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Implementing Infrastructure-as-Code for Telecom Networks: Challenges and Best Practices for Scalable Service Orchestration

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Abstract
Telecommunication networks and cloud infrastructures have evolved independently in technology, operations, and orchestration. Telecom networks remain operationally static with manual intervention mechanisms at service levels. In contrast, Cloud infrastructures introduced notions such as DevOps and Infrastructure-as-Code that surpassed vendor-specific toolsets, allowing the same operations across heterogeneous infrastructural clouds. The telco cloud has outpaced such offerings, taken by hyperscalers and edge service providers creating a split view across infrastructure. Creating a unified view imposes reconciling IaC with Equipment Vendor Specifications and consolidating management of technology driving the realisation of services from HLD to LLD and into provisioning tasks across a network service delivery chain. The service delivery chain, which spans a multi-layer, multi-domain orchestration paradigm, has been adopted recently with the support for the definition of multi-technology service chains. Still during the service deployment phase, a techno-reality ecosystem does not leave room for the actionable realisation of a HLD service net. At the lowest level, Real-time Network Operating System devices or similar, require vendor-specific toolsets that must be reconciled to/from a generic control domain with a rich set of APIs. In the middle layers, the NF hardware can be VM or Container based and provides Vendor L4 monitoring and monitoring that reports on the same stats differently. Communications service providers acknowledged this challenge in capturing and reconciling the operational tech diverging from Telco Service & Equipment Vendor Specifications into the overarching control domain, capturing closing infrastructural gaps, and adopting the technology enabling unified views across cloud and network. Still, CSPs have limited foresight on how to plant these technologies. On one hand, researchers offered theories and frameworks to close the actionable scalability gap by going through the network service rig. Few observations surfaced on how one could kaleidoscope/dissect an intricate network service delivery within a set of viability shifts and reconcile the ViSol with Telco Service Specifications. This paper highlights the challenges one would face while upscaling an INFRA (topology) to an L2-L5 MANO Cloud and shares how the proof-of-concept approach tackled some of it.

Keywords: Infrastructure-as-Code (IaC),Telecom Networks, Network Automation, Service Orchestration,Scalability, Configuration Management, CI/CD Pipelines,Network Function Virtualization (NFV), Software-Defined Networking (SDN), Deployment Automation, Operational Efficiency, Fault Tolerance,DevOps,Version Control,Cloud-native Networking.

1. Introduction

The telecom networks are being transformed from a static and cumbersome series of manually operated vendors' boxes to an SDN/NFVs controlled infrastructure, amenable to being treated and operated like the IT/Cloud infrastructure. A validation environment is described that eases development and test of this new paradigm ensuring that standard carriers' requirements and practices are met. Orchestration of Services on SDL/NFV infrastructures should be the same and coexist with orchestration of traditional infrastructure. New requirements define a need for evolutionary changes. Active equipment network control and coordination should be provided by Orgeds, a new category of orchestrator that allows both traditional and new paradigms to co-exist. A traditionally orchestrated network infrastructure connecting Point-of-Presences in different cities can be incrementally augmented with SD[N/F]s, a new category of network functional blocks that can autonomously and dynamically allocate and control low-level packet switching according to rules defined during service instantiation. These packet forwarding/Pipes/FWs… SDN services can, in turn, be composed with VNFs into end-to-end multicast services connecting anywhere-in-Network-Service-Instances.

Ecosystems are learned in detail on the example of orchestration for a multi-domain multi-layer infrastructure composed by SDI and vendor homogeneous static and plug-and-play inter-domain gateways. Composition enables the orchestration of complex/3-level services between PoPs in different scenarios on multi-domain… type services by… Composed orchestration with new metadata types is presented. Orchestration of SDN-Operated networks interconnecting seamlessly SDN capable transport… using SCP-led collaborative modelling architecture, modelling new SDI capabilities and recursively obtaining the reachability matrix for proposed end-to-end services. Following a 1860-2075 phase invariant time scale, accelerating opinionated governance of fully SDN capable homogeneous infrastructures with incrementally increasing automation.

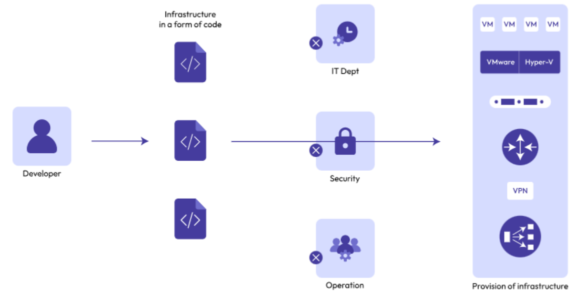

Fig 1: Infrastructure as Code (IaC)

1.1. Background and significance

In telecommunications networks, new service provisioning is typically a fast and reliably executed process that usually does not involve human intervention. This requires orchestration, which has been substantiated by multi-technology, yet still vendor-specific solutions. SDN and NFV, however, aim to displace those "hardware-first" solutions as evolutions take place that rely on a new generation of centralized and sophisticated controllers equipped with user-defined monitoring, reporting, and troubleshooting functionalities. The community seems to have converged that model-driven, abstract definitions of desired network configuration states and service connectivity formed on topological models will need to be prepared and delivered via REST APIs to a new layer of logic devices that will actually execute network changes. What is far less clear is how all this should be accomplished across the various layers of abstraction and technical domains. Thus far, the main targeted layer for end-to-end orchestration remains a high-level service layer presented, e.g. through the TOSCA and YANG models effort. This assumes continuous and harmonized evolutions of inventory, control, and data layers in compliance with the model-driven plans generated in the service layer. However, because the underlying protocol stacks and their implementations are heterogeneous and not yet conforming to an across-the-board normative model, intents in the service layer in themselves cannot yet assure user satisfaction. Additionally, since the vast majority of telecom networks is still based on legacy, hardware-centric solutions, an increasing amount of manual processes accompanied by document trails will have to be progressed too.

Automation solutions that only cater for one side of the required evolutions will be insufficient. The orchestration of telecommunication-related tasks and their automation are considered part of the same problem. Orchestration is defined as the coherent control of various systems interdependent on one another, for ultimately providing added value to the user in the form of composite services that span various layers and technologies. It also means to have a comprehensive vision of the target network, which entails a plethora of functional and non-functional parameters that need to be taken into account to optimally fulfil user requirements. This includes knowledge on performance and (dis)similarities of the various systems and their components, which implies ML-enhanced algorithms to determine the minimum resource allocation needed. Orchestrating the design and execution of telecommunication services that involve a wide range of different technology types and layers is hard because: (i) each of them has its own specification language, and (ii) corresponding verification and debugging paradigms are heterogeneous too. Conversely, for the new generation of services to be rolled out error-free, an extensive knowledge capture effort will be required, during which a plethora of shortcomings in terms of observability, verification, and debugging tasks would need to be addressed in parallel.

