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ScienceDirect
Procedia Computer Science 97 (2016) 157 – 166
Procedia Computer Science

CLOUD FORWARD: From Distributed to Complete Computing, CF2016, 18-20 October 2016, Madrid, Spain

Initial 2016 HOLACloud Roadmap

Keith G Jeffery[a]*, Lutz Schubert[b]

[a]*Keith G Jeffery Consultants, 71 Gilligans Way, Faringdon, UK*
[b]University of Ulm, Albert-Einstein Allee 43, 89081 Ulm, Germany

Abstract

The HOLACloud initial 2016 roadmap has been generated by a process similar to that for 2015 using the input to the CLOUD Forward Conference 2016. The analysis of the position papers, and ideas from the scientific papers, provided the synopsis of future R&I (Research and Innovation) topics. These are: advanced systems development method(s) based on model-driven technology; placement and locality of data, software, resources and users; autonomic SLA management pervasively through the software stack including trust, security and privacy; interoperability both across hybrid CLOUD platforms and across heterogeneity of data and software. Business models for CLOUD Computing and beyond featured less prominently than in 2015.
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Peer-review under responsibility of organizing committee of the international conference on cloud forward: From Distributed to Complete Computing

Keywords: complete computing; systems development environment; placement; locality; non-functional requirements; big data; edge; fog; elasticity; environmental

1. Introduction

1.1. Roadmap Purpose

A key deliverable from the HOLACloud project[1] is a roadmap for research and innovation in CLOUD Computing and beyond, encompassing Complete Computing. The roadmap is provided to the EC (European

* Corresponding author. Tel.: +44 7768 44608
E-mail address: keith.jeffery@keithgjefferyconsultants.co.uk

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Peer-review under responsibility of organizing committee of the international conference on cloud forward: From Distributed to Complete Computing
doi:10.1016/j.procs.2016.08.296

Commission) DG-CNECT as a contribution synthesised from the community of 'CLOUD and beyond' researchers represented by Clusters of EC-funded projects, by CSA (Cooperation and Support Action) projects addressing 'CLOUDs and beyond', individual projects and individual researchers.

The authors were previously respectively chair and rapporteur then co-chairs of the successive EC Expert Groups in Cloud Computing 2009-2014[2,3,4] which identified key challenges and the need for research and innovation.

1.2. Roadmap Construction

A first HOLACloud roadmap was produced in 2015 based on the rapidly-arranged CLOUD Forward Conference that year (CF2015). Subsequent to the synthesis paper produced for CF2015[5] and discussions at CF2015, the authors of that roadmap were asked to produce several subsequent documents for the EC to be used in constructing the research and innovation programme of H2020.

The HOLACloud 2016 roadmap has been generated by a process similar to that for 2015 using the input to the CLOUD Forward Conference (CF2016). The conference consists of scientific papers and position papers; the latter formed the 'backbone' of this synthesised summary roadmap with elaboration drawn from the scientific papers. The HOLACloud Portal was also used in identifying topics and this also provides evolutionary continuity from the 2015 roadmap, justified by the 2016 contributions from the community.

1.3. Setting the Scene

CLOUD Computing is a phenomenon of our times. Based on advances in virtualisation and in hiding service management complexity, it offers better resource utilisation and cost savings. PaaS (Platform as a Service) provides the base infrastructure; IaaS (Infrastructure as a Service) provides an environment for applications while SaaS (Software as a Service) provides the applications themselves. It is assumed throughout that the CLOUD computing environment with the application(s) deployed satisfy the FRs (functional requirements) of the business. The overall result is that ICT – as seen by the end-user – is less expensive, more reliable and with complexity hidden. With recent business and market developments, CLOUD Computing has furthermore brought together several emerging trends in ICT: mobile devices, 'intelligent' networking, global connectivity, elastically scalable computing, environmentally-aware computing etc.

