

Introducing Engineering Undergraduate Students to Network Management Techniques: a Hands-on approach using the Citylab Smart City

1st Henrique Carvalho de Resende
IDLab - Faculty of Applied Engineering
University of Antwerp - imec
Antwerp, Belgium
henrique.carvalhoderesende@uantwerpen.be

2nd Nina Slamnik-Krijestorac
IDLab - Faculty of Applied Engineering
University of Antwerp - imec
Antwerp, Belgium
nina.slamnik@uantwerpen.be

3rd Cristiano Bonato Both
Applied Computing Graduate Program
Universidade do Vale do Rio dos Sinos
Porto Alegre, RS , Brazil
cbboth@unisinis.br

4th Johann Marquez-Barja
IDLab - Faculty of Applied Engineering
University of Antwerp - imec
Antwerp, Belgium
johann.marquez-barja@uantwerpen.be

Abstract—The computer network industry is preparing for the revolution caused by the virtualization of the network infrastructure. The virtualization of network functions, together with the network programmability, is a fundamental skill-set required in both electrical engineers and computer scientists, which will become even more significant in the upcoming years. Therefore, in this article, we present an educational framework for Service Function Chaining (SFC) practical teaching to undergraduate students aiming to prepare them for future Information and Communication Technologies (ICT) and communication networks market that will demand skillful professionals in the domain. The educational framework was designed for the Network Management course at the University of Antwerp. To structure the content of the framework's sessions, we explain the fundamental concepts behind the SFC. Moreover, we detail the framework objectives, sessions, and how we plan to evaluate it. We also present facts and works that endorse the hands-on teaching preparing students for the research and development in the new generation communication networks arena. After, we discuss the methodology of the educational framework alignment with joint ACM/IEEE Computer Engineering Curricula for Network Management courses. Next, we present possible outcomes during the course evaluation using the survey. We conclude which this educational framework achieves the necessary core learning outcomes to empower students concerning the practical steps when deploying and managing communication networks and the virtualization techniques which nowadays are being applied.

Index Terms—Service Function Chaining, Virtualization, Network Management, Educational Framework

I. INTRODUCTION AND MOTIVATION

Currently, a synergy of network programmability, softwarization, and virtualization is already recognized as inseparable from the industry. Big companies like Google [1] and Amazon [2] have already implemented programmable, and virtualized networks in their datacenters. Network virtualization enables companies to optimize and to dynamically

steer the traffic of services among hundreds of servers at their disposal [3]. Moreover, with the emerging popularity of network virtualization, not only big companies will benefit from its implementation, but also the market will boost the demand for professionals with practical knowledge in this area. Academia and industry are united towards the goal to study programmability, softwarization, and virtualization in two major research areas, which are Network Function Virtualization (NFV), and Software-Defined Networking (SDN).

NFV is the virtualization of the legacy physical network functions, while SDN enables the detachment of the network control plane from the data plane [3]. The merge of these two paradigms opened a whole new research area. This area has pros and cons, which are jointly studied under the umbrella of Service Function Chaining (SFC) [3]. For example, the virtualization of network functions brought by NFV enhanced both the scalability and the maintainability of the network infrastructure [3]. Additionally, SDN enables the programmability of the network, which improves the connectivity by allowing dynamic, and fast setup of the data traffic route [3]. However, new challenges such as placement and migration of Virtual Network Functions (VNFs) have arisen as a consequence of such an approach.

To understand the complexity of such a plethora of enhancements, and challenges brought by the network virtualization era, it is crucial to discern how the network virtualization is implemented, deployed, and managed. Therefore, a fundamental skillset to have nowadays is the ability to use and manage SFCs, especially for undergraduate students whose aim is to compete for the vacancies of the Information and Communication Technologies (ICT) market in the upcoming years [4]–[6]. Hence, the essential practical knowledge of virtual network management should be provided pedagogically

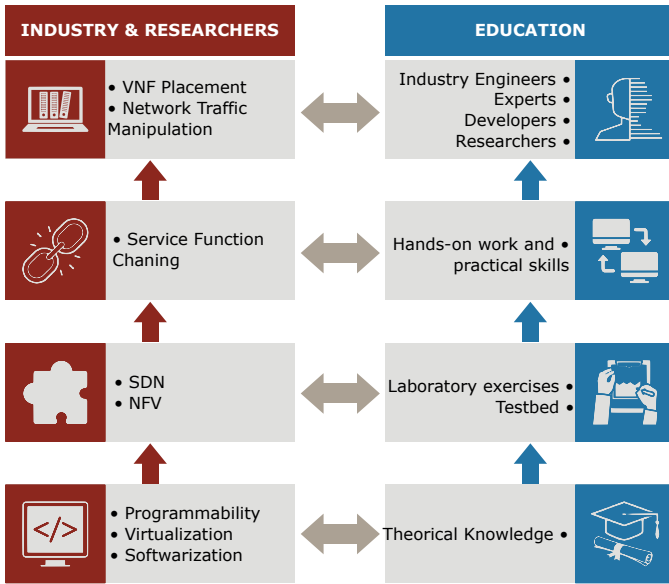


Fig. 1: The position of SFC in industry and education nowadays

during their study and should be considered in the curricula of every network management course. In this context, for improving the students' skills, it is expected to appraise the best available tools to use in the academic teaching of virtual networks and to find out how the lectures should be structured, and reinforced by hands-on laboratories, to achieve satisfactory learning outcomes in a shorter time.

