A Comparative Review of High-Performance Computing Major Cloud Service Providers

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***Abstract*— This paper reviews the top leading cloud providers, surveys their offering related to High Performance Computing (HPC). Four top cloud provider are selected, Microsoft Windows Azure, Amazon Elastic Compute Cloud (Amazon EC2), Google Compute Engine and Oracle Cloud. Each one of them has its unique value proposition that enables it to survive in the market and make it a real competitor. A comparative analysis of the offerings and relative benefits of each are provided. This study is an introduction to our extensive work in the HPC field.**

Keywords— High-Performance Computing, Microsoft Azure, Amazon EC2, Google Compute, Oracle, price, performance.

I. Introduction

1.1 High-Performance Computing on the cloud

High-Performance Computing (HPC) on the cloud is one of the most trending research topics nowadays. Performing HPC jobs on the cloud is a cost effective solution that overcomes and replaces real dedicated cluster. Cloud architects focus on developing a potential alternative for costly real clusters that were used for this purpose for many years. Many big companies such as Amazon Elastic Compute Cloud (EC2), Microsoft Azure and Google invest hundreds of millions of dollars on cloud technology, delivering many scalable cloud computing solutions to serve users and satisfy their needs and expectations. Cloud computing providers use service-driven models. All hardware, platform and software resources are leased to customer on-demand [14]. Cloud providers offer services that can be classified into three types: Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS). Amazon EC2 and Microsoft Azure are the most popular cloud providers. Both offer the IaaS platform. Both providers support a wide range of hardware and software varieties that complicate the selection of the compute node and its operating system [4].

1.2 Benefits of using cloud for High-Performance computing purposes

Moving HPC applications from real traditional clusters to virtual cloud clusters has many benefits. It offers the Computing as a Service paradigm which enables HPC solutions to reach wide industrial and scientific communities. Cloud HPC guarantees exclusive execution of jobs without any interference with other user tasks. This feature enables HPC users to achieve maximum performance from leased resources. Cloud providers offer virtual machines with a heterogeneous configuration of processors, network and memory [4]. These benefits encourage all researchers in this domain to investigate the migration of HPC applications. Researchers now are studying all factors that affect executing applications on the cloud. The following benefits increase the value of cloud offerings; meanwhile, these advantages increase the value of research in this field.

1. **On-demand pricing.** All resources used to build virtual clusters such as virtual machines, storage accounts, connected networks, network addresses etc. are priced based on the usage time of resources, (Dollar per hour). However, if the reserved resources are underutilized or idle, users can manually turn off any unused resources, or the cloud provider can automate this process when the usage of the resources drop to a certain threshold. The payment policy in the cloud is pay as you go [3].
2. **Elasticity.** Cloud providers offer the Auto-Scale feature when deploying resources on the cloud. Resources will automatically expand or shrink to fit the currently executing jobs. This will reduce the underutilization of resources that may occur. In real clusters, resources remain idle and unused during weekends, nights and the time between major tasks execution. These features proves those cloud services, in general, are scalable and will reflect on the cost of running HPC jobs on the cloud [1].
3. **Resources control, security, maintenance and management are the responsibility of the cloud provider.** No need for a dedicated team to do regular maintenance, updates and upgrades. Machines are automatically upgraded by the provider team, which also reduces the operational cost usually paid to the IT and help desk team in real dedicated clusters [1].
4. **Cloud resources are reliable and guaranteed by the cloud provider**. Services are on, reachable and operational all the time. Many replicas of resources are deployed. The redundancy policy is chosen according to user choice. Resources may be replicated in the same data center or in another one in the same geographical region or in another region. This will help systems to recover quickly in case of any unexpected crash or disaster [11].
5. **Queuing time almost does not exist in virtual clusters.** Resources are automatically created or released

This work has been carried out during sabbatical leave granted to the author Ali El-Mousa from the University of Jordan during the academic year 2017.

based on the workload of the task. No more waiting in the cluster scheduler. This will reduce the total turnaround time of task execution [3].