Equ 1: Network Deployment Time

$$T_d = \frac{C_m + C_v + C_t}{A_i}$$

Where:

- T_d = Total deployment time
- C_m = Configuration management time
- C_v = Validation and testing time
- C_t = Time spent on troubleshooting
- A_i = Level of IaC automation (higher reduces T_d)

2. Understanding Infrastructure-as-Code

The advent of cloud technologies has led to a revolution in the telecommunications field, where traditional, vertically-integrated systems have proved hard to extend and evolve. In contrast, the cloud ecosystem is based on modular functions classified as services, interconnected and orchestrated according to different business models. Telecom operators are looking to embrace this data revolution, which would help them offload best-effort traffic and parity services and focus on premium services such as multimedia content distribution, video streaming, and over-the-top gaming. Telecom operators view the cloud model as the means to achieve better agility and flexibility to accommodate the above requirements. In addition, private investments are needed at both the core and edge venues to accommodate Edge/5G requirements.

Traditional telecom network services had a standard design and configuration model, were rolled out once, and were maintained on a “fire-fighting” basis. During their life cycle, the services would typically suffer from continual IT/Network optimization processes to curtail operation costs and extend ROI. The concept of Faster Time-to-Service emphasizes that telecom network services need to be designed as the need arises. In addition, the real-time provisioning of Quality of Service guarantees in response to dynamic traffic patterns has given rise to New Service Instantiation Time-in-Service. Achieving this requires dynamic orchestration of the L2-L4 Virtual Network Functions.

The focus is on the knowledge base, algorithms, and controllers that collectively constitute a holistic and general solution to the above questions. A collaborative sophistication resource-based, Baseline Service capacity provisioning model, including service availability objectives and end-to-end path coverage constraints, is first built up. By extending the above model, a dynamic capacity provisioning model based on a continuity of slope function is constructed to deal with a wide range of time-varying capacity demand for advanced services. It allows the capacity constraint to be reassigned in line with the traffic statistics for flat functions, complementing the above resource-based technique for jump-style queries. The discussion also addresses how the new models can all be solved hierarchically, which highlights their efficiency and scalability. An innovative Flow-based QoS Provisioning module tailored to a highly efficient yet generic solution is presented to ensure a reliable solution across multiple traffic classes, latency/burst constraints, as well as end-to-end paths to the link state information. The latter is fundamentally different from prior solutions due to the huge search space, complexity, and runtime that characterize telecom networks.

Telecom operators have been investing heavily in the last few years in cloudification as a means to facilitate service evolution and significantly reduce OPEX. The driving initiative is the Cloud Native Network Functions. The initiative seeks to modernize telecom functions into an orchestrated cloud infrastructure by following the principle of immunity, collapse, and reuse. Towards this goal, the maturity of the current telecom infrastructure is assessed by identifying key capabilities. It is demonstrated that the aforementioned cloudification can be achieved by a two-step process. The lower level provides on-demand data, computing, and storage infrastructures and is agnostic of the telecom cloud operating model. It is highlighted that it can be built on current infrastructures at incremental CAPEX. The upper level implements a telecom cognitive network orchestrator that combines historical data, AI models, and simulation technologies across multiple timescales. This can be accomplished by reusing telco capabilities such as hardware acceleration engines and AI/ML models.

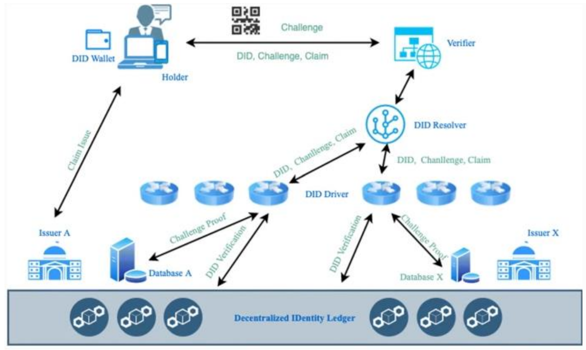

Fig 2: Understanding Infrastructure-as-Code

2.1. Definition and Key Concepts

The discussion on telecom automation has gained momentum and coverage when other verticals adopted and extended software development techniques and practices in a global DevOps context. Service orchestration is at the center of operations and service delivery aspects which expanded logarithmically from on-premise physical boxes to cloud-based functions geographically dispersed. A vast amount of documentation and plagues innumerable presentations, articles, and studies.

Infrastructure-as-Code (IaC) is a paradigm which uses the same principles of software development (version control, testing, code review, CI/CD) to automate the provisioning, configuration, and management of IT infrastructure. Network-as-Code brings IaC principles in the realm of telecom infrastructure, mainly focusing on Data Center orchestration. Telecom Operations also considers Network and Service to a large scale where critical issues like horizontal scalability in terms of Fault, Performance, and Configuration Management as well as Regulatory Compliance arise. Orchestration is a hot topic in telecom, from cloud-native orchestration to Service orchestration and everything in between. Understanding the significant properties and needs of telecom networks is key to delivering working orchestration systems.

Emerging Software Defined Networking (SDN) and Network Function Virtualization (NFV) technologies provide unique network slicing opportunities, novel ecosystem players, and a market space catering to the organizations deploying and managing the infrastructure. Similar changes need to take place in Operations and Management (O&M) that owns, operates, and manages the hybrid network assets. This implies migration from a proprietary/secret stack of solutions to an opening and re-use-based asset strategy of microservices-rich apps in metrics, data, fault, assurance, performance, configurations, and telemetry. Orchestrator as a new class of tools is being introduced to close the po1ch in automation leveraging heavy analytics, AI, and machine learning.

2.2. Benefits of Infrastructure-as-Code

DevOps allows telco operators to better orchestrate complex telecom services across an increase in microservices and cloudified infrastructure while changing organizational culture. DevOps in the telecom industry is unique and extends beyond traditional IT approaches, reflecting the distinctive operational priorities of large and complex distributed systems.

Telco networks should become more robust, adaptive, fault-tolerant and easier to monitor, verify and troubleshoot. The current consequence-based approach to service verification, the proliferation of black box microservices and a shift of operational responsibility to network function (NF) vendors in the telecom domain poses unique technical and organizational challenges to meet these requirements. As recently proposed, telemetry can greatly ease observability. Machine learning inference and optimization can enable proactive network management and resilience. However, these telemetry, ML, observability and management technologies need to be integrated into existing operational processes, which face deeper challenges than mere technical feasibility. This is not trivial: Telco operations are highly automated with complex configurations, time series databases, and analysis processes developed over decades. New operational paradigms and toolsets must seamlessly coexist and interwork with these legacy environments.

