

Cluster, Grid and Cloud Computing: A Detailed Comparison

Naidila Sadashiv

Dept. of Computer Science and Engineering
Acharya Institute of Technology
Bangalore, India
sadashiv@acharya.ac.in

S. M Dilip Kumar

Dept. of Computer Science and Engineering
University Visvesvaraya College of Engineering (UVCE)
Bangalore, India
dilipkumarsm.uvce@bub.ernet.in

Abstract—Cloud computing is rapidly growing as an alternative to conventional computing. However, it is based on models like cluster computing, distributed computing, utility computing and grid computing in general. This paper presents an end-to-end comparison between Cluster Computing, Grid Computing and Cloud Computing, along with the challenges they face. This could help in better understanding these models and to know how they differ from its related concepts, all in one go. It also discusses the ongoing projects and different applications that use these computing models as a platform for execution. An insight into some of the tools which can be used in the three computing models to design and develop applications is given. This could help in bringing out the innovative ideas in the field and can be explored to the needs in the computing world.

Index Terms—Cluster Computing, Grid Computing, Cloud Computing, Computing Models, Comparison.

I. INTRODUCTION

High-performance computing (HPC) was once restricted to institutions that could afford the significantly expensive and dedicated supercomputers of the time. There was a need for HPC in small scale and at a lower cost which lead to *cluster computing*. The emergence of cluster platforms was driven by a number of academic projects, such as Beowulf [1], Berkeley NOW [2], and HPVM [3]. The popularity of the Internet and the availability of powerful computers and high-speed network technologies has changed the way computers are used. *Grid computing* originated in academia in the mid 1990s with an aim to facilitate users to remotely utilize idle computing power within other computing centers when the local one is busy [1]. Initially, it only referred to a compute grid and had a rather limited audience. However, after years of development the grid gained momentum and came to mean an effective way for coordinated resource sharing and problem solving in dynamic, multi-institutional virtual organizations. Cloud computing, is a kind of computing model that came into existence around the end of 2007. It provides a pool of computing resources which the users can access through Internet. The basic principle of cloud computing is to shift the computing done from the local computer into the network [4]. This makes the enterprise use the resource which includes network, server, storage, application, service and so on that is required without huge investment on its purchase, implementation, maintenance rather use it for other significant purpose. Resources are requested on-demand

with out any prior reservation and hence eliminates over-provisioning and improves resource utilization.

To the best of our knowledge, in the literature, only a few comparisons have been appeared in the field of computing. In this paper we bring out a complete comparison of the three computing models. Rest of the paper is organized as follows. The cluster computing, grid computing and cloud computing models are briefly explained in Section II. Issues and challenges related to these computing models are listed in Section III. Section IV compares these three models from different perspectives. Section V discusses projects and applications. Tools and simulation environment are part of Section VI. Concluding remarks is presented in Section VII.

II. THREE COMPUTING MODELS

In this section, we briefly explain the three computing models: cluster, grid and cloud.

A. Cluster Computing

For many years supercomputer was the leader in the field of computing. But due to some of the problems faced in the area of science, engineering, and business, which could not be effectively dealt with using supercomputers. They were replaced with clusters [5] with the aim of overcoming these problems and also offered a very cheap way for gaining access to potentially huge computing power.

Definition: A cluster is a collection of parallel or distributed computers which are interconnected among themselves using high-speed networks, such as gigabit Ethernet, SCI, Myrinet and Infiniband. They work together in the execution of compute intensive and data intensive tasks that would be not feasible to execute on a single computer. Clusters are used mainly for high availability, load-balancing and for compute purpose. They are used for high availability purpose as they maintain redundant nodes which are used to provide service when system components fail. The performance of the system is improved here because even if one node fails there is another standby node which will carry the task and eliminates single points of failure without any hindrance [5]. When multiple computers are linked together in a cluster, they share computational workload as a single virtual computer. From the users view point they are multiple machines, but they function

as a single virtual machine. The user's request are received and distributed among all the standalone computers to form a cluster. This results in balanced computational work among different machines, improving the performance of the cluster systems. Often clusters are used mainly for computational purposes, than handling IO-based activities.

B. Grid Computing

Grid computing [6] combines computers from multiple administrative domains to reach a common goal, to solve a single task, and may then disappear just as quickly. It is analogous to the power grid [7]. One of the main strategies of grid computing is to use middleware to divide and apportion pieces of a program among several computers. Grid computing involves computation in a distributed fashion, which may also involve the aggregation of large-scale cluster computing-based systems. The size of a grid may vary from small a network of computer workstations within a corporation to large collaborations across many companies and networks.