6. **Cost-effectiveness**. Especially for small-to-medium size jobs. The cost of running these HPC applications on dedicated clusters is more expensive than leasing the same resources on the cloud [2].

7. **RDMA Support.** Remote Direct Memory Access (RDMA) also called one-sided communication. RDMA is used to read and write data from another node memory with minimum latency directly. This will reduce communication overhead and minimize the communication to computation ratio of an application [12].

1.3 Cloud providers market share

Gartner, Inc. publishes a periodic magic quadrant every quarter. The Magic Quadrant of June 2017 as shown in Fig. 1, shows that the AWS cloud used by Amazon and the Azure cloud used by Microsoft dominate the field of IaaS. Both providers take almost all IaaS market share, while other providers are niche competitors. In this paper we survey the previous work done on these cloud providers, listing their current and up-to-date HPC services, and then we compare them to each other. This work aims to help cloud customers to select the best provider according to their applications. Prices are not listed in the comparison due to its fluctuation. The rest of the paper is organized as follows: Section 2 provides a literature review of HPC previous work on different cloud providers. Section 3 presents the top cloud providers that were selected to be discussed in this work. Discussion and comparison between the cloud providers are presented in Section 4. Section 5 contains the conclusion.

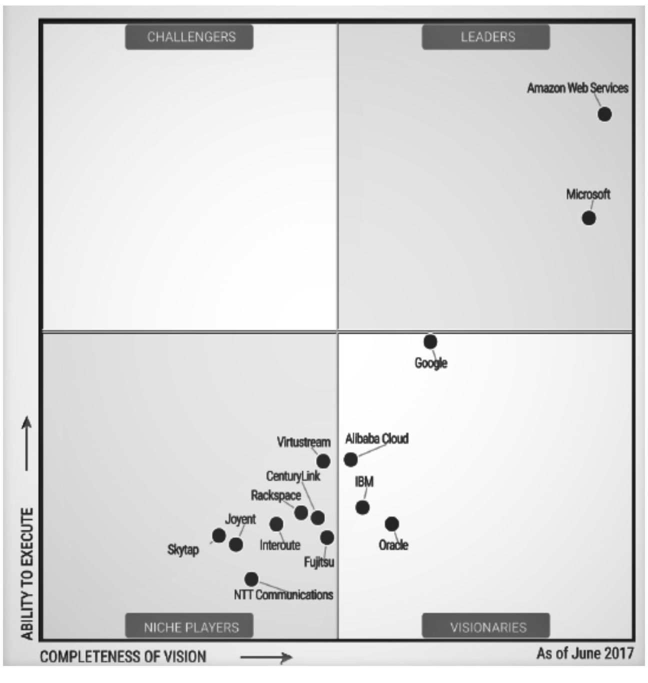

Fig. 1. Gartner's Magic Quadrant for Cloud Infrastructure as a Service, Worldwide June 2017

II. RELATED WORK

2.1 HPC application enables much academic research

Scientists, researchers and engineers use HPC to solve many scientific and industrial problems. Cluster hardware is used efficiently to execute HPC applications in a short time. HPC can reduce the execution time of these applications from weeks or days to few hours. Past surveyed studies that will be presented in the next subsection shows that many different cluster architecture can be designed to work as HPC clusters. These clusters vary in specifications such as: computing resources, type of networks connected to it, disk size and type, memory size and many other deterministic parameters. As presented in [3], there is no one size fits all HPC virtual cluster. Consequently, not all benchmarks will execute with the same performance on all cluster architectures.

2.2 Cloud Provider role in HPC

High-Performance computing on the cloud architecture is one of the promising topics in research nowadays. Many researchers work in this field, studying the possibility of architecture improvement and the possibility of using it efficiently.

