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Network service orchestration standardization: A technology survey

Charalampos Rotsos[a,*], Daniel King[a], Arsham Farshad[a], Jamie Bird[a], Lyndon Fawcett[a], Nektarios Georgalas[b], Matthias Gunkel[c], Kohei Shiomoto[d], Aijun Wang[e], Andreas Mauthe[a], Nicholas Race[a], David Hutchison[a]

[a] Infolab21, School of Computing and Communications, Lancaster University, United Kingdom
[b] British Telecom, United Kingdom
[c] Deutsche Telekom, Germany
[d] NTT, Japan
[e] China Telecom, China

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ABSTRACT

Network services underpin operator revenues, and value-added services provide income beyond core (voice and data) infrastructure capability. Today, operators face multiple challenges: a need to innovate and offer a wider choice of value-added services, whilst increasing network scale, bandwidth and flexibility. They must also reduce operational costs, and deploy services far faster - in minutes rather than days or weeks.

In the recent years, the network community, motivated by the aforementioned challenges, has developed production network architectures and seeded technologies, like Software Defined Networking, Application-based Network Operations and Network Function Virtualization. These technologies enhance the highly desired properties for elasticity, agility and cost-effectiveness in the operator environment. A key requirement to fully exploit the benefits of these new architectures and technologies is a fundamental shift in management and control of resources, and the ability to orchestrate the network infrastructure: coordinate the instantiation of high-level network services across different technological domains and automate service deployment and re-optimization.

This paper surveys existing standardization efforts for the orchestration - automation, coordination, and management - of complex set of network and function resources (both physical and virtual), and highlights the various enabling technologies, strengths and weaknesses, adoption challenges for operators, and areas where further research is required.

1. Introduction

> Flexibility, agility and automation and a much faster time-to-market cycle, where the latter is something that we, as operators, lack today
> (Christos Kolias, Network Architect, Orange [1]).

Network services are the primary value-added products for Network Operators (operators), enabling them to monetize their infrastructure investments. Operator service portfolios cover a wide range of functionalities, spanning from basic Internet connectivity services, such as IPTV delivery, to highly-available and secure connectivity between business sites. This operator business model has been highly successful, their user base continuously expands [2], while new services are adopted by end-users.

As a direct consequence, network infrastructures have grown significantly in the recent years and operators face significant challenges maintaining high revenues, while supporting innovative new network services. On the one hand, traffic volumes increase exponentially [3] and forces operators to upgrade infrastructures frequently. Additionally, the established service management model relies extensively on manual device reconfiguration by the network engineers, coordinated through Operational Support Systems (OSS), while link over-provision is used to enforce SLAs. Effectively, the predominant service management model incurs significant capital (CAPEX) and operational expenditures (OPEX) for the operator [4]. On the other hand, network infrastructures employ a widening range of heterogeneous technologies to support the diverse characteristics and dynamic demands of residential and enterprise network services. Unfortunately,

* Corresponding author.
E-mail addresses: h.rotsos@gmail.com, cr409@cl.cam.ac.uk (C. Rotsos).

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the control and management interfaces of the relevant technologies do not keep abreast with the requirements of network applications for fluid and dynamic control. The different technological domains and layers exhibit significant interface proliferation, while vertical control integration in network devices impairs management flexibility and responsiveness. As a result, the futuristic vision of network operators to provide service-oriented control interfaces to end-user applications, still remains unfulfilled.

These limitations have motivated the network and systems community to develop new paradigms and architectures which improve network infrastructure flexibility, agility, programmability and elasticity and ensure low OPEX. Recent network paradigms, like Software Defined Networking (SDN) and Application-based Network Operations (ABNO), promote control convergence across network layers and logical centralization of network infrastructure management through the specification of common device control interfaces. In parallel, the Network Function Virtualization (NFV) paradigm promotes the "*softwarization*" and virtualization of network functions, in order to enable data plane processing with similar elasticity, scalability and resilience available in cloud environments. Furthermore, new network architectures including Service Functions Chaining (SFC) and Segment Routing (SR), simplify service deployment and allow seamless integration of traffic-engineered (deterministic) network services and network policy.

To capitalize on the fluidity of these novel networking paradigms and architectures, operators a require new control and management system, capable to *orchestrate* the different technologies and resource types available in modern network infrastructures. These systems are responsible to converge control and management heterogeneity between technologies, in an effort to synthesize innovative service-oriented interfaces, and enable autonomous and automated service deployment and adaptation. The development of service orchestration architectures and interfaces has been accelerating, but since each vendor typically develops its own protocols and mechanisms, integration remains a challenge. Towards the goal for automated, flexible and cost-effective service orchestration, interoperability and standardization play a crucial role for its success.

