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Cloud Federation: a Comparative Study and Exploration of Multi-Cloud Solutions in the Digital Era

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Abstract— **In today's digital era, organizations increasingly adopt cloud technologies to enhance flexibility, scalability, and efficiency. The rise in cloud providers, their offerings, and the complexity of corporate requirements have led to the emergence of multi-cloud solutions or cloud federation. This approach allows multiple cloud environments to be managed as one ecosystem, providing unique benefits. This article focuses on cloud federation, comparing it with multi-cloud, and discusses current approaches to federative cloud solutions. It concludes with a discussion of the technical and architectural aspects of federative solutions. This innovative approach brings unique benefits to organizations by choosing efficient and customized use of cloud resources according to changing needs.**

Keywords—architecture, functions, benefits, multi-cloud, cloud federation

I. INTRODUCTION

In the current era of dynamic development of information technologies, the view on the use of cloud services is constantly being transformed. In this context, a new trend of integration of cloud computing (CC) systems is emerging, called the Federated Cloud, which is the result of conceptual innovations in the field of cloud computing. A federated cloud, otherwise referred to as federated cloud architecture or cloud federation, represents a new approach that allows organizations to manage and combine multiple cloud environments, often from different providers, as one integrated ecosystem [1]. This architecture is designed to enable simple and effective management of cloud resources and applications used by the organization.

Today, this concept is in the phase of active and dynamic development, which brings several challenges and also leads to terminological problems. In this context, different sources and authors use the term federated cloud (or cloud federation) with different meanings, leading to misunderstandings and ambiguities. The most common misunderstanding in this area is confusing the concepts of a multi-platform cloud solution with a cloud federation. While the federated cloud and the multi-platform cloud solution represent significantly different concepts in the management of cloud resources and the integration of different cloud platforms [2].

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The goal of this article is therefore to provide a comprehensive view of the federated cloud and its differences from multi-platform CC solutions. To analyze the concept of federation, clearly define it and provide terms and descriptions that will help remove ambiguities and create a unified view of cloud federation within cloud computing. In this way, the article aims to contribute to the consolidation of knowledge in the field of federated cloud and to create a solid foundation for further research in this innovative and rapidly developing field.

II. ANALYSIS, AND COMPARISON OF CLOUD FEDERATION AND MULTIPLATFORM CLOUD SOLUTIONS

The concepts of cloud federation and multi-platform cloud solutions represent innovative approaches to the use and management of different cloud environments. Cloud federation is a concept that enables organizations and users to seamlessly integrate resources from different cloud providers so that organizations can transparently use services from different environments individually or in combination. This is about coordinated and cooperative functioning (integrity, interoperability) between different cloud platforms or providers to achieve better flexibility, scalability, and efficiency in the form of moving data, applications, and virtual environments between cloud systems without losing functionality or efficiency[2].

While cloud federation aims to create a single integrated ecosystem where different cloud environments are managed as a whole, multi-platform cloud solutions strive to achieve a flexible approach by selecting and combining different cloud platforms, their entities, and functions according to the needs and preferences of the organization. In the context of a multi-platform solution, organizations are not limited to one specific cloud service provider or a specific cloud architecture but can optimize their cloud environment based on specific needs and at

the same time use the advantages of different cloud providers to maximize the performance, security, and efficiency of their applications and processes [2].

The main difference between a cloud federation and a multi-platform cloud solution is their basic approach to the integration and management of cloud environments [2]. In this chapter, we will present a comparison of the differences between these two concepts, to identify their main characteristics, advantages, and limitations.

