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Comparing the Cost of IaaS and CaaS Services

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ABSTRACT

Cloud computing environments allow businesses to deploy applications in a fast and scalable way. Infrastructure-as-a-service (IaaS) and container-as-a-service (CaaS) models can be adopted for the deployment of cloud-based applications. The current paper presents a specific near-real-world scenario of a cloud-based application, deployed by the two aforementioned cloud models. The deployment cost differs between the cloud models and relies on the number of utilized resources, which is driven by the user demand. Since the cost is a major importance factor that finally determines the adoption of cloud technology, it is challenging to estimate and examine the cost of each proposed approach. This research can help cloud computing professionals pick a model that meets their goals and budget. It's also useful for cloud cost analysis. The corresponding costs of the two deployments are estimated based on the pricing policies of major providers, Amazon, Google, and Microsoft.

KEYWORDS

CaaS, Cloud-based application, Cost Comparison Analysis, Costing, IaaS

1. INTRODUCTION

The digital world has noted an essential increase in the demand for cloud-based applications (Statista, 2021). Therefore, the demand for cloud application development has increased, forming a competitive and fast-growing industry. In 2021, the global cloud applications market had a value of 133.6 billion U.S. dollars and is expected to reach 168.6 billion U.S. dollars by 2025 (Statista, n.d.-b).

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Cloud-based applications provide businesses with significant benefits. A cloud-based application can be a cost-efficient solution for organizations since only the utilized resources are charged. In addition, cloud applications offer reliability, high scalability, security, and flexibility. By providing simple data sharing, editing options, and remote and real-time collaboration, they facilitate the smooth and effective collaboration of business personnel (Moghaddam et al., 2015).

However, the spectrum of cloud services is wide, and businesses can adequately take advantage of the opportunities that cloud services offer in terms of infrastructure and application deployment. One or more hosting models, including Infrastructure as a Service (IaaS) and Container as a Service (CaaS), can be used to deploy cloud-based applications. Each model's specifications and pricing are unique. Cloud computing costs vary greatly between different services and vendors. While the majority of businesses can accurately estimate the costs of setting up and maintaining on-premise IT infrastructure, many cannot accurately estimate the costs of deploying their services to the cloud.

In this paper, cloud-based applications deployed by various cloud services are discussed. It explores infrastructure as a service (IaaS) and container as a service (CaaS) as delivery approaches for cloud-based applications. CaaS and IaaS are two of the most widely-used cloud computing services available today. IaaS is the most straightforward cloud service and provides companies and administrators with the most control and power over software and hardware (Garg et al., 2011). In contrast, CaaS has introduced an entirely new perspective by establishing an intermediate layer between PaaS and IaaS (Boukadi et al., 2020). However, cloud users frequently associate CaaS with IaaS environments. A better understanding of the deployment differences between CaaS and IaaS can be challenging for most business owners and cloud users. In order to reveal and discuss the differences between IaaS and CaaS deployments, a cloud-based application is presented and deployed by the two models. In addition, a comparison analysis is introduced in terms of cost and the number of utilized resources. The corresponding costs of the two deployments are estimated based on the Amazon (Amazon, 2022), Google (Google, 2022) and Microsoft's (Microsoft, 2022.) pricing.

The remaining sections are organized as follows: Section 2 introduces related work, while Section 3 describes the architecture of a cloud-based application. Section 4 discusses cloud deployment, adopting IaaS and CaaS services, whereas Section 5 presents the mathematical formulation of the utilized resources based on user demand and presents the costs for both cloud models. The results are discussed in Section 6 and the paper is concluded in Section 7

2. RELATED WORK

Several articles compare the costs of various cloud models and cloud versus proprietary IT infrastructure. Konstantinos K. et al. (2010) compared the cost of purchasing proprietary IT infrastructure to the cost of cloud services, concluding that cloud adoption is more cost-effective than purchasing and maintaining IT infrastructure.