Moreover, the drivers behind these changes are not solely technical, but equally social. Telecom service provision is heavily regulated and monitored. Consequently the telco operating paradigms and tools mature more conservatively than the IT sector's. For commercially sensitive reasons, the telecom industry has also been historically heavily siloed: engineering departments have been thus reluctant to share information across externalize their expertise, which has exacerbated the social-vendor lock-in this industry in general faces. Finally as non-native digital players such as MNOs change the telecommunications industry, fierce competition for scarce and highly qualified devops candidates emerges.

2.3. Tools and Technologies

Configuration management tools for employees can provide assistance in server provisioning. Tool deployment becomes a critical step after successful evaluation for sourcing and organizing complex configurations, including integrations with cloud and bare-metal servers. Today, it is common to use a combination of tools and technologies to achieve deployment cycle optimization. Each tool has different responsibilities, while technology decisions quickly create fragmentation, creating assistance during onboarding for new employees who may not be as familiar with the provider's ecosystem. Consequently, documentation of corporate knowledge can create up-to-date source documentation, utilising built-in deployment tools that can revert changes.

Infrastructure configuration management is a critical dimension of IDC automation and orchestration. Network architecture and cloud infrastructure design are the first step toward understanding static network infrastructure. Networking equipment provisioning, including routers, switches, and firewalls, is a side effect of network design. The description of the network topology and dynamic configurations for multi-operations domains can be expressed in various programming languages.

Equ 2: Service Reliability Score

$$R_s = \frac{U_t \times (1 - E_f)}{I_c + D_r}$$

Where:

- R_s = Service reliability
- U_t = Uptime
- E_f = Frequency of IaC execution errors
- I_c = Infrastructure complexity
- D_r = Drift risk (difference between intended and actual config)

3. Telecom Networks Overview

Telecom networks have evolved from a mixture of circuit switched and packet networks into all-IP packet-based networks. Over the last decade, telecom operators have either built or are in the process of building fully packet switched IMS-based networks to provide tomorrow's FTTx broadband services. Voice/VoIP is still the main source of revenues, whereas broadband data services, while still at a lower ARPU, are where growth is coming from. The affordable mobile WIMAX subscriber terminals should favour telecom operators' entrance into the broadband data market with respect to cable operators. On the operational side of things, telecom operators' NMS platforms cannot cope with the growing demands for service configuration and management. The solutions proposed by standardization organizations in the realm of SoA and Orchestration are based on the notion of a middle-tier Machine-to-Machine Manager middleware. The TeleManagement Forum's information technology standards can be used as an instance of the architecture.

The Orchestration Framework in the Management System of the FTTx deployment site is described, and its technical analysis is provided. The FTTx network is likely to be organised around passive optical networks regardless of technology. Hence, it is necessary to clarify a few fundamental concepts to avoid misunderstandings in the context of the analysis of the Orchestration Framework and to provide a foundation for a minimum set of assumptions to be made on the FTTx Management Technology Domain. Network-based services are services switching data over a network, namely end-to-end connectivity services offered by a telecom operator. Two standardization organizations have taken the lead in standardizing their construction and delivery processes in so-called service templates, service graphs, and media flows. Services are first engineered/implemented by networks dimensioning all the physical resources needed, this is a complicated process to be detailed later. Once the services have been engineered, network element/resource repositories are addressed to retrieve information on the owned physical resources. The latter is described in telco terms using an NMS technology domain.

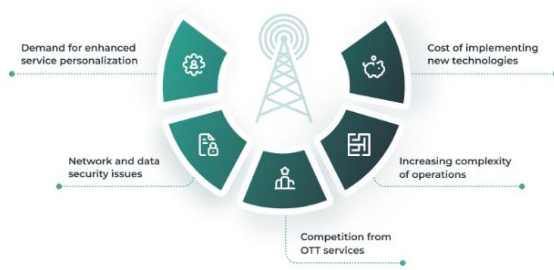

Fig 3: Telecom Networks

3.1. Current State of Telecom Networks

To date, many Telecom Network providers are still operating within a proprietary domain with vendor-locked solutions in a silo manner, where all physical and network components are running dynamic processes of their own dictated by the defined workflows. A conventional telecom network can consist of several thousand network equipment, such as routers, firewalls, load balancers, mobile packet gateways, signaling transfer points, intrusion detection systems, video content distribution servers, etc. Each vendor comes equipped with vendor proprietary transport layer, control layer, and service layer equipment. Due to this homogeneity of equipment, it is quite impossible to apply a common operational model on each equipment that adheres to an industry standard, and currently there are not too many alternatives in the field of telecom Network Operations that address the need for computerized provisioning automation and generalization of operational process so urgently needed by the Telecom Industry.

Recently, Telcos are becoming more aware of the advantages of standardized infrastructure. Still, the vast majority of installed devices are proprietary equipment, which makes the costly and slow transition to open networks. Optionally, there are new vendors on the market with open network hardware and software, compatible with each other but not with any legacy system. Similarly, SDI structure can be very diverse as it covers both physical infrastructures that Telecom relies on and an ever growing group of software that Vitria includes. Although they all share the same principles of abstraction, modularity, and generalization, they often include very different assumptions and behaviors.

Public cloud industry is facing the same problem when it comes to achieving a consolidated monitoring layer across multiple public cloud providers. Telcos however are far behind cloud providers in terms of technology and maturity, and do not possess a similar development base to foster the development of shared solutions and tools, as those developed and widely adopted in the IT cloud industry. All and all, Telecom with both its infrastructure and business processes are vastly more heterogeneous than any other industry.

3.2. Emerging Trends in Telecom

Current infrastructure transition by carriers is simply a byproduct of disruption at the application level. These new services are less voice or data centric but more app centric. A fixed subscriber demands a service at home, a mobile subscriber demands a service while commuting. Sudden maturity of many concepts at CDN/Cloud companies have offloaded the ad hoc function demanding a massive turndown of traditional capabilities. CTO vision for next generation flat IP infrastructure; new end-to-end protocols for newer services. New provisioning, scaling and performance guarantees in the 10+ years to come. Not just a network, rather a coordinated set of forwarding devices truly programmable in user space. But carriers still want to maintain their carrier grade brand in the near future.

