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RESEARCH ARTICLE

A COMPARATIVE ANALYSIS OF GRID AND CLOUD COMPUTING SYSTEM

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ABSTRACT

Grid and cloud computing paradigms are two defining computing models that have come to revolutionise the computing landscape in so many ways. Grid computing as the predecessor to cloud computing entails virtualization of computing resources over the internet. Cloud computing which is the dominant computing paradigm in our contemporary time involves the provision of computing resources as web services. These concepts as important in defining our digital experience are not well understood. In this paper, we attempt to make a comparative analysis of these two computing technologies with a view to highlighting their areas of similarities and differences within the context of attributes or characteristics, advantages, disadvantages, enabling technologies, tools, architectural, business, resource management, programming, security and application models respectively. This is informed by the need to provide insight and clear the fog surrounding the relationship between the two technologies, as there is divergence of opinion within the research and scientific community as to what constitutes the computing grid and computing cloud respectively. Recommendations on the best computing model to adopt in various use-case scenarios and current and future research directions in grid and cloud computing security frameworks will be examined.

INTRODUCTION

The twenty-first century information-driven globalised world has witnessed a number of key transformations occasioned by the influence of globalization accelerated by discoveries in microelectronics, information and communication technologies, space science, telecommunication, engineering, medicine, nanotechnology, trade, commerce and finance which have combined to make the world a global village. The computing community as a microcosm of the larger technological community is not left out of this transformation bug. Miniaturization and proliferation of device form factors e.g. personal computers, notebooks, mobile phones and satellites courtesy of advancements in microelectronics and nanotechnology, evolution of novel internet technologies such as web 2.0, utility, grid, high performance and cloud computing paradigms, development of general-purpose graphic processors and powerful multi-core processors, superior software methodologies, explosion of domain applications, ambient intelligent systems e.g. Bluetooth and radio frequency identification devices, virtualization leveraging powerful hardware, wider bandwidth access for communication and most importantly digital information deluge estimated in 2007 by Hilbert *et.al* to be 295 Exabytes as shown in figure 1 below, signifying how digital and data-intensive the world has become.

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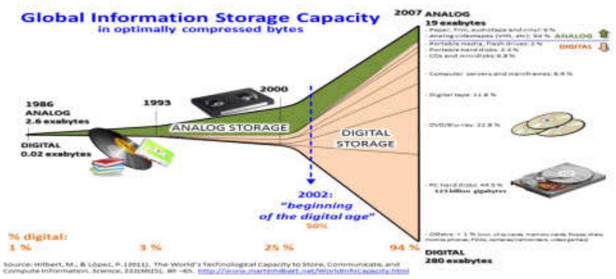

Figure 1 Growth and Digitization of Global Information Storage Capacity

Source: Hilbert & López (2011).

In this paper, we will take a broader view of these two computing technologies with a view to providing a comparative analysis within the context of characteristics, advantages, disadvantages, enabling technologies, tools, architectural, business, resource management, programming, security and application models respectively. This is informed by the need to provide insight and clear the fog surrounding the relationship between the two technologies, as there is divergence of opinion within the research and scientific community as to what constitutes the computing grid and computing cloud respectively. The other section will highlight recommendations and proposed computing vision beyond the present era.

Definitions, Characteristics, Merits and Demerits of Grid and Cloud Computing Models

According to Foster (2008), there is an on-going confusion about the relationship between Computing Grids and

Computing Clouds. Sometimes viewing Grids as being "on top of" Clouds, *vice-versa* or even identical. More surprising, even elaborate comparisons such as: (EGEE-II, 2008; Vaquero, *et al* (2009); & Harris, 2008) still have different views on what "the Grid" is in the first instance, thus making the comparison cumbersome. Grid computing originated in academia in the mid-1990 with an aim to facilitate users to remotely utilize idle computing power within other computing centers and coordinated resource sharing and problem solving in dynamic, multi-institutional virtual organizations and in a distributed fashion, which may also involve the aggregation of large-scale cluster computing based systems (Iosup & Epema, 2011). With grid computing an organization can transparently integrate, streamline, and share dispersed, heterogeneous pools of hosts, servers, storage systems, data, and networks and sensors into one synergistic system. One of the main strategies of grid computing is to use middleware to divide and apportion pieces of a program among several computers. General grid middleware and open-standards allow heterogeneous systems to work collaboratively to deliver the appearance of a large virtual computing environment, while offering a variety of virtual resources (Pourqasem *et al,* 2014).