This paper surveys standardization efforts towards enabling network service orchestration from an operator perspective. To elaborate on available interfaces, standards and recommendations we follow a top-down approach. We begin with a definition of the document terminology, and we elaborate on the network service orchestrator requirements and objectives from the perspective of four of the world's largest and complex network operators —British Telecom, Deutsche Telekom, NTT and China Telecom — (Section 2). Furthermore, to motivate our discussion on network services, we present the design and requirements of three popular network service use cases, namely Radio Access Network and Mobile Evolved Packet Core connectivity services and end-to-end content distribution service (Section 3). We then elaborate on the capabilities and interfaces of the predominant network (Section 4) and function (Section 5) management and control architectures. Finally, we discuss the future directions for network orchestration standardization efforts (Section 6) and conclude this paper (Section 7).

2. What is network service orchestration?

2.1. Terminology

A *network service* is a high-level network functionality that generates business value for customers and/or the operator. Network services are typically represented as directed graphs, where the nodes of the graph represent low-level network functions and the directed edges describe ordering and connectivity.

A *network or service function (NF)* is a specialized network element, designed to efficiently perform a restricted set of low-level operations on traffic. An NF can manipulate traffic at multiple layers of the protocol stack and it is common to manipulate packets traversing the network, as well as terminate network flows. Virtual software instances, such as a Broadband Network Gateway (vBNG) or IP Multimedia Subsystem (vIMS) running on a virtual machine, or specialized physical hosts, such as hardware load-balancers, are both common approaches to realize NFs. Furthermore, virtualization allows instantiation of multiple NFs on a single physical node, while a single physical node can potentially support the instantiation of multiple different NF types. Finally, NFs predominantly are designed to modify network traffic, but passive monitoring NFs are equally popular, such as intrusion detection systems.

A *Service Orchestrator* is a control system for the provision, management and re-optimization of network services. Effectively, a service orchestrator receives network service requests from individual applications, service consumers and the operator. Based on the received service requests, the available infrastructure resources and the topological properties of the underlying network, the orchestrator is responsible to define and execute a deployment plan that fulfills the NF and connectivity requirements of each service. In parallel, the service orchestrator monitors the performance of all services and dynamically adjusts the infrastructure configuration to continuously ensure the performance guarantees and cost goals.

Service Orchestration aims to support a wide range of infrastructure technologies and resource types and depends on technical standards to broaden its applicability. A technical standard reflects an established set of requirements or norms to precise technical systems. They are typically formal documents that establish uniform engineering or technical criteria, procedures, protocols and practices. This survey paper investigates the myriad of SDN and NFV standards (both formal and de-facto) across a range of Standards Development Organizations (SDO), and rapidly expanding environment of Open Source software projects. Typically, the impedance mismatch between SDOs and Open Source is at least 2:1 (two years to a paper standard versus one year to a product that creates a de-facto standard) [5].

2.2. Requirements

A Service orchestration is a complex high-level control system and relevant research efforts have proposed a wide range of goals for a service orchestrator. We identify the following functional properties:

Coordination: Operator infrastructures comprise of a wide range of network and computation systems providing a diverse set of resources, including network bandwidth, CPU and storage. Effective deployment of a network service depends on their coordinated configuration. The network manager must provision network resources and modify the forwarding policy of the network, to ensure ordering and connectivity between the service NFs. This process becomes complex when considering the different control capabilities and interfaces across network technologies found in the metropolitan, access and wide area layers of the operator network. Furthermore, the network manager must configure the devices that will host the service NFs, either in software or hardware. The service orchestrator is responsible for abstracting the management and configuration heterogeneity of the different technologies and administrative domains [6,7].

Automation: Existing infrastructures incur significant operational workload for the configuration, troubleshooting and management of network services. Network technologies typically provide different configuration interfaces in each network layer and require manual and repetitive configuration by network managers to deploy a network service [8]. In addition, vertical integration of network devices requires extensive human intervention to deploy and manage a network service in a multi-vendor and multi-technology environment. A key goal for service orchestration is to minimize human intervention during the deployment and management of network services. Efforts in programmable network and NFV control, like SDN, ABNO and ETSI NFV