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Secure and effective cloud infrastructure

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***Abstract*—The paper analyzes cloud service providers in order to determine the most suitable solution for KIS FRI UNIZA (Department of Information Networks, Faculty of Management science and Informatics, University of Žilina in Žilina). The theoretical part models the basic concepts of cloud, SaaS, PaaS and IaaS and compares services from AWS, Azure, Google Cloud, Alibaba Cloud and Open Telekom Cloud.**

The practical part brings a business analysis of the current use of the cloud for KIS, focusing on performance, security and administration. Based on the results, a provider is proposed that best meets the requirements. The findings include a comparison of costs, compliance with security standards and integration with existing systems. The work ends with specific recommendations.

***Index Terms*—Remote access, Virtual laboratory, Academic education**

I. Introduction

In an era of increasing digitization, cloud computing (CC) is influencing the fundamental structures of research and education. Institutions around the world are integrating CC as both a tool and a subject of teaching. Approximately 60% of the members of KIS FRI UNIZA (Department of Information Networks, Faculty of Management and Informatics, University of Žilina in Žilina) use CC in teaching, influencing seven subjects in the ASI and IaST programs through the IaaS model.

The departmental cloud was created in 2014 as a response to the limitations of older tools (VirtualBox, XenServer), which were not sufficient for teaching needs. In an effort to improve conditions for students and research, OpenStack was deployed, which brought scalability and efficiency. Since then, the cloud infrastructure has been continuously developed and is also supported through final theses, which contribute to its further improvement [1].

The aim of the work is: to perform a comprehensive business analysis of the current use of CC KIS services at KIS FRI UNIZA and, based on this analysis, to propose an external cloud provider that best meets the specified criteria.

This includes evaluating potential providers for their ability to offer a more accessible and versatile platform for both teachers and students, addressing current limitations and supporting future plans for expansion and management automation.

The paper

II. Theoretical Background

Cloud computing (CC) provides a wide range of computing services over the Internet, including servers, storage, networks, and software. It allows companies to access these resources without the need for their own infrastructure, saving costs and simplifying management. CC operates as an on-demand service, where the user only pays for the resources actually used.

A. Model of cloud services

The cloud can interact with a user or application in a variety of ways. Each service model offers a certain level of abstraction that simplifies the development of systems and software.

- **SaaS (Software as a Service)** - allows customers to use applications from the supplier that run on the cloud.
- **PaaS (Platform as a Service)** - It allows users to develop applications using available tools and languages without managing the infrastructure. They only control the application itself and some of the environment configuration.
- **IaaS (Infrastructure as a Service)** - It provides a virtual data center with access to computing resources, storage, and networking. The user can install their own operating system, databases, and run any software [2].

B. Types of deployment models

The deployment model determines how cloud services are delivered and managed. We distinguish four main types based on resource availability and target user group.

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- **Public cloud** - The provider owns and manages the infrastructure located in data centers and offers scalable services over the Internet. The public cloud is popular for web applications, data storage, and software development due to its low cost and ease of deployment [3].
- **Private cloud** - A private (internal) cloud belongs to a single organization and is centrally managed. It provides a high level of control, security, and customization, making it ideal for businesses with strict data management and infrastructure requirements [2].
- **Hybrid cloud** - A hybrid cloud combines public and private clouds and allows for flexible data movement between them. It is suitable for organizations that want to combine the security benefits of a private cloud with the scalability and efficiency of a public cloud [4].
- **Community cloud** - A community cloud provides services to a group of organizations with common interests, security requirements, and policies. It can be hosted internally or externally and is used to collaborate on shared projects and goals [5].

C. Overview of cloud service providers

In the rapidly evolving CC environment, choosing the right cloud provider is crucial to exploiting the full potential of cloud services. For the purposes of this work, providers were selected based on their market share and the features they offer to educational and research institutions. These are: Amazon AWS, Microsoft Azure, Google Cloud, Alibaba Cloud and Open Telekom Cloud.