Some of the definitions on grid computing are given below:

Definition: Buyya et. al. [7] defined grid as 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.

Definition: Ian Foster [8] defined grid as a system that coordinates resources which are not subject to centralized control, using standard, open, general-purpose protocols and interfaces to deliver nontrivial qualities of service.

C. Cloud Computing

Cloud computing [9] refers to both the applications delivered as services over the Internet and the hardware and system software in the data centers that provide those services.

Definition: According to Buyya et. al. [10] a cloud is a type of parallel and distributed system consisting of a collection of interconnected and virtualized computers that are dynamically provisioned and presented as one or more unified computing resources based on service-level agreement. 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 [11]. Cloud computing provides basically three kinds of service: Software as a Service (*SaaS*), Platform as a Service (*PaaS*) and Infrastructure as a Service (*IaaS*).

- *SaaS* is a kind of services where in many users can make use of the software hosted by the service provider and pay only for time its being used. It will be better than buying the hardware and software as keeps off the burden of updating the software to the latest version, licensing and is of course more economical. Some example service providers are Salesforce, Customer Relationships Management(CRM) system and Google Apps.

- *PaaS* provides a high-level integrated environment to design, build, test, deploy and update online custom applications. Some example service providers are Google's App Engine , Microsoft Azure , RightScale and Salesforce .
- *IaaS* refers to the services provided to the users to use processing power, storage, network and other computing resources, to run any software including operating systems and applications. Some of the IaaS providers are AWS, Eucalyptus, Open Stack, GoGrid and Flexiscale.

III. CHALLENGES IN CLUSTER, GRID AND CLOUD COMPUTING

Every computing model has similar or unique challenges, needs to convert challenges into opportunities and has scope for further research. In this section, we highlight some of the challenges of the three computing models considered.

A. Challenges in the Cluster Computing

The research challenges of cluster computing are as follows:

- 1) **Middleware:** To produce software environments that provides an illusion of a single system image, rather than a collection of independent computers.
- 2) **Program:** The applications that run on the clusters must be explicitly written which incorporates the division of tasks between nodes, also the communication between them should be taken care of.
- 3) **Elasticity:** The variance in real-time response time when the number of service requests changes dramatically.
- 4) **Scalability:** To meet the additional requirements of a resource thus effecting the performance of the system.

B. Challenges in grid computing

The research challenges faced in grids include:

- 1) **Dynamicity:** Resources in grid are owned and managed by more than one organization which may enter and leave the grid at any time causing burden on the grid.
- 2) **Administration:** To form a unified resource pool, a heavy system administration burden is raised along with other maintenance work to coordinate local administration policies with global ones.
- 3) **Development:** Problems are concerned with ways of writing software to run on grid-computing platforms, which includes to decompose and distribute to processing elements, and then assembling solutions.
- 4) **Accounting:** Finding ways to support different accounting infrastructure, economic model and application models that can cope well with tasks that communicate frequently and are interdependent.
- 5) **Heterogeneity:** Finding ways to create a wide area data intensive programming and scheduling framework in heterogeneous set of resources.
- 6) **Programming:** The low-coupling between nodes and the distributed nature of processing make the programming of applications over grids more complex.

C. Challenges in the cloud computing

The challenges of cloud computing includes the following:

- 1) **Dynamic scalability:** The compute nodes are scaled up and down dynamically by the application according to the response time of the user's queries. The scheduling delays involved are real concern which leads to the need of effective and dynamic load management system.
- 2) **Multi-tenancy:** When the number of applications running on the same compute node increases, it will reduce the amount of bandwidth allocated to each application which may lead to performance degradation.
- 3) **Querying and access:** Scalable provenance querying and secure access of provenance information are open problems for both grid and cloud environment.
- 4) **Standardization:** As every organization has their own APIs and protocols used which makes the user data or vendor lock-in. Thus integration and interoperability of all the services and application is a challenge.
- 5) **Reliability and fault-tolerance:** Tools for testing the application against fault tolerance and compute failures are required which help in developing a reliable system.
- 6) **Debugging and profiling:** Parallel and remote debugging has always been a problem for developing HPC programs and is an issue in cloud computing also.
- 7) **Security and Privacy:** The user has no idea where data is stored and who will use it as there are more hackers than developers.
- 8) **Power:** Though cloud computing offers many type of services finally to meet the needs of users, enormous amount of power is consumed. An autonomic energy aware resource management is very much required.