Despite, its impact in the IT domain, grid computing has varied definitions. It is simply the consolidation of computer resources from multiple administrative domains so as to reach a common goal. The computing grid can be likened to a distributed system with non-interactive workloads that involve a large number of files, loosely-coupled, heterogeneous, and geographically dispersed. According to IBM (2007) grid computing is: *"the ability, using a set of open standards and protocols, to gain access to applications and data, processing power, storage capacity and a vast array of other computing resources over the internet*". It is a "*type of parallel and distributed system that enables the sharing, selection, aggregation of resources distributed across 'multiple' administrative domains based on their resources availability, capacity, performance, cost and users' quality-of-service requirements"*. An illustration of the conceptual view of grid computing concept is shown in figure 2 below.

Figure 2 Grid computing concept

Source: (Kaur & Rai, 2014)

CERN, one of the world's largest users of grid technology, defines it as: "*a service for sharing computer power and data storage capacity over the internet"*. According to Buyya *et.al* (2009) Grid computing is: *"a type of parallel and distributed system that enables the sharing, selection, and aggregation of geographically distributed `autonomous' resources dynamically at runtime depending on their availability, capability, performance, cost, and users' quality-of-service requirements"*. Grids can be categorized with a three stage model of departmental grids, enterprise grids and global grids respectively. It is a combination of resources from multiple administrative domains to reach a common target, and this group of computers can be distributed on several locations and each group of grids can be connected to each other (Gandotra *et al.* 2011). The grid is multiple owned, it could be owned by several companies. Interconnection network is mostly internet with high latency and low bandwidth. The security in the grid is public and private based on authentication and mapping user to an account. And it has limited support privacy, its capacity is not stable, it varies, but it's high. The self-healing in the cluster is limited; it often restarts the failed tasks and applications. Its service negotiations are based on service level agreements, and the user management is decentralized (Gandotra *et al*, 2011). In the view of Omer, Mustapha & Alghali (2014), grid computing paradigm is characterised by loose-coupling, diversity and dynamism, distributed job management and scheduling. Other attributes include-resource sharing, multiple administration, resource coordination, transparent access, dependable access, consistent access and pervasive access. Grid computing paradigm have a number of advantages inherent in it viz: access to additional computing Resources, efficient utilization of idle computational resources, reliability and ease of management. Despite these inherent merits, it is limited by unstable software and protocols, need for high speed internet connection and varying administrator domains respectively. "*Grid computing is used in predictive modeling and simulations, engineering design and automation, energy resources exploration, medical, military, basic research and visualization respectively"*.

While the Globus Toolkit remains the *de facto* standard for building global grid systems, in 2007 the term "cloud" computing which is conceptually similar to the canonical power grid came to renown. The term cloud computing has become a buzzword in the information technology universe after Web 2.0. "Cloud" computing, builds on decades of research in virtualization, distributed computing, utility computing, and more recently networking, web and software services, (Chervenak, *et al.* 2001). It implies a service-oriented architecture, reduced information technology overhead for the end-user, great flexibility, reduced total cost of ownership, on-demand services and many other things (Vouk, 2008).

