End-to-End Network Slices: From Network Function Profiles to Fine-Grained SLAs

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Abstract. *Towards end-to-end network slicing, diverse envisioned 5G services (e.g., augmented reality, vehicular communications, IoT) call for advanced multi-administrative domain service deployments, arising open challenges from vertical customers of communication service providers leading to complex distributed Service Level Agreement (*SLA*)-based orchestration hazards. Through different proposed methodologies and demonstrated prototypes, this work showcases: the automated extraction of network function profiles; the manners to analyze how such profiles compose programmable network slice footprints; and the means to realize fine-grained auditable SLAs for end-to-end network slicing among multiple administrative domains. Sustained on state-of-the-art networking concepts, this work presents contributions detaining roots on standardization efforts and best-of-breed open source embodiments, each one standing prominent future work topics in shape of its shortcomings.*

Resumo. *Rumo ao fatiamento de redes fim-a-fim, diversos serviços 5G (ex.: realidade aumentada, comunicações veiculares, IoT) exigem implantações de serviços em múltiplos domínios administrativos, desafios abertos decorrentes de clientes verticais de provedores de serviços de comunicação que levam a riscos de orquestração baseados em Acordo de Nível de Serviço (SLA) complexos e distribuídos. Por meio de diferentes metodologias propostas e protótipos demonstrados, este trabalho propõe: a extração automatizada de perfis de função de rede; as maneiras de analisar como esses perfis compõem alocações de fatias de rede programáveis; e os meios para realizar SLAs auditáveis e granulares para o fatiamento de rede fim-a-fim entre vários domínios administrativos. Sustentado em conceitos no estado da arte de redes, este trabalho detêm raízes em esforços de padronização e em excelentes tecnológias de código aberto, apresentando contribuições contendo tópicos de trabalhos futuros proeminentes nos moldes de suas deficiências.*

1. Introduction

In the last ten years, network softwarisation processes have been continuously diversified and gradually incorporated into production, mainly through the paradigms of Software-Defined Networking (SDN) (e.g., programmable network flow rules) and Network Function Virtualization (NFV) (e.g., orchestration of virtualized network functions). Based on this process [Ordonez-Lucena et al. 2017], the concept of network slice [NGMN Alliance 2016] emerges as a way of defining

end-to-end network programmable paths, possibly over shared network infrastructures, requiring strict performance metrics associated to a particular business case [5GPPP Architecture Working Group 2018].

This work investigate the hypothesis that: *the disaggregation of network function performance metrics impacts and composes a network slice footprint incurring in diverse slicing feature options, which when realized should have their* SLA *life cycle management transparently implemented in correspondence to their fulfilling end-to-end communication business case*. The validation of such assertive takes place in three aspects: the degrees of freedom by which performance of virtualized network functions can be expressed; the methods of rationalizing the footprint of network slices; and transparent ways to track and manage network assets among multiple administrative domains.

In order to achieve such goals, a series of contributions were achieved by this work, among them: the construction of a platform for automating methodologies for performance testing of virtualized network functions; an elaboration of a methodology for the analysis of footprint features of network slices based on a machine learning classifier algorithm and a multi-criteria analysis algorithm; and the construction of a prototype using blockchain to carry out smart contracts involving service level agreements between administrative systems.

In summary, through experiments and analysis we suggest that: performance metrics of virtualized network functions depend on the allocation of resources, internal configurations and test traffic stimulus; network slices can have their resource allocations consistently analyzed/classified by different criteria; and agreements between administrative domains can be performed transparently and in various forms of granularity through *blockchain* smart contracts. In the structure of this paper, we present the motivating research questions in Sec. 2, the main goals and contributions in Sec. 3, and the final remarks in Sec. 4.

2. Motivation

The research questions explored onto the confirmation of this work hypothesis follow based on the arguments explained before each one of them below. Such synthesis characterizes the common ground of each one of the main contributions of this work, respectively, and how they complement each other to establish the line of thought delineated along this work.

The problem statement of Virtual Network Function (VNF) benchmarking based on "trust, but verify" principles seeks standardized performance testing to allow the proper evaluation of candidate platforms and locations to host (chains of) VNFs with respect to target Key Performance Indicators (KPIs) (e.g., [Blendin et al. 2016, Peuster and Karl 2016]). Outcomes of automated performance tests can be used as inputs of orchestration embedding algorithms and/or parameters to support business decisions such as pricing and allocation of resources to fulfill SLAs [Cao et al. 2018]. As noted by the vision behind NFV-VITAL [Cao et al. 2015], standardized characterization of VNF performance enables analyzing optimal sizing and configuration of VNFs in order to automatically: for a given resource configuration, estimate the VNF capacity; for a given workload, determine optimal resource configuration; evaluate different operational system virtualization footprints and/or hardware alternatives and compute system overhead

associated to dynamic scaling (up/out/down/in); fine-tune VNF implementation and performance debugging. Towards such resolutions, throughout chapter 2, "Disaggregating Performance Metrics", we pose the following research question:

Research Question #1: What are the degrees of freedom by which VNF performance metrics can be expressed?