IV. COMPARISON OF CLUSTER, GRID AND CLOUD COMPUTING

Viewed in a broad sense, the concepts of cluster, grid and cloud computing seems to have similar features. This section puts light to differentiate in different perspectives and give an end-to-end comparison. It could be understood easily when represented in a tabular form as given in table I.

V. PROJECTS AND APPLICATIONS IN CLUSTER, GRID AND CLOUD COMPUTING

In this section, we present some of the projects and applications in cluster, grid and cloud computing.

A. Cluster computing projects and applications

Some of the projects in the field of cluster computing are:

- 1) **Condor [12]:** It is a multifaceted project engaged in five primary activities.
 - a) Research in distributed computing.
 - b) Participation in the scientific community.
 - c) Engineering of complex software.
 - d) Maintenance of production environments.
 - e) Education of students.

TABLE I
COMPARISON OF CLUSTER, GRID AND CLOUD COMPUTING

	<i>Clusters</i>	<i>Grids</i>	<i>Clouds</i>
SLA	Limited	Yes	Yes
Allocation	Centralized	Decentralized	Both
Resource Handling	Centralized	Distributed	Both
Loose coupling	No	Both	Yes
Protocols/API	MPI, Parallel Virtual	MPI,MPICH-G, GIS,GRAM	TCP/IP,SOAP, REST,AJAX
Reliability	No	Half	Full
Security	Yes	Half	No
User friendliness	No	half	Yes
Virtualization	Half	Half	Yes
Interoperability	Yes	Yes	Half
Standardized	Yes	Yes	No
Business Model	No	No	Yes
Task Size	Single large	Single large	Small & medium
SOA	No	Yes	Yes
Multitenancy	No	Yes	Yes
System Performance	Improves	Improves	Improves
Self service	No	Yes	Yes
Computation service	Computing	Max. Computing	On demand
Heterogeneity	No	Yes	Yes
Scalable	No	Half	Yes
Inexpensive	No	No	Yes
Data Locality Exploited	No	No	Yes
Application	HPC,HTC	HPC, HTC, Batch	SME interactive apps.
Switching cost	Low	Low	High
Value Added Services	No	Half	Yes

- 2) **ShaRCS (Shared Research Computing Services) [13]:** This pilot project has been designed to define, demonstrate and measure how shared computing and storage clusters residing in regional data centers can provide computing services to investigators.

Some of the applications in the field of cluster computing are:

- 1) **The Weather Research and Forecast (WRF)** is a collaborative project by several institutions to develop a next-generation regional forecast model and data assimilation system for operational numerical weather prediction and atmospheric research.
- 2) **Hadoop [14]** is an open-source framework for running data-intensive applications in a processing cluster built from commodity server hardware. Some customers use Hadoop clustering to analyze customer search patterns for targeted advertising. Other applications include filtering and indexing of web listings, facial recognition algorithms to search for images in a large database.

- 3) Clusters were also used for solving grand challenging applications such as weather modeling, automobile crash simulations, life sciences, computational fluid dynamics, nuclear simulations, image processing, electromagnetic, data mining, aerodynamics and astrophysics. Clusters were used as a platform for data mining applications which involve both compute and data intensive operations. They are also used for commercial applications like in banking sector to have achieve high availability and for backup. Clusters are used to host many new Internet service sites like Hotmail, web applications, database, and other commercial applications.

B. Grid Projects and applications

Some of the projects in grid computing are briefed here.

- 1) *Globus* [15][16]: It is an open source grid software that addresses most challenging problems in distributed resource sharing. The first release of Globus DemoGrid [17], a tool that will build an instructional grid environment that can be deployed using virtual machines on a cloud or on physical resources. The main goal of DemoGrid is to provide easy access to an environment with various grid tools, without having to install the tools themselves or needing an account on an existing grid.
- 2) *EGI-InSPIRE* [18] project (Integrated Sustainable Pan-European Infrastructure for Researchers in Europe): Started in 2010, co-funded by the European Commission for four years, as a collaborative effort involving more than 50 institutions in over 40 countries. Its mission is to establish a sustainable European Grid Infrastructure (EGI) to join together the new Distributed Computing Infrastructures (DCIs) such as clouds, supercomputing networks and desktop grids, for the benefit of user communities within the European Research Area. The ultimate goal of EGI-InSPIRE is to provide European scientists and their international partners with a sustainable, reliable e-Infrastructure that can support their needs for large-scale data analysis.
- 3) Some other grid projects are the NSF's National Technology Grid, NASA's Information Power Grid, GriPhyN, NEESgrid, Particle Physics Data Grid and the European Data Grid.

