling techniques of web applications in cloud computing. This survey supports the research community to find the requirements in auto-scaling techniques. We present a taxonomy of reviewed articles with parameters such as auto-scaling techniques, approach, resources, monitoring tool, experiment, workload, and metric, etc. Based on the analysis, we proposed the new areas of research in this direction. © 2019 SCPE.
AUTHOR KEYWORDS: Auto scaling; Cloud computing; Resource estimation; Resource provisioning; Web applications

Singh, S.P., Nayyar, A., Kaur, H., Singla, A.
56647808100;55201442200;57202540714;57208668557;
Dynamic task scheduling using balanced VM allocation policy for fog computing platforms
(2019) Scalable Computing, 20 (2), pp. 433-457. Cited 24 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85065505357&doi=10.12694%2fscpe.v20i2.1538&partnerID=40&md5=bc97c1431378fbaa7ddc953053891518

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AFFILIATIONS: Computer Science and Engineering Department, Thapar Institute of Engineering and Technology, Patiala, India;
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Computer Science and Engineering Department, Chandigarh University, Mohali, Punjab, India;
Computer Science and Engineering Department, Sant Longowal Institute of Engineering and Technology, Longowal, Punjab, India
ABSTRACT: The fog computing models are getting popular as the demand and capacity of data processing is rising for the various applications every year. The fog computing models incorporate the various task scheduling algorithms for the resource selection among the given list of virtual

machines (VMs). The task scheduling models are designed around the various task metrics, which include the task length (time), energy, processing cost etc. for the various purposes. The cost oriented scheduling models are primarily built for the customer's perspectives, and saves them a handful amount of money by efficiently assigning the resources for the tasks. In this paper, we have worked upon the multiple task scheduling models based upon the Local Regression (LR), Inter Quartile Range (IQR), Local Regression Robust (LRR), Non-Power Aware (NPA), Median Absolute Deviation (MAD), Dynamic Voltage and Frequency Scheduling (DVFS) and The Static Threshold (THR) methods using the ifogsim simulation designed with the 50 nodes and 50 virtual machines, i.e. 1 virtual machine per node. All of the models have been implemented using the standard input simulation parameters for the purpose of performance assessment in the various domains, specifically in the time domain and effective consumption of energy. The results obtained from the experiments have shown the overall time of 86,400 seconds during the simulation, where the DVFS has been recorded with the 52.98 kWh consumption of energy, which shows the efficient processing in comparison to the 150.68 kWh of energy consumption in the NPA model. Also, there are no SLA violations recorded during both of the simulation, because no VM migration model has been utilized among both of the implemented models, which clearly shows that the VM migrations are the major cause of SLA violation cases. The LRR (2520 VMs) has been observed as best contender on the basis of mean of number of VM migrations in comparison with LR (2555 VMs), THR (4769 VMs), MAD (5138 VMs) and IQR (5352 VMs). © 2019 SCPE.
AUTHOR KEYWORDS: Fog computing; Ifogsim simulator; Task scheduling; VM allocation; VM selection

Kaur, A., Gupta, P., Singh, M., Nayyar, A.
56517666100;57221036106;57224793813;55201442200;
Data placement in era of cloud computing: A survey, taxonomy and open research issues
(2019) Scalable Computing, 20 (2), pp. 377-398. Cited 24 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85065491134&doi=10.12694%2fscpe.v20i2.1530&partnerID=40&md5=5f42a865c9a509400f0d36b0dafc49b8

DOI: 10.12694/scpe.v20i2.1530
AFFILIATIONS: Lovely Professional University, Phagwara, India;
Guru Nanak Dev Engineering College, Ludhiana, India;
Graduate School, Duy Tan University, Da Nang, Viet Nam
ABSTRACT: In cloud computing, data placement is a critical operation performed as part of workflow management and aims to find the best physical machine to place the data. It has direct impact on performance, cost and execution time of workflows. Number of data placement algorithms is designed in cloud computing environment that aimed to improve various factors affecting the workflows and their execution including the movement of data among data centers. This paper provides a complete survey and analyses of existing data placement schemes proposed in literature for cloud computing. Further, it classifies data placement schemes based on their assess capabilities and objectives. Further objectives and properties of data placement schemes are compared. Finally future research directions are provided with concluding remarks. © 2019 SCPE.
AUTHOR KEYWORDS: Cloud computing; Data placement; Replication; Workflow

Prasad, V.K., Bhavsar, M., Tanwar, S.
57196721184;37010697800;56576145100;
Influence of montoring: Fog and edge computing
(2019) Scalable Computing, 20 (2), pp. 365-376. Cited 22 times.

https://www.scopus.com/inward/record.uri?eid=2-s2.0-85065478353&doi=10.12694%2fscpe.v20i2.1533&partnerID=40&md5=cf106721dd999e781edf1d1e4253ca65

DOI: 10.12694/scpe.v20i2.1533
AFFILIATIONS: CSE Department, Nirma University, Ahmedabad, Gujarat, India
ABSTRACT: The evolution of the Internet of Things (IoT) has augmented the necessity for Cloud, edge and fog platforms. The chief benefit of cloud-based schemes is they allow data to be collected from numerous service and sites, which is reachable from any place of the world. The organizations will be benefited by merging the cloud platform with the on-site fog networks and edge devices and as result, this will increase the utilization of the IoT devices and end users too. The network traffic will reduce as data will be distributed and this will also improve the operational efficiency. The impact of monitoring in edge and fog computing can play an important role to efficiently utilize the resources available at these layers. This paper discusses various techniques involved for monitoring for edge and fog computing and its advantages. The paper ends with a case study to demonstarte the need of monitoring in fog and edge in the healthcare system. © 2019 SCPE.
AUTHOR KEYWORDS: Cloud computing; Edge compuitng; Fog computing; IoT; Monitoring

Sai, K.B.K., Ramasubbareddy, S., Luhach, A.K.
57213821404;57201195237;56905448400;
IOT based air quality monitoring system using MQ135 and MQ7 with machine learning analysis
(2019) Scalable Computing, 20 (4), pp. 599-606. Cited 16 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85078057254&doi=10.12694%2fscpe.v20i4.1561&partnerID=40&md5=b0e88bf8606dc7b1f82060a1ed90e6f6

DOI: 10.12694/scpe.v20i4.1561
AFFILIATIONS: School of Computer Science and Engineering (SCOPE), VIT University, Vellore, India;
Information Technology, VNRVJIET, Hyderabad, India;
Department of Electrical and Communication Engineering, The PNG University of Technology, Papua New Guinea
ABSTRACT: This paper deals with measuring the Air Quality using MQ135 sensor along with Carbon Monoxide CO using MQ7 sensor. Measuring Air Quality is an important element for bringing awareness to take care of the future generations and for a healthier life. Based on this, Government of India has already taken certain measures to ban Single Stroke and Two Stroke Engine based motorcycles which are emitting high pollution. We are trying to implement a system using IoT platforms like Thingspeak or Cayenne in order to bring awareness to every individual about the harm we are doing to our environment. Already, New Delhi is remarked as the most pollution city in the world recording Air Quality above 300 PPM. We have used easiest platform like Thingspeak and set the dashboard to public such that everyone can come to know the Air Quality at the location where the system is installed. Machine Learning analysis brings us a lot of depth in understanding the information that we obtained from the data. Moreover, we are proviing a reducement of the cost of components versus the state of the art. © 2019 SCPE.
AUTHOR KEYWORDS: IoT; Machine learning; MQ135; MQ7; Thingspeak

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Pahl, C., Jamshidi, P.
55049859200;34880055700;
Microservices: A systematic mapping study
(2016) CLOSER 2016 - Proceedings of the 6th International Conference on Cloud Computing and Services Science, 1, pp. 137-146. Cited 133 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84979776387&doi=10.5220%2f0005785501370146&partnerID=40&md5=94816e1cdc3499c59e0ca0d8fce25ab4

