Systematic survey on evolution of cloud architectures

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Abstract: Cloud architectures are becoming an active area of research. The quality and durability of a software system are defined by its architecture. The architecture approaches that are used to build cloud-based systems are not available in a blended fashion to achieve an effective universal architecture solution. The paper aims to contribute to the systematic literature review (SLR) to assist researchers who are striving to contribute in this area. The main objective of this review is to systematically identify and analyse the recently published research topics related to software architecture for cloud with regard to research activity, used tools and techniques, proposed approaches, domains. The applied method is SLR based on four selected electronic databases proposed by Kitchenham and Charters (2007). Out of 400 classified publications, we regard 121 as relevant for our research domain. We outline taxonomy of their topics and domains, provide lists of used methods and proposed approaches. At present, there is little research coverage on software architectures for cloud, while other disciplines have become more active. The future work is to develop a secure architecture to achieve quality of service and service level agreements.

Keywords: cloud computing; software architectures; quality of service; service level agreement; resource and service management; security.

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1 Motivation and background

Cloud architectures are becoming an active area of research. As we know the architecture plays a crucial role in the design and development of software systems. A good architecture can ensure that a system will satisfy key requirements in such topics as performance, reliability, scalability and interoperability. In spite of this, the on-demand, scalable and rapid provisioning nature of cloud poses serious obstacles to any architecture. So the task is to design and develop an effective security architecture that will support cloud environment. As of now there is little contribution to systematic literature review for mapping software architectures and cloud environment.

This literature review aids researcher who is ambitious to contribute in this area, without investing time in doing a detailed literature survey.

1.1 Introduction to cloud computing

Cloud computing is an emerging new computing paradigm for delivering IT services, cloud computing became an attractive option for cloud service providers and consumers. Cloud is a pool of shared resources which can be served rapidly with minimal

management (Blank, 2011). The main cloud services are software; platform and infrastructure are provided as services. The deployment models are private cloud, public cloud, hybrid cloud and community cloud. The key feature of this computing is the ability to deliver services as pay per use basis. Service level agreements are used for specification of QoS (Duan et al., 2012) requirements between cloud service providers and cloud service users, which helps to meet quality of service. However, software as a service refers to applications that are delivered to customers over the network on the basis of pay-as-you-go. The idea behind platform as a service is to provide a software development platform as a service, including deployment, execution and testing. The infrastructure as a service provides computational infrastructure as a service which are processed, desktop, storage and a lot more. A cloud environment that is shared among different clients is called public cloud, the infrastructure which is owned and maintained by an organisation will provide as services on the basis of billing. Some organisations build or rent to have an own cloud infrastructure because of security reasons. This is called private cloud, operated exclusively for an organisation. Hybrid cloud is a combination of private and public cloud, where part of an application runs on a public cloud and other part runs on a private cloud. If two or more organisations have similar interests they build or rent dedicated environment, then it is community cloud (Buyya et al., 2009; Ali et al., 2015). To conclude, no other technology has shown greater impact as cloud computing on IT industry, research and academics.

1.2 Software and cloud architectures

The software architecture of a computing system is a representation of the system that helps in understanding of how the system will work. A good architecture can help and ensure that a system will satisfy key requirements in such topics as performance, reliability, portability, scalability, and interoperability. The software architecture of a system is the set of structures needed to reason about the system, which comprise software elements, relations among them, and properties (Bass and Kazman, 2012). So architectures play a crucial role in the design and development of software systems.

Cloud architecture aids in the design and development of cloud application which must be scalable, on-demand, automated and ubiquitous services. The application which runs on cloud infrastructure should utilise the resources when it requires and release them after a job is finished and the resources can be elastically provisioned based on application demand. The cloud architectures must ensure the provisioning of services, security, load balancing, scheduling, service level agreement, quality of service and lot more. However, rapid provisioning and flexibility that cloud computing offers to pose serious obstacles to any cloud architecture.

The NIST cloud reference architecture is a high level architecture which is not specific to any cloud vendor that helps in discussing the requirements, structures and operations of cloud (Liu et al., 2011). It defines a set of actors, activities, methods and standards in order to develop cloud architecture. The actors are cloud consumer, cloud provider, cloud broker, cloud auditor, and cloud carrier which helps to gather functional and non-functional requirements from stakeholders to develop cloud enabled application satisfying service level agreements and quality of service. The IBM cloud reference architecture (Stifani et al., 2012) is also widely accepted architecture which presents three main roles which are cloud service provider, cloud service consumer and cloud service creator.

1.3 Research questions

The main intention of this paper was to find and interpret the published literature related to software architecture and cloud environment. This is further detailed in the following research questions:

RQ1 How much activity was carried out in the last four years?

RQ2 What research topics are being addressed?

RQ3 What are the different tools, standards and technologies that were used?

RQ4 What are the different application domains/case studies implemented?

RQ5 What are the different cloud setups that have been adopted?

1.4 Related work

There are systematic literature reviews on different topics in cloud computing. And Chauhan (2014) conducted a systematic mapping of software architectures for cloud environment. They did a systematic literature review of journals and conferences from January 2008 to July 2011.

Since then, the number of publications in the domain has increased and we focused on a systematic literature review from January 2011 to August 2014 from all repositories with different search strings.