However, there are major challenges with CLOUD Computing as identified in the 2015 roadmap (and indeed by the EC Expert Groups before): trust, security and privacy represented then the top rated concern among actual and potential users; interoperability across CLOUD platforms and the avoidance of 'lock-in' was the second concern while provision of adequate business plans to justify CLOUD Computing was third. An additional major concern was provision of adequate systems development environments – especially managing the disconnect between application requirements and the capabilities of one or more CLOUD platforms

With the growing need for ever more demanding services, complex data processing, distributed collaborative environments etc. comes the increasing expectation to exploit the (hardware) resources to their maximum. Multi-core configurations require increased computational and algorithmic awareness. While increases in storage density and access performance are – more or less – keeping up with demand, networking (at all levels from broadband to local area to inter-processor) is not and the introduction of software controlled networks aims to overcome this challenge.

The emergence of Fog or Edge CLOUD computing has reinforced the above challenges. Identified already before 2015, but perceived more clearly now, this is part of the challenge of locality and placement: starting from given localities of available (effective, efficient) computing resources (including detectors and instruments or mobile devices i.e. IoT (Internet of Things)), given localities of the required software components or composed workflows as services and given localities of the appropriate datasets – all relative to the end-user – the requirement is to optimise the overall task execution respecting NFRs (non-functional requirements like security, privacy, cost, performance, rights).

These infrastructure aspects are increasingly complex in management, especially in distributed heterogeneous configurations. To this we add the complexities of CLOUD computing platform provision (with Fog and Edge variants especially in dynamic hybrid CLOUDs) including the challenges mentioned above. Finally we add the application complexity – demanding dynamically reconfigurable, context-aware microservices (components) with associated user-demanded (or organisationally policy-defined) NFRs. In 2015 the authors brought this together with a proposal for 'Complete Computing' also known as I^3 or 'triple-I' computing (Information, Intention, Incentive) utilising respectively properties of the data and information, the algorithm or software characterisation and NFRs to optimise computing[6].

2. Major Issues and Directions

2.1. Requirements

The requirements identified for research and innovation in CLOUD Computing and Beyond include those from the 2015 roadmap[5] but with additional emphasis on certain aspects and particularly identifying fog/edge CLOUD computing aspects where IoT meets the CLOUD. The underlying requirement is: The end-user neither knows nor cares where and how the computing task is done as long as the FRs and NFRs are respected (including trust and security concerns). CLOUD Computing – continuing from GRID computing - provides this through virtualisation but with additional emphasis on efficient resource utilisation with cost and environmental implications.

Better Security and Privacy: The management of policies and associated NFRs remains a continuing requirement. The requirements identified initially in 2015 are now expressed with more depth and in particular the requirement for consistent, pervasive, penetrative NFR management within the application and the platform software – relating to the rights and legalistics concerning users, data, software components, services and resources – has become of high importance and some urgency. A growing concern is thereby also the potentially sensitive data that can be extracted from Big Data analysis.

Platform Choice: Interoperability also remains a strong requirement. It not only avoids commercial lock-in of applications to platforms, but also allows novel business workflows between applications and across multiple platforms to be supported. In a market where application deployments are short-lived and fast changing, bringing the different applications - with their characteristics and their dependencies - together is challenging. This is not constrained to interfaces, but increasingly to data structures too.

Business justification of CLOUD Computing: Effective business models to justify the use of CLOUD computing have much improved since 2015 but there are many remaining problems in quantifying in financial terms the characteristics and capabilities of CLOUD platforms, and of user requirements - especially of NFRs such as security and privacy and the benefit to an organisation of deploying applications in a (multi-)(hybrid)CLOUD environment.

Environmental justification of CLOUD Computing: The provision of dynamic elasticity – both scale up and down (processor power, storage size etc.) and scale out and in (amount of hosts) remains a requirement although more platforms now support this to a greater or lesser extent. In general it appears more difficult to provide efficient scale down and scale in yet this may have the greatest effect on ICT costs and environmental costs. Also the impacts of scale appear to be not fully known or controlled: not all services or types of resources easily scale, as is e.g. the decade old concern of High Performance Computing.