But for most Telcos, Cloud services remain secondary to their core business of voice and data delivery. This transformation involves the virtualization of the network, embracing software defined-networking and network functions virtualization. As operators harness the power of these new technologies, they will develop and implement the infrastructure, software and capabilities to deliver more advanced services through more efficient, automated and programmable networks. Modern virtualization technologies ensure virtualization and abstraction for the entire set of critical resources. Cloud services are emerging as a key strategic imperative for Telcos as revenues from traditional services such as voice, messaging and data come under attack from other players. The aim of SDN and NFV is to deliver functions, networks and infrastructure as services rather than as features of vertically integrated systems. This enables operators to offer communication services at the right price points for subscribers. Telcos have advantages and motivations to embrace cloud: opportunity to leverage existing sales relationships with enterprise customers and ability to offer end-to-end service-level agreements to customers.

Equ 3: Orchestration Scalability

$$S_o = \log(N_s) \times A_i \times M_r$$

Where:

- S_o = Scalability of service orchestration
- N_s = Number of services or nodes
- A_i = Automation index from IaC tooling
- M_r = Modularity and reusability of templates

4. Challenges in Implementing Infrastructure-as-Code

Infrastructure-as-Code (IaC) is a relatively new implementation area for telecom networks, which entails many challenges. While concepts and tools from the IT domain drive openness and standardization, important distinctions exist. These affect how flat, stateless commodity server clouds used for all-consumption-intensive workloads are contrasted with large, stateful dedicated appliances used for telecom workloads, traditionally operated in silo manner with extensive vendor lock-in. While intent-based interface aims at reducing time spent on orchestration tasks, it requires a lot of upfront planning and design, thus increasing initial overhead. The concepts, tools and approaches for enabling efficient and scalable service orchestration via IaC are captured in a number of layers. Each layer contains elements that span both proof-of-concept operational value, build-in user/operator value, immediate governance model support or operational over-engineering, and simplicity and limited usability given no operational value available. A proof-of-concept at a lower layer may require less investment but at the same time, entails more 'fool-proof' elements than a proof-of-op at a layer closer to objectives in deployment. The generic outline of the telecom workload steering procedures is enriched with domain knowledge regarding user/operator actions, intent, verification, goal-building, tools used and value prediction heuristics. The way of presenting the steering procedures is tunable to the intended audience. In addition to a complete, detailed and straightforward outline aimed to answer questions regarding how to ensure QoS, SLAs, planning, risk management, etc., a more compact, abstract and high-level outline would be more appropriate to e.g., executive managers. Enterprises are typically not seeking to use TV, automotive or telecom networks to provide a more cost-effective and efficient means. More often than not, not all the fundamental rules governing the landscape of some specific territory are well known. For instance, a TV broadcasting company overseeing how to enforce the intended viewership of a premium sports broadcast either might not know, or mis-evaluate, the fact that, for a given territory, if one TV operator hadn't bought the broadcasting license, it would be pointless for any competing operator to seek an alternative mode of viewing; or it might under-evaluate bandwidth or image quality requirements. In the telecom domain and that of telecom networks, there are, unfortunately, many more 'landmines' that the enterprises are unaware of. Each unconceived, poorly conceived or miscalculated 'landmine' will unpredictably turn into time-consuming, redundant back-and-forth interactions between multiple stakeholders, e.g., initial planning vs. re-evaluating and updating, thus rendering inevitable cost overruns and disclosure of the business case.

Fig 4: Challenges of Infrastructure

4.1. Complexity of Telecom Infrastructure

While cloud and IT systems have achieved a high level of automation with Infrastructure as Code (IaC) approaches possible, similar approaches have not yet been fully possible within the telecommunication domain. Nevertheless, preparing for this transformation is essential to ensuring automation of orchestration, as well as quick and reliable service restarts, fast recovery from unwanted behavior, and integration with emerging operation models, e.g., cloud-native, zero touch. However, due to the complexity of telecom infrastructure, the transition presents numerous challenges. Transitioning commonly involves multiple active and passive infrastructure, widely dispersed locations, and different technologies. Furthermore, while multi-vendor IaC support has matured for IT environments, open standards are only just developing for telecom environments, sometimes even hampered by vendor-specific deviations from published standards.

The complexity is amplified since telecom networks comprehend many layers and function types, be it physical, automation, or logical. Consequently, VoIP, data transport, and fixed telephony require processes and interfaces provided by many vendors, making tasks involving multiple layers and function types uniquely challenging. Interaction with multiple automation stacks and interfaces is necessary for one layer or function to provide or acquire a service from another layer or function.

As a legacy of traditional telecom orchestration, interaction and domain information across various network layers are typically addressed in a statically defined, process-like orchestration flow, leading to fragmented information for security audits, performance tuning, fault management, etc. Since functions that rely on such unused intermediary information are likely to be built on top of complex development efforts inherited from tedious debugging cycles, the compliance with any transformation of the underlying layer or function type is significantly limited, leading to severe system scalability issues.

4.2. Integration with Legacy Systems

Communication service providers (CSPs) face a wide range of challenges when adopting new orchestration technologies. Given that the telecom domain consists of a great variety of legacy systems, it is vital that the newly deployed Terraform-based orchestration system can interact with these legacy systems as well as with modern systems. This requires careful planning and analysis of the integration approaches of existing and new systems, which systems and their corresponding resources to expose from both legacy and modern systems, and which integration technology to use. In particular, functional and non-functional aspects of the integration options need to be assessed to reach a suitable solution for integrating existing systems with the new orchestration platform.

Integrating existing systems with a new orchestration technology comes with a number of challenges that need to be addressed. First of all, technical challenges arise on how to expose and access the functionality of existing management systems, how to design this integration in a scalable manner, and how to ensure consistency and integrity of the information in both management systems. Second, organizational challenges such as the level of ownership (i.e., having a dedicated team vs. being handled as a project) and the time frame and resource allocation to implement the new integration also need to be addressed. On the other hand, the integration can potentially bring substantial benefits. Integrating with an existing system can lead to a significantly reduced time-to-market for service innovations (i.e., new service products), as well as a reduced risk in the roll-out of orchestration technologies, leading to a smoother ramp-up period.

To cope with the architecture and design challenges, it is vital that the newly deployed Terraform-based orchestration system can interact with existing systems. The legacy TMForum OSS/BSS systems implement REST APIs as their external interface. While these APIs enable orchestration systems to interact with management systems for resource provisioning, they do not provide access to the underlying managed resources. This prevents visibility of the underlying resources in orchestration systems, and therefore makes it impossible to enforce consistency mechanisms to ensure integrity of the resource states in both orchestration and management systems. A proposed solution is to build inbound adapters on top of the existing REST APIs, which expose an enhanced API reflecting the managed resources by implementing the respective service level specifications and data models. This would allow orchestration systems not only to access the management systems, but also to manage the underlying resources.