2 Search strategy

We performed our search on scientific electronic databases which includes high impact factor conferences, journals and articles. The search process follows the guidelines suggested by (Kitchenham and Charters, 2007). Refer to Table 1 for a list of selected electronic databases.

Table 1 Selected electronic databases

Electronic database	*URL*
IEEE	http://ieeexplore.ieee.org
ACM	http://dl.acm.org
Science direct	http://www.sciencedirect.com
Springer	http://www.springerlink.com

2.1 Search string

Search string helps to capture all results related to cloud architectures and software architectures. The reasons for searching with cloud services and architecture as keywords is to ensure all relevant papers are included. The search string used on all databases is:

(Cloud architecture OR cloud framework OR cloud model OR cloud computing) AND (Software architecture) AND (Software as a service OR platform as a service OR infrastructure as a service)

2.2 Inclusion criteria and exclusion criteria

In order to include relevant publications in our review, we defined selection criteria and based on that we performed inclusion and exclusion of published literature. We selected papers published in peer review conferences, journals from 1/1/2011 to 18/8/2014. We selected papers that are relevant to our research questions. We excluded papers that are not related to software architecture and cloud. Table 2 shows our inclusion and exclusion criteria.

Table 2 Inclusion and exclusion criteria

Inclusion criteria	*Exclusion criteria*
Publications from 1/1/2011 on software architectures related to cloud.	Publications before 2011 and after 18/8/2014
Papers published in journals and conferences	Articles, book reviews and editorials
Published in peer reviewed studies	Published in non-peer reviewed studies
Publications that are related to research questions	Architectures from general and other computer science areas apart from cloud

2.3 Roles and responsibilities

- Bharath Bhushan (VIT, research scholar): result classification and detailed analysis for various journals and papers from IEEE, ACM, Science direct, and SpringerLink
- Dhenesh V Subramanian (VIT, expert reviewer): assessment of classification and detailed analysis
- Pradeep Reddy and Gao, expert reviewers: assessment of search result classification and detailed analysis.

2.4 Conference and journal selection process

The process was conducted as follows:

1 the researchers perform the search on each database and save the references in bibliography files

2 the scholar reads all titles and abstracts and checks the inclusion and exclusion criteria for each entry

3 the scholar classifies the conferences and journals according to type, topic, and domain

4 the expert reviewer reassesses the classification and inclusion/exclusion of search results.

2.5 Data analysis

The data is analysed to show:

1 the databases and number of query results

2 the publications are listed as per databases with respect to authorship, reference, date, publication type, type of content, topic of content and domain

3 the number of relevant publications per year with respect to venues

4 the graph that will show publication of journals and conferences, which are generated from the final results

5 a detailed selection process performed on selected databases.

3 Results

The distribution of results for each database related to search criteria is listed in Table 3.

Table 3 Number of results per database

Database	*Search date*	*Results (%)*
IEEE	12/8/2014	37.19
ACM	12/8/2014	23.96
Science direct	14/8/2014	27.27
Springer	14/8/2014	11.57

All results were ordered 'by relevance' as shown by the databases. From these results, we considered the first 100 results of each database in our first repetition of the study. In total we reviewed 400 publications.

The following acronyms are used to categorise the results in Tables 4–7.

- *Publication:* The included publications classified as journals, conference paper.
- *Type:* What kind of information was presented in the publication, e.g., method, model, review, tool, case study.
- *Topic:* The exact intention and purpose of the publication.
- *Area:* We classified publications into five areas, namely: resource management, service management, quality of service, security and cloud application. This will also ensure the publications are relevant to include in the review.

RQ1 How much activity was carried out in last four years?

We plotted a number of relevant publications per databases in Figure 2, per publication type in Figure 3 and per year in Figure 4. In the last four years, there was a noteworthy increase in number of publications compared with 2008 to 2011 that shows the significance of the review on cloud architectures. The first paper on cloud architectures was published in 2008 addressing architecture of cloud for applications. Kitchenham and Charters (2007) did a literature review on cloud architectures from 2008 to 2011, where a significant increase in number of publications that focused mainly on quality, multi-tenancy, frameworks, security and application domains. The papers mainly focused on horizontal research rather than a vertical approach. Figure 4 shows numbers of papers published from 2011 to 2014.

However, there are only 18 papers in 2014. We performed searches in August 2014 and all the papers had not been available by that time it might be the reason for less number of papers in 2014.

The reviewed papers will help in building up a body of knowledge in cloud architectures.