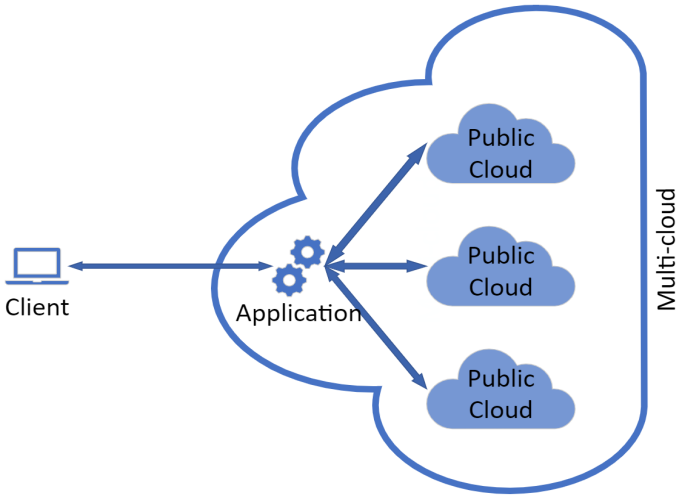

Fig. 1. Example of a Multi-cloud architecture model

A. *Similarities between multi-cloud and federative cloud*

First, both federated cloud and multi-cloud strategies involve the use of multiple cloud service providers. This multi-provider approach is a fundamental aspect of both strategies and allows organizations to leverage the unique strengths and capabilities of different providers. For example, one provider may offer superior machine learning capabilities, while another may have better data storage capabilities. By using multiple providers, organizations can choose the best services that meet their specific needs[2].

Second, both strategies help avoid seller lock-in. Vendor lock-in is when an organization is overly dependent on one cloud service provider and finds it difficult to switch providers due to high costs, technical incompatibility, or contractual restrictions. By using multiple providers, organizations can avoid this situation and ensure that they have the flexibility to change providers when needed[3].

Third, both federated cloud and multi-cloud strategies offer flexibility. This means that organizations can choose the best services to meet their specific needs. For example, an organization may choose to use one provider's machine learning services and another provider's database services. This flexibility allows organizations to tailor their cloud strategy to their specific needs, rather than being limited by a single provider's offerings[4].

Another similarity is the potential for improved resilience and redundancy. By using multiple providers, organizations can ensure that if one provider experiences an outage, services running on other providers can continue to function. This can be especially important for organizations that rely on their cloud services for critical business operations[1].

Finally, both federated cloud and multi-cloud strategies can help optimize costs. By using multiple providers, organizations can choose the most cost-effective services for their needs. Additionally, in a federated cloud strategy, workloads can be moved between providers to take advantage of price fluctuations[1].

B. *Differences between multi-cloud and federative cloud :*

The differences between a multi-cloud and a federated cloud solution can be divided into the following categories:

1) Goal and architecture:

A federated cloud is an architectural concept that focuses on integrating and managing multiple cloud environments as one integrated ecosystem. Its main goal is to simplify management and coordination between different cloud resources and platforms within a single organization [5].

A multi-platform cloud solution focuses on the use of multiple cloud platforms and providers for different purposes. In this case, the organization can actively use different cloud platforms for its different needs without having to integrate them into one common ecosystem.[6]

2) Integration and interoperability:

A federated cloud strives to achieve a high level of integration and interoperability between different cloud environments. It ensures unified management and communication between these environments [6].

In the case of a multi-platform cloud solution, it is not necessary to integrate between platforms. An organization can use different platforms independently without trying to manage them centrally [6].

3) Flexibility and diversification:

A federated cloud can be less flexible in the sense that an organization seeks to integrate different platforms into a single ecosystem to simplify management and ensure uniform security policies[1].

A cross-platform solution offers greater flexibility as an organization can use different platforms independently based on specific needs. This means that an organization can actively choose and combine cloud platforms for different tasks without trying to integrate them into one common ecosystem[4].

4) Administration and management:

A federated cloud focuses on centralized management and control of multiple cloud environments. Each service provider in the federated cloud has rules defined by the SLA according to the terms of which they must be fulfilled [7].

In the case of a multi-platform solution, management and administration are more decentralized and the organization can have more control over individual platforms[4].

5) Usage of Services:

In a multi-cloud strategy, different cloud services are used for different applications or services. For example, an

organization might use AWS for data storage, Google Cloud for machine learning, and Azure for its business applications. In contrast, a federated cloud strategy distributes workloads across multiple cloud services. This means that a single workload can be split between multiple providers to take advantage of the best features of each [6].

6) Optimization Goals:

Multicloud is often about finding the best cloud service for a specific need. For example, an organization may choose to use AWS S3 for data storage because it offers the best price-performance ratio. Federated cloud, on the other hand, is about optimizing workload distribution to take advantage of competition and innovation. This means that workloads are distributed to take advantage of the competitive dynamics between different cloud providers[8].

7) Cost Management:

A federated cloud can help optimize costs by moving workloads to the most cost-effective provider at any given time. This means that if the cost of running a workload with one provider is too high, the workload can be moved to another provider that offers a better price. While cost management can be part of a multi-cloud strategy, it is not the primary focus[9].