The grid applications range from advanced manufacturing, numerical wind tunnel, oil reservoir simulation, particle physics research, High Energy Nuclear Physics (HENP), weather modeling, bio-informatics, terrain analysis of nature observation, scientific database, and popular science web services.

- 1) *MammoGrid* [19]: It is a service-oriented architecture based medical grid application. The aim is to deliver a set of evolutionary prototypes to demonstrate the mammo-gram analysts, specialist radiologists working in breast cancer screening who can use the grid information infrastructure to resolve common image analysis problems.
- 2) *DDGrid* (Drug Discovery Grid) [20]: This project aims to build a collaboration platform for drug discovery using the state-of-the-art P2P and grid computing technology.

This project intends to solve large-scale computation and data intensive scientific applications in the field of medicine chemistry and molecular biology with the help of grid middleware. Over 10^6 compounds database with 3-D structure and physiochemical properties are also provided to identify potential drug candidates.

C. Cloud Projects and Applications

Some of the initiative projects in the area of cloud computing are briefly presented below: .

- 1) *CERN*: The European organization for Nuclear Research is developing a mega computing cloud to distribute data to scientists around the world as part of the LHC project.
- 2) *Unified Cloud Interface (UCI)*: This project is proposed by the Cloud Computing Interoperability Forum (CCIF) working on the development of standard APIs which can be used by all cloud service providers to overcome the interoperability issues.
- 3) *Cloud-Enabled Space Weather Platform (CESWP)*: The purpose is to bring the power and flexibility of cloud computing to space weather physicists. The goal is to lower the barriers for the physicists to conduct their science, i.e., to make it easier to collaborate with other scientists, develop space weather models, run simulations, produce visualizations and enable provenance.
- 4) *OpenNebula*: This project is successful with the release of the most advanced and flexible enterprise-ready cloud management tool, and the growth of an active open-source community. They aim to develop the most-advanced, highly-scalable and adaptable software toolkit for cloud computing management. They plan for operation network to simplify the management of OpenNebula cloud instances, fault tolerance functionality to maximize uptime in the cloud, enhanced management of images and templates, new security functionality, enhanced support for federation of data centers and support for multi-tier architectures.
- 5) *TClouds* [21] : The goal of the project is to prototype an advanced cloud infrastructure that can deliver a new level of secure, private and resilient computing and storage that is cost-efficient, simple and scalable. To achieve security, resiliency and scalability needed when outsourcing critical IT-systems to a cloud, scientists will build an advanced *Cloud of Clouds* framework for the project. This framework provides multiple back-ups of the TClouds data and applications in case of a hardware failure or intrusion.

Some of the applications that can be deployed on cloud include web hosting, media hosting, multi-tenant service, HPC, distributed storage, multi-enterprise integration, etc.

- 1) With the expansion of cloud computing and establishing a public cloud among many University libraries, it can conserve library resources and improve its user satisfaction. Although there are OPAC (Online Public Access Catalog) and ILL (Inter-library loan) services, access to the shared resources through an uniform access platform

is difficult which can be made possible with the adoption of cloud computing in such libraries [22] [23].

- 2) *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, environments, and tasks. Researchers at ASORO (A-Star Social Robotics Laboratory, Singapore) have built a cloud-computing infrastructure that allows robots to generate 3-D maps of their environments much faster than they could with their onboard computers [25].
- 3) *Cloudo*, a free computer that lives on the Internet, right in the web browser. It allows to access documents, photos, music, movies and all other files from any computer or mobile phone.
- 4) *Panda Cloud* antivirus [26], the first free antivirus from the cloud. Regular updates is not a problem and it occupies very little system resources, uses collective intelligence servers for fast detection, simple interface and protects PC offline.

VI. TOOLS AND SIMULATION ENVIRONMENT

In this section, we highlight some of the tools and simulators that can be used to develop applications on the three computing models.