Figure 1 Selection process

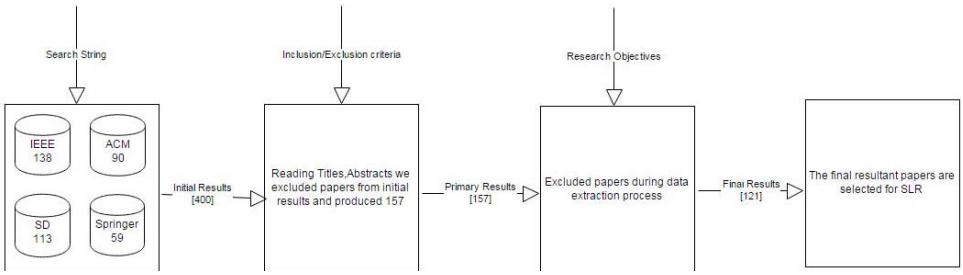


Figure 2 Included results per database

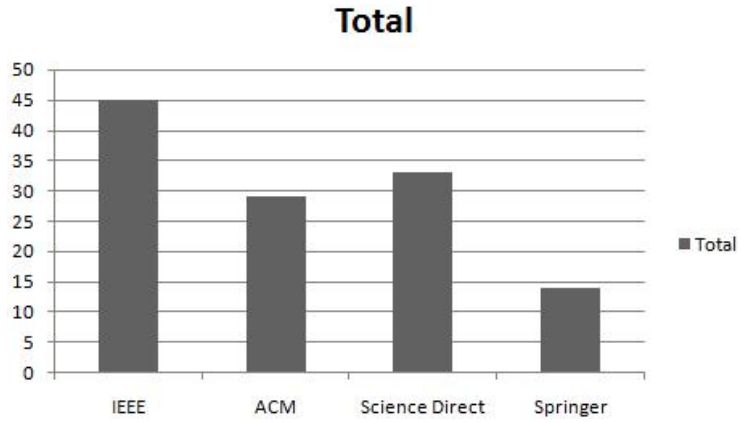


Figure 3 Included results per publication type (see online version for colours)

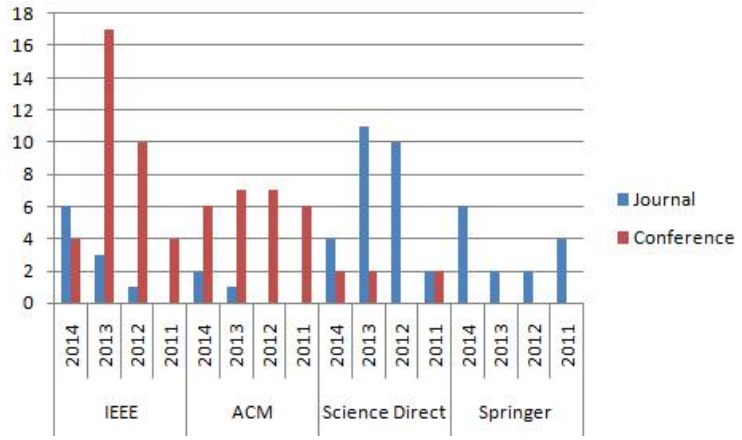
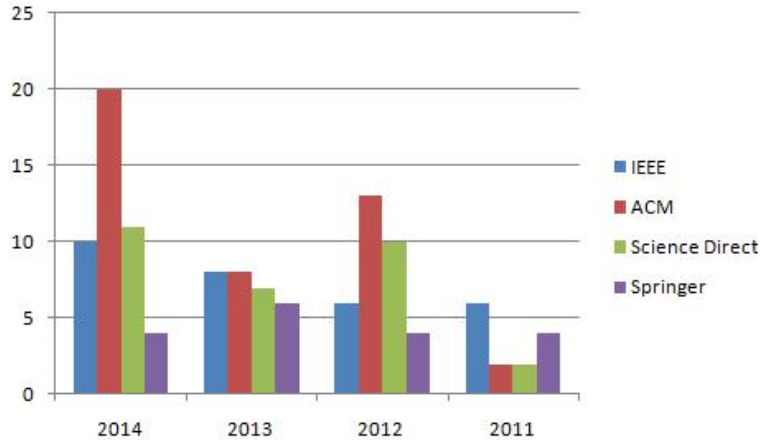


Figure 4 Included results per year (see online version for colours)



RQ2 What research topics are being addressed?

To know the research topics that are focused in cloud architectures, we have generated a weighted topic and taxonomy in Figure 5, which are derived from titles, keywords and topics are shown in Tables 4–7. The research topics are broadly classified into, resource management, service management, quality of service (QoS), security and cloud application domain.

The research topics that are considered under resource management deals with management of infrastructure like servers, storage, computing power, network, topics that deal with management of services that are delivered by the cloud service provider like cloud applications, infrastructure, platform and anything as a service is under resource management, topics that deal performance, reliability, availability, fault tolerance, incident response, SLA is under quality of service, topics that deal with cloud network, data security, trust management, secure architectures, secure services and a lot more are under security management, the papers that deal with cloud applications are under the application domain (Xu et al., 2014).

RQ3 What are the different tools, standards and technologies that were used?

There is a wide variety of tools and technologies being used in studies listed in Table 7. We classified them according to research topics where they were explicitly used. A possible reason for it can be, they tend to provide generic solutions. Eucalyptus, open nebula, nimbus and open stack tools are chosen by most of the researchers for cloud setup. Aneka, Greencloud and Cloudsim tools are used for building applications and managing resources in a cloud environment. Many of the researchers have chosen Java because of their platform independent nature and the virtualisation technologies they used like Xen, VMware and KVM. They have used Microsoft azure and Google app engine as a platform for their experiments. And few use Nagios for network, infrastructure monitoring and IBM Tivoli for network management (Vasilakos, 2008). Most of the studies adopted standards for communication and security.