In addition, Manner (2019) presented a cost simulation framework among Function-as-a-Service (FaaS), Platform-as-a-Service (PaaS), and Container-as-a-Service (CaaS), highlighting the cost-effectiveness of FaaS. In Adzic et al. (2017) two industrial case studies were discussed, indicating how migrating an application to serverless computer services greatly reduced hosting costs. Finally, in Villamizar et al. (2016), authors addressed a comparative cost analysis of web applications deployed by a monolithic architecture, a microservice architecture operated by the cloud customer, and finally a microservice architecture operated by the cloud provider. According to the results, the microservices' approach was the most cost-efficient deployment.

Moreover, Jiang et al. (2022) present a comparison between IaaS and SaaS in cloud ERP implementation. The paper described the evolution of enterprise resource planning (ERP) implementation in various industries and delivery models facilitated by cloud computing. IaaS and SaaS deployment models were chosen, concluding that IaaS and SaaS can both be utilized in cloud ERP implementation.

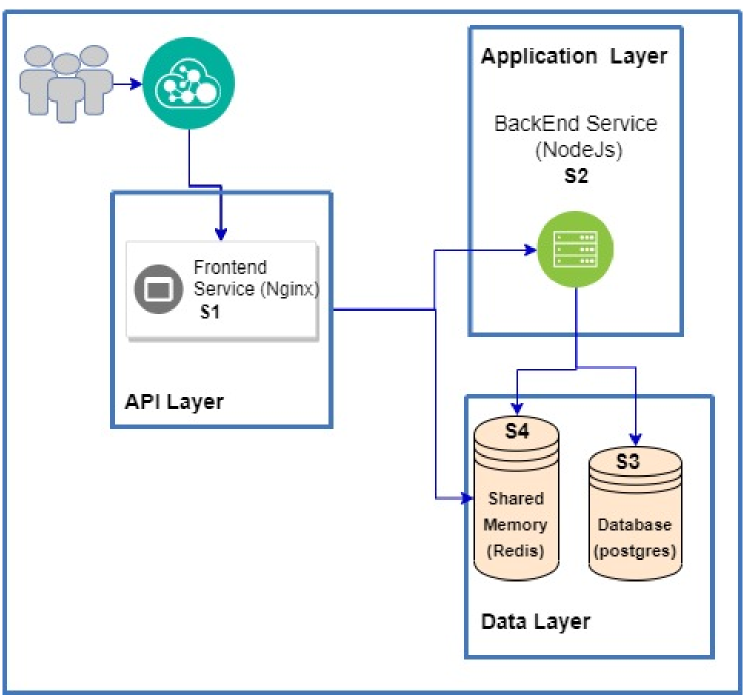
As cloud computing and services grow in popularity, businesses around the world adopt cloud services. It is difficult for cloud users to keep track of all the available models and select the one that best meets their organization's requirements and budgetary constraints. The present study compares IaaS and CaaS deployments in terms of cost and to the best of our knowledge, there are no papers that describe and compare IaaS and CaaS deployments, despite the fact that several works present a cost comparison analysis between different cloud services. A deployment scenario adopted by a small to medium-sized business is presented and described in order to highlight the cost and resource utilization differences between the two deployments. The outcomes of this study can provide guidance not only to cloud computing professionals whose primary concern is cost but also to researchers who conduct cost analyses in the cloud market.

3. CLOUD-BASED APPLICATION ARCHITECTURE

To evaluate the implications of deploying an application using IaaS versus CaaS cloud services, it is necessary to specify the application's design. This section describes a cloud-based web application that employs a microservice architecture (Silveira et al., 2016), as shown in Figure 1.

The application is presented in a simplified form and consists of four distinct types of microservices. Each of them, including the front-end service (S1), the Backend Service (S2), the Database Service (S3), and the Shared Memory service (S4), implements a limited business capability. The Frontend service is the one with which users interact directly and that translates user actions into internal messages for transmission to the Backend service. The latter process these messages to provide the functionality of the application. Database and Shared Memory, which are the last two services, make up the application's data tier by storing application data and session data, respectively. An example of the high-level application's architecture is illustrated in Figure 1.

