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Chapter 9

Automation and orchestration in hybrid clouds

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Abstract

Automation and orchestration are key enablers of efficiency and agility in hybrid cloud environments, allowing businesses to streamline complex workflows across public and private cloud platforms. This abstract explores how automation tools facilitate the provisioning, scaling, and management of cloud resources, while orchestration ensures seamless coordination of these tasks across multiple cloud environments. It highlights the role of technologies like containerization, microservices, and CI/CD pipelines in optimizing cloud operations. By implementing automation and orchestration, organizations can improve operational efficiency, reduce human error, and enhance resource utilization, enabling faster deployment and more responsive IT operations in hybrid cloud settings.

Keywords

Automation, Orchestration, Hybrid Cloud, Cloud Operations, Cloud Provisioning, Cloud Scaling, Containerization, Microservices, CI/CD Pipelines, Cloud Management, Workflow Automation, Resource Utilization, IT Operations, Cloud Efficiency, Hybrid Cloud Environments, Cloud Coordination, Operational Efficiency.

9.1. Introduction

Private cloud infrastructures have been widely deployed across technology industries, research institutions and e-infrastructures in the past few years. The main motivations for this dedicated cloud infrastructures are the need to execute applications with bias in a single hardware architecture or software framework, security concerns and compliance with approved methodologies. However, as cloud federation is being adopted in commercial and open access environments, the limitations of relying on a single cloud provider have become apparent in terms of asset portability (virtual machine (VM) images, network/software configurations, user management, credentials, etc.), cloud interfaces and performance of public APIs (Nampalli, 2023). The natural evolution of this approach has been the development and deployment of application level plugins, capable of orchestrating the capabilities of several cloud interfaces.

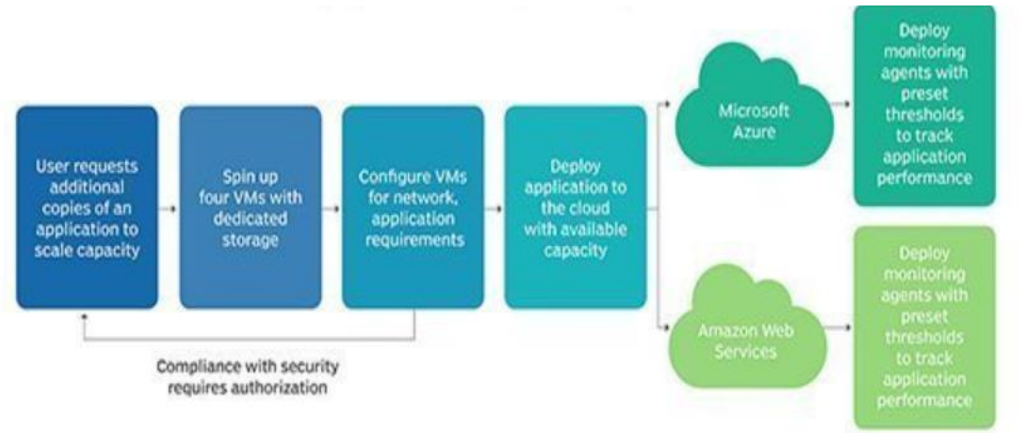

Fig 9.1: Cloud Automation vs Cloud Orchestration

9.1.1. Background and Significance

Hybrid environments of data, applications, and services hosted in data centres, either on-premise or in the cloud, intersected by data flows across the network, have been used in many use cases. It is time to provide guarantees about the quality of the data and the computational resources that are exchanged. Through a layered architecture, we propose a novel solution to guarantee the Service Level Agreement compliance of complex applications in hybrid environments that cross administrative domains. This solution includes monitoring and control mechanisms capable of generating real-time alerts and coarse/fine grained actions in the data-centre and end-host transport devices to provide timely responses. In addition, controllers in each domain are fed-on with data plane metrics such as network and server performance. It is operators' duty to deploy and operate the tools needed to monitor and manage the domain carefully. Therefore, we rely on widely supported standards for modelling and orchestrating the behavior of complex applications, and for the definition of a common control plane with the enterprise.