Table 4 Included results from IEEE Xplore

Author	*Date*	*Publication*	*Type*	*Topic*	*Area*
Xu et al.	2013	Journal	Model	Efficient framework for resource management	Resource management
Bohli et al.	2013	Journal	Method	Multicloud architectures	Security
Xiao et al.	2014	Journal	Model	Automatic scaling of cloud applications	Resource management
Konig et al.	2012	Journal	Model	Elastic monitoring framework	Resource management
Kaewpuang et al.	2013	Journal	Model	Framework for cooperative resource management	Resource management
Paik et al.	2014	Journal	Method	Architecture for automatic service composition	Service management
Misra et al.	2014	Journal	Model	Learning automata-based QoS	QoS
Varadharajan et al.	2014	Journal	Model	Security as a service model	Security
Castro et al.	2014	Journal	Method	Architecture for service management	Service management
Ignacio et al.	2014	Journal	Model	Goal-oriented discovery of resources	Resource management
Waqas et al.	2013	Conference	Method and model	Security-based survey and classification of cloud architectures	Security
Galloway et al.	2012	Conference	Study	Power aware load balancing	QoS
Bojanova et al.	2011	Conference	Model	Cloud computing delivery architecture	Service management
Acharya et al.	2013	Conference	Method	Dynamic provisioning mechanisms	Service and resource management
Polito et al.	2013	Conference	Method and model	Discovery of end-to-end QoS resources	QoS and resource management
Talib et al.	2011	Conference	Model	Data storage based on multi agent system	Resource management
Zou et al.	2013	Conference	Model	Hybrid cloud architecture based on cloud bus	Service and resource management
Xu et al.	2013	Conference	Model	Management as a service cloud	Service and resource management

Table 4 Included results from IEEE Xplore (continued)

Author	*Date*	*Publication*	*Type*	*Topic*	*Area*
Saad et al.	2012	Conference	Model	Cloud architectures based ids	Security
Horrow et al.	2012	Conference	Model	Secure cloud architecture for mobile iaas	Security
Hassan et al.	2012	Conference	Model	Architecture for cloud applications	Service and resource management
Liao et al.	2011	Conference	Method	Dynamic vpn architecture for private cloud	Security and QoS
Dong et al.	2013	Conference	Method and model	Proactive cloud management architecture	QoS and resource management
Gudenkauf et al.	2013	Conference	Model	Architecture for cloud services	Service management
Baron et al.	2013	Conference	Method	Architecture for a resilient cloud infrastructure	Security
Zhang et al.	2012	Conference	Model	Cloud architecture based-on soa	Service management
Khalil et al.	2013	Conference	Method and model	Cloud architectures based multi tenant ids	Security
Yongqing et al.	2012	Conference	Method and model	Desktop cloud-based authentication	Security
Al-Rayis et al.	2013	Conference	Model	Load balancing architectures for cloud	Resource management
Alodib et al.	2013	Conference	Method	Qos-aware energy management architecture	QoS
Thorpe et al.	2013	Conference	Model	Forensic-based service oriented architecture for auditing	Security
Sugumaran et al.	2014	Conference	Method and model	Architecture for data security	Security
Lohmosavi et al.	2013	Conference	Model	E-learning ecosystem based on soa	Service and resource management
Hulkury et al.	2013	Conference	Model	Integrated green cloud architecture	QoS
Abolfazli1 et al.	2012	Conference	Model	Market-oriented architecture for mobile cloud	Service management
Khaldi et al.	2014	Conference	Model	Secure cloud computing architecture design	QoS and resource management
Ponte et al.	2014	Conference	Model	SOA for flexible pricing in cloud	Service management
Srivastaval et al.	2011	Conference	Model	Proactive model for security in cloud	Security
Gall et al.	2013	Conference	Method	Community clouds using concepts of the intercloud	Resource management and security
Hayward et al.	2013	Conference	Method	Fully homomorphic cryptography on cloud	Security
Waqas et al.	2014	Conference	Model	Resources sharing between clouds	Resource management
Kulkarni et al.	2012	Conference	Method	Cloud storage architecture	Resource management
Mechtri et al.	2013	Conference	Model	Inter-cloud networking gateway architecture	Resource management
Luo et al.	2012	Conference	Model	QoS architecture for cloud-based media	QoS
Fusenig et al.	2012	Conference	Model	Secure architecture for cloud	Security

Table 5 Included results from ACM

Author	*Date*	*Publication*	*Type*	*Topic*	*Area*
Mitchell et al.	2014	Journal	Study	Intrusion detection techniques for cyber-physical systems	Security
Toosi et al.	2014	Journal	Study	Interconnected cloud computing environments	Resource and service management
Noor et al.	2013	Journal	Method	Trust management of services in cloud	Security
Murakami et al.	2014	Conference	Method	Protecting guest information from malicious operators with memory management	Security
Ahmad et al.	2014	Conference	Method	Architecture-driven migration of legacy systems to cloud-enabled software	Resource and service management
Fernandez et al.	2014	Conference	Model	A security reference architecture for cloud	Security
Kim et al.	2011	Conference	Model	Infrastructure as a service architectures	Resource and service management
Cardellini et al.	2011	Conference	Case study	Flexible and modular architecture for a private cloud	Service management
Leite et al	2014	Conference	Case study	An autonomic cloud architecture for executing parallel applications	Resource and service management
Dash et al.	2012	Conference	Method	Privacy preserving k-medoids clustering	Security
Faniyi et al.	2012	Conference	Method	Self-managing SLA compliance in cloud	Resource and service management
Chen et al.	2012	Conference	Method and model	Symbiotic and sensitivity-aware architecture	QoS
Kelley et al.	2014	Conference	Model	Distributed architecture for intra- and inter- cloud data management	Resource management
Comer et al.	2011	Conference	Model	Future internet architecture to supports cloud computing	Resource and service management