Ease of programming: The provision of an appropriate applications development environment continues to be an important requirement. The need for application development in such a way that the application can be deployed on one or more heterogeneous and scalable CLOUD platforms – as a whole or as a partitioned and possibly replicated application - is a pressing requirement. This implies application characterisation to allow the middleware to make deployment decisions across the characterised platforms including not only the application software (as components or monolithic) but also locality of users (with smart devices), data, other software required (e.g. software libraries or middleware), platforms with particular characteristics (both functional and non-functional).

Big Data and Location: However, the emerging requirement of high importance is for efficient data access and usage through support of locality optimisation in CLOUD computing emphasised by the emergence of Edge/Fog CLOUD computing. The problem centres on the relatively poor price/performance of networking at all scales compared with storage and processing leading to problems of latency. The problem is compounded for processing requiring access to multiple distributed heterogeneous sources. Big data is expensive to transport from one locality to another and takes much time. Another aspect is that certain localities – from large data centres to individual instruments or smart devices - have particular processing and storage capabilities, both technical (FRs) and in terms of costs, rights and other NFRs. Such localities may also have particular management requirements to maintain software or data locally especially if there is frequent update or considerable local processing before making data available. Users are mobile and may initiate a task from one locality but require the results at another – or at many localities (end-user smart devices) if sharing with others - and for the task to be done respecting NFRs. Software components may be only available at certain localities (immobile code) or may be constructed for particular computing platforms while other code is mobile and redeployable from a shared software library facility – ideally open source. Also legal constraints play as yet - with no global legislation for data protection in place - a crucial role in the decision of locality. The need is for software components that are self-aware and intercommunicating to allow for dynamic (re-)deployment. Workflows composing users, data, software components (possibly grouped as composed services) and platform resources may be characterised and re-usable subject to appropriate NFRs.

2.2. Issues and Challenges

The issues – derived from the requirements outlined above - group quite naturally into the following inter-related topics:

Policies and NFRs: This topic covers (a) the representation of enduring policies and the extraction from policies of NFRs such as security, privacy, trust, rights, legal obligations (including environmental) on the user side; (b) the representation and - if necessary - knowledge-advised definition of NFRs for a particular task to be executed for a particular user; (c) the representation of enduring policies and the extraction from policies of NFRs such as security, privacy, trust, rights, legal obligations (including environmental) on the provider side probably composed as a SLA (Service Level Agreement); (d) the assurance that the deployed (and dynamically (re-) deployed software stack provides representation of the NFRs at all levels pervasively and penetratively to assure conformance throughout the application code, the deployment code and the platform code.

Interoperability and Elasticity: There is an increasing need for hybrid CLOUD deployment. Partly to provide a seamless extension of resources from in-house to external CLOUD platforms, and partly to permit choice of the best (price/performance/NFR factors), multicloud platforms combine for a particular application deployment. This implies interoperability and interoperability requires support from a rich catalog providing the required patterns and information on users, datasets, software components, services (including workflows) and platforms (including smart devices and detectors/instrumentation as well as conventional computing provision). The interoperability occurs at many levels relating to the platform: the need for a deployed application (or application fragment) to be moved from one platform to another seamlessly; the need for appropriate NFRs to be maintained during the transition despite different platform logging and cataloguing mechanisms; the need for software to execute correctly when moved from one platform to another with any appropriate middleware and libraries. The degree of 'containerisation' is important here; a packaged application in a single deployment container is simpler but partitioned and dynamically deployed application fragments may be more efficient and more resilient (fault tolerance, security, privacy). In addition there is the need for interoperation of data which may be associated (localised) with particular platforms in particular syntactic structures (logical) and storage structures (physical) and associated different, possibly multilingual, semantics.