Disaggregating Performance Metrics: The chapter 2 title stands the term *disaggregating* to reference the transformation of Network Functions (NFs) proposed by NFV. I.e., in the pre-NFV case, the performance metrics of network functions were totally tied to and dependent on the coupled soft/hard-ware layers. While in the full-NFV case, the virtualization decouples the execution environment capabilities, enabling varied abstraction layers and their incumbent resources on the execution of network functions. This creates the disaggregation of performance metrics. For instance, the throughput of a virtualized network function can be divided into (disaggregated) ranges of operational values according to its allocated set of vCPUs or memory.

Aiming at fine-grained orchestration and management of end-to-end slices, flexible to comply with diverse SLAs, there is a challenging demand of comprehensive manners to describe service characteristics, KPIs, and network element capabilities and requirements [Foukas et al. 2017, Sharma et al. 2017]. A step further, a proposed model of Network Slicing as a Service (NSAAS) presents advantages to operators differentiate data pipes, conceptually via service models and orchestration designated for application, network function, and infrastructure levels [Zhou et al. 2016]. Accordingly, sets of functionality requirements from different network slices would be translated into one or more mappings of infrastructure and network function matched SLAs, associated with service chain links addressing concise traffic characteristics of end-to-end programmable paths and corresponding Quality of Service (QOS) settings [Afolabi et al. 2018]. Such problem statement embraces the realization of a process for a comprehensive analysis of network slice characteristics and KPIs, and possibly their incurring SLAs. Such research perspective is addressed in chapter 3 of this work, named "Analysis of Slicing Footprints", which culminates in investigating:

Research Question #2: How to establish a dimensioning analysis of the footprint criteria involving a network slice?

Analysis of Slicing Footprints: the title of chapter 3 stands the term *footprints* to refer to the set of physical and logical infrastructure resources allocated for a network slice instance. Such resources contain, for instance, network functions, their needed execution environment capabilities and their interconnecting link requirements to compose an abstracted graph that may represent a network slice instance.

Similar to agile cloud environments in web-scale companies, networking actors (e.g., carriers, network operators, service providers) pursue fluid network infrastructures to uphold analytics, automation and distributed orchestration via software-centric innovations from radio access to the core [Samdanis et al. 2016]. To attend multi-administrative network slices, carrier-grade service orchestration urges for advances in transport and value-based network services to address distributed inter-connections among edge/cloud environments, on-demand fulfillment of business verticals to handle the expected quality of and growing-ever traffic needs from the edge, rendering per-

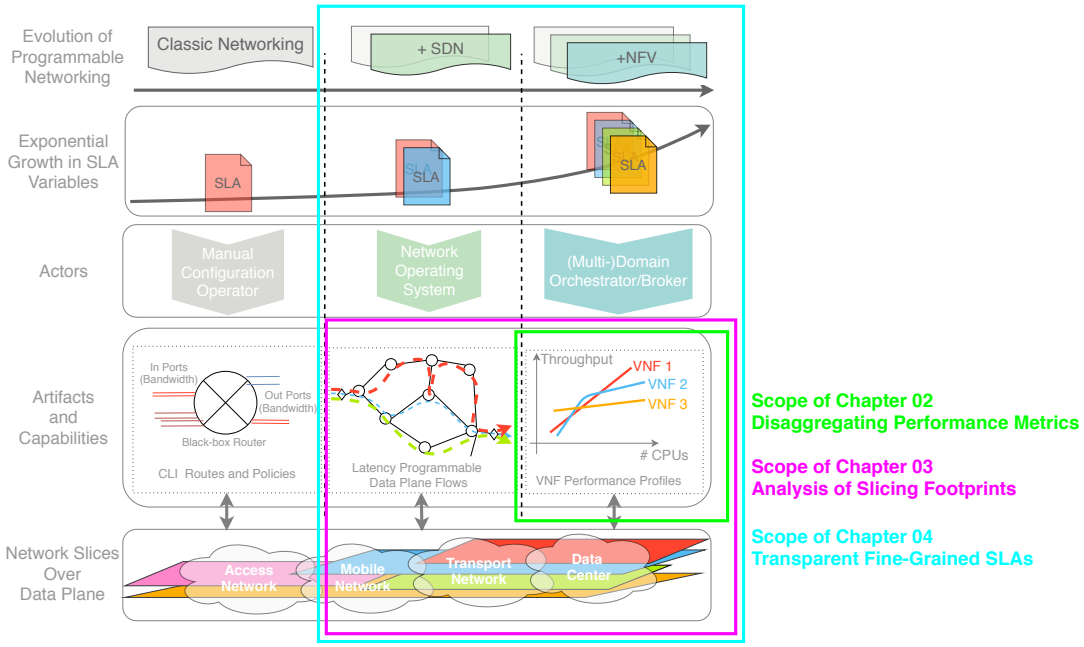

Figure 1. Scope of the work Chapters Towards End-to-End Network Slices: Evolving Programmable Networking Scenarios, Driving Paradigms/Artifacts and Incurring SLAs.