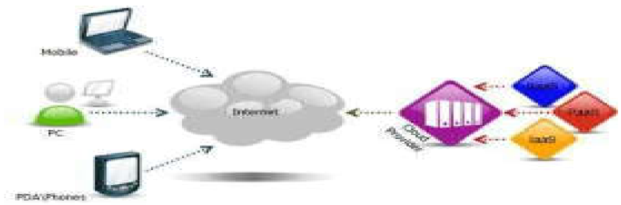

Figure 3 Cloud computing concept and architecture

Source: (Kaur & Rai, 2014)

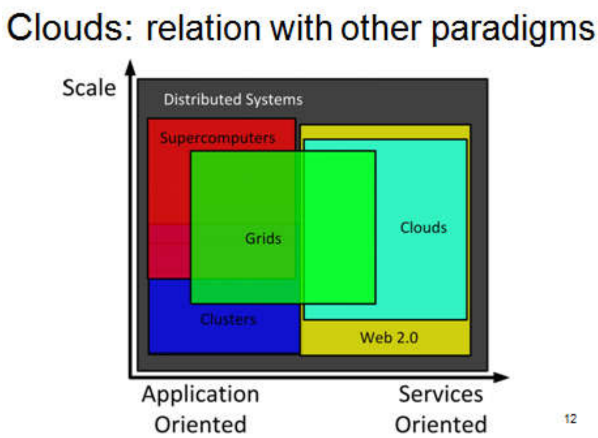

Figure 4 Relationship between Grid and Cloud Computing

Source: (Foster, Zhao, Raicu & Lu, 2008)

"Cloud computing" is the next natural step in the evolution of on-demand information technology services and products (Vouk, 2008). To a large extent, cloud computing will be

based on virtualized resources Vouk (2008). According to Forster & Kesselman (2004), cloud computing predecessors have been around for some time now, but the term became "*popular*" sometime in October 2007 when IBM and Google announced collaboration in that domain (Lohr, 2007). This was followed by IBM's announcement of the "Blue Cloud" effort (IBM, 2007). Since then, everyone is talking about "Cloud Computing". Cloud computing is not a completely new concept in computing; it has relationship to the relatively new but thirteen-year established Grid computing paradigm, and other related computing technologies such as – utility, cluster and distributed computing respectively as shown below in figures 3 and 4 respectively. Figure 4 below presents an overview of the relationship between Clouds and other domains that it overlaps with. Web 2.0 covers almost the whole spectrum of service-oriented applications, where Cloud Computing lies at the large overlaps with all these fields where it is generally considered of lesser scale than supercomputers and Grids [30].

According to Mell & Grance (2011) of U.S National Institute of Standards and Technology (NIST), "*Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction with five characteristics, four deployment models and three service models*" as shown in figure 5 below.

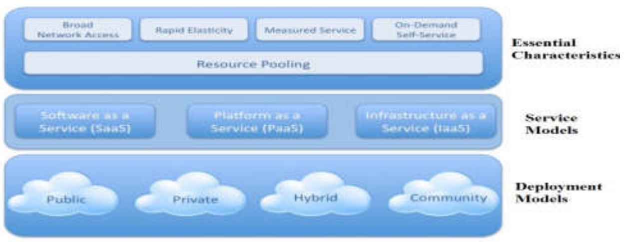

Figure 5 Components of cloud computing

Source: (Mell & Grance, 2011)

Cloud computing is the latest product of Information Technology (IT), with a huge potential to integrate the best features of software and hardware components and deliver the best computing service at a cost effective rate. Regarded as the most beneficial IT innovation and model, cloud computing currently is set out to transform the IT and IT-enabled services across the globe. The cloud model offers tremendous benefits which include: shared resources and increase storage, pay-as-you-go, better hardware management, cost saving and flexibility. On the flip side, it has a number of demerits viz: vendor lock-in, poor management capabilities, poor regulatory compliance, lack of security, privacy and confidentiality, data recovery and availability, internet-based and legal issues respectively. Since the evolution of grid and cloud computing models they have spurred the development of a number of computing initiatives courtesy of the research community like: large-scale federated grids (TeraGrid, Open Science Grid, caBIG, EGEE, Earth System Grid) that provide not just computing power, but also data and software, on-demand. Eucalyptus (the first open-source Amazon Web Service API-compatible platform for deploying private clouds), Eucalyptus (2016) was launched in early 2008. Also, in early 2008, OpenNebula, enhanced in the RESERVOIR European Commission-funded project, became the first open-source software for deploying private and hybrid clouds and for the federation of clouds (Forster, 1999). Similarly, in the same year, efforts were focused on providing quality of service (QoS) guarantees (as required by real-time interactive applications) to cloud-based infrastructure, in the framework of the IRMOS European Commission-funded project, resulting to a real-time cloud environment (Forster, Kesselman & Tuecke, 2001). In this paper, we took a broader perspective of these two computing technologies, with a view to providing a comparative analysis within the context of characteristics, advantages, disadvantages, enabling technologies, tools, architectural, business, resource management, programming, security and application models respectively. The other sections will highlight recommendations and proposed computing vision beyond the present era.