Elasticity is required to optimize the use of computing resources thus conserving availability and reducing the environmental footprint. Deeper utilization and management of elasticity is required to improve on current optimisations which all too frequently leave resources unused after allocation and thus result in a larger than necessary environmental footprint. Elasticity also relates to dynamic (re-)placement of software components and data segments across multiple resources.

Business Models: The overall issue is to cost-justify and cost-efficiently steer a move to - and use of - CLOUD computing. The first problem is that there are so many different CLOUD computing configurations that an organization might use that it is difficult to find a steady-state for characterization and comparison. While in general outsourcing (some of) an Organisation's ICT to a CLOUD provider is cost-effective - since OPEX (Operational expenditure) is used rather than CAPEX (Capital expenditure) - there are costs that may not appear prima facie. A detailed issue and challenge here is to quantify in financial terms (a) the costs of assurance of a SLA including NFRs; (b) the benefits to an organization of that assurance; both related to the overall business model of the organization. Further to (c) identify the appropriate and sustainable environment and (d) to assess the transition cost vs. gain. The real difficulty is to quantify risk in financial terms and to assess the required financial set-aside to mitigate the risk.

Applications Development Environment: Increasingly applications are composed of software components including commercially available or open source libraries. Moreover, the application components are commonly heterogeneous in design and in software programming style and language, and may not have appropriate detail in their interfaces (e.g. APIs or messaging interfaces) for the purpose especially for pervasive management of NFRs and any related logging of activity. Thus they may require some supplementation either with 'interstitial software' to fill the gaps and provide the additional required functionality or a higher level controlling software 'backbone' to provide such cohesion (although the latter may limit dynamic redeployment and any associated replication). How much characterising information can be derived from the software must be intrinsic to code structure (and language) and is as yet unknown.

Network Placement: While network latency was identified in the 2015 roadmap as an important emerging topic, the roadmap report for the European Commission delivered in February 2016 included a bullet point on network placement and Edge/Fog computing. During the last year this aspect of CLOUD computing has risen strongly in importance and urgency. It is fundamental since it relates not only to the execution environment and deployment across platforms, but also to the systems development aspect with characterisation, de-composition and re-composition of application fragments, relating application fragments (possibly replicated) to data locality and both software and data to resource capability. The increasing interest in sharing and exploiting data from a variety of sources requires not only intelligent placement, but structured and efficient distributed maintenance. To add to the complexity, NFRs have to be respected throughout implying that information has to be passed across software component interfaces or though messages either to every component/fragment or to some central controlling authority to which all components/fragments refer – the latter then becoming a bottleneck.

The proposal emerging from the 2015 roadmap exercise was a novel construction of software as microservices which were self-aware and intercommunicating with other components to achieve the functional requirements while respecting the NFRs. Furthermore, data maintenance was suggested with versioned and well-structured partial views on data and the increasing ability to deal with partially incorrect data. Further consideration indicates that this implies the microservices have inbuilt knowledge for self-determination and independent action but within an overall strategic plan for deployment of an application. An analogy might be ants or bees: individuals have local autonomy; they pass information to each other to perform cooperative tasks but act within a set of rules or constraints that define the strategic plan.

3. Initial Roadmap

The roadmap has to propose a way forward based on requirements and potential solutions. It has to somehow deal with the importance (benefit to the economy or quality of life), the urgency (when the requirement becomes important and when the solution can be made available), the complexity (of providing a solution), the cost of providing a solution and the dependencies and requirements of any solution on any other in an integrated solution environment.

3.1. Topics

The 2015 roadmap identified the topics as (1) security and privacy; (2) interoperability; (3) business models followed by (4) systems development environment. All of these remain important topics although the relative importance of business models has decreased. A fifth topic has emerged strongly: network placement. This topic was apparent in the 2015 roadmap and emphasised more in later documents prepared for the EC.

The Security and Privacy topic has broadened to include policies and their enactment thus including particularly SLA and representation of SLAs in a machine actionable way. This drives the requirement for penetrative NFRs through all levels of the software stack down to the network whether internal to the organisation or sourced externally.