ceivable aggregated value beyond just "dumb pipes" through improved operational practices [Contreras and Lopez 2018]. Here, the problem statement sits in the fact that current monolithic end-to-end connectivity services, slowly deployed through intra-domain manual configurations over redundant/costly infrastructure footprints, settle opaque SLAs to eventually assure inter-domain handshake agreements. As chapter 4 showcases, aiming "Transparent Fine-grained SLAs", we pursue:

Research Question #3: How to transparently track/manage networking assets and their SLAs in end-to-end slices over multiple administrative domains?

Transparent Fine-grained SLAs: the title of chapter 4 stands the term *transparent* to elucidate our aim in turning a SLA fully auditable by its counterparts. Besides, the term *fine-grained* refers to the possibility of a SLA be decomposed into multiple minor agreements. Together, *transparent fine-grained SLAs* aims to establish that chapter 4 argues in favor of multiple administrative domains realize partnership agreements for networking in diverse granularities (fine-grained) possible to be fully auditable (transparent) by its counterparts.

3. Goals and Contributions

In general, the main goal of this work involves the study of the disaggregation of VNF performance metrics composing the core for analytics of end-to-end slicing footprints that can be mapped into transparent fine-grained SLAs in multiple administrative domains. Such goal can be distilled into:

- Define automated mechanisms for the performance characterization of VNFs;
- Establish mechanisms to analyze the multi-criteria aspects of network slicing options and their utility for decision support processes;

- Define mechanisms for the establishment of transparent/auditable SLAs among administrative domains.

In synthesis, we attain such goals by the approaches and the contributions described in the next subsections, each defining an activity in the development of this work. Such activities are mapped to chapters of this work, as illustrated in Fig. 1. The open source code and guidelines to reproduce all presented experiments in this work will be available online.[1]

3.1. Disaggregating Performance Metrics

Towards this end, we propose a framework that defines a minimum set of standardized interfaces while allowing user-defined tests along a catalogue of reusable VNF testing procedures and reports with wide- and well-defined system configuration descriptors, workload parameterization (linking to specific traffic generation tools and their parameters), KPI computation, along all supporting code and data expected from a standardized and reproducible benchmarking methodology. Besides, we define an information model to be consumed and exported by such framework as a method to represent VNF performance metrics and their associated causes. And via the exercise of such framework over different VNFs, we validate its design principles, and consequently observed experimental results that allowed us to suggest an answer to the investigated research question #1, and attain the following contributions:

1. The development of a skeleton of software components delivering the abstractions and tool set in support of practical methodologies to validate, benchmark, and dimension VNFs, a framework implementation baptized as Gym;
2. The establishment of a standard methodology for VNF benchmarking automation;
3. An information model to represent a VNF benchmark descriptor and profile, jointly composing a VNF benchmark report.

These contributions lead to the following publications, which include a work on track towards standardization, a high impact journal, and a best paper award:

- ROSA, R. V.; ROTHENBERG, C. E.; SZABO, R. VBaaS: VNF Benchmark-as-a-Service. In: 2015 Fourth European Workshop on Software Defined Networks. [S.l.: s.n.], 2015. p. 79–84. ISSN 2379-0350.
- ROSA, R. V.; BERTOLDO, C.; ROTHENBERG, C. E. Take your vnf to the gym: A testing framework for automated nfv performance benchmarking. IEEE Communications Magazine, v. 55, n. 9, p. 110–117, 2017. ISSN 0163-6804.
- ROSA, R. V.; ROTHENBERG, C. Taking Open vSwitch to the Gym: An Automated Benchmarking Approach. In IV Workshop pre IETF/IRTF, Jul. 2017. (best paper award)
- ROSA, R. V.; ROTHENBERG, C. E.; PEUSTER, M.; KARL, H. Methodology for VNF Benchmarking Automation. [S.l.], 2018. Work in Progress. Available online: https://datatracker.ietf.org/doc/html/draft-rosa-bmwg-vnfbench-03.
- ROSA, R. V.; ROTHENBERG, C. E. Automated VNF Testing with Gym: A Benchmarking Use Case. In: Proceedings of the TMA Posters and Demos. Vienna, Austria: Jun, 2018.