Review of Related Works

Considerable studies on comparative analysis between grid and cloud computing have been reported in the literature. Pourqasem *et al. (2014)* proposed that Cloud computing emerged from internet technology that is distinguished from previous generation of distributed systems i.e. Grid Computing. They further asserted that Grid Computing and Cloud Computing have similarity and difference in basic components, made a comparison of Grid Computing and Cloud Computing in terms of principles, insights into the essential characteristics of both. Omer *et al.* (2014) carried out an overview of cluster, grid, utility, cloud and autonomic computing, and stated that they paved the way for other types of computing beside Autonomic computing, highlighted the differences between them, the characteristics and the advantages and disadvantages for each with a view to pointing out the importance of Autonomic computing and its wide open future in the computing industry. In 2014, Kaur and Rai proposed that grid, cluster and utility computing, have actually contributed in the development of cloud computing and also made a comparative analysis of all the technologies which led to the emergence of Cloud computing. In 2012, Al-Hakami *et al.* (2012) compared cloud computing to previous generations of computing models. At the end, the paper describes the similarities and differences between Grid and Cloud computing approaches. In 2012, Hashemi & Bardsiri (2012) proposed that *"Cloud computing is based on several other computing research areas such as high performance computing (HPC), virtualization, utility computing and grid computing."* They outlined the characteristics of these computing paradigms and distinguish it from other research areas. The paper compared and contrasted cloud computing with grid computing from various angles and gave insights into the essential characteristics of both. The research path on comparative analysis of grid and cloud computing technologies was further extended by Brandic & Dustdar (2011). In this seminal work they proposed that Cloud Computing represents a novel and promising approach for implementing scalable ICT systems for individual, communities, and business-use relying on the latest achievements of diverse research areas, such as Grid computing, Service-oriented computing, business processes, and virtualization. They further stated that there are many similarities and differences in both computing paradigms by evaluating two successful projects, namely for the provision of native light performance computing applications as Grid workflows and for the self-management of Cloud infrastructure. Buyya *et al.* (2009) presented the 21st-century vision of computing and described various computing paradigms that have promised or are promising to deliver this grand vision, differentiated Cloud computing from two other widely explored computing paradigms: Cluster and Grid computing, defined Cloud computing and provided the architecture for creating Clouds with market-oriented resource allocation by leveraging technologies such as virtual machines, provided insights on Market-based resource management strategies that encompass both customer-driven service management and computational risk management to sustain Service Level Agreement (SLA)-oriented resource allocation. These research efforts were further consolidated by Foster *et al (2008)*. This paper compared and contrasted Cloud Computing with Grid Computing from architectural, business, security and resource allocation models respectively. Forster & Kesselman (2004), popularised the concept of cloud and grid computing. The study focuses on highlighting the major features of the grid and cloud computing paradigms and their architectural, service and deployment models respectively.

Similarities/Differences between Grid and Cloud Computing

The prominence of different computing paradigms differs with time. One important analytical tool for comparing the popularity of one computing concept with another as a function of search volume index is the Google search trends. The Google search trends for grid and cloud computing are shown in Figures 6 and 7 below respectively. In blue is "Grid Computing" and in red is "Cloud Computing" in figure 7. If we compare the search trends for grid and cloud computing from the diagram, we can confidently claim that grid computing is on the decline as at 2006 and cloud computing which evolved from grid computing gained popularity from 2007.