Figure 1. Architectural design for a cloud-based application



3.1 Software Environment

In order to estimate the application's resource requirements, specific software platforms need to be considered. The NodeJS platform (Nodejs, 2022) is used as Backend server runtime. Also, the NGINX server (Nginx, 2022) is used for the Frontend Service. Last, the PostgreSQL database (Postgresql, 2022) and the Redis cluster (Redis, 2022) are used for the Database and the Shared memory services, respectively. The compute requirements and the supported users for an instance of each service rely on the corresponding vendors' best practice technical recommendations.

4. DEPLOYMENT IN CLOUD

Three architecture implementations are defined in order to compare the infrastructure costs required to host the proposed application in each cloud model.

First, an architecture is set up in which each service of the application is turned into a container and runs on a CaaS cloud model. Since the containers are isolated, they can be deployed and scaled independently. So, a similar architecture is also set up in the IaaS cloud model, where each VM runs just one service of the application so that the VMs can scale up or down independently. However, since in the real world the application microservices grow as more functionality is added, it is hard to run each service into separate VMs. Therefore, a second scenario in IaaS is also considered, in which one of the VM hosts runs more than one service.

4.1 Deployment in CaaS

In the CaaS model, the application is containerized. The four microservices are refactored into four different containers. As shown in Figure 2a, all containers run on a platform called a "container orchestrator." A cloud provider hosts and takes care of clusters of virtual machines that share this platform.

4.2 Deployment in IaaS

Deployment in IaaS-A In the first IaaS model scenario each service is de- serverployed into separate VMs. As it is shown in Figure 2b, the Frontend service (S1), the Backend service (S2), the Database service (S3) and the Shared memory service (S4) are deployed into VM_{S1}, VM_{S2}, VM_{S3} and VM_{S4} accordingly.

Deployment in IaaS-B The second scenario in IaaS model presents a similar infrastructure with the first one with the difference that in this approach the Frontend service (S1) and the Shared Memory service (S4) are collocated in the same VM host called VM_{FE}. The rest of two services, the Backend service and Database service, are split into VM hosts, called VM_{BE} and VM_{DB} respectively. The deployment architecture is given in Figure 2c.

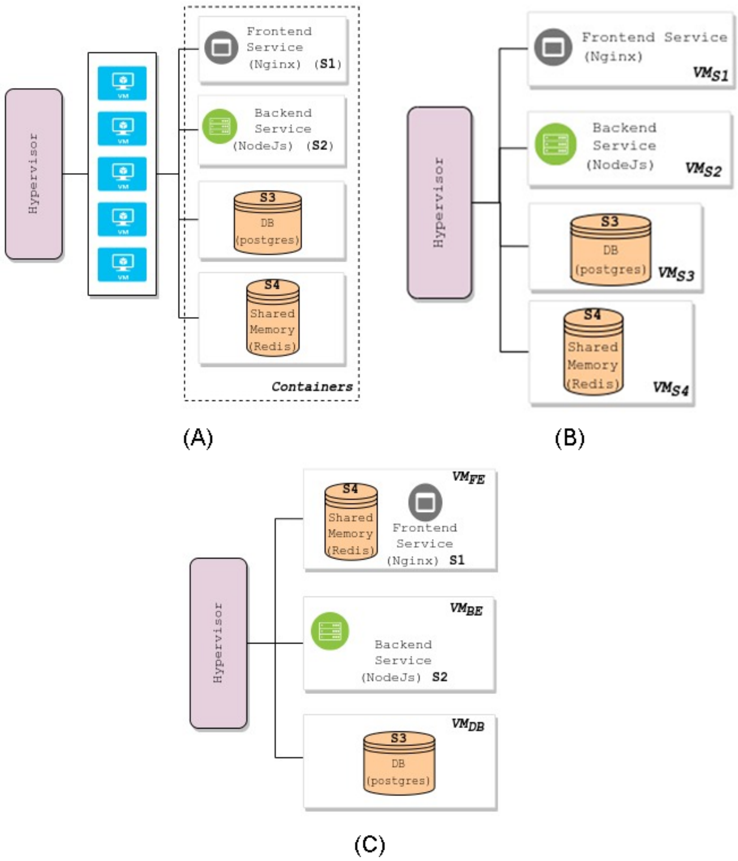
In all VM types for the IaaS scenarios, Ubuntu 20.04 LTS 64-bit (Ubuntu, 2021) is used as the host operating system. The hypervisor is hosted and maintained by the cloud provider. Furthermore, all VM types can be scaled to meet workload demands or to attain high availability.