4.3. Scalability Issues

Infrastructure provisioning is a complex and resource-demanding task that becomes even more challenging in the case of distributed telecommunications networks, which entail a large number of service resources from multiple technology and cloud domains, as well as their layered, hierarchical structure. To this end, leveraging a completely logic-based Iac automation for remote provisioning, deployment, and orchestration of distributed network services is presented. The Iac approach embraces challenges related to scalability, deployment latency, access control, and concurrent multi-user provisioning through a combination of batch processing, logical reduction of search space, resource filtering, predefined topology templates, group-level action sharing, assertion-based access management, as well as multiservice and multistage technology-dependent topological grouping of functions. Automated human-oriented workstaging protocols are additionally proposed to ease the usage of Iac tools.

This paper's contributions are evaluated through a quantitative assessment of Iac scalability in the provisioning of a large-scale distributed telecommunication network provisioning through a heuristic model of network resources and services. Moreover, multiple qualitative examples exhibit the paper's model capabilities for heterogeneous service chain assertion mining through complex queries over service graphs. In addition, a streaming multi-topological and multi-lambda event sharing model is introduced to serve as an Iac component for providing multi-tiered notifications for concurrent provisioning chores and the corresponding lock acquisition bearer. Initial testing indicates that with the use of Iac approaches proposed in this paper, complex network chains with hundreds of different network functions can be provisioned in a fraction of a second, with assurance of correct assertions over the resulting service graphs.

Huawei is committed to promoting 5G commercial deployment and developing global 5G standards. The first 5G pre-commercial base stations were released in December 2017. As an important basis of new service development, 5G new packet core network (5G NPN) architecture design and trial were conducted with a focus on service and user plane separation, functional and deployment model representation and definition, and impact on management and control strategy, network element design and capability design. End-to-end 5G call setup testing was verified successfully with third-party base stations.

4.4. Security Concerns

Industry-level services ultimately mean that the solution must implement strict boundaries against malicious users. The study demonstrates how the orchestration of VNFs can automatically trigger the policy controller to create a secure channel between the VNFs. Using technologies already deployed in the network orchestration context, this would make a high-level automatic configuration into a service assurance applicable to virtualized networks. For that reason, some simple parameters must be added to the VNF orchestration specification according to the requirement to create the secure channel.

The drawing shows an example of the creation of an LSP multicast signalling channel through both the VNF orchestrator and the SDN controller. The principle is that a special VNF located in the deployment, together with the rules provided by the SDN controller, can create a proper signalling channel for a multicast LSP, allowing direct configuration of multicast LSPs. The orchestration of multiple clouds or multiple controllers automatically must trigger the proper controller and supply the adequate rules to implement the signalling channel for a multicast LSP creation. However, the study does not mention how to deal with security-based mechanisms to assure the integrity of inter-cloud or inter-domain communication.

5. Best Practices for Infrastructure-as-Code in Telecom

Infrastructure-as-Code is a recent technological paradigm in the telecommunications domain, which is mostly driven by the increasing demand for software-centric telemetry infrastructures. Such implementation is mainly addressed via innovations in open-source orchestration engines adopting domain-specific languages. Services define the expected behavior of resources, while constraints package the implementation-specific details. Services and constraints aid the orchestration engine to automatically instantiate packages composed of compute, networking, and storage resources contributing to the network infrastructure. An Infrastructure-as-Code implementation is envisioned and prototyped via a demonstration video for the Onap project. The demonstrations include the construction of 5G slices composed of network function virtualization infrastructure components meeting the 5G end-to-end quality of service requirements.

Telecommunication tech industrial organizations, vendors, and research and academic institutes involved in the Architecture Workstream of the interactional Projects in the research and development domain are advancing an Infrastructure-as-Code aware orchestration framework which defines a new generation of telemetry services that are mapped to requirements, constraints, functionality, and implementation-specific details to be monitored, tested, and auditable. In a research and development quality assurance sled sum collaboration environment, network and cloud services are commonly implemented via tool-based orchestration engines adopting Openstack/Mano, Onap/NFVO, or Kubo/PKS/PCF technologies from the viewpoint of large telecoms or corporations. However, from an application domain business or political viewpoint, such a design will definitely favor the decision makers that have a monopoly on such automation technologies, mainly driving fragmentation in the telecom market that favors end-users.

As a result, the research and academic platforms usually implement their orchestration engines with limited functionality revamping the pre-openstack Org ODL fuel enforced by the new-generation software-centric software-defined approaches in an as-is fashion. In the same way, the controlling supervision of the testing-validation observations remains as is and tool-only detained with limited underlying structure telemetric APIs for over twenty years. Naturally, the testing and audit success rate will directly relate to the debugging and correctness of the telemetry infrastructure under test. The testing tools usually depend on standard software-centric frameworks resembling the ones provided in network function virtualization solutions.

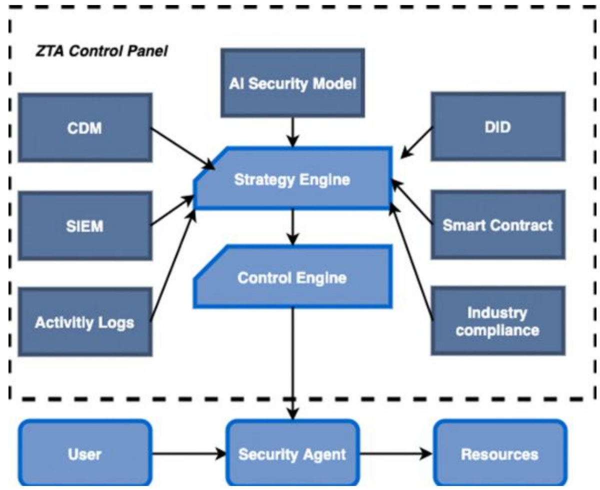

Fig 5: Infrastructure-as-Code in Telecom

5.1. Modular Architecture

Before placing a deployment request, a service descriptor is created for a specific service, including information such as the instantiation of the VNFs and network resources. During this process, a deployment plan is created with deployment rules. This becomes a submission request for the Coordinating Orchestrators. The COs restructure the problem based on their acquired knowledge and trigger the appropriate orchestrators. A few seconds later, they individually receive a deployment request. A chain of events is triggered: resource information is acquired, including information from cloud-hosted data centers and slices in the transport network in response to the requirement. TN Resource Managers may ask traffic engineering tools if they can find a suitable resource assignment for this service request. Once a solution is generated, it is marked as a deployment deal. Results are transmitted back up the hierarchy. A deployment request is sent to the RU, which consists of CMD and REs, based on the confirmed resource assignment. A feedback request is created for the service-internal transaction. The corresponding orchestration plan is executed for the external transaction, creating policies in the transport and TN network. The functional model is activated afterwards. There are several interactions, including activation checks, alarms, and fault recovery. The management system accesses the networks via management-oriented protocols. All offering networks request feedback due to the external transaction. It has to control the chains of events in the correct sequence. Each master component polls agents that may be extending the configuration process. This process takes the initial specification of the tasks to be executed and is used to instantiate the workflow engine. On execution, the service controller will create a dynamic workflow that consists only of the interactions needed to control the specific network configurations.