C. Approaches Used Inside:

Workload distribution: In a federated cloud, workloads are distributed across multiple cloud providers. This can be based on factors such as cost, performance, and specific capabilities of each provider. For example, the data processing workload can be distributed among several providers to take advantage of the best processing capabilities of each[10].

Service selection: In a multi-cloud strategy, services from different providers are selected based on their strengths and the specific needs of the application or service. For example, an organization may choose to use Google Cloud's BigQuery service for data analysis because it offers the best capabilities for their particular use case[4].

Redundancy and resiliency: Both strategies can improve redundancy and resiliency. In a multi-cloud strategy, this can be achieved by using different providers for different services. This means that if one provider goes down, services running on other providers can continue to function. In a federated cloud, this can be achieved by distributing workloads across multiple providers. This means that if one provider goes down, parts of the workload running on other providers can continue to function [3], [4].

In conclusion, it is important to note that the choice between a federated cloud and a multi-platform cloud solution depends on the needs and goals of a particular organization. Some organizations may find benefit in the integrated approach of a federated cloud, while others may prefer the greater flexibility and diversification offered by a cross-platform solution.

III. Architektúra cloud federácie

The architecture consists of four basic parts [11], which are described in detail as follows:

A. Cloud Exchange

Cloud Exchange acts as an intermediary between the Cloud Coordinator and Cloud Broker. Its main task is to evaluate the requirements of the Cloud Broker with the available services provided by the Coordinator. Cloud Exchange maintains records of current costs, demand trends, and a list of available cloud providers, which is regularly updated by the Cloud Coordinator[1], [6], [11].

Cloud Brokers communicate with Cloud Exchange to obtain information about existing Service Level Agreements (SLAs) and the availability of resources offered by different cloud providers [10].

Cloud Exchange offers several services for Cloud Brokers and Cloud Coordinators:

Database Repository: Cloud Exchange acts as a database repository or directory where Cloud Brokers announce their resources, services, and prices. Customers can then browse this repository to find the most appropriate service and price for their needs and submit service requests.

Mediator: Cloud Exchange constantly updates the policies of its participants and acts as an intermediary between Brokers and Coordinators.

Financial Intermediary: Cloud Exchange simplifies financial transactions between cloud vendors and their clients, thereby maintaining trust.

B. Cloud Coordinator

The Cloud Coordinator oversees cloud enterprises and their membership. It allocates cloud resources to remote users based on their quality of service requirements and available cloud account credits. The Cloud Coordinator develops marketing and pricing policies in accordance with SLA guidelines[1], [10], [11].

C. Cloud Broker

Represents the customer within the federation, communicates with the Cloud Coordinator, evaluates the SLA agreements created with them, and evaluates the resources offered by various cloud providers within the Cloud Exchange. The Cloud Broker concludes the most suitable agreements for its clients and then creates services/devices according to its requirements in a given computing cloud.[1], [10], [11]

D. Cloud Entity

It is one of the parts that provides computing or storage resources for users, it is the main unit of every cloud solution. Within the federation, each of its members has access to certain resources that they want to offer for use [6], [10].

IV. Defining goals and characteristics of federation users

In this chapter, we will describe both sides of the federation from the point of view of the user who wants to use the services offered within the federation and also from the perspective of the provider/future service provider. We will also describe what users must do or meet to join the federation.