DOI: 10.5220/0005785501370146
AFFILIATIONS: Faculty of Computer Science, Free University of Bozen-Bolzano, Bolzano, Italy;
Department of Computing, Imperial College London, London, United Kingdom
ABSTRACT: Microservices have recently emerged as an architectural style, addressing how to build, manage, and evolve architectures out of small, self-contained units. Particularly in the cloud, the microservices architecture approach seems to be an ideal complementation of container technology at the PaaS level However, there is currently no secondary study to consolidate this research. We aim here to identify, taxonomically classify and systematically compare the existing research body on microservices and their application in the cloud. We have conducted a systematic mapping study of 21 selected studies, published over the last two years until end of 2015 since the emergence of the microservices pattern. We classified and compared the selected studies based on a characterization framework. This results in a discussion of the agreed and emerging concerns within the microservices architectural style, positioning it within a continuous development context, but also moving it closer to cloud and container technology. Copyright © 2016 by SCITEPRESS-Science and Technology Publications, Lda. All rights reserved.
AUTHOR KEYWORDS: Cloud; Container; Mircoservices; Systematic Literature Review; Systematic Mapping Study
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Taibi, D., Lenarduzzi, V., Pahl, C.
55920884000;55348964400;55049859200;
Architectural patterns for microservices: A systematic mapping study
(2018) CLOSER 2018 - Proceedings of the 8th International Conference on Cloud Computing and Services Science, 2018-January, pp. 221-232. Cited 71 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85046716130&doi=10.5220%2f0006798302210232&partnerID=40&md5=367c93b2917946291fc45ebbdbcf270f

DOI: 10.5220/0006798302210232
AFFILIATIONS: Tampere University of Technology, Tampere, Finland;
Free University of Bozen-Bolzano, Bozen-Bolzano, Italy
ABSTRACT: Microservices is an architectural style increasing in popularity. However, there is still a lack of understanding how to adopt a microservice-based architectural style. We aim at characterizing different microservice architectural style patterns and the principles that guide their definition. We conducted a systematic mapping study in order to identify reported usage of microservices and based on these use cases extract common patterns and principles. We present two key contributions. Firstly, we identified several agreed microservice architecture patterns that seem widely adopted and reported in the case studies identified. Secondly, we presented these as a catalogue in a common template format including a summary of the advantages,

disadvantages, and lessons learned for each pattern from the case studies. We can conclude that different architecture patterns emerge for different migration, orchestration, storage and deployment settings for a set of agreed principles. © 2018 by SCITEPRESS - Science and Technology Publications, Lda. All rights reserved.
AUTHOR KEYWORDS: Architectural style; Architecture pattern; Cloud migration; Cloud native; DevOps; Microservices
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Brogi, A., Forti, S., Ibrahim, A.
57193752782;57195946378;57196263219;
Deploying fog applications: How much does it cost, by the way?
(2018) CLOSER 2018 - Proceedings of the 8th International Conference on Cloud Computing and Services Science, 2018-January, pp. 68-77. Cited 26 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85048885881&doi=10.5220%2f0006676100680077&partnerID=40&md5=eaf42d70321b17248ef73031297a5aca

DOI: 10.5220/0006676100680077
AFFILIATIONS: Department of Computer Science, University of Pisa, Italy
ABSTRACT: Deploying IoT applications through the Fog in a QoS-, context-, and cost-aware manner is challenging due to the heterogeneity, scale and dynamicity of Fog infrastructures. To decide how to allocate app functionalities over the continuum from the IoT to the Cloud, app administrators need to find a trade-off among QoS, resource consumption and cost. In this paper, we present a novel cost model for estimating the cost of deploying IoT applications to Fog infrastructures. We show how the inclusion of the cost model in the FogTorchΠ open-source prototype permits to determine eligible deployments of multi-component applications to Fog infrastructures and to rank them according to their QoS-assurance, Fog resource consumption and cost. We run the extended prototype on a motivating scenario, showing how it can support IT experts in choosing the deployments that best suit their desiderata. Copyright © 2018 by SCITEPRESS - Science and Technology Publications, Lda. All rights reserved.
AUTHOR KEYWORDS: Application deployment; Cost models; Fog computing; QoS; Resource consumption
DOCUMENT TYPE: Conference Paper
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SOURCE: Scopus

Lynn, T., Xiong, H., Dong, D., Momani, B., Gravvanis, G., Filelis-Papadopoulos, C., Elster, A., Khan, M.M.Z.M., Tzovaras, D., Giannoutakis, K., Petcu, D., Neagul, M., Dragon, I., Kuppudayar, P., Natarajan, S., McGrath, M., Gaydadjiev, G., Becker, T., Gourinovitch, A., Kenny, D., Morrison, J.
25825321500;36643048100;55816473000;35173366200;6701830580;38361378700;14021342800;57190403952;13105681700;7801499126;6603604868;35148079900;57190400722;57190400038;57190407407;24776464500;6603055485;24469651300;57217876292;26426302600;35311536400;
CLOUDLIGHTNING: A framework for a self-organising and self-managing heterogeneous cloud
(2016) CLOSER 2016 - Proceedings of the 6th International Conference on Cloud Computing and Services Science, 1, pp. 333-338. Cited 25 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84979752358&doi=10.5220%2f0005921503330338&partnerID=40&md5=a8de74dd451ff322bd0db99deede37a4

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AFFILIATIONS: Irish Centre for Cloud Computing and Commerce, DCU, Dublin, Ireland;
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Centre for Research and Technology, Hellas, Thessaloniki, Greece;
Institute E-Austria Timisoara and West University of Timisoara, Timisoara, Romania;
Intel, Leixlip, Ireland;
Maxeler, London, United Kingdom
ABSTRACT: As clouds increase in size and as machines of different types are added to the infrastructure in order to maximize performance and power efficiency, heterogeneous clouds are being created. However, exploiting different architectures poses significant challenges. To efficiently access heterogeneous resources and, at the same time, to exploit these resources to reduce application development effort, to make optimisations easier and to simplify service deployment, requires a re-evaluation of our approach to service delivery. We propose a novel cloud management and delivery architecture based on the principles of self-organisation and self-management that shifts the deployment and optimisation effort from the consumer to the software stack running on the cloud infrastructure. Our goal is to address inefficient use of resources and consequently to deliver savings to the cloud provider and consumer in terms of reduced power consumption and improved service delivery, with hyperscale systems particularly in mind. The framework is general but also endeavours to enable cloud services for high performance computing. Infrastructure-as-a-Service provision is the primary use case, however, we posit that genomics, oil and gas exploration, and ray tracing are three downstream use cases that will benefit from the proposed architecture.