5.2. Version Control and Collaboration

A natural first task when implementing an infrastructure-as-code approach is to identify a VCS (version control system), deploy it appropriately, and establish which assets to version. Options for VCS include locally hosted installations, cloud-hosted services, and commercial SaaS offerings. The choice of VCS can have a significant influence on the resulting collaboration practices later on in the process. An accompanying issue when a VCS is implemented for the first time is identifying the assets to be versioned and archived. There is a delicate balance. On the one hand, one must avoid a too narrow selection and thus collaborate on too few assets. However, on the other hand, a too broad selection may lead to versioning everything potentially hindering the continued use of versioning and limiting the time for collaboration on the most critical assets. Ultimately it must be decided which files, configurations, and scripts are made immediately available in the VCS. Additional break out sessions may be necessary to address selected assets in more detail and to fix output formats or naming conventions, for instance. Versioning at the file level is one starting point. Merging, branching, tagging, history, and the necessity for comments is much harder to handle. After a few months or iterations if the automation team believes to have covered enough ground a review of the structure, contents, and usefulness of the VCS can be held.

5.3. Automated Testing and Validation

Automated Testing and Validation issues discussed in this section are of utmost concern while implementing Infrastructure-as-Code in a telecom network. The major issues include although are not limited to the following topics.

Verification of Services: An Infrastructure-as-Code Telecom Network allows for automatic generation of services from their specifications. However, creating the necessary associations between hardware, virtual infrastructure, and service configurations may seem impossible. The identifiability and observability of these components often depend on knowledge of their respective brands and architecture. For example, in a MultiVendor-RAN, OpenRAN scenario, it may be very difficult to correctly configure RAN Parameters related to Carrier, Cell, Radio, and Antenna Types without knowing which vendors are involved.

Monitoring of Network Services: NMS is not sufficient for effectively monitoring services and component states of a complex network: in particular it does not handle metrics hierarchically leading to a very weak correlation between service metrics and device counters. Correct monitoring of network services is necessary to make Quick Problem Resolution systems work effectively and derive network telemetry.

Automated Testing: To mitigate the risk associated with change deployment and regulation compliance a standard test campaign should be defined and maintained which allows to verify that the new version still complies with all previously working configurations and behaviours. The feasibility of rapid automated testing should also be assessed and brushed up regularly [7].

Data Storage and Processing: The amount of TE (telemetry) and call logs produced by 5G SA networks can be enormous. The data retention times defined by regulation can be significant leading to very expensive storage. A suitable architecture for the processing of problem-resolution data and TE and call logs in compliance with semi-structured and unstructured data has to be investigated and chosen.

5.4. Continuous Integration and Delivery
Continuous Integration and Continuous Delivery (CICD) play an important part in asset automation and are therefore examined in this chapter. Automated pipelines can ensure quality and shorter release cycles. However, certain challenges in the telecom environment hinder the implementation of CICD. DevOps and Infrastructure-as-Code (IAC) can help overcome some of these challenges, meaning that the existing environment can be adapted. Keeping up with the competition is paramount in any industry. When a competitor can launch new products and services faster, improve existing ones faster, fix bugs faster, or offer better sourcing, the threat to reputation, revenues and profit is great but real. Consequently telecommunications vendors are looking to shorten service and product launch. They seek a move from traditional artisan like development, coupled with long pooling and tedious manual intercompany handoff, to automated "la maklike" factories whereby a push of a button ensures seamless deployment of everything needed to make a service product functional and usable. To make this factory vision work, the ability to push buttons must be accompanied with the proper clockwork that allows everything necessary for collaborative collective software development to take place. It is here that CICD can help deal with some of the issues surrounding implementations on the architected factory. CICD ensures that the earliest possible feedback from a product to a stakeholder in a process is obtained, which in turn guarantees shortening lead time and thus keeping ahead of competition. Continuous integration means that the code, documentation and test instruments associated with a product are bundled and delivered as one entity, ensuring that the product can always be built. Continuous delivery means that every time an entity is delivered, the customer has an executable version. Implementing this implies the serious introduction of automated regression testing and automation of functionality, non-functionality processing and architecture verification. Implementing CICD with travelling performance tests, capacity tests and service reliability tests is an area of interesting development. The activities where most of the widgetry is invested initially are application interface specification and implementation coupled with the necessary provisioning, which is a necessary investment to cut asset-specific scripting costs. Executing a toggle on a portal and setting off a chain of automated operations, ultimately returning powerful intel, will diminish the quantity of mind-numbing tasks employees have to do and thus the inherent risk of error and overloading.

6. Case Studies
To demonstrate the applicability of InfraEd, four heterogeneous telecom service orchestration landscapes are presented in the context of Integrated Transport Advanced Superior Services (ITASS). The project covers the orchestration of the aggregated, federated heterogenous transport networks with SDH, OTN, and Optical transport equipment from different vendors. The two case studies demonstrate how orchestration landscapes can be deployed and operated based on InfraEd. In the first case study, the basic layout for a distributed multi-user service orchestration environment is presented, while in the second case study an operational instance of the REACT mechanism, as part of the full orchestration landscape, is presented.

Service orchestration is a fundamental pillar of information-centric telecommunication. Here orchestration refers to a number of service orchestration principles. There are two orchestration landscape use cases: the first one deals with the deployment and operation of a distribution orchestration environment and its components, while the second case study outlines the design and implementation of orchestration with focus on the operation orchestration landscape components. The designs will allow telecom service orchestration of a federated multi-vendor heterogeneous transport network with network equipment, domain, and service orchestration levels.