In particular, in Fig. 1, we illustrate how the teaching flow should be synchronized with the pace of industry and research, for the specific field of SFC. From bottom-up, the theoretical educational approach would introduce the students to fundamentals of Programmability, Virtualization, and Softwarization, which supports the current computer networks tools. The Laboratory exercises reinforce the fundamentals already learned and teach concepts that put in practice the theoretical fundamentals such as SDN and NFV. The hands-on work is where the concepts merge, building up SFC, and the students apply to real-world use cases. In the last stage, the students will move to a specialization in the industry or academia and will be prepared to study more complex problems related to SFC.

Slamnik-Kriještorac et al. [7] study the impact of laboratory exercises on students' experience in learning. The authors emphasized the importance of gaining practical skills, and problem-solving abilities for undergraduate students, which can further motivate students to research this specific course-related field, and to exploit both practical knowledge and skills in their day to day work. Furthermore, despite the increase in the availability of diverse technology resources in laboratories, efforts to include them in education remain the same, *i.e.*, following the demonstration-related approach in which teachers demonstrate practical use cases, with students only repeating the examples [8]. Hence, Crocker et al. [8] point at the importance of the more significant involvement

of students throughout the learning process. Motivated to support such autonomous learning, and to provide real-world experimentation, in each laboratory exercise, we are going to exploit the capabilities of the large-scale wireless-networking testbed.

To provide real-world experimentation, we will use the Citylab¹ testbed built in collaboration between the University of Antwerp and imec Belgium, which has proved to be the next step in academic research and teaching [9]. Citylab is a smart city large-scale wireless networking testbed which enables experimentation at a city neighborhood level in the unlicensed spectrum. The testbed is located in the city of Antwerp, and its experimentation nodes are attached to buildings and streetlamps. The testbed is equipped with an infrastructure that enables easy remote access. Citylab will be an excellent instrument for academic teaching due to its reliable experimentation, heterogeneous network technologies, and close-to-real environments.

This article presents a pedagogically teaching methodology to introduce undergraduate students to theoretical and practical SFC, providing them with useful knowledge on virtualization of a real-life networking environment, such as smart city testbed. To the best of our knowledge, this is the only work that addresses course modernization towards network programmability applying service function chaining in practical classes. Our methodology was designed for a sixth-semester Network Management course under the Faculty of Applied Engineering, University of Antwerp. The method comprises nine sessions with theory and practice in which the students are going to deploy an SFC on the CityLab testbed. The outcome of our teaching methodology will facilitate the incorporation of the lectures into the virtual networks hands-on lab environment, with the ultimate goals: (i) to provide undergraduate students solid knowledge on performing basic SFC operations, (ii) to increase the interest of students for this or similar topics, and (iii) to improve the quality of their learning experience. The module design comprises appropriate steps of an extensive experiment setup on deploying SFC on top of the CityLab SmartCity testbed.

This article is structured as follows. In Section II, we present the fundamentals concepts of the learning framework for the Network Management course are introduced. In Section III, we present the educational framework methodology, including the objectives, sessions, and evaluation. The alignment of the education framework with recent network management practices and market preparation is presented in Section III. In Section IV, we elaborate on a discussion about the framework and which are the envisioned pros and cons. In Section V, we conclude and future work.

II. FUNDAMENTAL CONCEPTS

In this section, we present the fundamental concepts that students need to understand to proceed with the deployment of a virtual network and SFC. For that, we first describe

¹https://doc.lab.cityofthings.eu/wiki/Main_Page

NFV, its usage, and the standardization behind this essential concept. Furthermore, we define SDN and detail on how this concept enhances the legacy network flow. SFC is introduced as the union of both NFV and SDN to provide a dynamic and highly customizable network environment. In Fig. 2, we address the view of computer communication networks from hardware-implemented distributed networks to virtualized and centralized networks. In this view, we present the legacy networks, which are composed of mostly specialized hardware and distributed control plane. Moreover, with the advent of virtualization, NFV enabled the execution of Network Function (NF) in generic hardware. SDN comes next, implementing the concept of centralized control plane optimizing the network infrastructure with the feedback of virtual switches in generic hardware or specialized programmable hardware. Finally, SFC surges as an outcome of the merge of NFV and SDN structure with the sophisticated knowledge of these two areas.

A. Network Function Virtualization (NFV)

Back in the days, computers did not have much processing power, which made companies develop most of your high requirements functions in hardware. Over the years, the processing power of generic hardware computers improved, and several components that were available in hardware only started to have a software implementation with similar performance. In computer communication networks, the same phenomenon happened, and the NFs had software-based variants and in the virtualization [3].