In another scenario, the web search popularity, as measured by the Google search trends during the last 12 months, for terms "cluster computing", "Grid computing", and "Cloud computing" is shown in Figure 8.

Table 1 Differences between Grid Computing and Cloud Computing Paradigms

Feature	Grid computing	Cloud computing
Architecture	Service-Oriented	User-chosen architecture
Business Model	Dominated by public good or privately assigned, rigid	Utility pricing, discounted for larger customers, flexible
Resource management	Distributed, Collaboration (VOs, fair share)	Centralized/distributed, Assigned resources are not shared
Programming model	Application domain-dependent software	Application domain-independent software
Application model	Open-source	Proprietary-based
Security model/Privacy	Security through credential delegations/public and private key pair-based authentication and mapping a user to an account. Limited support for privacy	Security through isolation/ Each user/application is provided with a virtual machine. High security/privacy is guaranteed, Support for setting per-file access control list (ACL)
Resource heterogeneity	Aggregation of heterogeneous resources	Aggregation of heterogeneous resources
Virtualization	Virtualization of data and computing resources	Virtualization of hardware and software platforms
High level services	Plenty of high level services	No high level services defined yet
Platform awareness	The client software must be grid-enabled	The SP software works on a customized environment
Software workflow	Applications require a predefined workflow of services	Workflow is not essential for most applications
Scalability	Nodes and sites scalability - 1000s	Nodes, sites, and hardware scalability: 100s-1000s
Self-management	Re-configurability	Re-configurability and self-healing
Centralization degree	Decentralized control	Both Centralized/Decentralized control
Usability	Hard to manage	User-friendliness
Standardization	Some open grid forums (e.g. OASIS and OGF)	Web services (SOAP and REST)
User access	Access transparency for the client	Access transparency for the client
Quality of Service (QoS) guarantee	Limited support, often best-effort only	Limited support, focused on availability and uptime
Population	High-end computers (servers, clusters)	Commodity computers and high-end servers and network attached storage (NAS)
Node Operating System (OS)	Any standard OS (Dominated by Unix)	A hypervisor (VM) on which multiple OSs run
Ownership	Multiple	Single
Discovery	Centralised indexing and decentralised information services	Membership services
Service Negotiation	Yes, SLA-based	Yes, SLA-based
Application Drivers	Collaborative scientific and high throughput computing applications	Dynamically provisioned legacy and web applications, content delivery
Internetworking	Limited adoption, but being explored through research efforts such as Gridbus InterGrid	High potential, third party solution providers can loosely tie together services of different clouds
Single system Image	No	Yes, but optional
Potential for Building Third-Party or Value-Added Solutions (VASs)	Limited due to strong orientation for scientific computing	High potential – can create new services by dynamically provisioning of compute, storage, and application services and offer as their own isolated or composite Cloud services to users
Sphere of influence	1.Predictive Modeling and Simulations 2.Engineering Design and Automation 3.Energy Resources Exploration 4.Medical, Military & Basic Research 5.Visualization	1.Banking 2.Insurance 3.Weather Forecasting 4.Space Exploration 5.Software as a service 6.PaaS 7.Infrastructure- as -a-Service
Characteristics	1: Loosely coupled (Decentralization) 2: Diversity and Dynamism 3: Distributed Job Management & scheduling	1: Dynamic computing infrastructure 2: IT service-centric approach 3: Self-service based usage model 4: Minimally or self-managed platform 5: Consumption-based billing

Source: (Shawish & Salama (2014)., AlHakami, *et al*. (2012)., Gandotra, *et. al* (2011)., & Buyya, *et al*. (2009)).

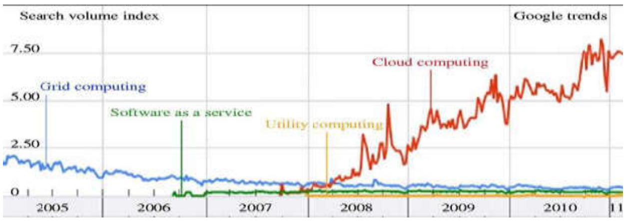

Figure 6 Growth of grid and cloud computing paradigms since 2005

Source: Wikipedia (2016)

From the Google search trends, it can be observed that cluster computing was a popular term during 1990s, from early 2000 Grid computing became popular, and recently Cloud computing started gaining popularity in 2007 [32]. The diagram below illustrates the relationship between grid and cloud computing models.