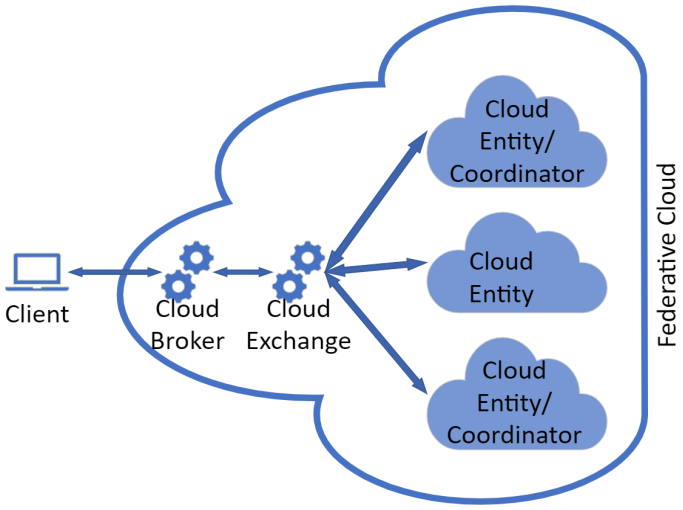

Fig. 2. Example of a cloud Federation architecture model

A. Membership applicant

The applicant first needs to determine his basic components and, according to their choice, define the field of his operation according to his resources, he must ensure the parts and resources that he will provide within the federation. According to its resources, it creates separate Cloud entities (Compute, Storage) and defines the functions that will be provided on them (infrastructure as a service, platform as a service, software as a service). Subsequently, after defining its resources, it creates an offer to Cloud Exchange, where it communicates directly with it, and then together they define a service level agreement, and then Cloud Exchange accepts the applicant into the cloud federation and starts publishing the services defined in the SLA within the Federation[6]. Ultimately, the applicant's task is to ensure a functional and stable connection with Cloud Exchange and establish a connection with other Cloud Coordinators[7], [12].

B. Member of the Federation

The task of the federation member is to ensure the connection with Cloud Exchange and maintain the functionality of the services defined in the service level agreement. In case of failure to comply with the SLA, the member may be removed from the federation [13]. The second main task of a member of the federation is to create a connection with the users of the federation. Furthermore, the member must check the number of resources used by users and send this information to Cloud Exchange for processing[1], [2], [5], [11].

C. Používateľ služieb federácie

To use the offered services of the federation, the user must register with the Cloud Broker, which keeps information about user identities, then the Cloud Broker distributes the unique identifier of the Cloud Exchange user to other entities within the federation to identify the use of the federation's resources [14]. Subsequently, the user can ask the broker to create a service, and he tries to get the best offer for him from Cloud Exchange. After receiving the most favorable offer, the user communicates directly with the service that was made available/created according to his requirements at the Cloud Coordinator[1], [11].

V. TECHNICAL, APPLICATIONAL AND ARCHITECTURAL ASPECTS OF THE CLOUD FEDERATION

We described the functions of each entity in the previous chapter. In the current chapter, we will discuss the individual parts of entities, what is necessary for their creation, and how the user communicates with the federation with them. On the other hand, what tasks do the individual members of the federation have, what tasks must they perform and what do they jointly provide

Federation users do not need any special resources to connect and use cloud federation. In their case, the only requirement is to connect to the Internet. This part is necessary for registration and communication with the cloud broker and subsequently for controlling the services created for it [5], [6], [14].

Cloud Broker is an entity whose role is to act as a communication tool between users and Cloud Exchange. For this reason, from the technical and application part, he must mediate communication. For this, it is necessary that he should be able to send other members of the federation and that users of the federation should be able to communicate with him. In this case, for example, it can be a web server with a database for communication with users and for keeping information about them[14]. In the practical sphere, however, it can be any middleware interface that mediates communications between users of the federation and mediates information for other members of the federation.

Like Cloud Broker, Cloud Exchange is a communication tool for connection and communication. From a technical point of view, its role is rather similar to middleware. Its task is to receive information, archive, and process it, but as a tool, it does not only communicate with end devices. As already mentioned, it primarily communicates with Cloud Broker and Cloud Coordinator. From a technical point of view, it can be a separate application on a similar basis as Cloud Broker (Web server/other type of application, with the possibility of communication with other devices and the possibility of storing information). On the other hand, it often happens that in the federated space Cloud Exchange and Cloud Broker are one entity, these logical units are divided into modules located in it. In the next chapter, we will describe the tools used to create a cloud federation, and most of them have the same logical approach. From a technical point of view, Cloud Broker and Cloud Exchange are implemented as web applications with a database server (or access to it) and in most cases with the possibility of control via a REST API[2], [6], [12].

The last is the technical and architectural aspect of the Cloud Coordinator. In his case, it's a bit more complicated, but for the basics, he as an independent unit only needs a certain form of Cloud management platform (OpenStack, CloudStack, Eucalyptus, OpenNebula) [1], [6], [11].