Virtualization is one crucial technology that has been widely explored in data centers to enable hardware sharing with data and process isolation. Currently, the most popular technology utilized for virtualization is the Virtual Machines (VMs). However, recently, an alternative for the VM, the containers base virtualization, is gaining momentum. The container enables a lightweight deployment of services and applications, compared to traditional VMs, due to the sharing of the host kernel with user-space isolation. Containers are being considered as part of the emerging 5G technologies, as proposed by Bolivar et al. [10], to use containers to deploy NFV.

The virtualization of NFs had the potential to decrease the Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) of computer networks infrastructure. The low costs and the new possibilities open by virtual computer networks attracted the interest of the industry, which began to invest in the area. For instance, South Korea Telecom (SKT) and Viva Kuwait already started the migration of physical to virtual network infrastructure, and this trend will only get more popular [11]. The qualification of students to fill the future vacancies are essential to attend this increasing industry demand, as highlighted by Agoria [12].

In the research perspective, Virtual Network Function (VNF) are the main components in NFV, a hot topic that arises from the virtualization of such functions. For instance, this concept enabled network operators and system administrators to deploy VNF instances given different network traffic demands. However, with this possibility of dynamic deployment,

challenges such as VNF placement and migration have arisen [13].

B. Software-Defined Networking (SDN)

SDN is the decoupling of the network control plane from the data plane [3]. This paradigm came with the necessity to create more efficient network flows by dynamically steering the network traffic and load-balancing it among the network nodes. Nowadays, computer networks are still connected in a distributed way. It means that each switch or router has its control plane, which is used to discover new devices, and to route the data to the destination. Therefore, a single component/entity does not control communication among the devices.

SDN is already a consolidated technology, and have robust software implementations such as OpenDaylight [14] and Ryu [15]. The former is used in industry and has a big community that turns OpenDaylight into a more secure solution. The latter is more used for academic research because it is more straightforward than OpenDaylight. This characteristic helps in an educational point of view because it implements only the necessary components for a simple SDN deployment.

For the research perspective, the decoupling of the control plane from the data plane enabled the network operators to centralize the control and have a broader view of the network infrastructure. Therefore, the network operators could be able to create and manage routing tables and set up layer two network rules in several devices from a single point. In this context, SDN raised new challenges, for example, to enhance the SDN architecture to enable communication among SDN controllers and allow the integration of the computer networks from different operators. Moreover, by centralizing the SDN controller, the network control is a single point of failure, which can affect the availability of the whole network.

The understanding of SDN is fundamental for a computer network professional. For example, the SDN controller is responsible for stitching the computer network mesh by steering the traffic among components. Therefore, SDN is an indispensable topic in the educational framework and the students' preparation for the market.

C. Service Function Chaining (SFC)

SFC is the deployment of at least two NFs, which together will provide a network service to the user. A simple example of SFC is the Dynamic Host Configuration Protocol (DHCP) server behind a firewall. When accessing the DHCP server, the client network traffic passes first into the firewall, which will filter the requests and, then, these requests go to the DHCP server. This managing of the network flows to pass through different functions besides the destination points is called chaining. There are several utilities for this method, such as security in the case of firewalls and Intrusion Detection Systems (IDSs) and statistics in the case of packet counters.

The function chaining can be done by statically setting up the network to steer the traffic through specific functions in the infrastructure. Legacy networks and hardware can be