AUTHOR KEYWORDS: Cloud Architecture; Cloud Computing; Cloud Computing Models; Cloud Infrastructures; Cloud Orchestration; Cloud Services Self-organisation; Data Flow Engine; DFE; FPGA; GPU; Heterogeneous Resources; Many-integrated Cores; MIC; Resource as a Service; Self-management
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Byrne, J., Svorobej, S., Giannoutakis, K.M., Tzovaras, D., Byrne, P.J., Östberg, P.-O., Gourinovitch, A., Lynn, T.
34869266100;56736898300;7801499126;13105681700;35365897500;24385207800;57217876292;25825321500;
A review of cloud computing simulation platforms & related environments
(2017) CLOSER 2017 - Proceedings of the 7th International Conference on Cloud Computing and Services Science, pp. 651-663. Cited 22 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85025167176&partnerID=40&md5=be2a67bca711cfb249173dc80e2cfd1d

AFFILIATIONS: Irish Centre for Cloud Computing and Commerce, Dublin City University, Glasnevin, Dublin 9, Ireland;
Centre for Research and Technology Hellas, Information Technologies Institute, 6th km Xarilaou-Thermi, Thessaloniki, 57001, Greece;
Dept. Computing Science and HPC2N, Umeå University, Umea, SE-901 87, Sweden
ABSTRACT: Recent years have seen an increasing trend towards the development of Discrete Event Simulation (DES) platforms to support cloud computing related decision making and research. The complexity of cloud environments is increasing with scale and heterogeneity posing a challenge for the efficient management of cloud applications and data centre resources. The increasing ubiquity of social media, mobile and cloud computing combined with the Internet of Things and emerging paradigms such as Edge and Fog Computing is exacerbating this complexity. Given the scale, complexity and commercial sensitivity of hyperscale computing environments, the opportunity for experimentation is limited and requires substantial investment of resources both in terms of time and effort. DES provides a low risk technique for providing decision support for complex hyperscale computing scenarios. In

recent years, there has been a significant increase in the development and extension of tools to support DES for cloud computing resulting in a wide range of tools which vary in terms of their utility and features. Through a review and analysis of available literature, this paper provides an overview and multi-level feature analysis of 33 DES tools for cloud computing environments. This review updates and extends existing reviews to include not only autonomous simulation platforms, but also on plugins and extensions for specific cloud computing use cases. This review identifies the emergence of CloudSim as a de facto base platform for simulation research and shows a lack of tool support for distributed execution (parallel execution on distributed memory systems).
AUTHOR KEYWORDS: Cloud computing; Cloud simulation tools; Data centre; Fog computing
DOCUMENT TYPE: Conference Paper
PUBLICATION STAGE: Final
SOURCE: Scopus

IET Communications

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Jeong, S., Simeone, O., Kang, J.
55210226900;23993347300;7404517651;
Mobile cloud computing with a UAV-mounted cloudlet: Optimal bit allocation for communication and computation
(2017) IET Communications, 11 (7), pp. 969-974. Cited 42 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85019926716&doi=10.1049%2fiet-com.2016.1114&partnerID=40&md5=d50772703b9e0eb7464fd5446e88eea7

DOI: 10.1049/iet-com.2016.1114
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Department of Electrical Engineering, Korea Advanced Institute of Science and Technology (KAIST), 291, Daehak-ro, Yuseong-gu, Daejeon, 34141, South Korea
ABSTRACT: Mobile cloud computing relieves the tension between computation-intensive mobile applications and battery-constrained mobile devices by enabling the offloading of computing tasks from mobiles to a remote processors. This study considers a mobile cloud computing scenario in which the 'cloudlet' processor that provides offloading opportunities to mobile devices is mounted on unmanned aerial vehicles (UAVs) to enhance coverage. Focusing on a slotted communication system with frequency division multiplexing between mobile and UAV, the joint optimisation of the number of input bits transmitted in the uplink by the mobile to the UAV, the number of input bits processed by the cloudlet at the UAV and the number of output bits returned by the cloudlet to the mobile in the downlink in each slot is carried out by means of dual decomposition under maximum latency constraints with the aim of minimising the mobile energy consumption. Numerical results reveal the critical importance of an optimised bit allocation in order to enable significant energy savings as compared with local mobile execution for stringent latency constraints. © 2017 The Institution of Engineering and Technology.
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Namasudra, S., Roy, P.
56418611000;35759182400;
Time saving protocol for data accessing in cloud computing
(2017) IET Communications, 11 (10), pp. 1558-1565. Cited 33 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85027502056&doi=10.1049%2fiet-com.2016.0777&partnerID=40&md5=d9ce6cce16d10c7f49661b8b4660c7b0

DOI: 10.1049/iet-com.2016.0777
AFFILIATIONS: Department of Computer Science and Engineering, National Institute of Technology Silchar, Silchar, Assam, India
ABSTRACT: Cloud computing is a very trending technology because of its efficiency, cost effectiveness, pay-per-use, flexibility and scalability. Data security and access control are two significant issues experienced while availing these advantages of cloud computing. Access control can be defined as a procedure by which a user can access data or file or any kind of resources from a server. A new data access control model has been proposed in this paper for efficient data accessing, which can minimise many problems, such as high searching time for providing the public key of the data owner,

high data accessing time, maintenance of the database, etc. The proposed scheme is evaluated in terms of both theoretical and experimental results, which show the proficiency of the proposed scheme over the existing schemes in a cloud computing environment. © The Institution of Engineering and Technology.
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SOURCE: Scopus

Li, Q., Zhao, J., Gong, Y.
57203224347;13608337100;14010782600;
Computation offloading and resource allocation for mobile edge computing with multiple access points
(2019) IET Communications, 13 (17), pp. 2668-2677. Cited 27 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85073719633&doi=10.1049%2fiet-com.2019.0446&partnerID=40&md5=e87da2126aa246ab931de07fa897989e

DOI: 10.1049/iet-com.2019.0446
AFFILIATIONS: School of Electronic and Information Engineering, Beijing Jiaotong University, Beijing, 100044, China;
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School of Information Engineering, East China Jiaotong University, Nanchang, 330013, China
ABSTRACT: Mobile edge computing (MEC) is an innovative computing paradigm to enhance the computing capacity of mobile devices (MDs) by offloading computation-intensive tasks to MEC servers. With the widespread deployment of wireless local area networks, each MD can offload computation task to server via multiple wireless access points (WAPs). However, computation offloading can bring a higher system cost if all users select the same access points to offload their tasks. This study proposes a computation offloading strategy and resource allocation optimisation scheme in a multiple wireless access points network with MEC, which aims to minimise the system cost by providing the optimal computation offloading strategy, transmission power allocation, bandwidth assignment, and computation resource scheduling. The proposed scheme decouples the optimisation problem into subproblems of offloading strategy and resource allocation since the problem is NP-hard. The offloading strategy involves the optimal access point selection, which is analysed by the potential game. The resource allocation is obtained using Lagrange multiplier. The authors' analysis and simulation results verify the convergence performance of the proposed scheme, and the proposed scheme outperforms the simple resource allocation scheme and the offloading strategy optimisation scheme in terms of the system cost. © The Institution of Engineering and Technology 2019
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Deng, Y., Chen, Z., Zhang, D., Zhao, M.
57193626608;56984606000;57201567461;57189875649;
Workload scheduling toward worst-case delay and optimal utility for single-hop Fog-IoT architecture
(2018) IET Communications, 12 (17), pp. 2164-2173. Cited 27 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85055640052&doi=10.1049%2fiet-com.2018.5077&partnerID=40&md5=4b2f152319ab3dfb61391e44fa73f67f

DOI: 10.1049/iet-com.2018.5077
AFFILIATIONS: School of Information Science and Engineering, Central South University, Yuelu District, Changsha, China;
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ABSTRACT: Fog computing is a distributed computing model that can utilise the storage, analysis and processing capabilities of fog nodes near edge devices. Although fog computing can support task processing for various Internet of Things (IoT) systems, Fog-IoT architecture faces several new challenges with the rapid development of IoT systems, especially delay-sensitive IoT systems, such as stochastic and dynamic data arrival, optimal utility and deadline of tasks. To address these challenges, workload scheduling toward worst-case delay and optimal utility for single-hop Fog-IoT architecture are studied and the workload dynamic scheduling algorithm (WDSA) is proposed. The proposed WDSA algorithm can maximise the average throughput utility while guarantees the worst-case delay of task processing. In addition, it is online and needs no prior information about future. The algorithm performance is analysed from the perspective of optimality and worst-case delay, demonstrating that the proposed WDSA algorithm can get an approximate optima and worst-case delay guarantees. Finally, simulation results demonstrate that the efficiency and efficacy of this kind of the algorithm can meet the requirement. © The Institution of Engineering and Technology 2018.
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Jahantigh, M.N., Rahmani, A.M., Navimirour, N.J., Rezaee, A.
57213825837;57204588830;57213840930;55392412200;
Integration of Internet of Things and cloud computing: A systematic survey
(2020) IET Communications, 14 (2), pp. 165-176. Cited 21 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85078043034&doi=10.1049%2fiet-com.2019.0537&partnerID=40&md5=109be07946a74fd9b9cb791e6f5fa7b8