9.1.2. Research Objectives

Research has been initiated with the aim of contributing to the state-of-the-art in Automation and Orchestration in Hybrid Clouds. There are three key objectives: (1) to analyse novel approaches and commercial tools for Automation and Orchestration in Hybrid Clouds, (2) to propose a theoretical model and solution for the Automation and Orchestration of Hybrid Clouds considering heterogeneous cloud computing environments and multiple providers, and (3) to validate the proposed automation and orchestration model and solution by applying it to a practical use-case scenario—a Science Gateway for a bioinformatics VRE.

Starting with an analysis of existing work in the field, the focus on open-source tools often based on general-purpose programming languages stands out. Containerization technologies are favoured for this purpose, either combined with a Container Orchestrator (Syed, 2023). Relatively little attention is paid to modelling languages in the Cloud Application Programming Interface domain or to commercial platforms. However, novel approaches and commercial tools for the subject under study are being continuously developed and disseminated. Amongst other objectives throughout this work, a systematic review is presented of the available approaches and tools for Automation and Orchestration in Hybrid Clouds encompassing cost and efficiency issues plus new demands which may factor into the choice of tools or methods.

9.2. Fundamentals of Automation and Orchestration

There is no denying the pervasion of cloud technologies into any kind of ICT environment: having in 2016 passed the tipping point of application workloads running in the cloud in data centers versus running on traditional IT, projections estimate that the ratio might be in 80%/20% (cloud/IT) by 2024. Cloud services reach or exceed a most privileged position in the 5G E2E service provisioning chain. Within the cloud stack, as type of usage estimate increases, and software-defined clouds generalize, the pressure of exposing and consuming cloud services/APIs increases (Danda, 2024). Enhanced cloud services/APIs for real-time scaling, chaining, metering, charging, QoS, KPI exposure and transfer across CSP domains, end-to-end analytics, SLA negotiation and enforcement are foreseen. Such enhancements will span across cloud-orchestration interfaces and will apply on both public and private clouds. In addition to enhancing cloud functionalities, there is a considerable part of those enhancements to extend or partially overlap on the contact point to the carrier cloud, consisting in NFV POPs with additional capabilities. It applies particularly in the case of closed groups of NFVI within a Carrier DC. Besides APIs and policies, enhancements relate to VNF/PNF modeling, descriptors, and monitoring data.

Equation 1: Load Balancing Equation

$$L_{balance} = \frac{T_{cloud}}{T_{cloud} + T_{onprem}} = \frac{R_{cloud}}{R_{cloud} + R_{onprem}}$$

Where:

- $L_{balance}$ = Load balancing ratio (proportion of the load sent to cloud resources)
- T_{cloud} = Time spent processing in the cloud
- T_{onprem} = Time spent processing on-premises

9.2.1. Definition and Concepts

Private cloud infrastructures are now widely deployed and adopted across technology industries and research institutions. Public cloud providers offer large compute and storage resources on-demand and deliver a pay-as-you-go model. Although cloud computing has emerged as a reality, a single cloud provider cannot fully satisfy the complex requirements of some scientific user communities who need specific applications, particular software stacks and special configurations. In this context, there is a growing interest in developing hybrid cloud solutions that bind together distinct and heterogeneous cloud infrastructures. Those approaches aim at simplifying the access to global and integrated e-resources for the final users. Moreover, the seamless integration of resources accessible through public or private cloud systems and through grid middleware is a major challenge for the Hybrid Grid/Cloud Activity.