[1] at https://github.com/raphaelvrosa/work - Accessed on 2018-11-01

3.2. Analysis of Slicing Footprints

The main motivating threads behind the analysis of slicing footprints are related to the creation of a platform capable of dealing with the information overburden behind network slicing opportunities. As any other outcome from information production, advent from infrastructure capabilities and customers requirements, an overload incurs in situations where the decision making process exceeds the capacity to assimilate and act on the information as well as the ability to evaluate every alternative [Greco et al. 2005]. Our analysis of the infrastructure slicing quest begins with the joint modeling of certain infrastructure (network, compute, storage) capabilities exposed to a network service orchestrator. Based on network service characteristics from the literature, we bear the study of the dimensionality of choices among network infrastructure capabilities in face of variable requirements of slices. Suggesting answers for the research question #2, through the construction of an analytics platform, we focus on an approach to apply machine learning and multi-criteria analysis to the dimensioning angles of network slices, developing a methodology to extract slicing criteria and analyze their facets. The main contributions can be summarized as follows:

1. Characterization of dimensioning facets of infrastructure capabilities for network slicing;
2. A methodology for the construction of feature vectors encompassing slice descriptors;
3. An analytical investigation of machine learning and Multi Criteria Analysis (MCA) algorithms in scope of network slices dimensioning.

These topics are covered by one article re-submission after the first review round:

- ROSA, R. V.; ROTHENBERG, C. E. The Pandora of Network Slicing: A Multi-Criteria Analysis. In Submission To Transactions on Emerging Telecommunications Technologies, John Wiley & Sons, 2019.

3.3. Fine-grained SLAs

To attend decentralized non-trusting administrative domains in need of chained smart contracts (inter-domain transactions and billing) for consensus (composed SLAs), here we approach the opportunities unlocked by a shared ledger of abstracted capabilities (end-to-end service slices) via blockchain-based Decentralized Applications (DAPPs) for multi-administrative domain networking. Such native distributed and dynamic scenarios built for robustness and fault-tolerance are hardly addressable by trusted centralized databases or intermediate marketplaces, therefore we approach the mapping of network assets characteristics and their SLA agreements into blockchain smart contracts. A platform built to explore the dynamics of inter-domain orchestrated network slices showcases mechanisms and metrics that illustrate the investigative approach to suggest answers for the proposed research question. Altogether, the following contributions have been achieved:

1. Establishing a Multi-Domain Orchestrator (MDO) walk-through from background baselines, via the definition of requirements and a formal categorization of operational phases;
2. Motivating perspectives and potential candidate strategies and implementation options to incorporate blockchain-based DApps into multiple administrative domain scenarios;

3. Proof-of-concept prototype experiments of blockchain-based MDOs showcasing smart contracts for lifecycle management of network services across administrative domains;
4. A standardization outlook discussion towards feasibility prospects of incorporating blockchain-based DApps into three Standards Developing Organization (SDO) use case scenarios.

From the initial motivating aspects to detailed design and experimental validation, the topics above have been addressed in the following publications:

- ROSA, R. V.; SANTOS, M. A. S.; ROTHENBERG, C. E. Md2-nfv: The case for multi-domain distributed network functions virtualization. In: 2015 International Conference and Workshops on Networked Systems (NetSys). [S.l.: s.n.], 2015. p. 1–5.
- ROSA, R. V.; ROTHENBERG, C. E. Blockchain-based decentralized applications meet multi-administrative domain networking. In: To Appear in Proceedings of the SIGCOMM Posters and Demos. New York, NY, USA: ACM, 2018. (SIGCOMM Posters and Demos '18).
- ROSA, R. V.; ROTHENBERG, C. E. Blockchain-based Decentralized Applications for Multiple Administrative Domain Networking. IEEE Communications Standards Magazine, v. 3, n. 2, 2018.

4. Final Remarks

As far as we know, this work was the first to: *(i)* on the grounds of standardization efforts, propose and demonstrate (TMA 2018) a full methodology and prototype to perform the automated extraction of network function profiles; *(ii)* establish a methodology to analyze network slices on the basis of algorithms from machine learning and multi-criteria analysis; *(iii)* rationalize the operational phases involved in partnership agreements for multi-administrative domain networking integrated to blockchain DAPPs, demonstrating an enabling prototype as an embodiment of our ideas (SIGCOMM 2018). Mostly established on solid related work outcome from SDOs, this work turns state-of-the-art ideas into experimental prototypes through best-of-breed open source (SDN and NFV enabling) technologies. In our publications, we discuss important related work involved in each one of their associated subjects, and present their shortcomings that we believe in being prominent research topics for future work. Finally, towards open models of innovation and business for the Internet, this work sheds light on important topics being discussed in the prospective phases of end-to-end network slicing, distinguished by connecting the dots between SDOs and the academia.

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