DOI: 10.1049/iet-com.2019.0537
AFFILIATIONS: Department of Computer Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran;
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ABSTRACT: There are two different concepts [Internet of Things (IoT) and cloud computing] influencing our lives in many ways as they will further be used and highlighted in the future of the Internet. The present systematic study discusses a combination of these two concepts. Many studies have focused on IoT and cloud computing separately. These studies lack a deep investigation of their combination, which has new challenges and issues. Yet, the recent integration of them has been paid a primary focus. This systematic study attempts to analyse how the combination of IoT and cloud has been presented and detects the challenges and metrics of such integration. Further, this analysis aims to develop an understanding of the current affair of this integration by overviewing a collection of 38 recent papers. The contributions of this study, in brief, are: (i) overviewing the current challenges correlated with combination of cloud computing and IoT; (ii) presenting the anatomy of some proposed combination platforms, applications, and integrations; (iii) summarising major areas to boost the integration of cloud and IoT in the upcoming works. © The Institution of Engineering and Technology 2019.
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Mdpi computation

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Priyadarshini, R., Barik, R.K., Dubey, H.
57195339620;36109948200;36975043000;
DeepFog: Fog computing-based deep neural architecture for prediction of stress types, diabetes and hypertension attacks
(2018) Computation, 6 (4), art. no. 62, . Cited 15 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85059228815&doi=10.3390%2fcomputation6040062&partnerID=40&md5=b40ddab255b9b683e6841d0771f146d7

DOI: 10.3390/computation6040062
AFFILIATIONS: School of Computer Science and Engineering, KIIT Deemed to be University, Bhubaneswar, 751024, India;
School of Computer Application, KIIT Deemed to be University, Bhubaneswar, 751024, India;
Center for Robust Speech Systems, The University of Texas at Dallas, Richardson, TX 75080, United States
ABSTRACT: The use of wearable and Internet-of-Things (IoT) for smart and affordable healthcare is trending. In traditional setups, the cloud backend receives the healthcare data and performs monitoring and prediction for diseases, diagnosis, and wellness prediction. Fog computing (FC) is a distributed computing paradigm that leverages low-power embedded processors in an intermediary node between the client layer and cloud layer. The diagnosis for wellness and fitness monitoring could be transferred to the fog layer from the cloud layer. Such a paradigm leads to a reduction in latency at an increased throughput. This paper processes a fog-based deep learning model, DeepFog that collects the data from individuals and predicts the wellness stats using a deep neural network model that can handle heterogeneous and multidimensional data. The three important abnormalities in wellness namely, (i) diabetes; (ii) hypertension attacks and (iii) stress type classification were chosen for experimental studies. We performed a detailed analysis of proposed models' accuracy on standard datasets. The results validated the efficacy of the proposed system and architecture for accurate monitoring of these critical wellness and fitness criteria. We used standard datasets and open source software tools for our experiments. © 2018 by the authors.
AUTHOR KEYWORDS: Connected health; Deep learning; Deep neural network; Diabetes mellitus; Fog computing; Hypertension attack; Smart health; Stress prediction
DOCUMENT TYPE: Article
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Ruiz-Rosero, J., Ramirez-Gonzalez, G., Khanna, R.
57196219147;36603157500;16238735100;
Field programmable gate array applications-A scientometric review
(2019) Computation, 7 (4), art. no. 63, pp. 1-111. Cited 7 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85077365375&doi=10.3390%2fCOMPUTATION7040063&partnerID=40&md5=30ca3d431751b2a2d30b7fceadfb7de2

DOI: 10.3390/COMPUTATION7040063
AFFILIATIONS: Departamento de Telemática, Universidad del Cauca, Calle 5, No. 4-70, Popayan, Cauca, 190002, Colombia;
Intel Corporation, 2111 NE 25th Ave., Hillsboro, OR 97124, United States
ABSTRACT: Field Programmable Gate Array (FPGA) is a general purpose programmable logic device that can be configured by a customer after manufacturing to perform from a simple logic gate operations to complex systems on chip or even artificial intelligence systems. Scientific publications related to FPGA started in 1992 and, up to now, we found more than 70,000 documents in the two leading scientific databases (Scopus and ClarivativeWeb of Science). These publications show the vast range of

applications based on FPGAs, from the new mechanism that enables the magnetic suspension system for the kilogram redefinition, to the Mars rovers' navigation systems. This paper reviews the top FPGAs' applications by a scientometric analysis in ScientoPy, covering publications related to FPGAs from 1992 to 2018. Here we found the top 150 applications that we divided into the following categories: digital control, communication interfaces, networking, computer security, cryptography techniques, machine learning, digital signal processing, image and video processing, big data, computer algorithms and other applications. Also, we present an evolution and trend analysis of the related applications. © 2019 by the authors.
AUTHOR KEYWORDS: Applications; Big data; Digital control; Field programmable gate array; FPGA; Image processing; Machine learning; Networking; ScientoPy; Security
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Holm, H.H., Brodtkorb, A.R., Sætra, M.L.
57215609643;25122143700;54394232400;
GPU computing with python: Performance, energy efficiency and usability
(2020) Computation, 8 (1), art. no. 4, . Cited 4 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85081724575&doi=10.3390%2fcomputation8010004&partnerID=40&md5=aa6ac6947841534689b0ecec312207f5

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Research and Development Department, Norwegian Meteorological Institute, P.O. Box 43, Blindern, Oslo, NO-0313, Norway;
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Information Technology Department, Norwegian Meteorological Institute, P.O. Box 43, Blindern, Oslo, NO-0313, Norway
ABSTRACT: In this work, we examine the performance, energy efficiency, and usability when using Python for developing high-performance computing codes running on the graphics processing unit (GPU). We investigate the portability of performance and energy efficiency between Compute Unified Device Architecture (CUDA) and Open Compute Language (OpenCL); between GPU generations; and between low-end, mid-range, and high-end GPUs. Our findings showed that the impact of using Python is negligible for our applications, and furthermore, CUDA and OpenCL applications tuned to an equivalent level can in many cases obtain the same computational performance. Our experiments showed that performance in general varies more between different GPUs than between using CUDA and OpenCL. We also show that tuning for performance is a good way of tuning for energy efficiency, but that specific tuning is needed to obtain optimal energy efficiency © 2020 by the authors.
AUTHOR KEYWORDS: CUDA; GPU computing; High-performance computing; OpenCL; Power efficiency; Shallow-water simulation
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da Silva, E.C., Gabriel, P.H.R.
57217196047;56524187400;
A comprehensive review of evolutionary algorithms for multiprocessor DAG scheduling
(2020) Computation, 8 (2), art. no. 26, . Cited 2 times.

https://www.scopus.com/inward/record.uri?eid=2-s2.0-85086722474&doi=10.3390%2fCOMPUTATION8020026&partnerID=40&md5=023912b77305645f6c62392e5d003e15

DOI: 10.3390/COMPUTATION8020026
AFFILIATIONS: Faculty of Computer Science, Federal University of Uberlândia, Uberlândia, MG, 38408-100, Brazil
ABSTRACT: The multiprocessor task scheduling problem has received considerable attention over the last three decades. In this context, a wide range of studies focuses on the design of evolutionary algorithms. These papers deal with many topics, such as task characteristics, environmental heterogeneity, and optimization criteria. To classify the academic production in this research field, we present here a systematic literature review for the directed acyclic graph (DAG) scheduling, that is, when tasks are modeled through a directed acyclic graph. Based on the survey of 56 works, we provide a panorama about the last 30 years of research in this field. From the analyzes of the selected studies, we found a diversity of application domains and mapped their main contributions. © 2020 by the authors.
AUTHOR KEYWORDS: Computational environment; DAG scheduling; Evolutionary algorithms; Optimization criteria; Systematic literature review
DOCUMENT TYPE: Article
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Tsakalidis, G., Georgoulakos, K., Paganias, D., Vergidis, K.
57193920146;57195505131;57222073089;16246571400;
An elaborate preprocessing phase (P3) in composition and optimization of business process models
(2021) Computation, 9 (2), art. no. 16, pp. 1-15. Cited 1 time.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85101248454&doi=10.3390%2fcomputation9020016&partnerID=40&md5=55298d70fdfcaaecba4b1711696cc13d