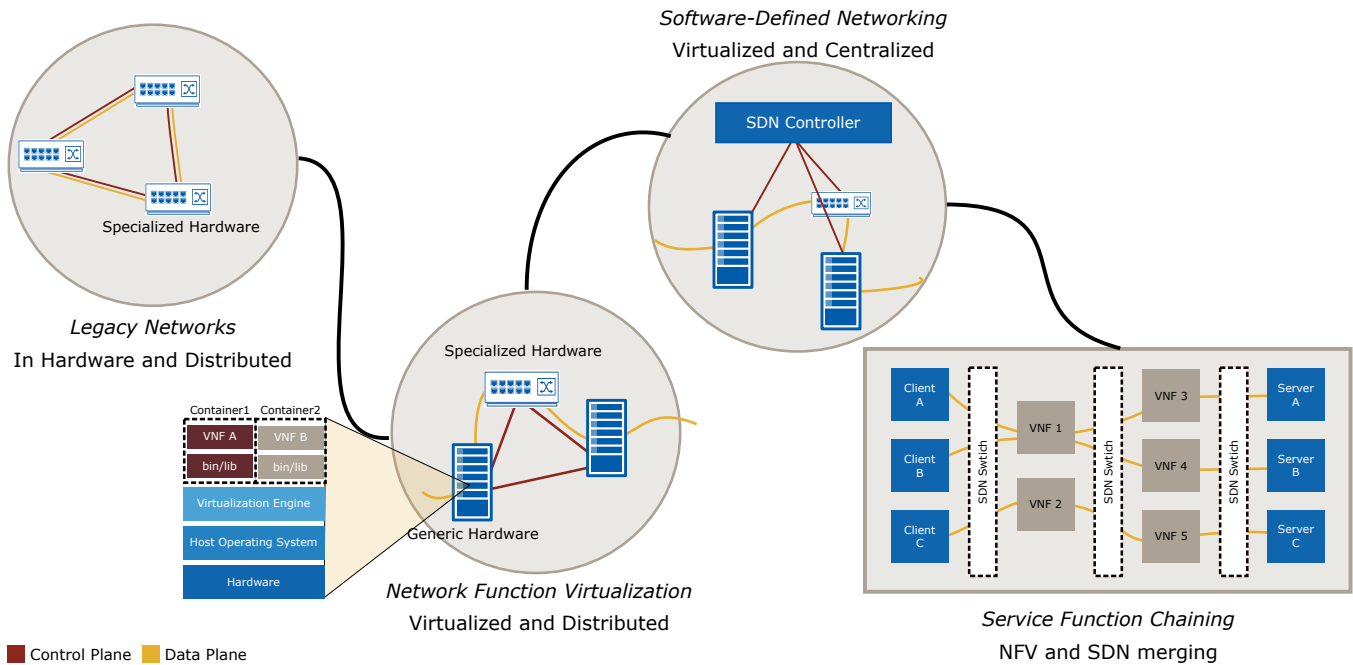


Fig. 2: Fundamental Concepts relationship diagram

chained as well. However, with the rise of the use of NFV and SDN, the setting up of the network became more dynamic, which turned SFC to be more complex with several functions receiving different traffic flows in the same hardware. In the legacy network, the concept of linking different network functions already existed. However, with the fast development of virtualization technologies and the softwarization of NFs, this deployment and management of several network instances became more dynamic. Therefore, research to solve challenges on SFC are several such as chain order optimization.

The teacher will necessarily introduce to NFV and SDN, which are the basis of future computer networks when teaching SFC. VNFs will provide the deployments of different network services, and the SDN will enable the operators to program the network and steer different network flows on-demand. These characteristics will allow the customization of the network, for instance, per service or per user, which are essential to advancements in the computer networks area. The concepts, use cases, tools of virtual, and programmable networks will provide all fit together under SFC the necessary knowledge to young professionals to pursue the future virtual network vacancies.

III. METHODOLOGY

In this section, we aim to detail what are the objectives of this educational framework and how we plan to achieve them. First, we list and emphasize the objectives of bringing SFC practice to the Network Management course at the University of Antwerp (III-A). Moreover, we present step-by-step of the course and show how the knowledge structured is built from a bottom-up teaching approach (III-B). We designed a students

survey to validate and adjust the educational framework's content and methodology (III-C).

A. Objectives

The maintenance, creation, and debug of the complex virtual network infrastructure will be daily tasks for computer network engineers. These professionals will avail from software to orchestrate and manage the virtual infrastructure to achieve their duties. However, these professionals will front unusual scenarios that will challenge their knowledge to solve network-related problems. Therefore, in this educational framework, we focus on hands-on laboratories and activities to:

- i) provide undergraduate students with solid knowledge on performing basic SFC operations,
- ii) increase the interest of students for this or similar topics,
- iii) improve the quality of their learning experience.

We achieve these objectives by composing the framework in six sessions: Remote access to the testbed, VNF deploying with Docker, first contact with OpenFlow (OF) switch, using of OFs rules, creation of a WiFi access point, and network bandwidth manipulation. The sessions are mapped in Fig. 3, where the content of one session supports the teaching of the next.

B. Sessions

1) *Setup testbed Environment:* Citylab will be the testbed used, which will provide the students to deploy their experimental tools in a real city scenario. This testbed is accessible through jFed [16], which is a tool that groups several testbed facilities and enables remote access through Secure Shell (SSH). The students will also be able to configure the network

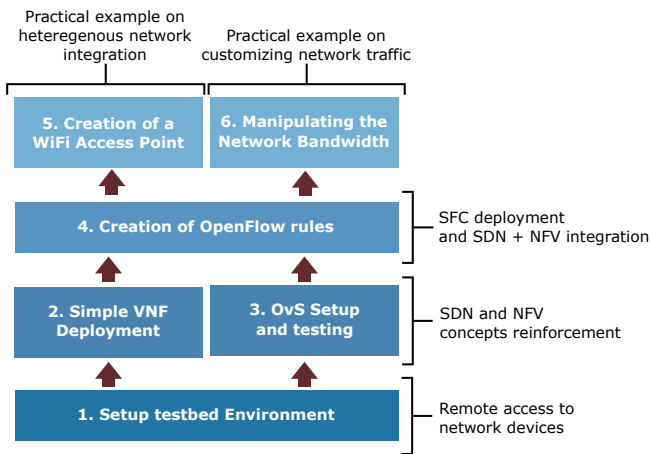


Fig. 3: Educational framework mapping

topology with jFed, which will connect the nodes selected in the testbed available resources.