III. Related works

Many authors compare cloud service providers in their works, whose services they subsequently use for educational or research purposes. Cloud services are used by the following providers: Amazon AWS [6], Microsoft Azure [7], Google Cloud [8], Alibaba Cloud [9], [10] and Open Telekom Cloud [11].

The higher education environment has brought many challenges and opportunities that have arisen as a result of the restrictions of the COVID 19 pandemic. With the need for distance learning arising, this area has become the subject of research by many researchers [12]–[14].

Many learning materials are available online [15], [16]. And despite the increasing quality of simulators, simulation is not the same as interacting with real devices [1].

IV. Current state

The Department of Information Networks (KIS) of the Faculty of Management and Informatics of the University of Žilina in Žilina provides education and research in the field of information and communication networks with a special focus on computer communication networks and their security. With 14 employees, 6 doctoral candidates and more than 260 students, KIS plays a key role in expanding knowledge and innovation in the field of network technologies. Six teachers actively integrate CC KIS into their teaching, using the department's state-of-the-art cloud infrastructure.

The cloud implementation supports three IaaS deployment models, it can provide either directly accessible virtual machines, or a private network consisting of several virtual machines accessible through the controller and a private network consisting of several virtual machines accessible through the pfSence virtual firewall. Within the educational process, KIS services are used in the following subjects:

- Integration of information and communication systems in the ASI engineering program.
- Network Design 1, Network Design 2 in the ASI engineering program.
- Network Operating Systems in the ASI Engineering Program.
- Computer Networks 3 in the IaST Bachelor's Program.
- Security Incident Management in the IaST Bachelor's Program.

A. Stakeholder identification

Understanding the key stakeholders involved in CC at KIS FRI UNIZA is essential for business analysis. These stakeholders play different roles in the effective use and management of cloud services.

- **Employees of KIS FRI UNIZA** - The primary users of cloud infrastructure are teachers and staff. Their involvement in the cloud platform ensures the provision of the latest and innovative educational methods, thereby improving the quality of both teaching and learning.
- **Students** - End users leverage the cloud for teaching, projects, and research. They gain access to tools and resources that support flexible and innovative learning regardless of location.
- **IT administrators** - IT administrators are responsible for managing and maintaining cloud infrastructure. They ensure system reliability, technical integrations, troubleshooting, security, and performance optimization.
- **Head of department** - The head of department ensures that the cloud infrastructure supports strategic educational goals, oversees integration into instruction, budget decisions, and implementation of new technologies.

B. Technical specification

- **CC management** - The management node in the data center manages the cloud infrastructure. It coordinates network operations, resource allocation, monitors performance, provides access and scalability, thereby ensuring the efficient functioning of the system. The technical specifications of the management nodes are listed in Table I.
- **Compute nodes** A compute node is used to launch virtual machines and process tasks. It is responsible for their performance, lifecycle management, and efficient resource allocation. The technical specifications of the compute nodes are detailed in Table II.

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- **Software** Software components simplify the management and deployment of virtual machines with intuitive interfaces and automation. They reduce complexity and enable efficient, scalable cloud management.

Web interface – Horizon is an OpenStack web interface that enables easy management of virtual machines, networks, and storage through a browser. It makes it easier for administrators and users to work without the need for a command line.

OpenStack is the key platform for managing the cloud infrastructure at KIS FRI UNIZA. It provides services for computing, storage and networking and, thanks to its modular architecture, offers flexibility, scalability and integration of components such as Nova, Swift and Neutron.

MAAS (Metal as a Service)simplifies the management of physical servers by automatically converting them to cloud instances. Enables rapid deployment and management of large clusters, saving time and reducing maintenance effort [17].

Juju is an orchestration tool that simplifies the deployment and management of applications in the cloud. It uses charms to automate the entire application lifecycle, including scaling and integration, increasing management efficiency and agility [18].