Interoperability remains important to avoid commercial lock-in and to allow dynamic cross-platform deployment for elastic scalability. However, the higher levels of interoperability allowing cross-domain sharing of data and software are increasingly recognized as important especially among the ESFRI (European Strategic Forum for Research Infrastructures) community. Such interoperability is also important for commercial organisations cooperating in supply chains, co-production or in distributed marketing and supply.

The topic of business models attracted much less attention in 2016. Possibly the challenges have been addressed in the intervening year, possibly the community has increased knowledge and experience of the advantages of OPEX over CAPEX including within-organisation accounting using an internal CLOUD environment.

Systems Development environments optimized for deployment on CLOUDs remains an increasingly difficult challenge. Part of the problem is the complexity: it is necessary to take into account all the FRs and NFRs of the business; another part of the problem is the dynamicity – the requirements and the available platform resources change rapidly; and a final part is the programmability vs. legacy: new applications need to be easily developed, but also transitioned easily from existing code. This is difficult enough for new application development; legacy applications require either wrapped characterization or rewriting to take advantage of the facilities (e.g. elastic scalability, partitioning, replication) of the CLOUD environment. In some ways it is this topic which brings together all the others, and also leads to the next.

Placement – especially related to big data – has emerged as a hot topic. Anticipated in 2015 it has now become centre-stage. The optimal placement of data and software – including partitioning and replication for distributed parallel operation across multiple hybrid platforms from supercomputers to smart devices at the edge of the network – is critical and affects not only performance and cost but has implications for security and privacy.

3.2. Importance and Urgency

There are many ways of classifying the papers accepted for CF2016. The approach taken has been to take the topics from the position papers and supplement with detail – especially novel ideas - from the scientific papers.

This leads to the most important topics being systems development environments, including model-driven development) and placement (including Edge and Fog CLOUD computing) but this may be because they include many of the other topics as sub-topics. Security expanded in the sense of policies and SLAs (with the policy enactment and representation pervasive through the software stack) and Interoperability (in the broader sense allowing application intercommunication) follow, with business models as the last topic.

In terms or urgency this should follow the importance rating of the topics. However, since different topics have different complexity, it is necessary to take on sub-topics.

The maximum urgency is for new models and approaches for systems development, based e.g. on model-driven and composable technologies but encompassing both FRs and NFRs and with the capability to generate deployments that are distributed, partitioned, replicated as necessary across hybrid platforms to meet the NFRs.

This implies deeper research into placement - especially across the spectrum of platforms from supercomputers to smart devices (IoT) – of data, software components, composed workflows and user access and interoperation. The research needed concerns characterization of the assets outlined above so that ‘intelligent’ composition for deployment can be achieved within the systems development environment. It also implies extensive monitoring to provide the data to be utilized in the ‘intelligence’ in the systems development process.

The importance of security and privacy – providing trust – and the provision of machine-actionable SLAs is unquestioned. The integration of the technologies developed in this topic into the systems development environment is progressive, but an overarching model across these NFRs and the structure of a systems development environment is urgent.

Interoperability also is progressive and requires a large effort to provide the necessary metadata to characterise the data, software components, services (including workflows) and platforms/resources including IoT devices. The urgency is to define a canonical metadata set of elements to provide the characterization to allow interconversion from existing metadata standards and thus provide basic machine-actionable interoperability. The inclusion of NFRs associated with the assets (such as privacy, security, rights, costs) within the metadata elements is a second related activity that requires close coordination.

Although the topic of business models is important, it appears to be sufficiently solved for the present although the deployments from the new systems development environments – including placement – may give rise to a need for further research in this area.

3.3. Initial Roadmap

All the above leads to a proposed initial roadmap for the EC workprogramme covering ‘CLOUDS and Beyond’ from 2018.