9.2.2. Key Technologies

Private cloud infrastructures are now widely deployed, adopted and well recognized across technology industries and research institutions, since they provide a new service-based approach for the flexible on-demand usage of virtualized resources (Syed, 2023). In particular, private clouds are considered a good choice for virtualizing industry and research legacy clusters in order to facilitate an evolution from traditional high performance computing to more complex and large scale processing and data analysis. However, they are often not enough by themselves and a growing interest is emerging for the development of hybrid cloud solutions that bind together distinct and heterogeneous cloud infrastructures. There is an increasing number of companies operating cloud marketplaces offering a very broad variety of different types of cloud resources. Joined with the developments carried out in the third platform technologies like Internet of Things (IoT) and big data analytics, complex hybrid cloud scenarios may be composed.

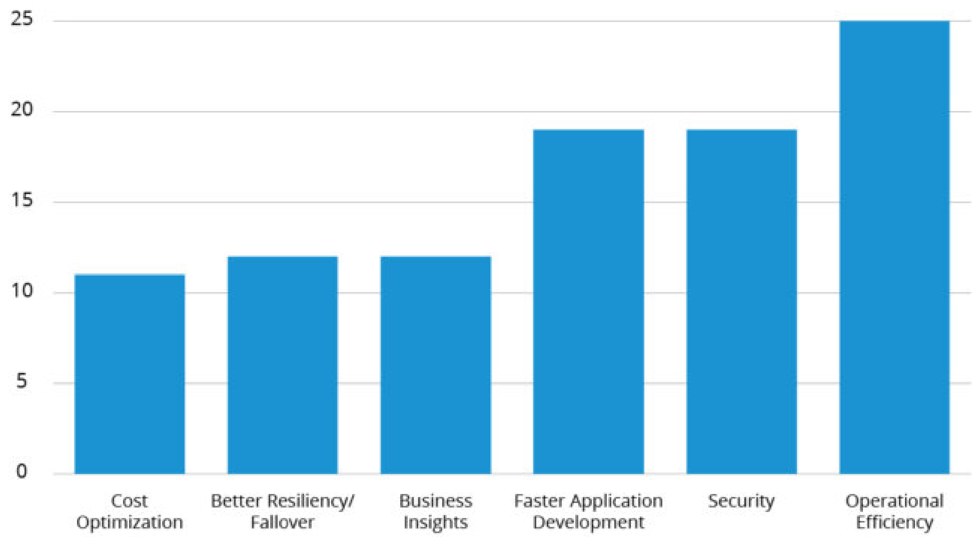

Fig: NetDevOps Is Driving the Future of Hybrid Cloud Automation

9.3. Challenges and Benefits in Hybrid Cloud Environments

Companies and organizations are increasingly enthusiastic about deploying applications, services, and storing data in public cloud environments, attracted by the flexibility, scalability and pay-per-use cost models offered by these services. However, private clouds are still essential for management of resources and storage of critical and data-sensitive applications inside the boundaries of companies and institutions. For these reasons, a growing number of industries and research organizations are now investing in solutions that combine private and public cloud platforms.

With the growth of hybrid cloud and multi-cloud infrastructures, interoperability can become an issue. Among the different technologies being developed to overcome this challenge, orchestration has gained a leading role. This technology can be understood as the automation of workflows representing complex services that contain other services with the aim of providing the requested service (Nampalli, 2022). In the context of cloud, these complex services are composed of simple services such as virtual machines, storage appliances, load balancers or application servers.

Fig 9.2: Hybrid Cloud Challenges

9.3.1. Security and Compliance

Today's demanding and evolving business environment forces companies to react quickly to innovations and new trends. Cloud computing was adopted to address flexibility, scalability and agility requirements. The advances in cloud technologies and adoption of IT as a Service (ITaaS) concept in enterprise environments lead to Hybrid Cloud infrastructures that allow the orchestration and automation of cross-domain services. After the infrastructure, that should be as a service itself, in its Infrastructure as a Service

(IaaS) approach, it is possible to orchestrate services across cloud providers using new mechanisms to automate the management and control of resources, security and networking aspects.