Table 5 Included results from ACM (continued)

Author	*Date*	*Publication*	*Type*	*Type*	*Area*
Masti et al.	2013	Conference	Model	Architecture for concurrent execution of secure environments	Security
Li et al.	2014	Conference	Model	Dynamic resource sharing architecture	Resource management
Paraiso et al.	2013	Conference	Method	Managing elasticity across multiple cloud providers	Resource management
Banerjee et al.	2013	Conference	Method	Lightweight mobile cloud offloading architecture	Resource management
Li et al.	2013	Conference	Method	Supporting user-configured privacy protection in cloud	Security
Ramanathan et al.	2013	Conference	Case study	Sense-respond cloud mediator architecture for services	Service management
Schroeter et al.	2012	Conference	Model	Modelling a variable architecture for multi-tenant saas-applications	Service management
Bates et al.	2013	Conference	Method	Secure provenance-based access control in cloud	Security
Rahaman et al.	2012	Conference	Model	Preserving privacy in cloud computing with user service dependent identity	Security
Torkashvan et al.	2012	Conference	Model	Service oriented framework for cloud	Service management
Xu et al.	2013	Conference	Model	Availability analysis for deployment of in-cloud applications	Resource and service management
Pervez et al.	2011	Conference	Method	Chord based session management framework for cloud	Resource management
Babaoglu et al.	2011	Conference	Model	Design and implementation of a p2p cloud system	Resource management
Dhage et al.	2011	Conference	Model	Intrusion detection system in cloud	Security
Wailly et al.	2012	Conference	Model	Multi-layered self-protection for cloud	Security

Table 6 Included results from science direct

Author	*Date*	*Publication*	*Type*	*Topic*	*Area*
Chunga et al.	2012	Journal	Simulation	Goal-oriented simulation approach for obtaining good private cloud-based system architectures	Cloud app
Alvaro et al.	2012	Journal	Method	Cloud computing architecture for music composition	Cloud app
Povedano-Molina et al.	2013	Journal	Model	Highly adaptable and scalable monitoring architecture for multi-tenant clouds	Resource and service management
Gu´erout et al.	2012	Journal	Method	QoS modelling for green scheduling in clouds	Resource management
Bernabe et al.	2012	Journal	Model	Semantic-aware multi-tenancy authorization system for cloud	Security
Dukaric et al.	2012	Journal	Study and model	Unified taxonomy and architecture of cloud	Resource management
Wang et al.	2014	Conference	Model	Workflow as a service in the cloud	Resource and service management
Rezaei et al.	2014	Journal	Method	Semantic interoperability framework for saas systems	Service management
Wang et al.	2013	Journal	Method	An interoperable solution for cloud	Service management
Li et al.	2011	Journal	Model	Security assurance architecture for green cloud	Security
Jin et al.	2011	Conference	Model	Multi-agent-based cloud architecture	Resource management
Tang et al.	2011	Conference	Model	Mobile thin client architecture in cloud	Resource management
Kaloxylos et al.	2013	Journal	Model	Cloud-based farm management system	Cloud app
Naqvia et al.	2014	Conference	Model	Quality-aware federated framework for smart mobile apps in cloud	QoS
Whaiduzzaman et al.	2013	Journal	Study and model	Survey on vehicular cloud computing	Resource and service management
Kertesz et al.	2012	Journal	Model	Interoperable and self-adaptive approach for SLA-based service virtualization	Service management
Fan et al.	2014	Journal	Model	Novel trust management framework for multi-cloud environments	Security

Table 6 Included results from science direct (continued)

Author	*Date*	*Publication*	*Type*	*Topic*	*Area*
Sookhak et al.	2014	Journal	Study and method	Remote data auditing in single cloud server	Security
Fabian et al.	2014	Journal	Model	Secure sharing of healthcare data in multi-clouds	Security
Vissers et al.	2013	Conference	Method	Ddos defence system for web services in a cloud	Security
Chen et al.	2013	Conference	Model	Dynamic QoS optimization architecture for cloud based dddas	QoS
Montesa et al.	2013	Journal	Model	Complete approach to cloud monitoring	Resource and service management
Li et al.	2013	Journal	Method	Privacy-preserving data utilization in hybrid clouds	Security
Emeakarohaa et al.	2011	Journal	Model	Autonomic detection of SLA violations in cloud	Service management
Calheiros et al.	2012	Journal	Model	Coordinator for scaling elastic applications	Resource and service management
Garg et al.	2012	Journal	Model	Framework for ranking of cloud services	Service management
Wu et al.	2013	Journal	Method	Energy-efficient scheduling algorithm	Resource management
Lloret et al.	2013	Journal	Model	Architecture and protocol for intercloud communication	Resource and service management
Liu et al.	2013	Journal	Method	Cloud service access control system based on ontology’s	Service management
Zou et al.	2013	Journal	Method	Trusted monitoring framework for cloud	Security
Caballer et al.	2013	Journal	Case study and method	Elastic cloud computing cluster	Resource management
Javadi et al.	2012	Journal	Method	Failure-aware resource provisioning for hybrid cloud	Resource management
Casalicchio et al.	2012	Journal	Method	Mechanisms for SLA provisioning in cloud	Service management