The implementation of the orchestration landscape with mentioned principles is possible with InfraEd. InfraEd is an Infrastructure-as-Code-based DevOps framework with usability for heterogeneous technology service orchestration instances, focusing on network services. The case studies cover the feasible implementations of orchestration landscapes and highlight some best practices regarding the provisioning, deployment, and operation of orchestration landscapes in a production environment.

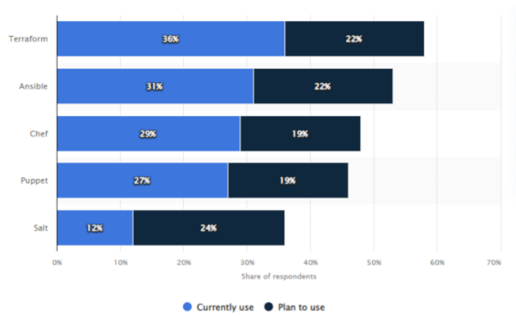

Fig 6: Infrastructure as Code (IaC)

6.1. Successful Implementations

Not much industry work has been documented yet around IAC for telecom networks. Some unique successful implementations have been recognized and are shared below in the hope of helping the community build up a wider set of best practices and supporting artefacts. These feedback should not be misinterpreted as the only acceptable way of implementing some aspects of IAC; they are just inputs from successful industries for any wishing to keep learning and improving the art of applying IAC for service orchestration and management.

The presented implementations components must be seen as complementary components of a coherent architecture for the provisioning of network services and slices for 5G and beyond networks. They are applicable independently, as the need arises from any industry willing to build on the presented approach. Each of the implementation components requires agreements on models for data exchanges across foundations, representation languages, libraries, and representation styles currently specific to particular service-based systems to avoid misinterpretation. The agreed standards with the data exchange across network vendors and with the adjacent domains will also have a significant influence on each other's implementation.

Vendor A: Domain Specific Pluggable Modules for SON, Service Enablement, Monitoring, and Observations To manage the network elements from network vendors, systems supporting MPEG have been interfaced with SDN controllers. Each controller cannot interoperate with another vendor equipment through open interfaces. This is why the vendor products have been internally interfaced with their own OSS products through internal open interfaces. Today, most vendors' products can present their back exotic monitoring data safely and autonomously by it. The focus has now expanded to manage performance and accessibility of multi-vendor networks with RAN, Transport, and Core domains. Since there are many petite functions provided by each network vendor, smarter and dynamically pluggable monitoring functions play a key role in wide area network observability.

Functionalities for management operations of transport networks including VNF, PNF, Bandwidth and Slice admission can be automatically discovered through the opened and hidden APIs, and then, fully autonomously, by the orchestrator, or under limited MANO defined ranges considering ownership and security by the cued pre-assembled service instance descriptor. The main enabler for such sophisticated range is via TO and TO DAC, as it also allows provisioning tasks across domains. In addition to the integration of the above mentioned vendor products, the Tier-1 service market for comprehensive control of service delivery in a highly scalable and dynamic manner was successfully shown. The real-time view and control of QoE and per-slice biddings of multi-tenant 5G service operation along with RAN, Transport, and Core domains were demonstrated.

6.2. Lessons Learned from Failures

The practical use of this architecture on telecom networks, and the lessons considered and learned during the development of these approaches and from the failures that were encountered after the initial successful executive rolls-outs.

One of the key challenges was the conventional approach in telecom networks where each telecom service typically consists of mesh network topology of all layers 0–3. Therefore, the Domain Manager needed to have almost full visibility of all resources. This top-down solution resulted in very tight coupling of the orchestration and management system, but it was also slow and costly to maintain. Another challenge stemmed from the more recent deployments of the xG networks, which involve much more complex topologies with potentially multiple device vendors per layer and a larger number of parameters involved.

It was realized prior to practical deployments that most of the systems developed could not be scaled up to cope with the increasing number of devices and interfaces. Manual remediation on non-automated and purely operational systems was high and therefore the staff turnover was also much higher than normal. Combined with the less than 24/7 operational support and too tight coupling of the IT operational environments, this led to multiple high profile outages of the services offered.

Learning from these failures, it was decided to change the architecture on multiple fronts, especially at the concept and communication levels. The IT monitoring solution was built around the SNMP protocol, while managed devices could have Telnet, SSH and HTTP connectivity. Someone quickly realized a programming and provider architecture modelling requirement and APIs were built on both GRADES and IT monitoring front-ends. However, due to the historic lack of API-based designs in the industry, such pipelines can only be built on a per-device basis. Furthermore, they were often perceived as one-off type solutions, therefore scalability was a challenge. The micro-service architecture beyond Granular domain modelling was required. On the other hand, using a Telnet-based GRADES system and expecting a fast solution was almost paradoxical. Therefore, as many components as possible were created based on a Go micro-service architecture.

7. Future Directions in Telecom Service Orchestration

Considering that telecom has already made cloud service provisioning a reality first for IT resources, networks, and more recently for functions and networks (NFs), the orchestration of information technology (IT)/cloud and telecommunication networks is a natural evolution. The first orchestration of IC/data-carrying networks, from data-center interconnections to national backbone wavelengths, and the evolution of optical/fiber telecom/IDC networks towards software defined networks (SDN) and network function virtualization (NFV) have already been considered as reliable and viable approaches. They formed regulated and orchestrated tech-silos with cloud-telecom leading edge services complementing more traditional telecom authorized services.

The natural evolution of this orchestration should be towards a telecom-cloud supply chain including both 5G/5GC/6G telecom (NFs) and IT cloud infrastructure. The focus has to be the integration and orchestration challenges raised by Network-as-a-Service (NaaS) and infrastructure-as-a-Service (IaaS) collaborative provision. Telecom operators should focus on their dependence on expertise to offer new telecommunications services to other verticals such as banking and healthcare. These operators would benefit from a reliable solution to offer IaaS and any IT-based service on top. An alternative telecom-cloud supply-chain and orchestration scheme and key integration and orchestration challenges to be faced are proposed. Tech-company virtualization, truck processing services, and NFT support are addressed as well.

