Thesis Overview:

Hybrid Networking SDN and SD-WAN: Traditional Network Architectures and Software-Defined Networks Interoperability in digitization era

Gustavo Salazar-Chacón
Universidad Nacional de La Plata, Argentina
PhD in Computer Science
Thesis Advisor: Luis Marrone
gsalazar.estudios@gmail.com, lmarrone@linti.unlp.edu.ar

Abstract

Software-Defined Networking (or SDN), since its creation and subsequent adoption, has promised to be the solution to network infrastructure management, configuration, and performance problems using techniques such as programmability, Open-hardware with programmatic capabilities, extreme agility, in addition to the use of secure Graphical Interfaces/APIs that provide full visibility and infrastructure telemetry.

This doctoral thesis takes a look at the evolution of data networks towards the SDN paradigm and its various adoptions (*SD-Access, SD-Data Center* and *SD-WAN*) in order to verify its ease of implementation, for which the fundamentals of these technologies are addressed, starting from what decoupling of the Control Plane from the Data Plane in network equipment implies, to the concept of cultural and technological change called *NetDevOps*, essential for the agile SDN ecosystem to work properly, going through the analysis of next-generation standardized protocols that allow the implementation of these environments in real networks: *LISP, VXLAN, OMP* and *Segment-Routing*, developing at the same time proofs of concept (PoCs) in emulation environments and with physical equipment, thus closing the investigative process that validates the integration of SDN-based programmability with traditional networks, this being precisely the greatest contribution of the present research.

Doctoral Thesis Contributions

Carrying out Proofs-of-Concepts about SDN, automation and programmable networks, as well as telemetry, Open-Networking and new transport protocols, also proposing innovative models of interoperability between traditional networks and networks defined by software are the main contributions of this research since they allowed to reach the final conclusions after an in-depth analysis of the obtained results in the simulation/emulation phase and tests on physical equipment, giving rise to a so called hybrid IP-SDN network where robust equipment or high traffic flows are not necessarily present as in Data Centers (SD-DCs).

Introduction

For a decade, business data networks have experienced a vertiginous evolution due to the adoption of cloud-based models, containers and microservices, primarily because they provide greater flexibility, effectiveness, and cost reduction in terms of Information Technology (IT). However, the requirements of current users and companies increasingly demand a better response from the telecommunications infrastructure. These requirements were more evident during the time of COVID-19 pandemic, leading us to a "Data and Wisdom Era", virtuality and Digital Transformation since most human and economic activities depend on an adequate and secure transfer of information. This is how data became the most important intangible asset of the 21st century.

The network infrastructure that accommodates these technological changes must also adapt to hyperconnectivity and new generation Data Centers, therefore, many protocols and transport technologies emerged along with end-user needs. Digitization gives relevant importance to data, in fact, every element that is part of a network will be able to generate some type of information. According to Juniper Networks, data traffic will increase 9.6 times by 2025, connecting more than 30 billion devices by 2020-2022 and close to 80 billion by 2025 [1].

SDN and Network Programmability

Nowadays, SDN is considered a fashionable technological topic since practically all network implementations in recent years encompass some variant of the Software-Defined concept. There is not a unique definition for SDN because it still depends on the manufacturer that deploys it, however, in all definitions, the pursuit of better performance patterns, security, and visibility using the Internet-Fabric as a transport are present.

Due to this diversity of concepts, the ONF (*Open Networking Foundation*), a non-profit consortium created to outline the path of new business and infrastructure models, working collaboratively as an open community to consolidate network unbundling projects, white-box networks, as well as to establish standards that will revolutionize the networking industry, defined SDN as the physical separation of the control plane from the data plane of a networking device in order to centrally control, monitor and program several devices at the same time through requests/responses from an API. SDN has the objective of creating much more agile, scalable, secure, and flexible infrastructures than traditional networks. One of the mechanisms to achieve this is through "Automation" and thus create programmable networks. "*If software is going to eat the World, then SDN will eat networking*" was already said in 2016 by [2]. Networks have become complex and one way to properly manage them is through SDN and programmability.