2.2.1 HPC efficiency studies on Amazon EC2 cloud

Many previous research about using cloud as a HPC environment was done on Amazon (EC2). Hence, it is the pioneer of the IaaS architecture in the cloud and one of the market leaders. Amazon shares the leadership with Microsoft Windows Azure and Google Engine clouds. These studies evaluated EC2 through many performance metrics such as: execution time and cost. Microsoft Azure is used as an HPC cluster provider but not much as Amazon EC2. The following subsection briefly explores these studies.

2.2.2 Comparing Amazon EC2 cloud with the real on-premises clusters

The work done in [2] provided a comprehensive study and evaluated the performance of many clusters that exist on EC2 cloud indicating the positive aspects of the cloud HPC cluster, such as: scalability and availability versus the cloud negative aspects such as virtualization, latency and low-speed networks compared with the relatively high computation capability. Many contributions are done in [4], the most important is the recommendation of disabling hyper threading in the cloud to enhance performance due to the sharing of the physical execution units between logical CPUs. This recommendation which was proved in [2], explained the effect of CPU affinity on the execution time and the performance. A problem occurs when using high scale clusters; EC2 does not assure the co-location of the virtual machines. When virtual machines are located in a different data center, the inter-communication time will increase especially in tightly-coupled applications. This will degrade performance due to the long network connections between farther virtual [4]. Work submitted in [3], completed the previous work done in [4], and introduced a full, comparative study of using the cloud for HPC.

This study compared the HPC cluster of EC2 with five real clusters that exist in Lawrence Livermore National Laboratory (LLNL) for research purposes. Compute nodes in these clusters differ in their computing capabilities, memory size, network technology; network bandwidth and speed used in the interconnection between compute nodes. After executing many benchmarks on various types of clusters, EC2 did not perform superbly based on measuring the execution time compared with real clusters, but it had significantly minimum queuing times due to its elasticity. Therefore, the turnaround time is less in most benchmarks, except the communication intensive ones because EC2 has the 10/Gbps Ethernet speed versus InfiniBand network in real clusters [3].

Evaluation done by [3] considered the tradeoff between performance and cost. They considered many factors while comparing different architecture such as: the applications themselves including computing and communication requirements of each, the resource utilization and the cost of executing tasks on the specific cluster. An important part of their work was developing a pricing model which was used to make a fair cost comparison when evaluating HPC applications. Work done in [12] focused on studying cloud bottlenecks that were evaluated by previous work done in [3] and [4]. These bottlenecks and challenges have the maximum effect in large and scalable applications; some of these challenges are the HPC network performance and the monitoring challenges. Authors of [12] try to overcome these challenges and recommended the best design practices to make efficient HPC networks. They discussed in details the network monitoring techniques that were proposed to improve existing methods, such as: the SNMP centralized methods, the scalable push-based approaches and data aggregation.

2.3 HPC efficiency studies on real on-premises clusters and virtualized local clusters

Work submitted in [1] surveyed many HPC architectures such as real HPC clusters, virtualized in-house HPC clusters using KVM, and then compared them with private and public cloud provides. The comparison considered many points of view to determine which architecture is the best for each type of applications as the authors in [4]. Authors defined the bottlenecks of each architecture after executing various types of benchmarks This work identified the main barriers that face HPC on the cloud, which directly affect the performance, such as: virtualization overhead, the choice of operating system effects and hypervisor visualization, storage and memory performance and the placement of the cluster virtual machines either in the same region or in different regions in many geographical places. The main conclusion which was an enhancement to the work done in [4], was that when we execute the same benchmarks on the same cloud architecture many times, there is a variation in the results due to the sharing of resources and network fluctuations. The work suggested many optimization techniques to reduce performance degradation in the cloud; such as: lightweight virtualization, using thin virtual machines with containers, and CPU affinity on the application level, and the hypervisor level to reduce the variation of execution time from run to run, answering two important questions: which application to migrate on cloud and which cloud architecture to migrate to.

2.4 HPC efficiency studies on Windows Azure cloud

Microsoft Windows Azure is a relatively new cloud provider. It provides both IaaS and PaaS. Azure became a leader in the market of cloud computing due to many integrated technical and industrial solutions that it offers to cloud customers. Meanwhile it takes its popularity from Microsoft's reputation in the market. It's a branded company that has customers trust all around the world over the past two-decades. Azure has many other benefits. It has more than thirty six regions scattered all around the world that has hundreds of data centers, to provide a high level of service to its customers.