Running a cloud service starting from the allocation of virtual network and computing resources to the plugging of specific security mechanisms normally requires not standardized and hardly programmable steps. Automation and orchestration technologies can be adopted for automating cloud infrastructures management. Orchestrators receive high level instructions and requests to provide some services and may decompose complex service manuals into a chain of individual API calls to low-level components. Hybrid Cloud Management allows to simplify the operations rules and the control of private and public resources, easing the automation and increasing the service level agreement guarantees that can be offered. Standards have been designed to ease the request of services to different providers. TOSCA can be the choice for this challenge, where the goal is to deploy complex web services.

9.3.2. Scalability and Flexibility

Existing solutions offer some automation with the advantage that most of them allow composing custom workflows, i.e., chaining multiple tasks that can range between deploying complex distributed applications in different clouds to simple steps like downloading and uploading files. The scalability and performance of cloud applications are improved with the suggested solution that is based on microservices and their dynamic orchestration in a cloud computing environment. The purpose is to define a generic microservices-based architecture for application-level cloud orchestration and to describe its reference implementation utilizing container-based open source cloud technologies (Kothapalli et al., 2022). Hybrid cloud setups combining private data centers and public cloud providers are a norm for a larger class of users, than public clouds alone. However, as a consequence, the number of involved sites often exceeds the support of existing solutions which are built either for a single infrastructure or rather focused on orchestrating a single application. Nevertheless, the scalability problem is investigated and (partially) solved in connection with the WS-PGRADE/gUSE gateway framework, particularly for the data staging service that needs such scalability.

9.4. Case Studies and Best Practices

Article writing is a very important part of automation as users either ask for more functionality, or try to adjust current functions to work more efficiently. This article presents an overview of current work on IT and cybersecurity challenges for the future Internet and presents perspectives on the responses and needs to manage the significant challenges that arise in the course of the advent of 5G and beyond mobile networks. New standards and new IT technologies, such as cloud computing, software-down networks, and network functions virtualization, are fundamentally changing the telecommunications sector. A task force has been established to explore the impact of cloudification of future telecommunication networks. The work relies on a two-strand approach: first, a set of scenarios are presented detailing the implementation of the cloud environment of the network operator in the short-term future; secondly, to evaluate the impact of scenarios on network performance and interpretation.

A new industry and academic report discusses a network operator's view of the changing environment and its effects, looking at network performance and other implications for regulation and general social networks comment.

Equation 2: Service Level Agreement (SLA) Compliance Equation

$$SLA_{compliance} = \frac{T_{SLAmet}}{T_{total}}$$

Where:

- $SLA_{compliance}$ = Proportion of time SLA is met
- T_{SLAmet} = Time the system was compliant with SLA
- T_{total} = Total operational time in the measurement period

9.4.1. Successful Implementations

Public and private clouds are now widely adopted by academia, research, and enterprise, to the extent that almost every institution lacks the capacity or will to maintain on-premises small or medium data centres. Still, the IT scenarios for institutions are so varied that no single cloud model can fit them all. Many institutions can leverage their private clouds to meet their unique requirements, while also exploiting capabilities of industrial clouds for heavy computations or offloading specific services. This is also the hybrid cloud model, where a private cloud solution is federated with one or more industrial clouds (Subhash et al., 2022). Despite being a very promising paradigm, it poses some challenges in application deployment, particularly when services from multiple clouds should be orchestrated.

There are several successful implementations of fully automated application deployments on public or federated clouds. Solutions for complex multi-instance architectures can deploy complex multi-instance architectures. There are solutions to manage and effectively use resources from different cloud providers. In the commercial scene, there are offerings for the management of a variety of public cloud providers.