According to [2], the principles of SDN lead networks to what was coined as Infrastructure-as-a-Code (IaaC or IaC), which allows automation and orchestration become a reality. NetDevOps is bringing Development Operation (in Software) to the network; this is how a DevOps engineer ensures the continuous delivery of the IT service, thereby changing the cultural-business aspect, good practices and tools that improve effectiveness. Under this model, both the development and operations teams are not separated, but instead come together in a single work team, getting involved in all stages of the life cycle of an application and infrastructure, therefore taking the network to a totally holistic concept. Building on that, request-response mechanisms can be used to automatically orchestrate, provision, configure, and monitor hosts and network operating systems (NOS).

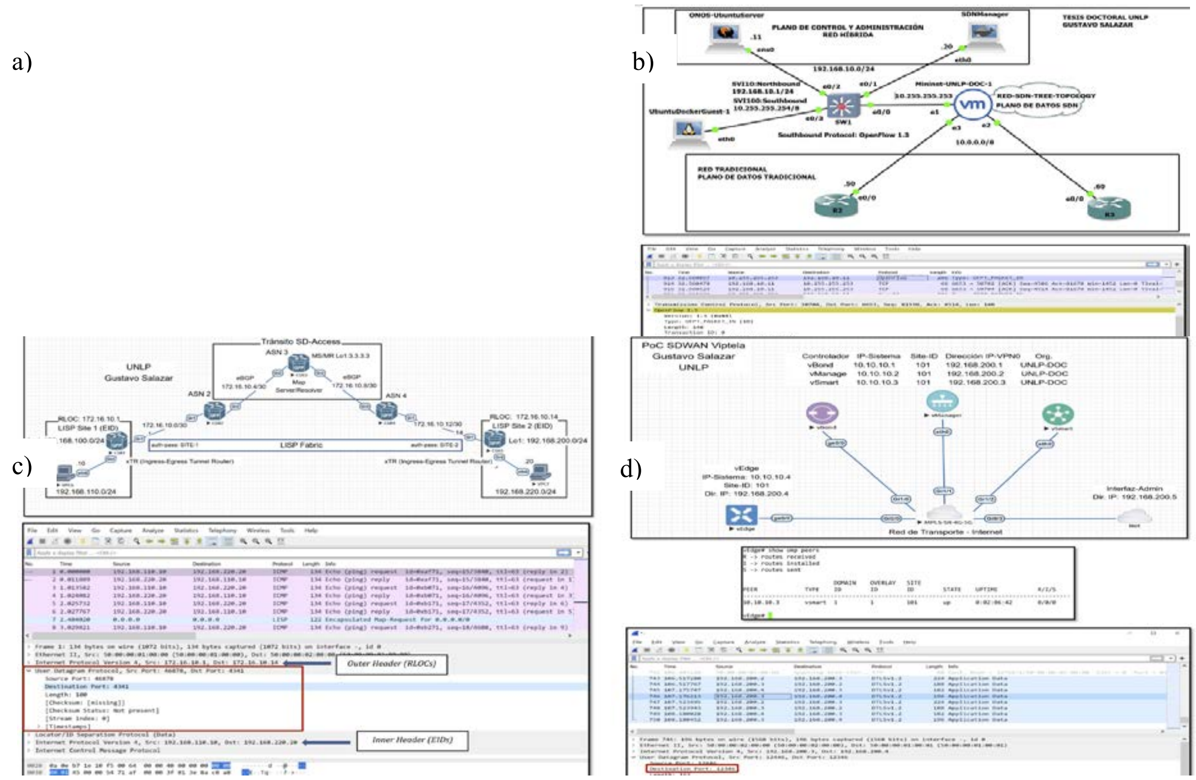
The success of this way of sending data depends on the Control Plane being separate and centralized through a Controller that have evolved over time. It can be said that there are two types of SDN-Controllers:

- SDN controllers for modern NFV, DCs, WAN and Access environments.
- Traditional SDN controllers to manage the data plane of a network.

There is a list of many SDN controllers that fit into either of these two groups, many have even served as a starting point for others due to their nature of open-source community. Based on the article by [3], most current SDN controllers work under OpenFlow as their Southbound protocol (*OpenSDN*).

Proofs-of-Concept (PoCs)

Several tests were carried out on high performance emulators to corroborate the feasibility of using these new technologies and their APIs, ending with a test on real *OpenSDN* equipment in wired and wireless environments.