V. Cloud provider ratings

The analysis of pricing models was performed using the pricing calculators of each cloud provider and the technical specifications of CC KIS, which estimated the price costs for each cloud service provider for individual taught subjects.

A. Total cost of CC services

When assessing the cost-effectiveness of cloud services, the total costs of non-stop operation for the subjects provided during the winter and summer semesters were taken into account. In the winter semester, the subjects Computer Networks 3, Security Incident Management and Network Operating Systems were analyzed. During the summer semester, these were the subjects Network Design 1, Network Design 2 and Information and Communication Systems Integration. The results of the analysis for the entire year are presented in Table III.

The analysis shows that Google Cloud and Alibaba Cloud offer the most cost-effective solutions for KIS FRI UNIZA. Alibaba Cloud has the lowest total cost for the entire academic year and both semesters, making it the most cost-effective choice.

B. Configuration comparison

This section focuses on comparing the prices of individual configurations at selected cloud service providers. Providers offer different prices for configurations with 2 CPUs and 4 GB RAM, 4 CPUs and 16 GB RAM, 8 CPUs and 32 GB RAM, and 16 CPUs and 128 GB RAM. (as shown in table IV) and provides a detailed comparison of these configurations among providers Alibaba Cloud, Google Cloud, Microsoft Azure, Amazon AWS, and Open Telekom Cloud.

The choice of pricing model and provider significantly affects the overall cost of cloud services. While the pay-as-you-go model offers flexibility and is suitable for variable workloads, reserved instances provide cost savings for stable and long-term use. The comparative analysis shows that Alibaba Cloud and Google Cloud offer the most cost-effective solutions for the given configurations.

C. Number of availability zones

Cloud providers use the concepts of regions and availability zones to structure their global infrastructure. This vast network enables data redundancy, fault tolerance, and low-latency connections. The figure below shows a comparison of the number of regions and availability zones (Table VI).

D. Security measures

When choosing a cloud service provider, it is important to consider security measures that will ensure the protection of sensitive data and compliance with global security standards. Each provider offers different levels of security, which can significantly affect the trust and reliability of their services. A comparison of security standards of cloud service providers is given in Figure 1.

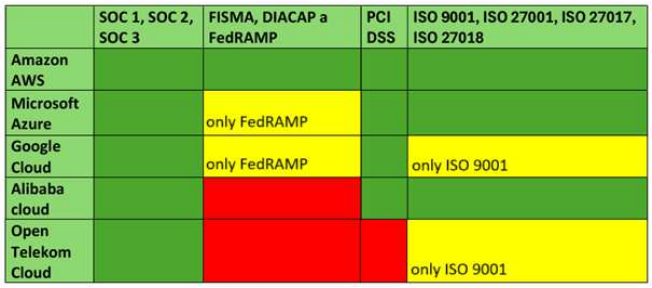


Fig. 1. Comparison of safety standards

The picture shows that the level of security varies among providers. Amazon AWS is the leader in security, as it complies with all selected standards such as SOC 1, SOC 2, SOC 3, FISMA, DIACAP, FedRAMP, PCI DSS, ISO 9001, ISO 27001, ISO 27017 and ISO 27018. Microsoft Azure and Google Cloud also provide strong levels of security with SOC 1, SOC 2, SOC 3, PCI DSS, ISO 9001, ISO 27001, ISO 27017 and ISO 27018 certifications, but they do not meet FISMA and DIACAP standards. Alibaba Cloud offers solid security, but lacks FedRAMP, FISMA and DIACAP certifications. Open Telekom Cloud has the most limited range of certifications, as it is only compliant with ISO 9001 and SOC 1, SOC 2, SOC 3. Overall, AWS provides the most comprehensive security protection, Azure and Google Cloud offer robust security measures, Alibaba Cloud has adequate security with some limitations, and Open Telekom Cloud lags behind other providers in compliance with global security standards.