For the rest of the paper, the VM units in IaaS and the container units in CaaS are called instances depending on which cloud solution they are referring to.

5. MATHEMATICAL FORMULATION IAAS & CAAS RESOURCES

The cloud providers take into account a wide variety of characteristics for billing IaaS and CaaS services. They are measurable, such as the amount of CPU and RAM, as well as non-measurable, such as location and redundancy. This study compares the costs based on three of the most important metrics, which are the number of virtual CPUs, the amount of memory, and the storage reserved for the compute instances (Filiopoulou et al., 2017) (Liagkou et al., 2022).

Figure 2. Deployment approaches (a) Deployment in CaaS (b) Deployment in IaaS_A (c) Deployment in IaaS_B



The estimated costs are based on user demand, denoted as $application_{users}$, which is an important factor since it drives the scaling of the compute resources to serve the traffic.

As shown in Equations 1, 2, and 3, the total compute capacity of an application is the sum of the compute capacity that each instance sets aside to handle user requests.

$$Total_{CPU} = \sum_{i=l}^{k} \frac{application_{users}}{instance_{user_{si}}} * CPU_{instance_i[vCores]} \tag{1}$$

$$Total_{Ram} = \sum_{i=l}^{k} \frac{application_{users}}{instance_{user_{si}}} * RAM_{instance_i}[GB] \tag{2}$$

$$Total - Storage = \sum_{i=l}^{k} \frac{application_{users}}{instance_{user_{si}}} * Capacity_{instance_i[GB]} \tag{3}$$

where $instance_{users}$ represents the maximum number of users an instance supports, and k denotes the number of instances in each scenario. More specifically, k equals 3 in the IaaS-B scenario, and k equals 4 in IaaS-A and CaaS deployments.

The equations are common in all three scenarios previously analyzed. When the user demand $application_{users}$ exceeds the $instance_{users}$ for each instance type, the instance scales out in each deployment scenario. All the calculated required resources are estimated as the average requirements for optimized application service performance to ensure quality of service (QoS). It is also assumed that asynchronous requests are used for each process.

Table 1 shows the compute requirements for each instance in three deployment scenarios.

The current study takes as a given that the compute requirements for software components themselves are the same whether the application is VM-based or containerized. In most cases, this can be considered the worst-case scenario since containers are more lightweight compared to VMs (Desai, 2016). The goal is to estimate and compare the infrastructure costs when moving the same software compute capacity from IaaS to CaaS. Thus, based on Table 1, the compute requirements in the CaaS scenario are the software requirements themselves. In the IaaS-A scenario the compute resources are increased by the operating system's compute resources as for example the CPU requirements for VM_{S1} presented in the Equation 4.

$$CPU_{VM}S1 = CPU_{S1} + CPU_{OS} \tag{4}$$

In IaaS-B, the capacity per instance is even higher than in the rest of the two scenarios since the S1 service resources are appended with S4's resources in the same instance, as shown in Equation 5.

$$CPU_{VM}FE = CPU_{S1} + CPU_{S4} + CPU_{OS} \tag{5}$$

It is worth noting that the amount of compute resources available is also affected by application-specific properties. For example, a certain application service may require four cores, but those may not be used at all times. However, the cost model of IaaS is per-VM-per-hour, meaning that the customer pays for compute capacity provisioned by the hour and not for the compute capacity actually used. In the CaaS cost model, some providers offer the pay-as-you-go option (Google, 2022), so as to charge only for the used capacity and not pay for idle compute capacity, but this is not considered in the current study. Both models were compared based on provisioned capacity.