2.4.1 Comparing Windows Azure cloud with other cloud providers

Work submitted in [8] and [9] studied three different cloud providers (Amazon EC2, Microsoft Azure and Rackspace), introducing very comprehensive details about virtual machines deployment details such as: setup procedures, hardware and software configurations, interconnection speeds, virtualization techniques used, booting time, deleting time, the ability of changing the VM size, supported operating systems etc. Beside many performance and cost analysis similar to that done in [1], [3] and [4], authors in [8] and [9] discuss briefly the history of the cloud providers. Amazon EC2 is more popular because it came before Microsoft Azure and introduced the IaaS offering while Microsoft Azure was delivering PaaS only at that time. Authors evaluated the performance of Amazon EC2 clusters and Microsoft Azure clusters. Many benchmarks were tested with the result that indicated that Microsoft Azure HPC clusters are closest to real clusters than Amazon EC2 HPC clusters. This paper also introduced the difficulties that face porting existing work and compute instances to the Microsoft Azure cloud, explaining the migration process, the needed perquisites that should be satisfied before porting applications to Azure, and proving that these challenges do not affect the performance. Azure is still better than EC2 due to its better interconnections.

2.4.2 Microsoft Azure Virtual machines performance

Work submitted in [10] presented a comparative analysis of the compute instances performance on multiple cloud providers, studying the performance of single nodes, and the speedup of executing parallel and distributed tasks on a large number of nodes. High scalable benchmarks are used to evaluate the computation capabilities of different kinds of virtual machines on the cloud by estimating the performance per single core in each of them. This work examined all Microsoft Azure virtual machine specifications. Azure classifies the virtual machines into many categories called series; this work presented a clear comparison between Azure VMs [10].

III. THE TOP FOUR HPC CLOUD PROVIDERS

In this paper, the top HPC solutions from the four leading cloud providers will be explained and then they will be compared with each other. Comparison criteria are selected according to the HPC user needs and expectations. This information was obtained from the official websites of each provider, and it is the most up-to-date information when this paper was submitted. Some features may have changed over time such as the number of regions, and other service may get available to users.

Table 1 compares these providers from many perspectives. Some related to performance and some related to price. The following subsection discuss each provider in detail.

Table 1 Amazon vs Azure vs Google vs Oracle

	Amazon EC2 and web services (AWS) [15]	**Microsoft Windows Azure platform [14]**	**Google Cloud [17]**	**Oracle Cloud [16]**
Starting Date	2006	2010	2011	2007
Available Regions	18 region	36 region	13 region, 11 additional new region in 2018	12 region
Virtual machines types	• General purpose • Compute optimized • Memory optimized • Storage optimized • Accelerated computing	• General purpose • Compute optimized • Memory optimized • Storage optimized • High performance compute	• Standard machines • High-memory machines • High-CPU machines • Mega-memory machines	• Bare Metal instances • Traditional virtual machines
Batch Processing (if exist)	Azure Batch	AWS Batch	N/A	N/A
SMB File Storage (if exist)	Amazon Elastic File System	Azure File Storage	N/A	N/A
Migration Tools (if exist)	Full Integrated package, AWS Snowball Edge	Simple Import and export process	N/A	N/A
Developer Tools (if exist)	AWS SDK	Azure SDK Visual Studio	Integrated tools for Android, Powershell and Eclipse	N/A
Management Tools (if exist)	AWS Managed Services	N/A	N/A	N/A
Pricing methodology	All cloud providers charge users for operating system images, except open source images such as Ubuntu Linux. In addition, static IP address assignment for virtual machines and VPN tunnels that are used to connect to virtual machines and between virtual machines is charged also.			
Pricing Policy	• On-Demand instances, billing is based on computing capacity per hour (Pricing Calculator) • Spot instances billing is based on number of used VMs, price may fluctuate based on the demand inside requested zone. • Reserved instances up to 75%) lower in price than the on-demand pricing. • Per-second instances, Price is nbased on user usage per minutes and seconds.	• All virtual machines are priced based on the usage of of resources per hour. • Not all VM are exist in all zones, this affect the price of VM's in the nearby zones. • Resources in different zones vary in their price according to the size of the datacenter, its utilization, country tax and currencies differences.	• All virtual machines are priced based on the usage of its resources per hour. • When using the custom virtual machines the price is flexibilty. Billing is based on the customer selected VM characterstices.	• Pricing is based on the subtype of the virtual machine if it is a standard virtual machines or if it a Dense I/O virtual machines. • The Dense I/O virtual machines have double price than the standard virtual machines.
Pricing Discount	Based on the contract period, longer contract saves more money, also based on the payment option, for example, if it's full upfront payment, more discount is obtained than the partial upfront. For example, Azure reduces resources billing if the user purchases them for one year commitment with up to 53% lower pricing and for three year commitment with up to 69% lower pricing.			