DOI: 10.3390/computation9020016
AFFILIATIONS: Department of Applied Informatics, University of Macedonia, Egnatias 156,, Thessaloniki, 54 636, Greece
ABSTRACT: Business process optimization (BPO) has become an increasingly attractive subject in the wider area of business process intelligence and is considered as the problem of composing feasible business process designs with optimal attribute values, such as execution time and cost. Despite the fact that many approaches have produced promising results regarding the enhancement of attribute performance, little has been done to reduce the computational complexity due to the size of the problem. The proposed approach introduces an elaborate preprocessing phase as a component to an established optimization framework (bpoF) that applies evolutionary multi-objective optimization algorithms (EMOAs) to generate a series of diverse optimized business process designs based on specific process requirements. The preprocessing phase follows a systematic rule-based algorithmic procedure for reducing the library size of candidate tasks. The experimental results on synthetic data demonstrate a considerable reduction of the library size and a positive influence on the performance of EMOAs, which is expressed with the generation of an increasing number of nondominated solutions. An important feature of the proposed phase is that the preprocessing effects are explicitly measured before the EMOAs application; thus, the effects on the library reduction size are directly correlated with the improved performance of the EMOAs in terms of average time of execution and nondominated solution generation. The work presented in this paper intends to pave the way for addressing the abiding optimization challenges related to the computational complexity of the search space of the optimization problem by working on the problem specification at an earlier stage. © 2021 by the authors. Licensee MDPI, Basel, Switzerland.

AUTHOR KEYWORDS: Business process; Evolutionary algorithms; Optimization; Preprocessing
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Kumar, J., Goomer, R., Singh, A.K.
7201862589;57200293023;57212846086;
Long Short Term Memory Recurrent Neural Network (LSTM-RNN) Based Workload Forecasting Model for Cloud Datacenters
(2018) Procedia Computer Science, 125, pp. 676-682. Cited 100 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85040679574&doi=10.1016%2fj.procs.2017.12.087&partnerID=40&md5=0473cfd3242cbd106a898b75813e801a

DOI: 10.1016/j.procs.2017.12.087
AFFILIATIONS: Department of Computer Applications, National Institute of Technology, Kurukshetra, India;
Department of Computer Science, Viterbi School of Engineering, University of Southern California, United States
ABSTRACT: In spite of various gains, cloud computing has got few challenges and issues including dynamic resource scaling and power consumption. Such affairs cause a cloud system to be fragile and expensive. In this paper we address both issues in cloud datacenter through workload prediction. The workload prediction model is developed using long short term memory (LSTM) networks. The proposed model is tested on three benchmark datasets of web server logs. The empirical results show that the proposed method achieved high accuracy in predictions by reducing the mean squared error up to 3.17 x 10-3. © 2018 The Authors. Published by Elsevier B.V.
AUTHOR KEYWORDS: Cloud Computing; Deep Learning; Forecasting; Resource Scaling
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SOURCE: Scopus

Alam, F., Mehmood, R., Katib, I., Albeshri, A.
56104468400;25643246000;26534538800;36617092600;
Analysis of Eight Data Mining Algorithms for Smarter Internet of Things (IoT)
(2016) Procedia Computer Science, 58, pp. 437-442. Cited 80 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84992364679&doi=10.1016%2fj.procs.2016.09.068&partnerID=40&md5=dd38f7f8d96a982fc14c390531fbe928

DOI: 10.1016/j.procs.2016.09.068
AFFILIATIONS: Department of Computer Science, Faculty of Computing and Information Technology (FCIT), King Abdulaziz University, Jeddah, Saudi Arabia;
High Performance Computing Center, King Abdulaziz University, Jeddah, Saudi Arabia
ABSTRACT: Internet of Things (IoT) is set to revolutionize all aspects of our lives. The number of objects connected to IoT is expected to reach 50 billion by 2020, giving rise to an enormous amounts of valuable data. The data collected from the IoT devices will be used to understand and control complex environments around us, enabling better decision making, greater automation, higher efficiencies, productivity, accuracy, and wealth generation. Data mining and other artificial intelligence methods would play a critical role in creating smarter IoTs, albeit with many challenges. In this paper, we

examine the applicability of eight well-known data mining algorithms for IoT data. These include, among others, the deep learning artificial neural networks (DLANNs), which build a feed forward multi-layer artificial neural network (ANN) for modelling high-level data abstractions. Our preliminary results on three real IoT datasets show that C4.5 and C5.0 have better accuracy, are memory efficient and have relatively higher processing speeds. ANNs and DLANNs can provide highly accurate results but are computationally expensive. © 2016 The Authors.
AUTHOR KEYWORDS: Artificial Neural Networks (ANNs); Big Data; C4.5; C5.0; Deep Learning ANNs (DLANNs); Internet of Things (IoT); K-Nearest Neighbours (KNN); Linear Discriminant Analysis (LDA); Naïve Bayes (NB); Smart Cities; Support Vector Machine (SVM)
DOCUMENT TYPE: Conference Paper
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Kumar, P.R., Raj, P.H., Jelciana, P.
56049215100;57197779169;57197780558;
Exploring Data Security Issues and Solutions in Cloud Computing
(2018) Procedia Computer Science, 125, pp. 691-697. Cited 79 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85040688923&doi=10.1016%2fj.procs.2017.12.089&partnerID=40&md5=34abb1b6e6ca75bea7b357bed705d11a

DOI: 10.1016/j.procs.2017.12.089
AFFILIATIONS: School of ICT, IBTE JB Campus, MOE, Kuala Belait, Brunei Darussalam;
School of ICT, IBTE SB Campus, MOE, Seria, Brunei Darussalam;
Laksamana College of Business, Bandar Seri Begawan, Brunei Darussalam
ABSTRACT: Cloud computing is one of the fastest emerging technologies in computing. There are many advantages as well few security issues in cloud computing. This paper explores the different data security issues in cloud computing in a multi-tenant environment and proposes methods to overcome the security issues. This paper also describes Cloud computing models such as the deployment models and the service delivery models. In any business or Cloud Computing data are exceptionally important, data leaking or corruption can shatter the confidence of the people and can lead to the collapse of that business. Currently cloud computing is used directly or indirectly in many businesses and if any data breaching has happened in cloud computing, that will affect the cloud computing as well as the company's business. This is one of the main reasons for cloud computing companies to give more attention to data security. © 2018 The Authors. Published by Elsevier B.V.
AUTHOR KEYWORDS: Access Control; Authentication; Availability; Cloud Computing; Cloud Services; Confidentiality; Data Security; Integrity
DOCUMENT TYPE: Conference Paper
PUBLICATION STAGE: Final
SOURCE: Scopus

Miloslavskaya, N., Tolstoy, A.
22950974400;22952485500;
Big Data, Fast Data and Data Lake Concepts
(2016) Procedia Computer Science, 88, pp. 300-305. Cited 66 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85006413324&doi=10.1016%2fj.procs.2016.07.439&partnerID=40&md5=ef39f156f2813edf87a928fb8388faaa