The students will set up the environment for testbed experimentation. The testbed setup includes registering to the testbed facilities, creating an experiment, selecting nodes, creating network topology, accessing the nodes, verifying the connectivity between the nodes, as shown in Fig. 4. We assume that the first stage will be a long process because students have different levels of experience in working with experiment allocation tools. Furthermore, the students need to use a command-line interface most of the time to access the testbed resources. Although it might be challenging for them at first, adding some overhead to the learning process, the skills on using the command-line interface will be highly appreciated as this is one of the most common practices in an ICT working environment.

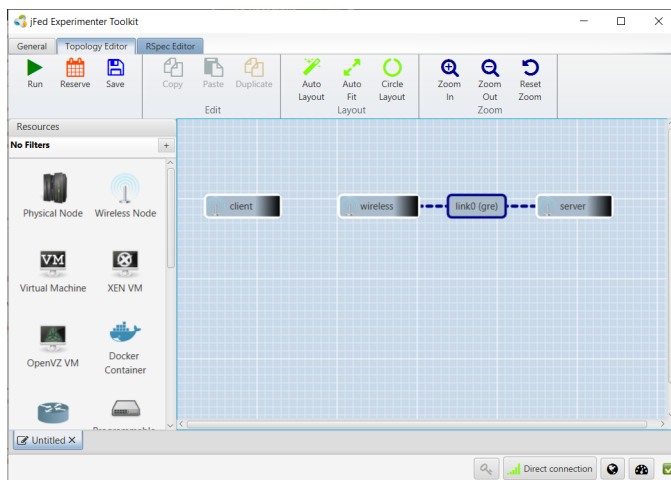


Fig. 4: jFed lab topology set up

As the physical nodes in the Citylab are limited, we will pre-reserve some nodes for this course within the testbed administrators. Moreover, we will split the reserved nodes to

the students, making sure that nodes that will be connected via WiFi are near to each other to establish the wireless connection, as can be seen in Fig. 5.

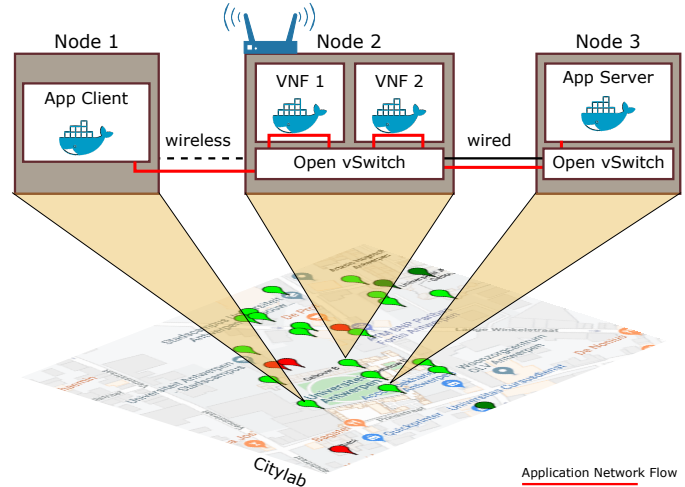


Fig. 5: SFC experiment setup in Citylab

2) *Simple VNF deployment*: VNF is a software implementation of an NF, which before was implemented in hardware. However, one of the problems faced by the software is the performance isolation among the programs deployed over the same hardware. Therefore, the usage of a virtualization solution is necessary so that we can isolate the VNFs and manage, scaling, and maintaining them separately. In this course, we are going to use Docker as the virtualization solution because it is the most popular container technology in the market today, which means that it has an active community that provides a plethora of documentation that can be beneficial to the students.

The students will receive a ready to deploy Firewall VNF in a Docker container. The objective of this session is to the students get used to the container virtualization and understand how the VNFs are deployed in a real-world scenario. However, there are some tools, such as Kubernetes, which automatize the process of deploying and manage the life-cycle of the container. However, we will not adopt such solutions since we want students to have a deeper understanding of containers.

3) *Open vSwitch (OvS) set up and testing*: The set up of the Open vSwitch (OvS) may be the first contact of the students with an SDN switch, and it will be necessary a closer look into the exploring of the routing features of OvS because some students may break the network connectivity with the testbed node. Citylab provides the restoring of the node; however, it will take extra time to redeploy the scenario and install the necessary tools again, but it will be considered part of the learning process.

The students will set up OvS in the Citylab nodes. Moreover, an OvS bridge will be created and attached to the experimental network interface. Therefore, all the traffic going out the node will necessarily go through the SDN switch. To ensure that the communication between two VNFs in the

host passes through the SDN switch, we will attach a network interface into the containers and will utilize this interface as default for the VNFs.

OvS will be tested by the students using traffic generators tools such as ICMP protocol and iPerf3 [17]. The students will deploy basic OF rules to block and tag the traffic that matches with the pattern described in the rule used. Following these steps, we guarantee that the students will have the fundamental knowledge to deploy OF rules and what are the possibilities of programmability.