3.1 Amazon EC2 and Amazon Web Services (AWS)

Amazon Web Services (AWS) was launched in 2003 as a retail company for computing infrastructure. But in 2006, Amazon expanded its work to provide a full, integrated package of online core services. Amazon is the pioneer of the cloud. Initially,, it delivered IaaS but now Amazon delivers PaaS offering also [15]. Nowadays, Amazon cloud consists of a set of services, providing virtual and cloud based computation, storage and other services [11]. Amazon EC2 cloud enables users to create and manage compute instances in data centers using a simple web interface and productive tools and utilities [11]. EC2 provides locations for creating resources on it. Locations are regions and availability zones, which enable cloud users to replicate virtual machines in multiple locations for redundancy purposes. In general, regions hold one or more availability zones, which are geographically dispersed [6]. Amazon EC2, the oldest cloud provider, offers four ways of payment to the customer: On-Demand instances, Spot instances, reserved instances and dedicated instances. When using On-Demand instances, there are no long-term commitments or agreement. Customers can expand or shrink the compute capacity manually based on the expected application workload. This type is recommended for short-term and unpredictable workloads. Amazon Spot instances allow the auto-scaling feature as spare computing capacity It can be used during peak hours. A pool of instances (virtual machines) are created and placed virtually in one Auto Scaling group. Customers can specify the minimum and the maximum number of instances in the group. Amazon recommends spot instances for urgent needs when some applications need more capacity and for applications with flexible beginning and ending times [15]. The third type of virtual machines offered by Amazon, are the Reserved Instances. Availability zones are created by customers to place the computing resources on it. Virtual machines inside the availability zone are reserved for the zone owner. This feature guarantees a certain level of confidence. These types of virtual machines are recommended for predictable usage. It can be used for applications that require steady-state computing behavior and high capacity. The last Amazon offering related to compute solutions is the Per Second Billing instances. These instances are used for applications testing, batch processing and data analytics [15].

3.2 Microsoft Windows Azure Platform

Microsoft Windows Azure platform was commercially available in 2010. It delivers more than six hundred Azure services. This wide variety of services can serve applications running on a wide range of systems, including: computation workloads, storage, mobile services, big data management, web development and machine learning [7]. Microsoft Azure was initiated for running applications on Windows virtual machines and storing the virtual machines data on the cloud [7]. Azure mainly consists of five components: **Compute.** Microsoft Azure provides Windows-based and Linux-based solutions that are used as a computing service. These virtual machines are used for many purposes such as: Desktop applications, simulations and HPC applications. **Storage.** Microsoft Azure provides many options for storing data; such as: blobs that store binary large objects, queues used for communication between many Azure applications, and also offers tables and files that store many type of files. **Fabric controller**. This component will be used to control more than one virtual machine that work together. The controller collects a large number of virtual machines into a single data center as a pool of resources. Other HPC Microsoft Azure components such as: compute and storage works on top of this pool of resources. **Content delivery network (CDN).** Windows Azure CDN uses many caching techniques to deal with storage accounts. Caching works well on the location of data to maintain it closer to the user. **Connect.** Windows Azure Connect service is used to interact with cloud applications; especially when there are on-premises components which are used beside cloud resources. Azure virtual machines allow users to deploy a wide range of computing solutions in an agile way. You can deploy virtually many compute solutions with many operating system options such as Windows, Linux, or a custom created operating system selected from Microsoft windows growing list of partners. Azure has many Virtual machines with different hardware and software configurations that fit all cloud user needs [7].