Table 7 Included results from Springer

Author	*Date*	*Publication*	*Type*	*Topic*	*Area*
Khan et al.	2012	Journal	Model	Integrating intelligence in urban management	Cloud app
Wang et al.	2012	Journal	Study	Enterprise cloud service architectures	Service management
Colombo-Mendoza et al.	2014	Journal	Model and app	Paas for cloud services-based mobile applications	Model and cloud app
Muñoz et al.	2013	Journal	Model	Constructing resilient services on federated hybrid clouds	Service management
Qi et al.	2014	Journal	Model	Sierpinski triangle-based data centre architecture	Resource management
Chapman et al.	2011	Journal	Model	Architecture for on-demand cloud provisioning	Service and resource management
Hussain et al.	2014	Journal	Model	Software quality in the clouds	Qos and security
Hu et al.	2011	Journal	Model	Green private cloud architecture	Qos
Chen et al.	2011	Journal	Model and method	Integrated management of diverse cloud resources	Resource management
Vilaplana et al.	2014	Journal	Method	Queuing theory model for cloud	Qos
Beach et al.	2013	Journal	Method	Cloud architecture for engineering & construction sector:	Cloud app
Ros et al.	2014	Journal	Method	Cloud architecture for web applications with load forecasting mechanism	Resource management
Perez-Sorrosal et al.	2011	Journal	Method	Consistent and scalable caching in multi-tier architectures	Resource management
Joshi et al.	2014	Journal	Method	Fault tolerance mechanisms for virtual data centre architectures	Resource management

RQ4 What is the different application domains/case studies implemented?

We classified publications as case studies when they were explicitly specified in the abstract. The study (Caballer et al., 2013) assessed the effectiveness of an elastic virtual cluster on a cloud infrastructure, tries to analyse the usage of EC3 solution and to execute an HTC-based scientific application. A similar study (Cardellini and Iannucci, 2012) implements Linux terminal server project (LTSP) which is a free and open source terminal server for Linux that allows many users to simultaneously use the same computer. Another study (Leite et al., 2014; Zhou et al., 2015) executes without auto scaling, by simulating user preferences, where an instance is selected either upon their

knowledge or the amount of computational resources offered by an instance, it also evaluates the architecture that will scale for a cloud unaware application. Study by Ramanathan et al. (2011) illustrates an adaptive complex environment and it accommodates service progression from simple to the complex, achieving the overall mayoral goals to make a city the finest place to live, work, and raise a family. The case studies imply that there is still relatively little research in having cloud applications. The application domains are listed in Table 9.

Figure 5 Weighted research topic cloud

Figure 6 Taxonomy of research topics (see online version for colours)

Table 8 Tools and technologies

Category	*Tools, standards and technologies*
Resource management	Python, Oracle Virtual Box, OAuth, XML, MySQL, health insurance portability and accountability act (HIPAA), Amazon EC2, Microsoft Azure, Xen, PHP, Google App Engine (GAE), Nagios, Gangila, Command Description Language (CDL), Groovy, Smart Frog, GoGrid, Open Stack, Aneka, Open Nebula, REST, Resource Description Framework (RDF), Scrappy, XPath, DOM, WADL, Template Design Language (TDL), Service Provider Markup Language (SPML), XMPP, XACML, SAML, VmwareVcloud, Cloud Sigma, JCloud, Open Science Data Cloud (OSDC), IBM Blue Cloud, Open Virtualization Format (OVF), Essential Meta -Object Facility (EMOF), Java, C++, HUTN (Meta Language), Business Process Execution Language (BPEL), VMWare, Xen.
Service management	Java, NASC Development Kit, OWL-S (Semantic Web Service Composition Framework), Web Service Modeling Ontology (WSMO), Web Service Modeling Language WSML,
	IBM Tivoli, HP Network Management Center, Nagios, Splunk, Jasper Report, Distributed Management Task Force (DMTF), Web based Enterprise Management (WBEM), Cloud Infrastructure Management Interface (CIMI), SPML, Nimbus, JSON, PHP, WS -BPEL (Business Process Execution Language), Java Messaging Service (JMS) API,
	Sniffer pro 4.70.04, Resource and Application Description Language (RADL), Kepler, Django.
Quality of service	WS-Agreement Specification, OMNET++, OpenVZ, Eucalyptus, Universal Description, Discovery and Integration (UDDI), IBM Tivoli Manager, JOnAS Java EE Application Server, CloudSim, Sage 5.3 Mathematical Software, Apache Jmeter.
Security	Security Assertion Markup Language (SAML), OpenID, Ontology Web Language (OWL), Sematic Web Rule Language (SWRL), FaCT++, Pellet, Payment Card Industry Data Security Standard (PCI DSS), FISMA (US Fedral Information Security Management Act), FedRAMP (Fedral Risk and Authorization Management Program), XACML, Host Based Security Tools (HBST), Intrusion Detection Message Exchange Format (IDMEF), Cloud Visor.
Cloud applications	SOAP,WSDL,KVM,XML-RPC, JSON, PHP, AJAX, Cloud BIM, Cloudsim, JSON, LISP, Python, SOA,

RQ5 What are the different cloud setups that have been adopted?

Cloud setup is a platform for experimentation of large development projects. We find various cloud setups that were used in our studies listed in Table 10. This setup uses different tools and technologies (see Table 8) for different purposes, but this body of knowledge provides to setup our own cloud environment with respective to our experiments.