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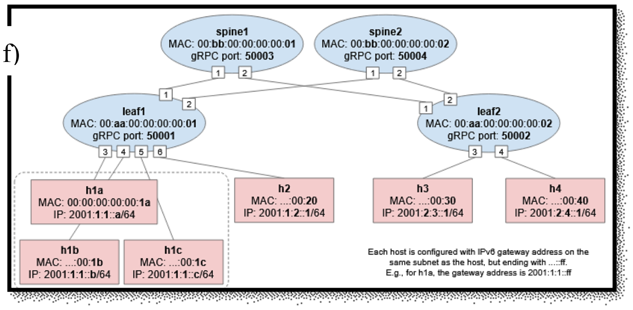

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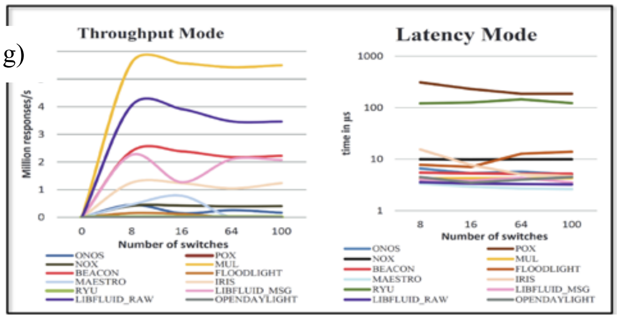

Figure 1 Proof-fo-Concepts-PoCs: a) Segment-Routing b) OpenSDN (ONOS), c) LISP and VXLAN - SDAccess, d) SDWAN (Viptela), e) Wired and Wireless SDN Real Equipment Implementation (Zodiac FX and Zodiac WX) with RYU Controller f) NG-SDN (uONOS with P4 Programming) g) Throughput and Latency Comparison between SDN Controllers[1]

Conclusions

After a research process and subsequent proof of concepts under the Test-Driven Development principle, the key elements to adapt traditional networks to the Programmability Era were identified through a proposed innovation model:

- End-to-end secure networks under the *Underlay-Overlay paradigm*, using robust encryption and authentication mechanisms, with multi-cloud connection capacity and delivery of virtualized services. This concept creates the hybrid IP-SDN network, in which traditional and SDN networks will coexist harmoniously.
- Capacity for orchestration, analytics, and monitoring (insights) through Open Networking APIs that reduce costs in CAPEX, OPEX and promote effectiveness in data networks.
- Use of multiplatform frameworks that facilitate the automation of network processes, configuration and problem solving (Model-Based Programmability), providing code version control and implementation agility. The use of clear and standardized design patterns solves common problems always present in the development of network controller software.
- Cultural, business, economic and technological change focused on the use of agile methodologies, *NetDevOps* and Digital Transformation consistent with the time of COVID-19 pandemic.

SDN/OpenSDN theoretical foundations were laid according to the previously proposed model and under the of Separation of Concerns (SoC) premise according to the MVC (Model-View-Controller) model, studying the standardization, encapsulation, and communication mechanisms of OpenFlow, concluding which, despite having different scopes and use cases, networks work well when it is integrated into a CI/CD-type SDN ecosystem (Continuous Integration / Continuous Deployment).

The main SDN controllers were analyzed in the same way at the time of writing this thesis to determine the best ones, concluding that ODL, RYU and ONOS have the best performance according to the proposed KPIs (throughput, latency, jitter, modularity, support and monitoring capacity) and stress tests (burst rate). It should be noted that the drivers developed in C/Java such as Mul, LibFluid and Maestro are more reactive in stress environments, but less adaptable to future improvements, while the more modern ones such as OpenDayLight and ONOS, their continuous evolution and changes in packages, have complicated their integration with traditional infrastructure.

The different forms that SDN can take in a real corporate infrastructure were studied: *SD-Access, SD-DC* and *SD-WAN*, maintaining the precept of decoupling the Control Plane from the Data Plane in order to improve the response of data networks. The use of next generation transport/routing protocols such as LISP, VXLAN, Segment-Routing and OMP were also studied. Its feasibility of implementation and interoperability with traditional networks was successfully tested in established PoCs.

[1] g) from Figure 1 was retrieved from [4]

The evolution towards the SDN ecosystem will be gradual, actually, we are still in a moment of adaptation, so the success of migrating to an SDN (SD-WAN/SD-Access/SD-DC) environment will be measured by its level of integration with traditional networks.

Scientific Publications related to the Doctoral Thesis

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