A. Tools for cluster computing

- 1) *Nimrod* [27] is a tool for parametric computing on clusters and it provides a simple declarative parametric modeling language for expressing a parametric experiment. By using this it can be easy to create a plan for a parametric computing and use the Nimrod runtime system to submit, run, and collect the results from multiple cluster nodes.
- 2) *PARMON* [28] is a tool that allows the monitoring of system resource and their activities at three different levels: system, node and component. It is used to monitor C-DAC PARAM 10000 supercomputer, a cluster of 48 Ultra-4 workstations powered by Solaris.
- 3) *Condor* [12][29] is a specialized job and resource management system for compute intensive jobs. It provides a job management mechanism, scheduling policy, priority scheme, and resource monitoring and management. Users submit their jobs, tool chooses when and where to run them based upon a policy, monitors their progress, and ultimately informs the user upon completion.
- 4) *MPI* and *OpenMP* [30]: Message passing libraries provide a high-level means of passing data between process executing on distributed memory systems. They help to achieve high performance out of collections of individual cluster nodes. MPI I is the de facto standard for parallel programming on clusters which consists of a rich set of library functions to do both point-to-point and collective communication among parallel tasks.
- 5) Other cluster simulators include *Flexi-Cluster* a simulator for a single compute cluster, *VERITAS* a cluster server simulator, etc.

The tools used in the field of grid computing for resource discovery, management and performance analysis are:

- 1) *Paradyn*, a performance analysis tool supports performance experiment management through techniques for quantitatively comparing several experiments and performance diagnosis based on dynamic instrumentation. Experiments have to be set up manually, whereas performance analysis is done automatically.
- 2) *Nimrod-G* [27] uses the Globus middleware services for dynamic resource discovery and dispatching jobs over computational grids. It allows scientists and engineers to model parametric experiments and transparently stage the data and program at remote sites, run the program on each element of a data set on different machines and finally gather results from remote sites to the user site.
- 3) *Condor-G* [12] represents the work of Globus and Condor projects which enables the utilization of large collections of resources that span across multiple domains as if they all belonged to the user's personal domain. From Globus comes the use of protocols for secure inter domain communications and standardized access to remote batch systems. From Condor comes the concern of job submission, job allocation, error recovery, and creation of a friendly execution environment .
- 4) *Globus*, an open source software toolkit that facilitates construction of computational grids and grid based applications, across corporate, institutional and geographic boundaries .
- 5) *Gridbus* (GRID computing and BUSiness) [31] toolkit project is associated with the design and development of cluster and grid middleware technologies for service-oriented computing. It provides end-to-end services to aggregate or lease services of distributed resources depending on their availability, capability, performance, cost, and QoS requirements.
- 6) *Legion* [32] is an object-based metasystem that supports transparent core scheduling, data management, fault tolerance, site autonomy, and a middleware with a wide range of security options.
- 7) Other simulators used in grid computing includes Gridsim [40], *ZENTURIO*, *Optorsim*, *Chicsim*, etc.

B. Tools used in Cloud Computing

Various tools and products which provide assistance in development applications on cloud computing are:

- 1) *Zenoss* a single, integrated product that monitors the entire IT infrastructure, wherever it is deployed (physical, virtual, or in cloud). It manages the networks, servers, virtual devices, storage, and cloud deployments.
- 2) *Spring Roo* is a next generation rapid application development tool, combined with the power of Google Web Toolkit (GWT) that enables developers to build rich browser apps in enterprise production environments.
- 3) *CloudSim* and *CloudAnalyst* are important for developers to evaluate the requirements of large-scale cloud applications in terms of geographic distribution of both

computing servers and user workloads. The former was developed with the purpose of studying the behavior of applications under various deployment configurations whereas the latter helps developers with insights in how to distribute applications among cloud infrastructures and value added services.

- 4) Cloudera [41], 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. It allows to explore complex, non-relational data in its native form.

VII. CONCLUSION

In this paper, we have presented a detailed comparison on the three computing models, cluster, grid and cloud computing. The issues and challenges related to these computing models are highlighted. The projects and applications in various fields are briefly discussed. Also the tools and simulation environments useful for development of applications are highlighted. Such a comparison in different perspectives will make easy to understand the computing models since the features of these computing models seems to be similar conceptually. It also helps in identifying the similarities and differences from each other. Grid and cloud computing appears to be a promising model especially focusing on standardizing APIs, security, interoperability, new business models, and dynamic pricing systems for complex services. Hence there is a scope for further research in these areas.

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