Table 9 Application domains

Application domains	*Reference*
Transportation system	Chung et al. (2012)
Music composition	Alvaro and Barros (2012)
Farm management	Kaloxylos et al. (2013)
Healthcare	Fabian et al. (2014), Fortino et al. (2014)
Urban management	Khan et al. (2012)
E-learning system	Ros et al. (2014)
Construction sector	Beach et al. (2013)
Vehicular computing	Whaiduzzaman et al. (2013), Vasilakos et al. (1998)
Video streaming	Luo et al. (2012)
Forensic	Thorpe et al. (2013)
E-government	Ramanathan et al. (2011)
E-commerce	Yao et al. (2013)
Cyber physical system	Dukaric and Juric (2012)
Enterprise cloud service	Colombo-Mendoza et al. (2014)
Mobile application	Heyong Wang et al. (2012)

4 Discussion

This section provides a discussion of the results and limitations for this study.

4.1 Conclusions on the state of the art

After synthesising data collected through this SLR, we observed number of research trends in resource management, service management, quality of service, security, CloudApp and few research challenges were not addressed properly. The maturity of cloud architectures is still in its early stages.

However, we can find a clear growth in maturity and researchers need to focus on a vertical approach. More case studies will improve the confidence of researchers and practitioners regarding the benefits of cloud architectures.

4.2 Conclusions for a body of knowledge

After analysing the results of SLR, the body of knowledge has areas that represent cloud architectures which deals with resource management, service management, quality of service, security, cloud-app and various tools and technologies those are used in the study. This is illustrated in Figure 7.

Table 10 Cloud setups

Study reference	*Cloud setup*
Xu and Li and (2013)	• 20 Dual-Core intelxeon 3.0 GHZ connected through Gigabit Ethernet • Each machine has 2GB Memory • Each VM have 1.5 GHZ CPU and 256 MB RAM. • All machines run Ubuntu 8.04.4 LTS with Linux 2.6.24–28 Server • A cluster of Dual intelxeon 2.4 GHZ servers are used to generate workload • Anchor machine with Ubuntu 8.10 server, Apache 2.2.9, PHP 5.2.6 and Mysql 5.0.6.7
Zhen Xiao et al. (2014)	Load Shifting • Three servers and three applications • Each server with Intel E5420 CPU, 8 GB RAM and run on Xen 3.3.1 Auto Scaling • 30 Dell power edge servers with Intel E5620 CPU, 24 GB RAM and 9 applications • Server runs on xen-4.0 and Linux 2.6.18
Misra et al. (2014)	• 3 vm's in Bangalore with nimbus 2.9 infrastructure. Hardware Specification Intel xeon 3.16GHZ, 1GB RAM, 100GB HD. Software Specification RHEL 5.1, Intel MK Libraries and Netcdf libraries. • 2 vm's in Hyderabad with nimbus 2.9 infrastructure. Hardware Specification Intel xeon 3.16GHZ, 1GB RAM, 120GB HD. Software Specification Scientific Linux • 2 vm's in Chennai with nimbus 2.9 infrastructure. Hardware Specification Intel xeon 3.16GHZ, 1GB RAM, 80GB HD. Software specification Centos, Intel MK Libraries

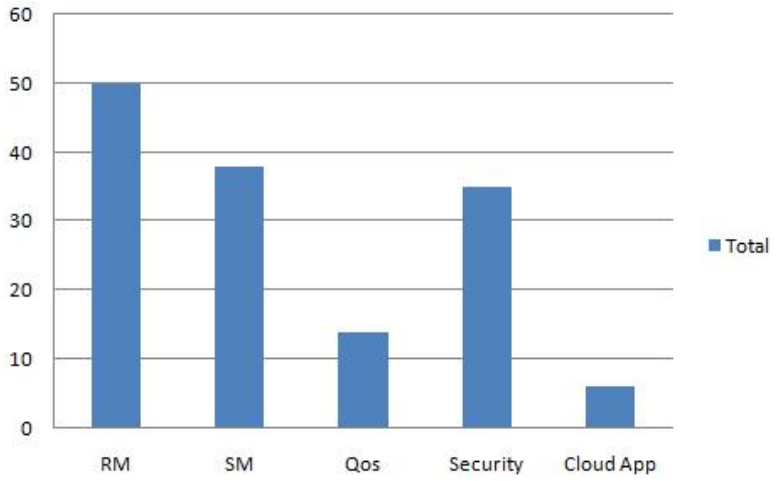
Table 10 Cloud setups (continued)