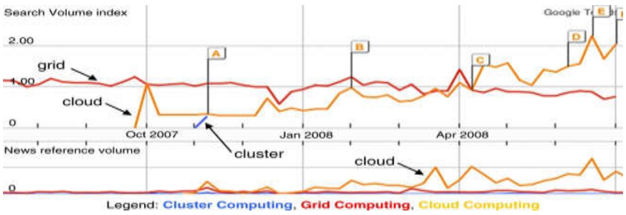

Figure 7 Google search trends for the last 12 months

Source: (AlHakami, Aldabbas, & Alwada'n, 2012)

The following points are adopted from [29, 32]

Spot points in this figure indicate the release of news related to Cloud computing as follows:

1. IBM Introduces 'Blue Cloud' Computing, CIO Today - Nov 15 2007.
2. IBM, EU Launch RESERVOIR Research Initiative for Cloud Computing, IT News Online Feb 7 2008.
3. Google and Salesforce.com in Cloud computing deal, Siliconrepublic.com - Apr 14 2008.
4. Demystifying Cloud Computing, Intelligent Enterprise - Jun 11 2008.
5. Yahoo realigns to support Cloud computing, 'core strategies', San Antonio Business Journal Jun 27 2008.
6. Merrill Lynch Estimates "Cloud Computing" To Be $100 Billion Market, SYS-CON Media July 8 2008.

Other more recent news includes the following

- Yahoo, Intel and HP form Cloud computing labs, Reseller News - Jul 29 2008.
- How Cloud Computing Is Changing the World, Pittsburgh Channel.com - Aug 4 2008.
- SIM tone Corporation Takes Cloud Computing to the Next Level with Launch of First

Wireless, "Zero Touch" Universal Cloud Computing Terminal, TMC net - Sep 8 2008.

Summary of Differences between Grid and Cloud Computing

At the fundamental level, the core issues that distinguish grid and cloud computing paradigms can be traced to: architecture, business model, resource management, programming model, application model, security model, threshold policy, interoperability, hidden costs, unexpected behaviour and security respectively. Table 1 summarizes the similarities and differences of Grid and Cloud Computing Models respectively.

Table 2 Grid and Cloud Computing Applications

Technology	Application	Comment
Grid	DDGrid (Drug Discovery Grid)	This project aims to build a collaboration platform for drug discovery using the state-of-the-art P2P and grid computing technology [74].
Grid	MammoGrid	It is a service-oriented architecture based medical grid application [75].
Grid	Geodise	Geodise aims to provide a Grid-based generic integration framework for computation and data intensive multidisciplinary design optimization tasks.
Cloud	Cloudo	A free computer that lives on the internet, right in the web browser
Cloud	RoboEarth	Is a European project led by the Eindhoven University of Technology, Netherlands, to develop a WWW for robots, a giant database where robots can share information about objects [76]
Cloud	Panda Cloud Antivirus	The first free antivirus from the cloud [77]

Source: Hashemi & Bardsiri (2012)

Table 3 Grid computing and Cloud computing tools

Technology	Tool	Comment
Grid	Nimrod-G	Uses the Globus middleware services for dynamic resource discovery and dispatching jobs over computational grids [53]
Grid	Gridbus	(GRID computing and BUSiness) toolkit project is associated with the design and development of cluster and grid middleware technologies for service-oriented computing [78]
Grid	Legion	Is an object-based meta-system that supports transparent core scheduling, data management, fault tolerance, site autonomy, and a middleware with a wide range of security options [79].
Cloud	Cloudera	An open-source Hadoop software framework is increasingly used in cloud computing deployments due to its flexibility with cluster-based, data intensive queries and other tasks [80].
Cloud	CloudSim	Important for developers to evaluate the requirements of large scale cloud applications.
Cloud	Zenoss	A single, integrated product that monitors the entire IT infrastructure, wherever it is deployed (physical, virtual, or in cloud).