The maximum importance and urgency rests with systems development methods appropriate to meet the challenges of both FRs and NFRs required by the business objectives in their applications. The most urgent sub-topic is the provision of models for such a systems development environment using model-driven systems development techniques. The Complete Computing paradigm[6] is particularly relevant here.

One urgent and important sub-topic is the provision of a canonical metadata model of elements (with which other metadata standards can interoperate) to characterize assets. R&I (Research and Innovation) in this area benefits not only systems development but also placement, interoperability, security (including SLAs) and business models. This metadata is utilised by the middleware to effect and optimize deployment.

Related to systems development, the topic of placement and its optimization requires R&I. The planning and deployment of applications based on knowledge gained from previous deployment monitoring and expert advice is critical to enhanced systems development deployments but also to interoperation. The canonical metadata elements mentioned above is a critical and urgent factor of success in placement and forms the basis for the knowledge base to be used in steering placement in systems development and in execution.

An appropriate machine-actionable representation of NFRs - including the elements of an SLA – is important and urgent and should be integrated with the canonical metadata described above so that the NFRs are taken into account in systems development, placement and execution. However, the key success criterion is the representation being carried pervasively though all the software stack deployed and used (i.e. external platforms) by the application. Only in this way can NFR integrity be guaranteed.

The urgent and important aspect of interoperability is the canonical metadata elements. This has been recognized by RDA (Research Data Alliance)[7] and there are several groups working on this aspect. Interoperation requires – as well as discovery – contextualization (including provenance) for assessing quality and relevance and then mapping and conversion based on the available metadata. This is a difficult R&I topic but is key to successful placement and systems development in CLOUD computing.

The inter-relationships are indicated in Fig. 1.

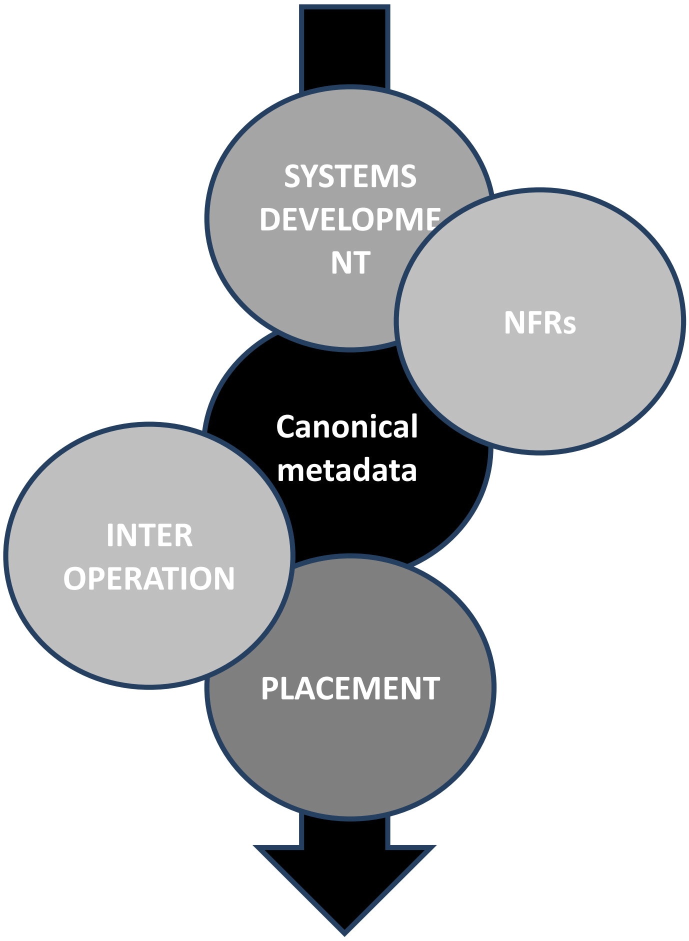

Fig. 1: Roadmap Item Relationships

Acknowledgements

The authors acknowledge gratefully the contributions from authors successful in CF2016. Their papers were abstracted and synthesized in this paper. The order of authors/papers below is the planned programme order at the conference.