3.3 Google Cloud Platform

Google basically offers the Google App Engine Platform as a full integrated service solution. Developers use it as a full package to write code, link code with services, SDK, development environments and other components, then hosting and running it as traditional web applications or mobile applications. All resources needed to give such a service are built and managed by Google cloud without engaging the developers in the underlying details of infrastructure [5]. Google App Engine is also available as a very high availability scalable solution on the cloud as a PaaS. This solution minimizes the management overhead caused by virtual machine utilization, especially during peak hours. This engine scales the number of virtual machines automatically to overcome the overload problem. Google decided later to enter the market of IaaS, and gave cloud users many other solutions on its infrastructure. The Google Compute Engine allows users to have complete control on their virtual machines running on the cloud via direct access to the hardware [17]. Users are not restricted to use a single solution, they can mix options and choose the right solution for the right application and then connect component together. Users can use the App Engine solution for the front end layer that interacts with users, while using the Redis virtual machine in the Compute Engine [17]. Google Compute Engine's virtual machines are available in many different configurations that create custom virtual machine types which are optimized for specific needs. There are a wide variety of virtual machines configurations characterized by VM sizes. Google also offers flexible pricing options and discounts for long-term workloads to ensure sustainable business. All these features make the Compute Engine of Google the leader of the price/performance competition between the four previously mentioned cloud providers [17].

There are many configurations from micro instances with one CPU to extra-large instances with 96 vCPUs and 624GB of memory. Types are categorized between standard, high CPU and, high memory configurations. The other offering from Google is the Custom Virtual Machines, this type is tailored according to user needs to fit their application [17].

3.4 Oracle Cloud

Oracle began to provide cloud services since 2007 as a database cloud services known as Database as a Service. Now, they entered the market of the cloud strongly by providing all other cloud offerings such as: IaaS, PaaS and SaaS at a lower competitive price. Oracle provides distinguishing Infrastructure as Service solutions: The Bare Metal Instances and the traditional Virtual machines instances. The Bare Metal instances are fully dedicated servers connected to each other using the software-defined network on the hypervisor operating system. Bare metal virtual machines offer unique raw performance. Each virtual machine has 36 processor cores with super SSDs that provide millions of IOPS. These virtual machines are ideal for HPC applications, input/output intensive applications such as big data workloads, and Oracle Database workloads [16].

Oracle Virtual Machine instances are used for other workloads that does not require dedicated and High-Performance virtual machines. These virtual machines are cloud-optimized, its hardware, storage, and networking infrastructure are accessible via predefined API's. Oracle offers two options under the Compute category: Bare Metal Instances and Virtual machine instances. The Bare dedicated instances come with three types of virtual machines with 36 vCPU with different memory sizes, Standard Compute Capacity virtual machine with 256GB memory, High I/O Compute Capacity virtual machine with 512GB memory and 12.8TB SSD disk and the Dense I/O Compute Capacity with 512GB and 28.8TB SSD disk [16]. The ordinary virtual machine instances have more CPU and memory configurations; from one CPU on the standard virtual machines to sixteen CPU for the DenseIO virtual machines. The DenseIO virtual machines have more memory than Standard; its memory reaches 240GB [16].