Table 1. Requirements for cloud-based application services and resources per instance (Virtual Machine or container)

	Instance	Max users	CPU [vCores]	RAM [GB]	STORAGE [GB]
IaaS-A	*VM_S1 - Nginx*	1024	9	9	267.5
	VM_S2 - NodeJS	65535	9	33	602.5
	VM_S3 - PostgreSQL	5000	9	25	102.5
	VM_S4 - Redis	1024	5	9	12.5
IaaS-B	*VM_FE - Nginx + Redis*	1024	13	17	267.5
	VM_BE - NodeJs	65535	9	33	602.5
	VM_DB - PostgreSQL	5000	9	25	102.5
CaaS	*S1 - Nginx*	1024	8	8	255
	S2 - NodeJS	65535	8	32	600
	S3 - PostgreSQL	5000	8	24	100
	S4 - Redis	10000	4	8	10

5.1 IaaS & CaaS Resources and Costs

As mentioned above, the present cloud-based application is addressed to small and medium enterprises; thus, the number of concurrent users that a cloud-based application can handle is approximately 350 users. Radhakrishnan, S. (2019). As the baseline for the comparison, a sample of 350 different values for the variable $application_{users}$ are randomly chosen. These values were applied to the aforementioned mathematical formulations so as to calculate the overall utilization of resources for each architectural scenario. Then, the monthly infrastructure costs were estimated for these resources in the three deployment scenarios according to providers' pricing. The pricing model taken into account was on-demand pricing, and the region selected was the US-Central region across all providers.

Amazon's IaaS costs are based on Amazon EC2 pricing, and CaaS costs are based on Amazon Elastic Container Service pricing (Amazon, 2022).

The general purpose a1.4xlarge, m6g.4xlarge, a1.2xlarge, t4g.2xlarge, and a1.xlarge instance types were used. Also, the "General Purpose SSD (gp2)" type was applied as a storage type.

Similarly, Google's Compute Engine (GCE) pricing and Google Kubernetes Engine (GKE) standard pricing (Google, 2022) are taken into account for IaaS and CaaS calculations accordingly. In all cases, the "General Purpose" machine family was used. Also, the E2 Series has "Custom Machine Type" selected as the machine type and "Zonal SSD Persistent Disk" as the boot disk type.

Finally, Microsoft's costs are calculated based on the Virtual Machines and Azure Kubernetes Service (AKS) pricing, respectively (Microsoft, 2022). The chosen instance types were B12ms, D8as, D16as, and D4as, and the "Standard LRS SSD" storage set for storage type.

One of the limitations of the current work is that it only considers compute costs for CPU, RAM, and storage. The billing is based on on-demand instances, and no commitment discounts are taken into account. Also, additional costs that shape the cloud pricing, such as networking, security, operation, monitoring, licensing costs, etc., are excluded from this work. Furthermore, the costs that are generally constant between IaaS and CaaS, such as external IP address costs, are not considered. Last but not least, no performance tests are executed to evaluate the services' compute limits for each deployment method.

6. RESULTS

Comparing the resources. Given three deployment application architectures in different cloud models, the overall amount of utilized resources, based on the user demand, is calculated with the goal to estimate the infrastructure costs between cloud models in the three leading providers, Amazon, Google and Microsoft.

Comparing first the average compute capacity between the three architectures, the results show that the IaaS-B architecture requires more compute resources than the other two, as illustrated in Figure 3. This is a consequence of the fact that IaaS-B is the less granular scenario. In all scenarios, new VM hosts in IaaS or new containers in CaaS are launched in response to user demand. In IaaS-A and CaaS scenarios, the services are deployed independently and can be scaled without impacting the others. On the contrary, in the IaaS-B scenario, the difference in resource requirements between S1 and S4 creates a scaling problem for VM_{FE} since both services are scaled at once, although their operations exhibit different workloads. This scaling mismatch has a negative impact on the total amount of resources in IaaS-B. In addition, the deployment in CaaS can reduce the compute capacity compared with IaaS-A, since the former lacks the operating system's resources for the initial deployment as well as through scaling.