E. Compatibility with systems used at KIS FRI UNIZA

The compatibility of cloud services with the systems used at KIS FRI UNIZA is a key factor in choosing a suitable

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TABLE I
CONTROL NODES

	Name	*Processor*	*Core count*	*RAM*	*Storage*
1	Cisco UCS C220M3	2x Xeon E5-2667v2	2x 8 (16)	128GB	300GB + 2x 256GB SSD + 600GB
2	Cisco UCS C220M3	2x Xeon E5-2630v2	2x 6 (12)	128GB	300GB + 2x 6006GB

TABLE II
COMPUTE NODES

Quantity	*Model*	*Processor*	*Core count*	*RAM*	*Storage*
4x	IBM x3650 M5	2x Xeon E5-2699v3	2x 18 (36)	512GB	300GB + 4x 1,2TB
2x	Lenovo x3650 M5	2x Xeon E5-2680v4	2x 14 (28)	512GB	300GB + 4x 1,2TB
2x	HP DL380 G9	2x Xeon E5-2650v3	2x 10 (20)	256GB	300GB + 1,8TB + 2TB SSD
1x	HP DL380 G9	2x Xeon E5-2620v4	2x 8 (16)	256GB	300GB + 1,8TB + 2TB SSD
1x	Dell R720	2x Xeon E5-2665	2x 8 (16)	384GB	300GB + 1,8TB + 2TB SSD
1x	IBM x3650 M3	2x Xeon x5650	2x 6 (12)	256GB	300GB + 1,8TB + 2TB SSD

TABLE III
PRICES CALCULATED FOR BOTH SEMESTERS

Provider	*Price (EUR)*
Amazon AWS	63 378,21
Microsoft Azure	69 874,05
Google Cloud	46 005,50
Alibaba Cloud	41 062,61
Open Telecom Cloud	57 916,12

provider. For effective education, it is important that cloud platforms support a wide range of software and services that are essential for various courses and projects.

VI. EVALUATION OF THE OBTAINED RESULTS

Rating of cloud service providers based on cost-effectiveness, availability zones, security measures and compatibility with subjects taught at KIS FRI UNIZA. In the Table V, for each category, the best provider received 4 points, the second best received one point less, etc. and the worst received 0 points.

Our analysis shows that Google Cloud is the best overall choice due to its balance of cost, availability, security, and compatibility, with Microsoft Azure and Amazon AWS also being strong competitors depending on specific priorities such as availability zones, security measures, and number of features.

VII. DISCUSSION

Based on the results of the analysis of cloud service providers, KIS FRI UNIZA must consider several key factors when selecting the most suitable cloud service provider. The evaluation focused on cost-effectiveness, availability zones, security measures, and compatibility with existing courses at KIS FRI UNIZA.

Cost-effectiveness Google Cloud and Alibaba Cloud offer the most cost-effective solutions (Table IV), for the required configuration. Despite the 30 percent discount, Open Telekom Cloud still lags behind Google Cloud and Alibaba Cloud in price. Given the budget constraints and the need for effective cost management, KIS FRI UNIZA should consider these two providers for their cost advantages.

Availability zones Microsoft Azure leads in availability zones, providing high redundancy, fault tolerance, and low latency connections with 160 zones across 60 regions (Table VI). Google Cloud also offers robust availability with 121 zones across 40 regions. For applications and services that require high availability and low latency, Microsoft Azure and Google Cloud are the preferred choices. KIS FRI UNIZA should prioritize these providers for mission-critical applications that require high availability and geographic redundancy.

Security measures Amazon AWS excels in security measures, meeting the widest range of global security standards including SOC 1, SOC 2, SOC 3, FISMA, DIACAP, FedRAMP, PCI DSS, ISO 9001, ISO 27001, ISO 27017, and ISO 27018. After AWS, Microsoft Azure and Alibaba Cloud offer high levels of security. Google Cloud also maintains significant security measures, but lags slightly behind in overall certifications. For applications that work with sensitive data and require robust security, AWS is the best choice. KIS FRI UNIZA should consider AWS for services that involve handling sensitive information and require strict security measures.