IV. CONCULSION

No cloud provider fit all user requirements. Each has its value proposition in the market. Some of the providers have a large market share due its seniority in the field such as Amazon EC2 cloud. Other providers have a good market share due to its reputation in the market. Microsoft Azure has its popularity from Microsoft reputation. Oracle already focuses their work on serving database and high I/O requirements. Google proposed new purchasing technique. Users can request any computing and storage requirement amount. In the information technology field, there are no clear predictions about what would happen in the next few years. All competitors invest millions of dollars to lead the market. They offer many services, many facilities to keep their old customers satisfied with their services and attract new customers to earn their loyalty.

Our work continues to provide detailed recommendations and guidelines for users of HPC applications. Currently, comprehensive HPC experiments using benchmarks are being conducted on the Microsoft Azure platform. Machine learning techniques are being used to evaluate results and to help determine the best recommendations from the various offerings. This paper introduced our current extensive work in the HPC field. However, due to lack of space, we are unable to show full experiment results.

REFERENCES

[1] A.Gupta, "Techniques for Efficient High-Performance Computing in the Cloud", University of Illinois, Urbana Champaign, 2014

[2] A.Gupta, L.Kale and F.Gioachin, "The Who, What, Why and How of High-Performance Computing Application on the Cloud", 2013.

[3] A.Marathe, R.Harris, D.Lowenthal, B.Supinski, B.Rountree, M.Schulz. and X.Yuan, "A Comparative Study of High-Performance Computing on the Cloud", In the International Symposium on High-Performance Parallel and Distributed Computing, pp. 239-250, 2013.

[4] A. Marathe, D. Lowenthal, B. Rountree, X. Yuan, M. Schulz and B. de Supinski, "A User Perspective of High-Performance Computing on the Cloud", The University of Arizona, Lawrance Livermore National laboratory, March, 2012.

[5] A.Zahariev, "Google App Engine", Helsinki University of Technology, 2009.

[6] C.Vecchiola, S.Pandey and R.Buyya, "High-Performance Cloud Computing: A View of Scientific Applications", 2009.

[7] D. Chappel, "Introducing Windows Azure", David Chappel and Associates, 2008

[8] E.Roloff, F.Birck, M.Diener, A.Carissimi and P.Navaux, "Evaluating High-Performance Computing on the Windows Azure Platform", In IEEE Fifth International Conference on Cloud Computing, pp. 803- 810, 2012.

[9] E.Roloff, M.Diener, A.Carissimi. and P.Navaux, "High-Performance Computing in the Cloud: Deployment, Performance and Cost Efficiency", In 4th International Conference on Cloud Computing Technology and Science, pp. 371-378, 2012.

[10] M.Mohammadi. and T.Bazhirov, "Comparative benchmarking of cloud computing vendors with High-Performance Linpack", Cornell University library, February 2017.

[11] Q.Zhang, L.Cheng and R.Boutaba, "Cloud computing: state-of-the-art and research challenges", In Journal of Internet Services and Applications, pp. 7–18, 2010.

[12] T.Groves, "Characterizing and Improving Power and Performance of HPC Networks", University of New Mexico and Sandia National Laboratories, 2016.

[13] V.Persico, P.Marchetta, A.Botta and A.Pescapè "On Network Throughput Variability in Microsoft Azure Cloud", University of Naples Federico, Italy, 2016.

[14] Portal.azure.com. (2017). Microsoft Azure. [online] Available at: https://portal.azure.com/ [Accessed 1 Dec. 2017].

[15] Amazon Web Services, Inc. (2017). Amazon Web Services (AWS), Cloud Computing Services. [online] Available at: https://aws.amazon.com/ [Accessed 1 Dec. 2017].

[16] Cloud.oracle.com. (2017). Enterprise Cloud Computing SaaS, PaaS, IaaS | Oracle Cloud. [online] Available at: https://cloud.oracle.com [Accessed 1 Dec. 2017].

[17] Google Cloud Platform. (2017). Google Cloud Computing, Hosting Services & APIs | Google Cloud Platform. [online] Available at: https://cloud.google.com [Accessed 1 Dec. 2017]