6.1 Cost comparison by provider.

Furthermore, the infrastructure costs for each architectural scenario between the three providers, Amazon, Google, and Microsoft, are depicted in Figure 4. The comparison of the architectures between

Figure 3. A comparison between IaaS and CaaS resources

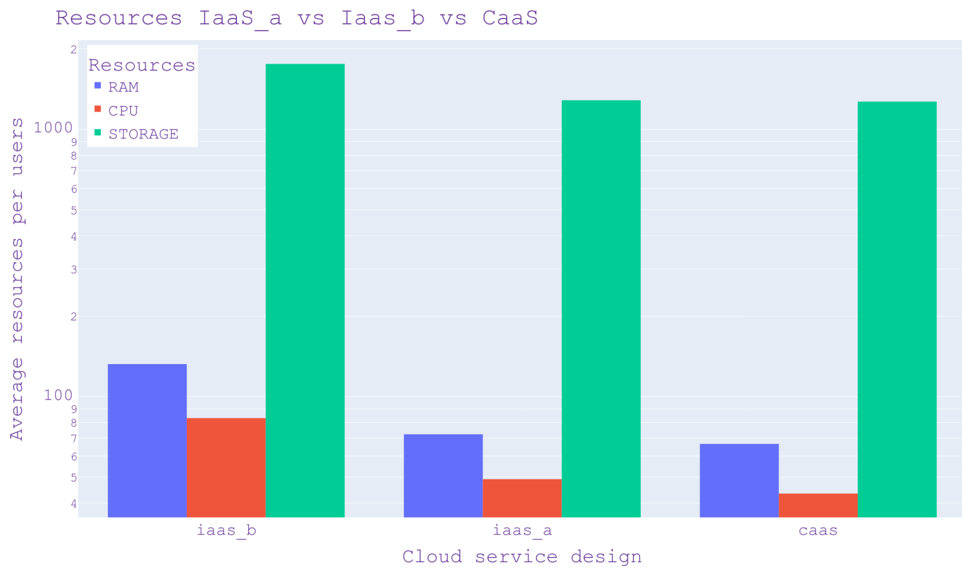
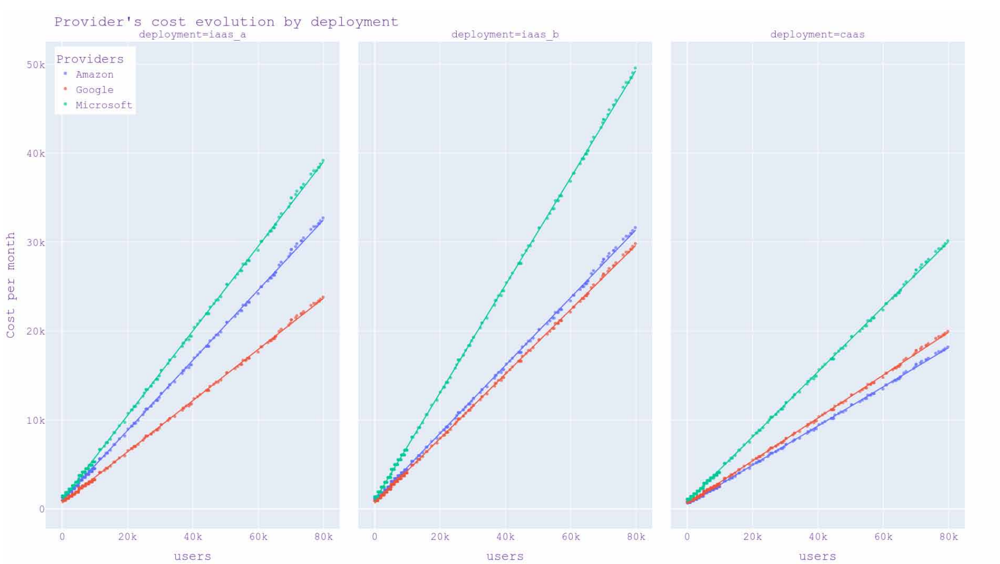


Figure 4. Cost comparison between IaaS and CaaS per provider



them for each provider indicates that the costs in CaaS are lower than the rest of the two scenarios in the provider's context. More specifically, for Amazon, the CaaS cost is reduced by 43.6% and by 42.1% in comparison to IaaS-A and IaaS-B, respectively. Likewise, for Google, the CaaS cost is reduced by 17.24% and 41.4%, and for Microsoft, it is reduced by 23.4% and 40%, compared to IaaS-A and IaaS-B, respectively. The decreased amount of costs in CaaS is influenced by the least amount of resources required on it. Similarly, the overall costs for IaaS-B are the highest compared with the rest of the two scenarios in the context of the provider since it requires the biggest amount of resources.