Source: Hashemi & Bardsiri (2012)

Convergence of Grid and Cloud Computing Paradigms

One of the most important issues in both approaches is scalability. It is accomplished through load balancing of application instances running separately on a variety of operating systems and connected through web services. Service provisioning in the Cloud as well as in Grid systems is based on Service Level Agreements (SLA) representing a contract signed between the customer and the service provider including the non-functional requirements of the service specified as Quality of Service (QoS). Other areas of similarities include - both systems share the same basic goal [81]: "to reduce the cost of computing, increase reliability, and increase flexibility by transforming computers from something that we buy and operate ourselves to something that is operated by a third party", CPU and network bandwidth is allocated and de-allocated on-demand.

Current and Future Research Direction

Massive user data and information hosted on the cloud poses serious threat to privacy of individuals. Users authenticate, store and perform computations on their data using cloud services. From the cloud's perspective, it gathers additional user data via ubiquitous devices mines this information to offer personalized services like recommendations and disseminates the results. However, the interaction between the cloud and user at each stage of this pipeline development is limited by privacy concerns (Sinha, *et. al*, 2013). Current research in cloud data and information privacy focuses on legal norms and regulations such as the EU Data Protection Act, Sarbanes-Oxley (SOX) Act and HIPAA *et cetera*; technological mechanisms like privacy-enhancing technologies (PETs) and other approaches such as self-regulation, education and training respectively. For data to be fully utilized, data security and privacy are critical. Instead of computer users bothering on details of technologies and regulations, the individuals concerned simply want to know *"can I trust a service provider to handle my information in accordance with regulations and personal preferences?"* This approaches as robust and intelligent as they seem are grossly inadequate in addressing the myriads of privacy issues associated with communication and data exchange over the internet. Since existing research does not directly address these issues it is imperative to investigate new issues and directions for future research and development. Future research and development direction in addressing privacy concerns on the cloud focuses primarily on adopting collaborative, privacy-preserving approaches and trusted computing models respectively. The vision is to develop information privacy mechanisms that allow a community of users to collaboratively identify privacy violations and share knowledge about privacy violations with others. In other to bring this vision to reality, a tripartite research focus is adopted viz: *basis technologies* needed to realize novel ubiquitous computing approaches using RFIDs, *privacy studies*, so as to know how society currently handles data privacy protection and *privacy mechanisms* for current and novel emerging information systems like: face recognition, privacy-aware folksonomies in web 2.0 paradigm that allow a community of users to collaboratively annotate digital resources. The annotations might reveal the habits and interests of the users. This approach encrypts and partitions data so that neither the folksonomy operator nor unauthorized other parties are able to learn about private information and privacy 2.0 framework which allows a community of users to collaboratively annotate privacy violations and to share those violations with others respectively. In the field of location-based services and trajectory privacy, research is tending towards four directions viz: (i). K-anonymity approach, (ii) hardware policy-based approaches, (iii) obfuscation-based approaches and (iv) trajectory hiding approaches respectively.

Recommendations

In adopting either grid or cloud computing models organisations, institutions and communities should define their requirement, budget and service domains so as to best determine the computing model that will suit their needs. Universities and research institutes can make do with hybrid models incorporating grid and cloud models. Corporate entities, micro, small and medium scale enterprises are best served with any of the cloud deployment models depending on whether they are into software development, insurance, stock broking, financial, telecommunication et cetera.

CONCLUSION

In this paper, we have presented a detailed comparison on the two computing models, grid and cloud computing. We believe a close comparison such as this can help the two communities understand, share and evolve infrastructure and technology within and across, and accelerate Cloud Computing from early prototypes to production systems. When it comes to grid and cloud computing, the two are often seen as the same computing paradigm under different names. In this paper, we sought to separate grids from clouds and provide a side by side comparison on how they are assembled and what services are offered.

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