4) *Creation of OpenFlow rules:* In this session, the students will combine the knowledge about NFV and SDN to create an SFC. In the previous sessions, we already deployed a containerized VNF and setup an OvS bridge. Now, the students will need to create virtual ports in the OvS bridge, which will connect to the VNF network stack inside the container. Once VNF is connected to the OvS bridge, the OF rules will be able to redirect the traffic to the port, which the VNF interface is linked in. Inside the container, the students will check if any network traffic is coming through the network interface.

The students will receive a basic packet forwarder script which its only function is to forward the packets out of the VNF with the data coming through the network interface successfully. The traffic generated will be able to reach its destination with the usage of this script. Moreover, the students will have a basic script to create new kinds of VNFs. This process has as its objective to teach how the OF switch and the VNF handle the packets. Moreover, how VNF forwards the packets to the next destination VNF or application.

5) *Creation of a WiFi access point:* Manipulating data traffic from traffic generators deployed in the same host is already enough to demonstrate how the SFC works. However, some extra configurations are necessary when receiving traffic from a different network. Therefore, the students will avail from the features of the Citylab smart city testbed and deploy a WiFi hotspot in one node and connect in the wireless network with another node. In such a way, the traffic coming from the wireless interface will need to be routed to the OvS bridge to pass through the SFC and reach its final destination.

6) *Manipulating the network bandwidth:* Exploiting the provided packet forwarder script, the students will extend the VNF to manage the network bandwidth from the traffic passing through it. This last session has as an objective to improve students' understanding of how the network operators can provide different Quality of Service (QoS) for different network traffic. Furthermore, the students will assess the trade-off between CPU utilization, network throughput, and latency with the use of VNFs.

C. Evaluation

Surveying the students and teachers helps the validation and the update of the course. The appliance of a questionnaire with the students may support the assessment of the efficacy of the teaching. Therefore, we identified three areas that support the evaluation of the educational framework: (i) Quality of Content, (ii) Potential Effectiveness, and (iii) Technical Basis.

Quality of Content evaluates how the content is delivered to the students, and the difficulty level perceived by them. The feedback of the students on how prepared they feel for the academia or industry will be studied in Potential Effectiveness. Technical Basis will assess the functional knowledge delta of the students, for instance, what is the level of expertise in a specific tool/area and how they perceive their knowledge after the educational framework being applied.

Given the characteristics of each area, the Quality of Content and Potential Effectiveness surveys will be applied only after the educational framework sessions, and Technical Basis, before and after. The Quality of Content and Potential Effectiveness questions are designed on a 5-Likert scale and one open question for remaining comment. While, in the Technical Basis area of interest, the questions are on a 1 to 10 scale of knowledge in the subject. The areas an example of questions is depicted in Fig. 6.

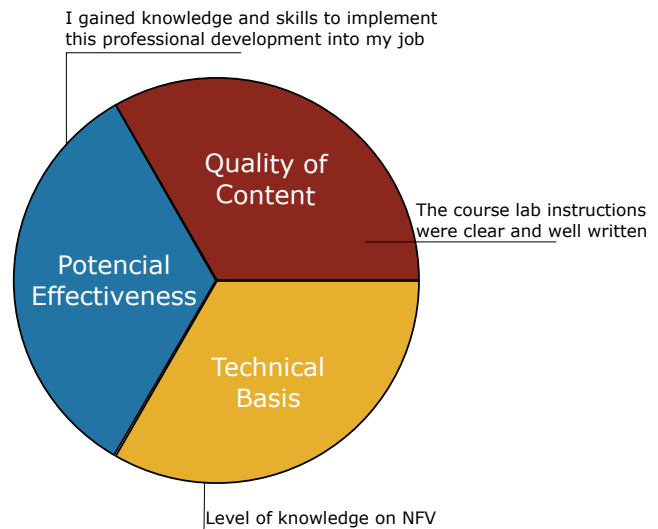


Fig. 6: Area of interest on students survey with examples

IV. NETWORK MANAGEMENT ON PRACTICE

Frequently, in undergraduate courses, network simulation tools are used to explain concepts and demonstrate the network behavior. These tools are precious to the scientific community because they extend the network resources beyond those available to the researcher. However, the simulation relies on setting network parameters that often cannot be predicted, resulting in unreliable conclusions. Therefore, for small-scale experiments, experimenting in a real environment becomes valuable, following unpredictable behaviors, and enhancing the significance of the research results. Moreover, in undergraduate courses, hands-on labs stimulate students' interest in using practical tools that can be used later in their careers [7]. By providing students with such an opportunity to gain practical skills in this emerging field at an early stage, we aim to encourage them to break the potential barriers towards hands-on work and to trigger the sparkle for experimenting in

general. This practical experience might motivate students to approach research and to expand knowledge later, at a more mature stage of the study.