The successfully reviewed position papers in CF2016 are:

Author(s)	Title
Pedro Garcia Lopez; Marc Sanchez Artigas; Raul Gracia Tinedo; Alberto Montresor	Towards Data-driven Software-Defined Infrastructures
Constantinos Vassilakis; Anastasios Zafeiropoulos; Eleni Fotopoulou; Panagiotis Gouvas	A Context Model and Policies Management Framework for Reconfigurable-by-design Distributed Applications
Emanuele Carlini; Patrizio Dazzi; Matteo Mordacchini;	An holistic approach for high-level programming of next-generation data-intensive applications targeting distributed heterogeneous computing environment
Lara Lopez; Francisco Javier Nieto; Sokol Kosta; Terpsichori-Helen Velivassaki; Cheol-Ho Hong; Raffaele Montella	Heterogeneous Secure Multi-level Remote Acceleration Service for Low-Power Integrated Systems and Devices
Ana Juan Ferrer; David García Perez; Román Sosa González	In-Network Programmability for next-generation personal cloUd service support (INPUT)
Mohit Taneja; Alan Davy	Resource aware placement of data analytics platform in fog computing
Ana Juan Ferrer	Inter-Cloud Research: Vision for 2020
Erkuden Rios; Massimiliano Rak	Inter-cloud challenges towards Free Flow of Data
Matthew Viljoen; Łukasz Dutka; Bartosz Kryza; Yin Chen	Towards European Open Science Common: The EGI Open Data Platform and The EGI DataHub
Stefano Souza	Client-side encryption for privacy-sensitive applications on the cloud

In addition to utilising the successfully reviewed position papers, the successfully reviewed scientific track papers were scanned for new ideas and proposals suitable for inclusion in a roadmap:

Author(s)	Title
Kyriakos Kritikos; Pierluigi Plebani; Dimitris Plexousakis	Semantic SLAs for Services with Q-SLA
Gaetano Anastasi; Massimo Coppola; Patrizio Dazzi; Marco Distefano	QoS Guarantees for Network Bandwidth in Private Clouds
Kyriakos Kritikos; Philippe Massonet	An Integrated Security Meta-Model for Run-Time and Design Time Cloud Deployment Adaptation
Massimiliano Rak; Valentina Casola; Alessandra De Benedictis; Erkuden Rios	Security-by-design in clouds: a Security-SLA driven methodology to build secure cloud applications
Iosif Alvertis; Sotirios Koussouris; Dimitris Papaspyros; Evangelos Arvanitakis; Sebastian Franken; Sabine Kolvenbach; Wolfgang Prinz	User Involvement in Software Development Processes
Beniamino Di Martino; Antonio Esposito	Semantic Techniques for Multi-Cloud Applications Portability and Interoperability
Giuliano Casale; Cristina Chesta; Peter	Current and Future Challenges of Software Engineering for

Deussen; Elisabetta Di Nitto; Panagiotis Gouvas; Sotiris Koussouris; Vlado Stankovski; Andreas Symeonidis; Vlassis Vlassiou; Anastasios Zafeiropoulos; Zhiming Zhao	Services and Applications
Hong-Linh Truong; Schahram Dustdar; Frank Leymann	Towards the Realization of Multi-dimensional Elasticity for Distributed Cloud Systems
Antonios Makris; Konstantinos Tserpes; Dimosthenis Anagnostopoulos; Vassiliki Andronikou	A classification of NoSQL data stores based on key design characteristics
Juncal Alonso; Marisa Escalante; Leire Orue-Echevarria	Transformational Cloud Government (TCG): Transforming Public Administrations with a Cloud of public services
Ana Juan Ferrer; David García Perez; Román Sosa González	Multi-Cloud Platform-as-a-Service Model, Functionalities and Approaches

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