DOI: 10.1016/j.procs.2016.07.439
AFFILIATIONS: National Research Nuclear University MEPhI, Moscow Engineering Physics Institute, Russian Federation
ABSTRACT: Today we witness the appearance of two additional to Big Data concepts: data lakes and fast data. Are they simply the new marketing labels for the old Big Data IT or really new ones? Thus the key goal of the paper is

to identify the relationship between these three concepts. © 2016 The Authors.
AUTHOR KEYWORDS: big data; data lake; fast data
DOCUMENT TYPE: Conference Paper
PUBLICATION STAGE: Final
SOURCE: Scopus

Vurukonda, N., Rao, B.T.
57190839276;56175301600;
A Study on Data Storage Security Issues in Cloud Computing
(2016) Procedia Computer Science, 92, pp. 128-135. Cited 64 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84983470006&doi=10.1016%2fj.procs.2016.07.335&partnerID=40&md5=2e4c4f81aa96a04e5e7644fbb4896fa4

DOI: 10.1016/j.procs.2016.07.335
AFFILIATIONS: Department of CSE, KLUniversity, Vijayawada, A.P, India
ABSTRACT: Cloud computing is a revolutionary mechanism that changing way to enterprise hardware and software design and procurements. Because of cloud simplicity everyone is moving data and application software to cloud data centers. The Cloud service provider (CSP) should ensure integrity, availability, privacy and confidentiality but CSP is not providing reliable data services to customer and to stored customer data. This study identifies the issues related to the cloud data storage such as data breaches, data theft, and unavailability of cloud data. Finally, we are providing possible solutions to respective issues in cloud. © 2016 The Authors. Published by Elsevier B.V.
AUTHOR KEYWORDS: cloud data storage; Cloud service provider (CSP); policies & protocols; security issues
DOCUMENT TYPE: Conference Paper
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Botta, A., De Donato, W., Persico, V., Pescapé, A.
8709893700;23566756000;56019815600;6602246931;
Integration of Cloud computing and Internet of Things: A survey
(2016) Future Generation Computer Systems, 56, pp. 684-700. Cited 1196 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84958935292&doi=10.1016%2fj.future.2015.09.021&partnerID=40&md5=396c659671089ad0aa3e4c1a0916fdc8

DOI: 10.1016/j.future.2015.09.021
AFFILIATIONS: University of Napoli Federico II, Department of Electrical Engineering and Information Technologies, Via Claudio 21, Napoli, 80125, Italy;
NM2 SRL, Italy
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analysis of the new CloudIoT paradigm, which involves completely new applications, challenges, and research issues. To bridge this gap, in this paper we provide a literature survey on the integration of Cloud and IoT. Starting by analyzing the basics of both IoT and Cloud Computing, we discuss their complementarity, detailing what is currently driving to their integration. Thanks to the adoption of the CloudIoT paradigm a number of applications are gaining momentum: we provide an up-to-date picture of CloudIoT applications in literature, with a focus on their specific research challenges. These challenges are then analyzed in details to show where the main body of research is currently heading. We also discuss what is already available in terms of platforms-both proprietary and open source-and projects implementing the CloudIoT paradigm. Finally, we identify open issues and future directions in this field, which we expect to play a leading role in the landscape of the Future Internet. © 2015 Elsevier B.V.
AUTHOR KEYWORDS: Cloud computing; Cloud of things; Internet of Things; Pervasive applications; Smart city; Ubiquitous networks
DOCUMENT TYPE: Article
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SOURCE: Scopus

Roman, R., Lopez, J., Mambo, M.
22735230000;26643374800;7003852899;
Mobile edge computing, Fog et al.: A survey and analysis of security threats and challenges
(2018) Future Generation Computer Systems, 78, pp. 680-698. Cited 544 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85008245198&doi=10.1016%2fj.future.2016.11.009&partnerID=40&md5=1f8ae180fab42a6d458da1e64e8d40e8

DOI: 10.1016/j.future.2016.11.009
AFFILIATIONS: Computer Science Department, University of Malaga, Ada Byron building, Malaga, 29071, Spain;
Faculty of Electrical and Computer Engineering, Institute of Science and Engineering, Kanazawa University, Kakuma Kanazawa, 920-1192, Japan
ABSTRACT: For various reasons, the cloud computing paradigm is unable to meet certain requirements (e.g. low latency and jitter, context awareness, mobility support) that are crucial for several applications (e.g. vehicular networks, augmented reality). To fulfill these requirements, various paradigms, such as fog computing, mobile edge computing, and mobile cloud computing, have emerged in recent years. While these edge paradigms share several features, most of the existing research is compartmentalized; no synergies have been explored. This is especially true in the field of security, where most analyses focus only on one edge paradigm, while ignoring the others. The main goal of this study is to holistically analyze the security threats, challenges, and mechanisms inherent in all edge paradigms, while highlighting potential synergies and venues of collaboration. In our results, we will show that all edge paradigms should consider the advances in other paradigms. © 2016 Elsevier B.V.
AUTHOR KEYWORDS: Cloud computing; Fog computing; Mobile cloud computing; Mobile edge computing; Privacy; Security
DOCUMENT TYPE: Article
PUBLICATION STAGE: Final
SOURCE: Scopus

Stergiou, C., Psannis, K.E., Kim, B.-G., Gupta, B.
57197316769;14061014300;7501567302;34770593700;
Secure integration of IoT and Cloud Computing
(2018) Future Generation Computer Systems, 78, pp. 964-975. Cited 486 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85008227599&doi=10.1016%2fj.future.2016.11.031&partnerID=40&md5=ac44a23aa25664ccc864fef7e86fb897

DOI: 10.1016/j.future.2016.11.031
AFFILIATIONS: Department of Applied Informatics, School of Information Sciences, University of Macedonia, Thessaloniki, Greece;
Department of Information Technology (IT) Engineering at Sookmyung Women's University, South Korea;
National Institute of Technology Kurukshetra, India
ABSTRACT: Mobile Cloud Computing is a new technology which refers to an infrastructure where both data storage and data processing operate outside of the mobile device. Another recent technology is Internet of Things. Internet of Things is a new technology which is growing rapidly in the field of telecommunications. More specifically, IoT related with wireless telecommunications. The main goal of the interaction and cooperation between things and objects which sent through the wireless networks is to fulfill the objective set to them as a combined entity. In addition, there is a rapid development of both technologies, Cloud Computing and Internet of Things, regard the field of wireless communications. In this paper, we present a survey of IoT and Cloud Computing with a focus on the security issues of both technologies. Specifically, we combine the two aforementioned technologies (i.e Cloud Computing and IoT) in order to examine the common features, and in order to discover the benefits of their integration. Concluding, we present the contribution of Cloud Computing to the IoT technology. Thus, it shows how the Cloud Computing technology improves the function of the IoT. Finally, we survey the security challenges of the integration of IoT and Cloud Computing. © 2016 Elsevier B.V.
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Cloud Computing and Distributed Systems (CLOUDS) Laboratory, School of Computing and Information Systems, The University of Melbourne, Australia
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AUTHOR KEYWORDS: Cloud computing; Cloud security; Cloudlet; Fog computing; Multi-cloud; Serverless computing
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Plageras, A.P., Psannis, K.E., Stergiou, C., Wang, H., Gupta, B.B.
57193017337;14061014300;57197316769;56178830400;34770593700;
Efficient IoT-based sensor BIG Data collection-processing and analysis in smart buildings
(2018) Future Generation Computer Systems, 82, pp. 349-357. Cited 233 times.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-85033213546&doi=10.1016%2fj.future.2017.09.082&partnerID=40&md5=af8763a9f1dddb9f16d5761aab358d65

DOI: 10.1016/j.future.2017.09.082
AFFILIATIONS: Department of Applied Informatics, School of Information Sciences, University of Macedonia, Thessaloniki, Greece;
Cornell University, United States;
National Institute of Technology Kurukshetra, India
ABSTRACT: Internet of Things (IoT) provides to everyone new types of services in order to improve everyday life. Through this new technology, other recently developed technologies such as Big Data, Cloud Computing, and Monitoring could take part. In this work, we survey the four aforementioned technologies in order to find out their common operations, and combine their functionality, in order to have beneficial scenarios of their use. Despite the boarder concept of a smart city, we will try to investigate new systems for collecting and managing sensors' data in a smart building which operates in IoT environment. As a bases technology for the proposed sensor management system, a cloud server would be used, collecting the data that produced from each sensor in the smart building. These data are easy to be managed and controlled from distance, by a remote (mobile) device operating on a network set up in IoT technology. As a result, the proposed solutions for collecting and managing sensors' data in a smart building could lead us in an energy efficient smart building, and thus in a Green Smart Building. © 2017 Elsevier B.V.
AUTHOR KEYWORDS: Big Data; Cloud Computing; Contiki OS; Data collection; Energy efficiency; Internet of Things; Sensor management; Sensor management; Smart Building
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AFFILIATIONS: Department of Applied Informatics, School of Information Sciences, University of Macedonia, Thessaloniki, Greece;
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APPENDIX B: RELEVANT VENUES AND TOPICS

This appendix shows the search criteria used for all the research venues analysed in order to facilitate the reproducibility of the analysis.