Nevertheless, the current undergraduate courses only explain the theoretical concepts of NFV and SDN, excluding any practical implementation. One reason for such phenomena might be the potential lack of proper documentation for the networking tools, and the access to such tools, which most of the time are high-performance laboratories. Therefore, our educational framework consisted of virtualization tools, followed by corresponding theoretical guidance, will support the practical implementation of network virtualization techniques for the undergraduate students and encourage them toward expanding their knowledge and experiencing this innovative and promising career direction. Moreover, the usage of virtualized testbeds such as Citylab for academic teaching is still not as widespread it should be, but efforts in this direction are already being made [18].

Given the importance of introducing hands-on laboratories to students, some researchers have already made some efforts into this. Slamnik-Kriještorac *et al.* created a low-cost network laboratory project for Distributed Systems using Raspberry Pis [7]. The authors structured the project in three stages: (i) Naming Server and Discovery, (ii) Replication, and (iii) Agents and GUI. The organization in three stages enabled them to explain the concepts to the students and develop the theory in practical labs. Moreover, the authors designed a survey for the students to evaluate their projects. Therefore, the survey gave them valuable feedback, such as the difficulties of each stage and the practical laboratory efficacy.

Gercek *et al.* dissert about how to implement hands-on laboratories in online courses [19]. The authors say that a practical approach, even in remote courses are essential to specific fields that are not fully theoretical such as computer networks. Gercek describes a five-stage course made by them from a local computer networks laboratory until a fully deployed laboratory in a private cloud. They explain step-by-step the advancements and how they were able to successfully extend the practical classes to online courses, reinforcing the importance of the students' contact with practical exercises.

The selection of the fundamental tools for network management and the efforts towards hands-on teaching in laboratories highlight the importance of this movement of network management courses to a practical teaching approach. The example of Slamnik-Kriještorac *et al.* first providing a low-cost laboratory for practical education in the Distributed System course and Gercek *et al.* bringing practical classes to online courses gives us a perspective on how aligned the educational framework for SFC is with the current educational trend.

V. DISCUSSION

In this section, we put our educational framework into check. First, we compare the sessions to the learning outcomes for network management specified by ACM/IEEE Computer Engineering Curricula 2017 (ACM/IEEE CE2017) to demonstrate that our framework comprehends the expected results

(V-A). Furthermore, we analyze the bottom-up approach, which our framework was based on, to a top-down approach, and present the pros and cons of each (V-B). The educational framework maintenance is discussed, concluding the section (V-C).

A. Curriculum alignment

The ACM, in collaboration with IEEE, has elaborated the ACM/IEEE Computer Engineering Curricula 2017 (ACM/IEEE CE2017) for information technology to guide institutions with specific strategic suggestions and recommendations. In this recommendation document, ACM/IEEE CE2017 specifies some learning outcomes for the course of network management, which is the focus of this article. The following list can summarize network management learning outcomes:

- A) Main issues.
- B) Typical architectures.
- C) Demonstrate the management of a network device
- D) Compare various network management techniques as they apply to wired and wireless networks.
- E) Discuss the Address Resolution Protocol (ARP).
- F) Exhibit the concepts of domain names and Domain Name Systems (DNS).
- G) Describe the Dynamic Host Configuration Protocol (DHCP).
- H) Describe several issues related to Internet Service Providers (ISPs).
 - I) Illustrate several Quality of Service (QoS) issues.
 - J) Describe ad hoc networks.
- K) Teach troubleshooting principles.
- L) Describe functional management areas related to networks.

Given the characteristic of practical sessions, some of the learning outcomes could not be fully introduced in the educational framework itself. However, the educational framework will be supported by four network management theoretical sessions, which has the main objective to present the main concepts of network management and topics that will not be discussed in the specific practical sessions due to time limitation. Moreover, some important concepts such as service reliability and security will be assessed during the theoretical classes in order to introduce students to common topics that network management has with other courses such as Fault Tolerance theory and Computer Security. Table I is shown the nine sessions of the network management course, which four are theory only and five that will be hands-on laboratories. The table also presents the content and the learning outcomes achieved at the end of each session.

The educational framework, with the support of the theory sessions, is fully aligned with the ACM/IEEE CE2017. This alignment with the recommendations reinforces that the educational framework innovates to prepare computer network professionals without skipping any essential knowledge in student development.

Week	Session Approach	Duration	Session	CS2017 - Network Management Core Learning Outcomes
1	Theory	2h	Introduction and Fundamental Concepts	A, L
2		2h	Typical architectures with the advance of virtualized and programmable networks	B, D, J
3		2h	Main protocols of Network Management	E, F, G
4		2h	Internet Service Providers and Network Management main issues	H, I
5	Practical	2h	Setting up the testbed environment	C, L
6		2h	Simple VNF deploying with Docker	C, L
7		4h	OvS set up and testing	C, E, I, K
8		4h	Creation of OpenFlow rules to deploy an SFC	C, I, K
9		4h	Creation of a WiFi access point to emulate a client-server application architecture	C, D, E, G, I
			Manipulating the network bandwidth using VNFs	C, H, I, K, L

TABLE I: Educational Framework alignment with ACM/IEEE Curricula 2017

B. Educational Approach

The Network Management course educational framework was developed utilizing the bottom-up teaching methodology [20]. This methodology is built by explaining to the students the more strict subjects, tools, or concepts to the more generalizing ones. The bottom-up approach for SFC practical lectures is very efficient because it permits the lecturer to present the ideas of NFV and SDN separately. Moreover, the intersection of these two concepts comes naturally by programming the network flows to connect to the VNFs.