Study reference	*Cloud setup*
Varadharajan and Tupakula (2014)	• Xen hypervisor • Vm Dom 0 is used for hosting and management of virtual machine • 1 Vm based on Linux and another windows Vm running on xen • SPECJvm benchmark were installed on DOM 0 of xen with following specifications, Intel i7 2.2 GHZ, 6M cache with 8 GB RAM, Xen 3.12 VMM, centos 5.1 • Vm running with windows xp sp2 and linuxos with 512 MB RAM
Munoz et al. (2013)	• The testing setup has 250 vm's in which 10 vm's for USC, 90 vm's for PIC and 150 vm's for CC.IN 2P3 • PIC hosts are BL460C Blade with 8 cores intelxeon L5420, 2.50 GHZ and 16 GB RAM • CC.IN2P3 hosts are Dell Power Edge C6100 systems with 24 cores intelxeon X5675 3.07 GHZ and 96 GB RAM • USC hosts are AMD 6400 MT with 16 cores AMD Opteron 6128 magany 2.0 GHZ and 16 GB RAM
Perez-Sorrosal et al. (2011)	• Cluster of 10 machines connected through 100mbps switch, each node have 2 AMD Athlon 2GHZ CPU's, 1GB RAM, two 320 GB HD and runFedro Linux • JEE application server • JonAS v.4.7.1 application server, postgresql v.8.2.1 and SPECjApp server 2004 • JGroup replication protocol, Apache HTTP Server
Kaloxylos et al. (2013)	• 5 WaspMote boards (ATmega1281 microcontroller, 128 KB Flash, 8 KB SRAM and 2 GB SD Card, Battery capacity 6600 mAh) each equipped with a 2W Solar Panel4 (80 X 100 mm) are deployed • Gateway is XBee-ZB • Cloud proxy with 256 MB RAM, an ARM 1176JZF-S core CPU@ 700 MHZ • The university server hosting liferay portal, an intel® core™ i5–2320 CPU@ 3.00 GHZ CPU, 4GB RAM and is running ubuntu server 10.04, linux kernel 2.6.32–38–generic with mysql 5.1.41 and Tomcat 7.0.23 • The server hosting the FMS controller has an intel® core™ 2 quad CPU Q9400 @2.66GHZ CPU, with 4 GB RAM, 10.04 linx kernel 2.6 .32–38-generic with mysql 5.1.41

Table 10 Cloud setups (continued)

Study reference	*Cloud setup*
Montes et al. (2013)	• Experiments are carried out on Grid 5000
	• 45 nodes from suno cluster on the Sophia site
	Physical Resources
	• 45 cluster nodes outfitted with debian GNU/linuxlenny with kernel 2.6.32, x86–64 intelxeon E55520 2.26GHZ CPU's, 32 GB of RAM and 2GB Ethernet (Broadcom Netxtremell BCM5716)
	Cloud Iaas
	• OpenNebula
	Virtual Resources
	• 80 vm's outfitted with debian GNU/linuxlenny with kernel 2.6.32, a single virtual x86–64 intelxeon E55520 2.26GHZ CPUs, 1 GB of RAM
	• 80 vm's are deployed at client side
Calheiros et al. (2012)	• One cloud exchange and two cloud coordinators are deployed in GlassFish V3 application server
	• Cloud coordinators have comprised of three xeonquard core 2.00 GHZ processors with 8GB of RAM and two 160 GB HD (mirrored RAID1)
	• Management of virtual resources are taken care by Eucalyptus 1.6.2 that runs on one server, two servers are hosting vm's
	• Second cloud coordinator mediates access to Amazon EC2 cluster
	• Three types of instances
	• Small (1 core, 1.7GB RAM, 1EC2 computing unit and costing $ 0.095 per instance per hour)
	• Large (2 cores, 7.5GB RAM, 2EC2 computing unit and costing $ 0.38 per instance per hour)
	• Extra large (4 cores, 15GB RAM, 2EC2 computing unit and costing $ 0.76 per instance per hour)
Lloret et al. (2013)	• Cloud exchange and cloud coordinator B run in an intel core2 6600(Dual core, 2.4GHZ) with 2GB RAM, 70 GB HD
	• Cloud coordinator a run in an intel core2 Duo E8400 (Dual core, 3GHZ) with 3GB RAM, 140 GB HD
	• Cloud topology composed by 24 computers with Intel Celeron 2 GHZ, 256 GB of RAM and 100BaseT links are used
	• The operating system is windows XP
	• To capture data Sniffer pro 4.70.04 is used

Figure 7 Areas of the body of knowledge for cloud architectures in cloud (see online version for colours)



4.3 Threats to validity

This SLR provides a study of software architectures for cloud computing. Though the results of reviews are reliable, they have potential threats to validity. The main threats of this review are the bias in our selection of studies to be included, data extraction and synthesis. In order to mitigate potential threats to validity, we define a research protocol, which contains research questions, inclusion/exclusion criteria, research strategy and followed the guidelines of a systematic review (Kitchenham and Charters, 2007). In our search strategies, the main idea was to regain as much as possible of the available literature to avoid any bias. Cloud architectures relate to different computer science communities in order to cover all and avoid bias. We searched for common terms and combined them in our search string, which decreases bias and increases search work.

The research protocol was developed by the first author and was reviewed by the second author, to ensure the review selection process and the search string was derived from research questions. To ensure correctness in data extraction, we defined a Meta document which contains consistent and relevant data with respective to search string, inclusion/exclusion criteria and research questions. In order to mitigate reliability threat several researchers are involved in reviewing the included papers to achieve high validity of the study.

5 Conclusions

The objective of this study was to consolidate existing research on cloud architectures and associated topics that allow for building up a body of knowledge. We considered 121 out of 400 reviewed publications significant with respect to research protocols, research question and categorised them according to the research area. On that basis, we provided taxonomy for representing research areas, application domain, tools and technologies. We identified unexplored areas by synthesising collected data, making those available for future research. We observed vast interests towards resource management, service management and security areas. We also observed a lack of tools and also lack of evidence for architectural adaption to develop common and secure architecture. The field is still in its early stages and in order to mature, cloud computing and software engineering researchers should come together by proposing a common research agenda.

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