Venue	Link	Selection criteria	Sorting method
Journal of Cloud Computing	https://journalofcloudcomputing.springeropen.com/	search in scopus.com with the following query: SRCTITLE (journal AND of AND cloud AND computing) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016))	sort on cited by (highest)
IEEE access	https://ieeeaccess.ieee.org/	SRCTITLE (ieee AND access) AND (LIMIT-TO (EXACTKEYWORD , "Cloud Computing") OR LIMIT-TO (EXACTKEYWORD , "Edge Computing")) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016)) AND (LIMIT-TO (EXACTKEYWORD , "Quality Of Service") OR LIMIT-TO (EXACTKEYWORD , "Mobile Edge Computing") OR LIMIT-TO (EXACTKEYWORD , "Distributed Computer Systems") OR LIMIT-TO (EXACTKEYWORD , "Fog Computing") OR LIMIT-TO (EXACTKEYWORD , "Fog") OR LIMIT-TO (EXACTKEYWORD , "Mobile Cloud Computing") OR LIMIT-TO (EXACTKEYWORD , "Monitoring") OR LIMIT-TO (EXACTKEYWORD , "Clouds") OR LIMIT-TO (EXACTKEYWORD , "Computing Environments")) AND (LIMIT-TO (EXACTKEYWORD , "Green Computing"))	sort on cited by (highest)
IEEE Transactions on Services Computing	https://ieeexplore.ieee.org/xpl/RecentIssue.jsp?punumber=4629386	SRCTITLE (ieee AND transactions AND on AND services AND computing) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016)) AND (LIMIT-TO (EXACTKEYWORD , "Cloud Computing") OR LIMIT-TO (EXACTKEYWORD , "Edge Computing") OR LIMIT-TO (	sort on cited by (highest)

Venue	Link	Selection criteria	Sorting method
		EXACTKEYWORD , "Green Computing") OR LIMIT-TO (EXACTKEYWORD , "Cloud Service Providers") OR LIMIT-TO (EXACTKEYWORD , "Cloud Services") OR LIMIT-TO (EXACTKEYWORD , "Cloud") OR LIMIT-TO (EXACTKEYWORD , "Cloud Storages") OR LIMIT-TO (EXACTKEYWORD , "Clouds") OR LIMIT-TO (EXACTKEYWORD , "Fog Computing"))	
IEEE Transactions on Cloud Computing	https://ieeexplore.ieee.org/xpl/RecentIssue.jsp?punumber=6245519	search in scopus.com with the following query: (SOURCE-ID (21100338351)) AND (cloud AND computing) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016))	sort on cited by (highest)
Journal of Systems and Software	https://www.journals.elsevier.com/journal-of-systems-and-software	search in scopus.com: (SOURCE-ID (19309)) AND (cloud AND computing) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016))	sort on cited by (highest)
Scalable computing	https://www.scpe.org/index.php/scpe	Search in scopus.com with the following query: (SOURCE-ID (21100208072)) AND (cloud AND computing) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016))	sort on cited by (highest)
International Journal of Computational Science and Engineering	https://www.inderscience.com/jhome.php?jcode=ijcse	Search in scopus.com with the following query: (SOURCE-ID (6100152804)) AND (cloud AND computing) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016))	sort on cited by (highest)
Future Generation Computer Systems	https://www.sciencedirect.com/journal/future-generation-computer-	search in scopus.com with the following query: SOURCE-ID (12264) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (	sort on cited by (highest)

Venue	Link	Selection criteria	Sorting method
	systems	PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016)) AND (LIMIT-TO (EXACTKEYWORD , "Cloud Computing") OR LIMIT-TO (EXACTKEYWORD , "Scheduling") OR LIMIT-TO (EXACTKEYWORD , "Parallel Processing Systems") OR LIMIT-TO (EXACTKEYWORD , "Quality Of Service") OR LIMIT-TO (EXACTKEYWORD , "Computer Simulation") OR LIMIT-TO (EXACTKEYWORD , "Algorithms") OR LIMIT-TO (EXACTKEYWORD , "Scheduling Algorithms") OR LIMIT-TO (EXACTKEYWORD , "Edge Computing") OR LIMIT-TO (EXACTKEYWORD , "Scalability") OR LIMIT-TO (EXACTKEYWORD , "Green Computing") OR LIMIT-TO (EXACTKEYWORD , "Resource Management") OR LIMIT-TO (EXACTKEYWORD , "Load Balancing") OR LIMIT-TO (EXACTKEYWORD , "Performance Evaluation") OR LIMIT-TO (EXACTKEYWORD , "Resource Utilizations") OR LIMIT-TO (EXACTKEYWORD , "Heuristic Algorithms") OR LIMIT-TO (EXACTKEYWORD , "Cloud") OR LIMIT-TO (EXACTKEYWORD , "Service Level Agreements"))	
Procedia Computer Science	https://www.journals.elsevier.com/procedia-computer-science	Search in scopus.com with the following query: (SOURCE-ID (19700182801)) AND (cloud AND computing) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016))	Sort on cited by (highest). Included from #2 to #6 as the first one was focused on breast cancer
Concurrency Computation Practice and Experience	https://onlinelibrary.wiley.com/journal/15320634	Search in scopus.com with the following query: (SOURCE-ID (27871)) AND (cloud AND computing) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016))	Sort on cited by (highest)
mdpi computation	https://www.mdpi.com/journal/computation/about	Search in scopus.com with the following query: (SOURCE-ID (21100857172)) AND ((cloud AND computing)) AND (cloud) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020	Sort on cited by (highest)

Venue	Link	Selection criteria	Sorting method
		) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016)) AND (LIMIT-TO (EXACTKEYWORD , "High-performance Computing") OR LIMIT-TO (EXACTKEYWORD , "Big Data") OR LIMIT-TO (EXACTKEYWORD , "Fog Computing") OR LIMIT-TO (EXACTKEYWORD , "HPC") OR LIMIT-TO (EXACTKEYWORD , "Optimization") OR LIMIT-TO (EXACTKEYWORD , "Optimization Criteria") OR LIMIT-TO (EXACTKEYWORD , "Security"))	
Springer Nature Computer Science	https://www.springer.com/journal/42979	Not indexed in scopus. Most downloaded articles with the following keywords: cloud computing, edge computing, fog computing. Manual search	Sort on cited by (highest)
Computing & Control Engineering Journal	https://digital-library.theiet.org/content/journals/cce	Published only between 2003 y 2007 - discarded	
IET Communications	https://digital-library.theiet.org/content/journals/iet-com	Search in scopus.com with the following query: (SOURCE-ID (5300152202)) AND (cloud AND computing) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016)) AND (LIMIT-TO (EXACTKEYWORD , "Cloud Computing") OR LIMIT-TO (EXACTKEYWORD , "Computation Offloading") OR LIMIT-TO (EXACTKEYWORD , "Fog Computing") OR LIMIT-TO (EXACTKEYWORD , "Fog") OR LIMIT-TO (EXACTKEYWORD , "Mobile Cloud Computing") OR LIMIT-TO (EXACTKEYWORD , "Resource Allocation Schemes") OR LIMIT-TO (EXACTKEYWORD , "Software Defined Networking (SDN)") OR LIMIT-TO (EXACTKEYWORD , "Cloud Environments"))	Sort on cited by (highest)