In this educational framework, three out of six sessions are the core of every SFC-based course. The first is the deployment of a VNF, which will reinforce what VNFs are and how they work. The second is the deployment of an SDN switch, which will enable the student to program the traffic flow. The third and last core session is the integration of the SDN switch with the VNF and further to connect multiple VNFs. In three steps, an SFC can be deployed and taught to the students. The other three practical sessions are designed to support the using of the SFC and to direct the attention of the students to concepts which the teacher finds necessary.

C. Educational Framework Maintenance

One fundamental characteristic of the aforementioned student survey is the maintenance of the quality of the course and adjust the content of the sessions for the students' needs. One cyclic process should be followed to implement a continuous repairing in the educational framework, as can be seen in Fig. 7.

The first step in the educational framework cyclic process is the creation of the educational framework adapted to the institution's schedule and expected outcomes. The appliance of the pre-survey before the beginning of the sessions is the second step. This pre-survey is a technical basis questionnaire that aims to evaluate the knowledge and skills of the students at an entry-level. The SFC classes should be taught after the pre-survey, and it is the most time-consuming step in the cyclic process lasting up a whole academic period. At the end of the academic period, the post-survey should be applied, gathering the feedback about quality of content, potential effectiveness, and the second part of the technical basis, which will provide

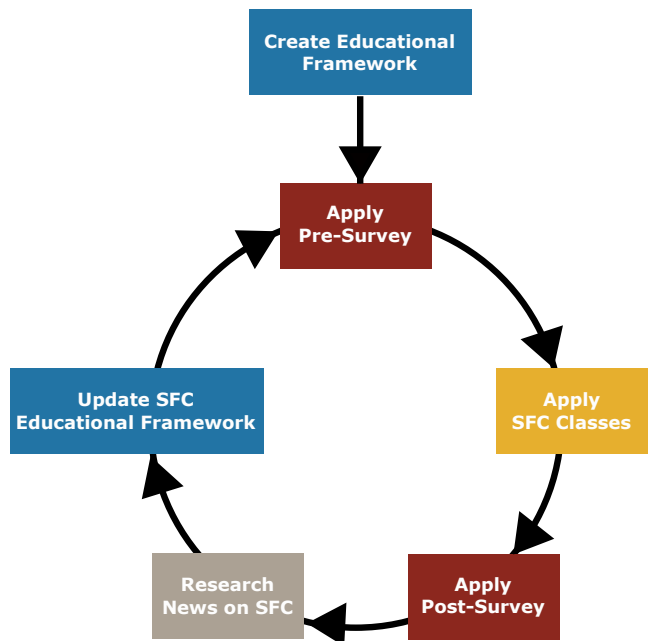


Fig. 7: Educational framework cyclic maintenance process

insights about the skills gained by students when compared with the pre-survey. After gathering the feedback, research about the recent advancements in SFC should be done to keep the sessions up to date. As the last step of the cycle, the educational framework should be updated with the latest advancements and students' feedback. The Pre-survey should be applied again and restarting a new educational framework maintenance cycle with the beginning of a new academic period. Notice that the focus of this paper is not on the discussion about the survey content per se; the focus is on presenting the Educational framework. Therefore, we do not describe the pre- and post-survey here; it is just mentioned as a component of the Educational framework.

VI. CONCLUSION AND FUTURE WORK

In this article, we present the fundamental concepts of an SFC, and the organization of practical lectures for a network

management course. The planning of practical sessions based on the content taught previously in other sessions helps reinforce and to embrace the theory. Therefore, we created a well structured and objective oriented educational framework for SFC teaching to guide the preparation of hands-on teaching laboratories.

As future work, we apply the educational framework in a network management course at the University of Antwerp. We will use the survey and gather feedback from the students. Therefore, we will be able to adapt sessions' difficulty level and the number of activities, aiming always to improve the quality of the teaching and preparing students for the future computer network market.

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ACRONYMS

ACM/IEEE CE2017 ACM/IEEE Computer Engineering Curricula 2017.

CAPEX Capital Expenditure.

DHCP Dynamic Host Configuration Protocol.

ICT Information and Communication Technologies.

IDS Intrusion Detection System.

NF Network Function.

NFV Network Function Virtualization.

OF OpenFlow.

OPEX Operational Expenditure.

OvS Open vSwitch.

QoS Quality of Service.

SDN Software-Defined Networking.

SFC Service Function Chaining.

SKT South Korea Telecom.

SSH Secure Shell.

VM Virtual Machine.

VNF Virtual Network Function.