However, it is observed that although the overall compute capacity in IaaS-A is less than that in IaaS-B, the former is more expensive on Amazon. This happens because Amazon's price bundles for VMs are less granular than the bundles at Google and Microsoft in terms of CPU and RAM and correspond to fixed server sizes. This is also amplified by the fact that the highest cost reduction for the CaaS model is detected in Amazon since the containers can fit in much lower and cheaper machines. In addition, the aforementioned comparative cost rates reveal that there is less cost reduction when moving from VMs to containers with the same provider as observed in Google, and especially when moving from IaaS-A to CaaS. This comes about since Google offers the option of customized virtual machines to the customers, resulting in higher costs for IaaS.

Finally, the results show that the lines in each graph are parallel in each architecture's context. This shows that the pricing policy of cloud providers is about the same for each cloud model. Also, in each architecture, Amazon and Google are cheaper than Microsoft for the specific application that this study looks at. It is also noticed that the CaaS scenario is not always the cheapest between providers for the same number of users on this specific application, e.g the IaaS-A in Google is less expensive than the CaaS in Microsoft. However, the IaaS-A scenario cannot be considered a common use case.

7. CONCLUSION

Cloud computing is evolving and bringing forward new computing models to satisfy large-scale applications. The cost of deployment in the cloud is tightly coupled with the number of utilized resources, which is in turn driven by cloud demand.

The current study presents cloud-based applications deployed by different cloud services. It explores Infrastructure as a Service (IaaS) and Container-as-a-Service (CaaS) as delivery approaches for cloud-based applications.CaaS and IaaS are two of the most widely-used cloud computing services available today. In addition, a cost comparison analysis of a certain cloud-based application, designed in three different architectures and deployed in two infrastructure solutions operated by the cloud providers, the IaaS and CaaS cloud models, was conducted. For the resource calculations, mathematical equations are formed based on the number of users. In addition, a sample of 350 random cases of application users was applied to the mathematical formulas to estimate the hardware requirements for CPU, RAM, and storage for each user base. Then, the corresponding costs of the three implementations are estimated based on the pricing policies of the leading providers, Amazon, Google, and Microsoft.

According to the findings, hosting applications in CaaS is a compelling way to reduce the compute footprint, which translates into lower infrastructure costs by up to 43.7 percent in a provider's context for the same software requirements. On the contrary, the IaaS solution turns out to be more expensive when deployed at scale, but the pricing can be different between providers for the same requirement. The cost reduction is an outcome of granular applications' scalability as well as granular pricing policies. In conclusion, containerization takes full advantage of cloud-native features. In conjunction with the cost savings benefits container technology achieves, enterprises are urged to invest in CaaS cloud models.

The results of this work can offer guidance to cloud computing professionals who aim to choose a suitable cloud model that serves their needs but also complies with budget constraints. In addition, it can be a helpful tool for researchers who conduct cost analysis in the cloud market. The limitations of this study include that it takes into account only the CPU, RAM, and storage computation costs for comparison purposes. In addition, the costs that contribute to cloud prices, such as networking and security costs, etc., are not examined in this work. Moreover, the costs that are generally constant between the cloud models, such as payment for external IP addresses or operation costs for migration from one cloud model to another, are also not considered. Lastly, no performance tests were executed to evaluate the limits of each deployment method.

Further extensions and future research directions include the deployment of the application in other cloud deployment models like PaaS or serverless models. Moreover, the implications for migration and operation costs from one cloud model to another are also interesting research areas.

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