Venue	Link	Selection criteria	Sorting method
IEEE INTERNATIONAL CONFERENCE ON CLOUD COMPUTING	https://www.computer.org/csdl/search/default?queryState=%7B%22searchType%22:%5B%22basic%22,%22proceeding%22%5D,%22basicSearchText%22:%5Bnull,%22%22%5D,%22doiSearchText%22:%5Bnull,%22%22%5D,%22publicationSearchText%22:%5Bnull,%22INTERNATIONAL%20CONFERENCE%20ON%20CLOUD%20COMPUTING%20(cloud)%22%5D,%22publicationSearchTextSubmitted%22:%5B%22%22,%22INTERNATIONAL%20CONFERENCE%20ON%20CLOUD%20COMPUTING%20(cloud)%22%5D,%22proceedingAcronymSearchTextSubmitted%22:%5B%22%22,null%5D,%22authorSearchTextSubmitted%22:%5B%22%22,null%5D,%22showMorePublications%22:%5Bfalse,true%5D,%22yearFacet%22:%7B%22selectedYearRange%22:%7B%220%22:%5B2016%5D,%22_t%22:%22a%22,%22_0%22:%5B1960,0,0%5D%7D%7D%7D	Search in https://www.computer.org/ : https://www.computer.org/csdl/search/default?queryState=%7B%22searchType%22:%5B%22basic%22,%22proceeding%22%5D,%22basicSearchText%22:%5Bnull,%22%22%5D,%22doiSearchText%22:%5Bnull,%22%22%5D,%22publicationSearchText%22:%5Bnull,%22INTERNATIONAL%20CONFERENCE%20ON%20CLOUD%20COMPUTING%20(cloud)%22%5D,%22publicationSearchTextSubmitted%22:%5B%22%22,%22INTERNATIONAL%20CONFERENCE%20ON%20CLOUD%20COMPUTING%20(cloud)%22%5D,%22proceedingAcronymSearchTextSubmitted%22:%5B%22%22,null%5D,%22authorSearchTextSubmitted%22:%5B%22%22,null%5D,%22showMorePublications%22:%5Bfalse,true%5D,%22yearFacet%22:%7B%22selectedYearRange%22:%7B%220%22:%5B2016%5D,%22_t%22:%22a%22,%22_0%22:%5B1960,0,0%5D%7D%7D%7D	Articles/2021-2016. Shorted by most relevant.

APPENDIX C: INTERVIEWS INVITATION AND LETTER OF CONSENT

European Commission

HUB4CLOUD

The purpose of the interview is to gather information from Stakeholders involved in Cloud Computing to help the European Commission within the pursue to "a Europe fit for the digital age" in which digital technologies and solutions are strongly rooted in the core European values, spanning fundamental individual rights to market openness and environmental sustainability.

We are open to hear from any actor involved within the Cloud Computing industry about their experience as well as their views on the present and future of this industry. Special interest relays on "Cloud Federation", "Edge Computing" and "Green IT".

The interview will be limited to a maximum of **20 minutes**. With the consent of the interviewees, it will be recorded using tools like "Zoom or similar". The interview might be edited to just change cosmetics, but its content will not be altered. The result will be shared with the interviewees before been published.

Interviews will start with the interviewees free time slot (up to 5 minutes) where they introduce their company/institution to be followed by their opinions on some of the following topics: "Business model or how to make money with CC", "Skills needed in CC", "Data Sovereignty/Governance" and "Energy efficiency".

Below, there is a description of the topics together with some examples of questions that could be asked during the interview.

This document is shared with the potential interviewees, and they have the freedom to decide on which topics they feel more comfortable with as well as select the questions they would like to answer.

Business Modelling: The effective digital transformation of Europe largely depends on the availability and uptake of innovative cloud infrastructures and services. Digital transformation encompasses both consolidated businesses that need to embark in a "migration to the cloud" and new cloud-native ventures, which require the appropriate context and support.

Technology Innovation/Skills: We would like to hear about the innovative cloud services based on cutting-edge technologies – edge computing – with a disruptive impact on business processes.

Governance/Organisational Structure: Regarding cloud federated model (or another collaborative model, such as a procurement alliance) to reach a substantial level of representation of the stakeholder ecosystem.

Data Governance: Efficient and effective data governance. How your company has addressed the following topics: Data protection compliant with regulations and good practices, Implementation of data sovereignty for stakeholders, effective and efficient data sharing, efficient and effective data security

Environmental and Sustainability Performance: Europe is very concerned about addressing green computing/energy efficiency. We would like to know your company position on: Efficient usage of IT cloud architecture and resources, Renewable energy sources, Energy efficient technologies

Open Source

Open source is a business model widely extended for software solutions. We would like to know your vision on OS usage and development.

Cybersecurity

Security ensures the proper behaviour of infrastructures and applications against external attacks or internal risks. Critical areas within Security are cybersecurity analytics, privacy, risk analysis, compliance, cybersecurity metrics, workforce education or penetration testing.

Software Engineering for the Cloud

The significance of software has recently grown to the point of merging the role of software developers with that of infrastructure operators, of which main focus is the automation of infrastructure-related activities through the use of software, giving birth to the Infrastructure as Code trend, the engine of the DevOps movement. DevOps is an organizational change that consists of using software engineering tactics that reduce the technical and organizational distance between development and operation, leading to the creation of a single, well-coordinated team of people. Software Engineering trends are needed for the application developers and operators to embrace IaC for the Cloud Continuum from the DevOps perspective: i.e. FaaS, Osmotic computing, Serverless, etc.

Thanks a lot for your collaboration

Enrique Areizaga

TECNALIA R&I

HUB4CLOUD Grant Agreement N°: 101016673 Topic: ICT-40-2020

https://www.h-cloud.eu/ict_40-projects/hub4cloud/

As I'm sure you're aware, we need to make sure that we comply with European data protection laws at all times. For that reason, I need to provide you with some legally required information. During the interview, we'll ask you several questions, and your answers (along with your name, contact information and affiliation) will be used to help us execute the HUB4CLOUD project. We also record interviews by default, so that we can keep notes more accurately, and in order to publish the interview on public channels, including our project website.

While TECNALIA R&I is in charge of the interview as a data controller, your data will be shared with other consortium partners of the project, as identified on our project website, if that's necessary to do the planned project work. In addition, if we record the interview, we aim to publish it on the **HUB4CLOUD** website, or on **HUB4CLOUD** social media channels, where we can promote the visibility of the interview and of **HUB4CLOUD**. Apart from that, your data won't be shared with organisations or persons outside of the project.

If you have any questions on the way we work, or if you want to exercise your rights under data protection law (e.g. to access, correct or delete your data), feel free to contact me, or our project data protection officer (hans.graux@timelex.eu). If you feel that we're not respecting your rights fully, you can also lodge a complaint with the data protection authority in your own country. We'll keep your data safe and will retain it only as long as we need it to show that we've done a good job in **HUB4CLOUD**, after which it will be deleted.

Finally, and most importantly of course, we only collect and use your data on the basis of your consent. If you prefer not to participate or want to withdraw your consent at some point in the future, please let us know and we'll respect your wishes.

Could you confirm via a short e-mail reply that you agree to this? If you have any doubts or questions, please feel free to let me know, of course!