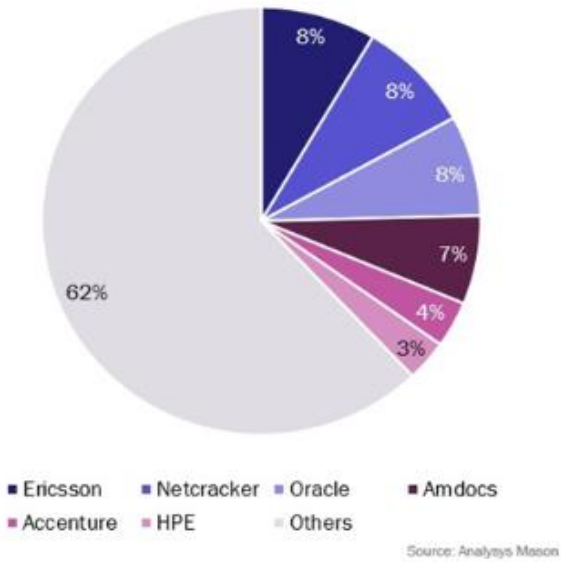

Fig: Service design and orchestration revenue grew

9.4.2. Lessons Learned

Hybrid Clouds are cost-effective solutions for enterprises aiming at expanding their in-house computational resources with computing capacity rented from commercial cloud providers. Expanding in-house resources with others on demand in public clouds constitutes a hybrid cloud scenario and it is a very good solution as it allows companies to operate profitably, being able to absorb sudden workload spikes. The System is composed of an in-house private cloud infrastructure, interfacing with the European private cloud infrastructure that offers connections to public cloud providers as well. A pilot deployment on private and public resources is considered. A basic requirement to enable hybrid clouds is to provide access to the internal private cloud (Cloud A in the rest of the document) and isolation also from other tenants, the user's workload will run on a new cheap Open Nebula cloud cluster installation located on its own premises. Once the simple initial setup is completed, a major service running on the private cloud demands the intensive usage of computational resources to consider a commercial public cloud (namely Cloud B) (Sondinti et al., 2023). Cloud configuration will be done automatically relying on software tools. Two tools work in sequence, the multi IaaS Orchestrator and the IaaS Agent. The former is asked by a client to set up a new environment and triggers the latter, which modifies the infrastructures in order to host applications of a given Topology and Capacity on private and/or public IaaS cloud providers. The implemented procedure and the scalability of the multi cloud service are described in context with the INDIGO initiative.

9.5. Future Directions

In this paper, automation of Virtualized Network Functions (VNFs) is considered, i.e., how to render inter-network element services to automatically instantiate VNFs over network domains that rely on different technologies and are under different administrations. The proposed approach, referred to as cross-domain Orchestration, is also able to configure underlying connectivity services required by the VNFs. The employment of a common Information Model (IM) and Southbound Interface (SBI) with common interface primitives and request/reply messages are proposed for the standardized API between domains. The functionality and interfaces of a multi-domain Orchestrator are also described. This work falls within the context of the T-NOVA project, which focuses on the definition of a reference architecture for a Stub-Orchestrator for Composition and Rendition (SOC-R) Platform. Two solutions for new service operations are presented, one for zero-touch operations and another for predictive maintenance and reconfiguration (Vankayalapati et al., 2023). Besides, federated access and controlled sharing of resources across different operators for the provisioning of advanced services are envisioned.

The cloud systems are an incarnation of the economic principles of software service delivery - effective utilization of common resources and commodification. This paper focuses on the automation of Virtualized Network Functions (VNFs) and the seamless instantiation of these functions across network domains that utilize diverse technologies and are governed by different administrations. The proposed solution, termed cross-domain orchestration, not only automates the instantiation of VNFs but also manages the underlying connectivity services necessary for their operation. A key feature of this approach is the use of a common Information Model (IM) and Southbound Interface (SBI), which facilitates standardized communication between different domains through consistent interface primitives and request/reply messages. The paper outlines the functionality and interfaces of a multi-domain orchestrator within the context of the T-NOVA project, which aims to develop a reference architecture for the Stub-Orchestrator for Composition and Rendition (SOC-R) platform.