Compatibility with existing courses AWS Marketplace provides extensive virtualization support for Cisco, Fortinet, Juniper, and MikroTik devices, making it highly versatile for KIS FRI UNIZA's needs. Microsoft Azure and Google Cloud also offer support for Cisco, Fortinet, and Juniper devices. However, Alibaba Cloud falls short in supporting Juniper, MikroTik, and Open Telekom Cloud does not have a marketplace, requiring custom installations. Given the diverse needs for device virtualization in today's classrooms, AWS is the most compatible choice, followed by Microsoft Azure and Google Cloud. KIS FRI UNIZA should prefer AWS for its convenient virtualization options.

Overall performance According to the overall scoring (Table V), Google Cloud achieved the highest total score (14 points) due to its balanced performance across all evaluated criteria—cost, availability, security, and compatibility with KIS FRI UNIZA's teaching needs. Microsoft Azure and

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TABLE IV
CONFIGURATION COMPARISON

Provider	*2 CPU 4 GB RAM*	*4 CPU 16 GB RAM*	*8 CPU 32 GB RAM*	*16 CPU 128 GB RAM*
Alibaba Cloud	51,36 EUR	132,49 EUR	256,08 EUR	578,12 EUR
Google Cloud	63,17 EUR	141,55 EUR	282,28 EUR	701,84 EUR
Microsoft Azure	36,20 EUR	144,68 EUR	289,36 EUR	900,39 EUR
Amazon AWS	37,31 EUR	149,20 EUR	357,48 EUR	944,71 EUR
Open Telecom Cloud	79,25 EUR	167,25 EUR	333,84 EUR	971,10 EUR

TABLE V
OVERALL SCORING

Provider	*Availability zones*	*Instance prices*	*Security*	*Total cost of teaching*	*Device virtualization*	*Sum*
Amazon AWS	2	1	4	1	4	12
Microsoft Azure	4	2	3	0	3	12
Google Cloud	3	3	2	3	3	14
Alibaba Cloud	1	4	1	4	1	11
Open Telecom Cloud	0	0	0	2	0	2

TABLE VI
AVAILABILITY ZONES

Provider	*Regions*	*Availability zones*
Microsoft Azure	60	160
Google Cloud	40	121
Amazon AWS	330	105
Alibaba Cloud	30	89
Open Telecom Cloud	3	9

Amazon AWS followed closely with 12 points each, while Alibaba Cloud achieved 11 points and Open Telekom Cloud significantly lagged with only 2 points.

VIII. CONCLUSION

Based on the comprehensive evaluation, Google Cloud stands out as the best overall choice for KIS FRI UNIZA, offering an optimal balance between cost, availability, and compatibility. It provides a reliable and affordable infrastructure suitable for both teaching and potential research purposes.

Microsoft Azure, with its extensive availability zones and strong compliance standards, is ideal for applications requiring high availability and resilience. Amazon AWS, recognized for its unmatched security and versatile virtualization options, is particularly suited for workloads involving sensitive data and advanced network configurations.

Alibaba Cloud remains a cost-effective option, though less suitable for complex virtualization needs. Open Telekom Cloud, despite its competitive discounting, lacks the scale and flexibility of the leading providers.

For optimal results, KIS FRI UNIZA is encouraged to adopt a multi-cloud strategy, leveraging the strengths of each platform—Google Cloud for balanced performance, Azure for high availability, and AWS for secure virtualization. Such an approach ensures maximum efficiency, reliability, and adaptability across educational and research domains.

Furthermore, while this study focused primarily on the educational use of cloud services, future implementations should also consider research applications requiring high-performance computing and large-scale storage. These capabilities could further enhance the overall value of cloud integration at KIS FRI UNIZA.

This work successfully met its objectives by providing actionable recommendations for improving cloud operations at KIS FRI UNIZA, laying a strong foundation for future advancements in educational and research infrastructure.

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