On a theoretical level, it is enough for him as an independent unit, but in practice, the Cloud Coordinator also takes care of his

parts (Compute, Storage, etc.), which need several types of technical parts for their functioning. In general, all its other offered services must support a certain form of virtualization and hypervisor (VMware, Hyper-V, KVM, Xen) and they almost always need some form of network elements (Open vSwtich, Cumulus Networks, Cisco ACI) [12]. Subsequently, as needed and according to the services provided, individual parts could contain parts for data storage (Ceph, GlusterFS, OpenEBS, NFS), orchestration of containers (Kubernetes, Docker Swarm, Apache Mesos, OpenShift) or controls for preventing problems using monitoring and logging (Prometheus, Grafana, ELK Stack, Nagios) or backup and recovery mechanisms (Veeam, Bacula, Amanda Backup)[1], [2], [11], [13]

VI. NON-FUNCTIONAL REQUIREMENTS OF CLOUD FEDERATION

In the previous chapter, we described the technical aspects of the federation, here we will focus more on the non-functional requirements that are necessary and required, either for the correct and safe functioning of the federation or for the satisfaction of the federation's clients. In our section, based on knowledge, we have divided them into these six parts:

A. Access the control interface from anywhere

Cloud federation users are diverse and connect from different networks, so it is critical to allow access to the federated control interface (GUI) from any location. This need arises from the variety of users who may access the federation from different geographical areas or with different network configurations. At the same time, it is important to mediate access to the created IaaS services, which ensures that users have efficient access to the infrastructure according to their needs. Such an approach ensures maximum flexibility and availability of services within the federation [1], [10], [11]

B. Availability and Outages

It is necessary to make cloud services available to users in as many cases as possible. It is also necessary to restore the functionality and availability of the managed service as soon as possible in the event of an outage [3], [6], [10], [11].

C. Network connectivity of data center

The data centers of individual members of the federation are located in different places, and therefore it is necessary to connect these data centers via a network. In this integration, it is necessary to emphasize the security and speed of the transfer of the transmitted data. Ensuring reliable and secure communication between these geographically distant data centers is a critical factor for the effective operation of the federation. A fast and secure network infrastructure guarantees that data can be transferred without problems and at the same time with minimal risk to the security of the federated environment[1], [5], [11].

D. Network connectivity to the instance across data centers

If customer instances are created in several locations and need to communicate with each other, it is necessary to design a method of connecting the instances. The essence of this condition is the expansion of one tenant's network across several data centers, while this fact is transparent to the customer himself[1], [11].

E. Data stream encryption

Given that data transmitted between devices located in different locations passes through a common network, this type of transmission must be secured. Therefore, in this case, it is crucial to solve the issue of data encryption to prevent interception and unauthorized attacks on the traffic in question. The introduction of encryption ensures that information is transmitted in a secure and unreadable form, thus minimizing the risk of leaking sensitive data and ensuring the security of communication between devices. In this way, the integrity and confidentiality of the transmitted data is ensured, even if it passes through normal network connections[2], [5], [10], [11].

F. Separation of data flow between individual tenants in a cloud federation

To ensure security, the data traffic of one tenant must be completely separated from the traffic of another tenant. This isolation ensures that one tenant's data is fully separated and protected from unauthorized access or interference by other tenants[3], [14].

CONCLUSION

In the digital era, a comparative study of cloud federation and multi-cloud solutions reveals a new perspective on cloud computing. Cloud federation offers a unified framework that enables interoperability between different cloud services, and improves resource optimization and service availability. Conversely, multi-cloud strategies involve the simultaneous use of multiple cloud services, providing redundancy, flexibility, and protection against vendor lock-in.

The analysis highlights that although both approaches aim to maximize the benefits of cloud computing, they differ in their operating models and strategic implications. Cloud federation emphasizes a collaborative model that potentially leads to standardized practices and economies of scale. On the other hand, multi-cloud solutions favor independence and customized services that match specific organizational needs.

Ultimately, the choice between cloud federation and multi-cloud depends on the organization's goals, regulatory requirements, and technical capabilities. As the cloud environment continues to evolve, organizations need to navigate these options carefully to harness the full potential of cloud computing in achieving their digital transformation goals. The comparative study serves as a guide for decision-makers to critically evaluate these paradigms and make informed decisions that align with their strategic vision in the digital era. Furthermore, we believe that this article will support knowledge in the areas of multi-cloud and federated solutions, which nowadays are increasingly necessary to expand.

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