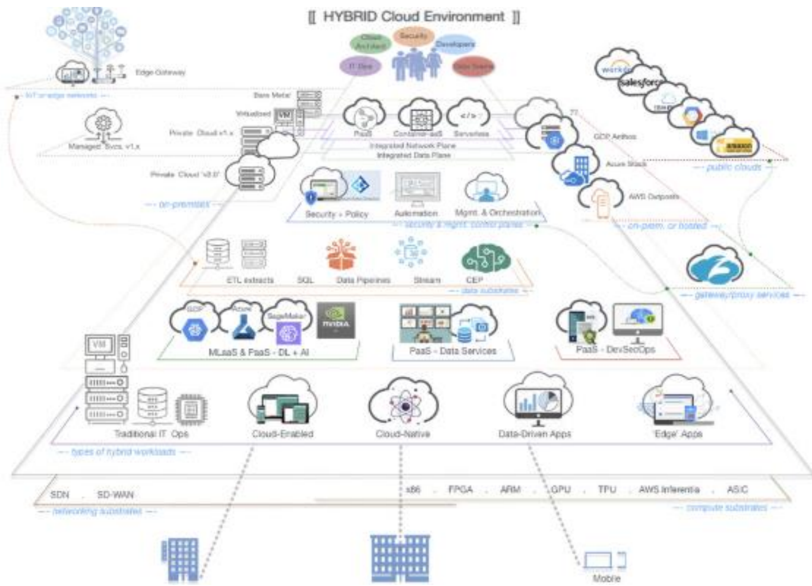

Fig 9.3: Thoughts on The Future of Hybrid Cloud IT

9.6. Conclusion

The automation of the service provisioning implies the dynamic allocation and management across different operative domains. The networking community is adopting cloud computing to answer to emerging requirements and use cases, whereas the cloud community is building geographically distributed computing infrastructure requiring interconnection. Furthermore, up to now, the focus on cloud automation has been set on the computational and the storage side, paying little or no attention to the corresponding required networking resources, which are fundamental to ensure the end-to-end performance required by the services. Common uses of orchestration involve heterogeneous network domains, known as network orchestration, or cloud and network resources, exemplified by the emerging use case of interconnection of segregated data centers.

A data-center could be defined as a centralized resource pool for the storage, management, processing and distribution of data and information organized pertaining to a particular business. Whereas at an early stage of the development of data-center terrestrial network access has been enough, the exponentially increasing amount and mobility of data have forced data-center to widely adopt hybrid satellite/fixed networks.

9.6.1. Future Trends

Private cloud infrastructures are widely deployed and adopted across technology industries and research institutions. This situation has led to increased interest in the development of hybrid cloud solutions that bind together distinct and heterogeneous cloud infrastructures. Nevertheless, this situation opens a new challenging landscape regarding the management of such hybrid cloud environments (Maguluri et al., 2022). The challenge can be approached by enabling interoperability among the distinct cloud environments. In this context two different conventions emerge when referring to the way the different cloud environments are interconnected: The Inter-Cloud and the Multi-Cloud. Broadly speaking, the Multi-Cloud is focused on bundling together different (similar or not) cloud providers to cope the computational needs of a given application. It refers to the fact that there are a certain number of commercial and/or academic cloud providers offering distinct cloud environments to deploy applications. In Multi-Cloud approaches, neither a priori agreements are necessary with the cloud providers about technologies, interfaces or services to be offered, nor affiliations are needed among the cloud providers. This way, the distinct cloud environments are hidden from the users.

Inter-Cloud approaches are focused on the federation of different cloud provider’s environments. This is achieved by establishing agreements between the cloud providers to define the interfaces and services to be offered, ensuring pre-defined Service Level Agreements (SLA). Such agreements refer to the formal thresholds in relation to the quality and value of the services.

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