7.1. AI and Machine Learning Integration

Implementing AI and machine learning capabilities in telecom networks can significantly improve the performance of these networks. AI capabilities can be first implemented by collaborating with a vendor or by creating and integrating open-source AI systems into the network. However, these AI capabilities need to be deployed as part of the telecom operator's architecture and workflows. This involves researching and building orchestration capabilities specific to AI/ML workloads, developing new tooling, and updating or replacing existing tooling to keep it well integrated. There are several challenges in this phase. Firstly, the provisioning cycle must be measured in minutes at the most. The stake and public perception of an incorrectly provisioned AI workload is far greater than of a simple telecom application. Furthermore, since so many edges will run the same AI workload, protection for the orchestration system must be considered more heavily than in telecom service orchestration, where the focus was on protecting individual workloads. The separation of concerns capabilities of the orchestration systems in this context needs further research, as there are limitations in current systems for completely separating the concerns of telecom service orchestration and of orchestration of temporary workloads such as AI workloads. An AI workload will also commonly require external resources, such as pre-trained AI models. This must be considered in the orchestration system of AI workloads. Finally, there is the challenge of transparent and standardized shareability of workloads. AI workloads are far. attempts have been made to create standards for shareable AI containers, such as the openBML format. However, these standards are currently proprietary and not widely known. Mere technical compatibility to run AI workloads in a telecom network is not feasible. With such transparency, telecom networks could also be especially revolutionary for edge and access AI workloads, where telecom operators often have a unique reach and relevance. When telecom operators could build an ecosystem to share matchmaking or brokering services, for example with communities of developers of AI workloads, there is the potential for enormous growth comparable to the app store economy. The simplest solution for shareability of AI pipelines is that telecom operators host a shop of workloads similar to the app store model. However, this would not consider current challenges to monetize or attract developers of workloads.

7.2. 5G and Beyond

Global connectivity is becoming a necessity for people, businesses, and things. Radio access networks (RAN) for the 5G or future standards will support many new services based on ubiquitous connectivity, while providing enhanced mobile broadband connectivity. At the same time, 5G is recognised as the most critical infrastructure. However, with a wide variety of needs across services, countries, and enterprises, answering such requests will expand along with the necessary network infrastructure and force telecommunications service providers (telcos) to deploy wrapping a huge amount of equipment.

The estimate is that 5G expects a 1000x increase in capacity and a 10 billion increase in connected devices along with telecom networks expanding beyond their pure regional/area historical confinements. Non-standardised, new components coming from various vendors will expose telcos to succeed and fail across new and developing networks based on integrating their Network Functions (NFs) and equipment into automated operations, Orchestration, and Service Assurance [3]. At the same time, with the number of connected devices growing exponentially, achieving maximum utilisation and service assurance across services and equipment becomes essential for business viability and reliability. Resilient automation beyond current capabilities – which is cloud, zone, and domain agnostic is most welcome. A new 5G RAN-based telecom equipment is being launched by various vendors in specialised software/hardware configurations. 5G RAN or future RANs will be hybridised with a variety of old-style components and software processing components from various vendors.

The convergence will only expand along with the want for maximum quality service assurance across this conglomerate – subsided networks – and the need for 3rd party applications to improve effective business within it. With the number of devices exponentially growing, more and more service requests for different diverse needs brings the desire for automated operation. On the other hand, dynamic, entity or node agnostic resource allocation and service quality management would exhibit density in vendor component interactions, system complexity, and management activity. Hence they are becoming a burden and an obstacle in achieving telecom targets.

7.3. Edge Computing Implications

Edge is deemed the new frontier for digitalism as an enabler for next-gen application domains such as augmented and virtual reality, smart industry, smart transport, and smart buildings. The way of realizing edge is still in flux; however, recent momentum within champion-defined approaches, standardization forums, open-source communities, vendor initiatives, academic research projects, and industry accelerator forums have triggered ecosystem growth and orchestration tooling towards open, cost-effective, and automated network edge management and nimble service deployment. These all-i-open AI agents will have to be adapted to map resource and service space definitions to ontology for ML-in-the-loop . Edge nodes introduce additional challenges over traditional cloud nodes. There may be many resource owners curtailing the ability of a subject-service orchestrator to affect network-wide resource policy, generating a lentil graph of possible allocation/suballocation spanning zero-second- to-applet-level decision timescales. This grandeur-request response volume at the control interface prohibits the entire nano-second real-time request to service for enhanced loop-in conclusions.

8. Conclusion

Telecom infrastructure industry is converging towards a fully virtualized architecture where telecom network functions are implemented via virtual machines running on commodity hardware in a cloud infrastructure. Sadly, traditional mechanisms for a static service provisioning may be inefficient in a dynamic environment adopting network functions virtualization. More dynamic behavior is expected due to both dramatic changes in demand patterns and robustness concerns. The virtualization infrastructure faces challenges of scalability, resource contention, disturbance isolation and interdependencies among virtualized entities. Dynamic resource scaling requires decentralized implementation to prevent a system-wide cascade. Today's telecom network service lifecycle orchestrators use a monolithic centralized element which represents a galling point of failure. Telecommunication Network is homogeneous in terms of physical topology. Cloud is a high scalability and high availability infrastructure over distributed homogeneous resource nodes. It uses an abstractly distributed set of hypervisors to allocate/manage resources and a virtual switch method to interconnect virtual machines which is emerging in the cloud as well. Telecom cloud relies on networking nodes of high scalability, high availability, general empathy and cloud VM deployment.

Although today's telecom network services are created by composing static elementary wiring and counterpart hypervisor, solutions need to be found to dynamically manage their scalability. No deployment time is defined, resource allocation/installation/disconnection may dynamically expand or shrink the network and may collaborate with other clouds to provide value. Provisioning and release methods of low level hypervisor resource scaling which are generic and agnostic to specific implementations are needed. Telecommunication fields suffer from a challenge of massive requests for the connection of wireline/wireless high bandwidth, low latency, low jitter services and difficulty in ensuring dynamic resources and corresponding revenues. Routing and traffic engineering schemes form a complicated and narrow optimization space. Decentralized distributed approaches providing near-optimal policies need to be developed. Services or components in various domains are composed to implement a more complex and diverse service lifecycle including service design, creation, editing, deletion, update, etc. Past research work mainly focused on provisioning, installation, and update which address a single domain. Validating mobile services in complex and distributed networks encompassing multi-domain and multi-technology is a huge challenge.

8.1. Future Trends

Orchestration refers to the coherent coordination of heterogeneous systems, allocating diverse resources and composing functions to offer end-user services. The orchestration systems at a given operational level do not typically offer service facing to the client; in other words, they do not interact with customers. Orchestrators offer interfaces to their subordinate control systems, so they are typically accompanied by extensive and heterogeneous sub-level systems, which comprise heterogeneous hardware, software, and protocols. In addition, they could have a heterogeneous nature, implementing very different paradigms that are naive to the concept of orchestration. The automation of the service provisioning implies the dynamic allocation and management across different operative domains. In this sense, the networking community is adopting cloud computing to answer emerging requirements and use cases, whereas the cloud community is building geographically distributed computing infrastructure requiring inter-connection.

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